ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

# JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS

Journal of Agronomy

ISSN 1812-5379
DOI: 10.3923/ja.2017.180.195

# Research Article
# Characteristics of Agricultural Landscape Features and Local Soil Fertility Management Practices in Northwestern Amhara, Ethiopia

[1]Kehali Jembere, [2]Tekalign Mamo and [1]Kibebew Kibret

[1]School of Natural Resources Management and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia
[2]Ethiopian Agricultural Transformation Agency, Addis Ababa, Ethiopia

## Abstract
**Background and Objective:** Detailed characterization of bio-physical resources in agricultural landscapes and documenting locally used soil fertility management practices is required for developing site-specific management scenarios in the study area. In view of this, a study was conducted to characterize the landscape features and related biophysical settings and to identify the local soil fertility management practices in the agricultural lands of Farta, Fogera and Gondar Zuria districts in Northwestern Ethiopia. **Materials and Methods:** The survey methodology used was spatially stratified grid sampling technique more skewed to agricultural lands. Semi-structured questionnaire was used to collect the required data at the field level. Soil samples collected from 0-20 cm depth were prepared and analyzed in the laboratory following standard procedures. For agro-ecological zone classification altitude measurement results (n = 549) and 10 years (2005-2014) mean monthly rainfall data were used. For data analysis and descriptive statistics, one-way ANOVA and DMR tests ($p<0.05$) were employed. **Results:** The high variability in major landforms resulted in the formation of five different agro-ecologies in a comparatively small (3385.17 $km^2$) geographic area. Differences in slope gradient classes significantly affected the selected soil properties. Thus, clay, pH, cation exchange capacity, exchangeable calcium, magnesium, extractable manganese, zinc, iron and copper generally showed a decreasing trend with increasing slope gradient. Six soil types, identified based on soil color, occupy the majority (72%) of the study area and were found to be uniformly deficient in nitrogen, phosphorus, sulfur and boron. Mineral fertilizer was identified as the widely used (84%) type of fertilizer as compared to farmyard manure. Nonetheless, the application rate of mineral fertilizers remained as low as 36.5 kg $ha^{-1}$ N and 13.2 kg $ha^{-1}$ P. **Conclusion:** In general, to conserve the biophysical resources and improve the fertility status of soils in the study area on a sustainable basis, the use of appropriate soil and water conservation practices, site-specific and balanced mineral fertilizer application and amelioration activities are recommended.

Key words: Agro-ecology, landforms, local soil names, slope gradient, soil fertility management

Received: June 28, 2017 Accepted: September 01, 2017 Published: September 15, 2017

Citation: Kehali Jembere, Tekalign Mamo and Kibebew Kibret, 2017. Characteristics of agricultural landscape features and local soil fertility management practices in Northwestern Amhara, Ethiopia. J. Agron., 16: 180-195.

Corresponding Author: Kehali Jembere, School of Natural Resources Management and Environmental Sciences, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia



Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

Being dominantly subsistence in nature, the agriculture sector in Ethiopia relies to a greater extent on availability of suitable land, moisture, climatic resources and many other inputs. The well-being of the biophysical environment, through its obvious influence on the agriculture sector, affects the well-being of those whose livelihood depends on farming[1].

Ethiopia's location in the tropics coupled with impressive altitudinal variations within a short distance allows the country to enjoy both temperate and tropical climates, which give rise to wealth of biophysical resources[2]. Similarly, the great variability of Ethiopian highlands gives rise to the formation of different physical landscapes which are in turn the causes for the variations in soil parent materials, agro ecological zones, flora and fauna[3-5]. Therefore, the success of agricultural production in the Ethiopian highlands is strongly influenced by these unique topographic settings and the underlying biophysical features[6].

In such physiographical heterogeneous Ethiopian highlands which have been extremely disturbed by human interferences, uneven spatial and temporal distributions of agricultural potentials are expected[7-8]. The implication of such heterogeneity is that within a given change in landscape positions and land use types, it is likely that the direction and magnitude of soil properties will also be changed. In relation to this, a decreasing trend in soil pH after the grass land was converted to different plantation forests in the Arsi highlands of Ethiopia has been documented[9]. In a similar study in Southern Ethiopia, higher values of soil pH, EC, available P, exchangeable K and Ca, extractable Zn and PBS under enset (*Ensete ventricosum*) fields as compared to the grassland and maize fields were reported[10].

In other studies conducted in Northern and Southern Ethiopia, variability in measured soil properties were also reported to have been related to observed differences in slope gradient classes and similar altitudinal changes[11-13]. In a very recent landscape characterization study conducted in Wolaita, significant variability in soil properties with respect to varying physiographic categories was recorded[14]. In this similar study, higher values of available P, exchangeable K and extractable micro nutrients (B, Cu, Fe and Zn) were recorded in soils on flat than on steep slope categories. Generally, many study results revealed that the amount and distribution of most nutrient elements were found to be higher on flat slope categories than steeper slopes[11-14].

Different soil fertility management practices being implemented by the majority of local farmers were found to be not comparable to the prevailing spatial and temporal variability in soil fertility status and to the required land management practices. The identified reasons for the observed under-management of agricultural lands were, among others, farmers' wealth ranking, high fertilizer costs and low credit availability[15-17]. Similarly, the importance of secured land tenure systems for promoting intensive soil fertility management has been highlighted[18-19]. From among the most common traditional soil fertility management practices, crop rotation has wider applicability in majority of the areas in Ethiopia[14,17,20]. On the other hand, fallowing and crop residue management were identified as the least implemented practices in many parts of the country mainly due to increased population pressure and related fragmentation of farmlands[14,17,21-23]. Moreover, the soil fertility replenishment roles of constructed physical structures were also documented by many authors[24-27].

Severe land degradation has been one of the problems observed in the highlands of Amhara region of Ethiopia, including the current study districts (Farta, Fogera and Gondar Zuria)[28]. Moreover, ever increasing population pressures in these districts[29-30] and the resultant demand for additional cultivable land has further exacerbated the problem. However, due to recent collaborative soil conservation works between local communities, regional government and other partner organizations, it was possible to avert further degradation at least from the conserved lands[24,28,31]. Nevertheless, land degradation is still noticeable in most parts of the Ethiopian highlands[32] as it is in the study area. Desta *et al.*[28] emphasized that solving soil degradation problems demands adequate quantitative information that indicates the magnitude and direction of the problems before embarking on developing likely management scenarios. Nevertheless, such types of data are mostly lacking in many parts of the country including the study area. As indicated by many authors Deressa *et al.*[33], Yu *et al.*[15] and Chamberlin and Emily[6], lack of such information on the highly varying biophysical characteristics has been hindering technological diffusion and their subsequent adoptions across large areas of the country.

The main reason suggested for poor adoption and dissemination of technologies was the blanket and non-customized nature of the released technologies that did not consider the observed variability in biophysical settings[6,32]. For developing site-specific technologies that are effective with greater impact, it is imperative to have site-specific landscape information generated through detailed characterization of biophysical resources.

The study area is continued to be affected by land degradation. On the other hand, the human population is growing at an increasing rate. This may create a pressure on marginal lands unless intensification is practiced as a viable option. Intensification to be effective, site-specific information based site-specific recommendation is mandatory. However, landscape information and related biophysical data, which can indicate site-specific agricultural potentials and limitations, is not yet available in the study area. Data concerning the current soil fertility management practices implemented in the study sites are not also well documented. Moreover, the blanket fertilizer recommendation in use is not paying anymore. This study was therefore, conducted to characterize the landscape features and related biophysical settings and to identify the currently implemented soil fertility management practices in the agricultural lands of Farta, Fogera and Gondar Zuria districts, in northwestern Ethiopia.

## MATERIALS AND METHODS

**Description of the study area:** The study area is situated in Farta, Fogera and Gondar Zuria districts of the Amhara national regional state, Ethiopia (Fig. 1). With a total estimated area of 3385.17 $km^2$ [34], the study area is situated within geographic coordinates ranging from 11°41'-12°40'N to 37°26'-38°15' E. Altitudinal variability in the study area ranges from 1762-4035 meters above sea level (m.a.s.l). The 10 years (2005-2014) mean annual rainfall amount is 1295 mm and the rainfall pattern is mono-modal, extending from May to October (Fig. 2). The annual minimum and maximum temperatures are 12 and 25°C, respectively and the annual mean temperature is 19°C (NWRMS, personal communication).

**Survey methodology and data collection:** Sampling point selection, soil sampling and data collection were performed following the Ethiopian Soil Information System (EthioSIS) protocol[35]. Equilateral sampling grid points (pre-defined sampling points) with 3 by 2 km sampling intervals were overlaid on specific district maps using Arc GIS Version 10 software. The combined district shape files and pre-defined sampling points were later converted to KML file for their import to Google Earth. After importing to Google Earth just by zooming in, different land uses were identified and classified. The pre-defined sampling points falling on agriculturally important land use types (cultivated lands and potential arable lands) were selected as important points for data and soil sample collection activities. In general, the survey methodology used was spatially stratified grid sampling technique more skewed to agricultural lands. For data

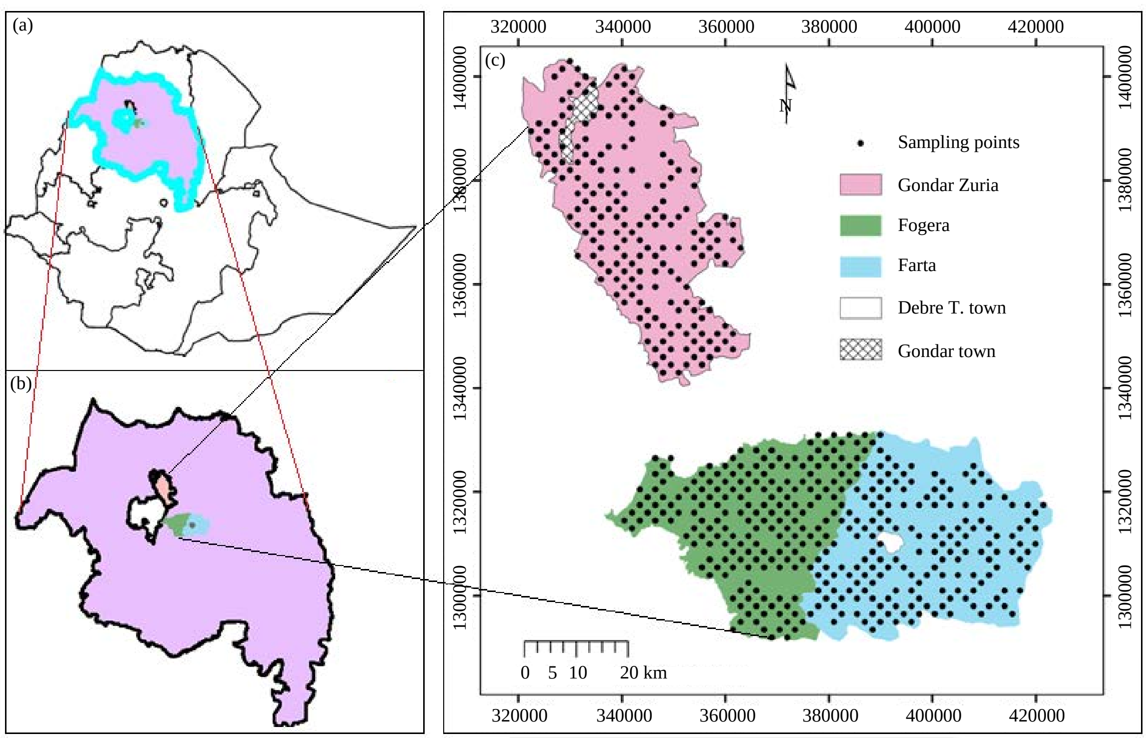


Fig. 1(a-b): Geographical location of the study districts and pre-defined sampling points, (a) Amhara in Ethiopia, (b) Study districts in Amhara and (c) Study districts

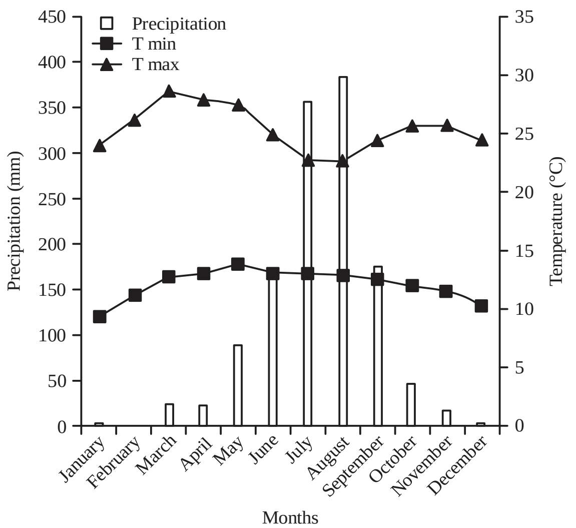


Fig. 2: Ten years (2005-2014) mean monthly maximum and monthly minimum temperatures and monthly precipitation of the study area
Source: NWRMS (North West Region Meteorological Service)

collection a semi-structured questionnaire (both in digital and hard copy formats) was used. Biophysical characterization of the study area was performed by conducting individual interviews with local farmers and also through personal observations. In addition, secondary data such as: Area of land under cultivation, fertilizer distribution and use history, cultivated crops and their productivity, were also collected from respective zonal and district agricultural offices.

**Soil sample collection, preparation and analysis:** In the field, pre-defined sampling points were navigated and the centers of the sub-plots were determined using a tablet uploaded by an application called Locus free (with GPS, altimeter and compass readings). From each pre-defined sampling point, a composite soil sample was collected from 9 sub-points: From the center of sub plots and from other eight equidistant points (15 m) encircling the central sub plot in crisscross manner. Generally, a total of 470 composite surface soil samples (0-20 cm soil depth) were collected from Farta, Fogera and Gondar Zuria districts. The collected soil samples were air dried and ground using mortar and pestle and passed through a 2 mm sieve at Bahir Dar Soil Testing Laboratory, in Ethiopia.

Soil analysis included the following parameters which were performed in three different laboratories: pH (Gondar Soil Testing Laboratory, Ethiopia); organic carbon (OC), total nitrogen (TN), cation exchange capacity (CEC) and particle size distribution at the National Soil Testing center, in Addis Ababa, Ethiopia; available P, available S, extractable micronutrients (Fe, Mn, Zn, Cu and B) and exchangeable Ca, Mg, K, Na at Altic B.V., Dronten, The Netherlands. Soil pH was measured in the supernatant suspension of 1:2 soil and distilled water mixture by using a pH meter[36]. For the determination of soil OC, TN and CEC, mid infra-red (MIR) spectral analysis technique was employed. Particle size distribution analysis was performed by using laser scattering particle size distribution analyzer (model HORIBA-Partica, LA-950V2). Mehlich III[37] multi nutrient extraction procedure was used to extract the following nutrient elements: Available P, available S, exchangeable cations (Ca, Mg, K and Na) and extractable micronutrients (Fe, Mn, Zn, Cu and B). The concentrations of each Mehlich III extracted macro and micronutrients were later determined by ICP-OES.

**Agro-ecological zone classification:** For agro-ecological zone classification, a methodology proposed by Hurni[38] was employed. Altitude measurement results (n = 549) and 10 years (2005-2014) mean monthly rainfall data were used to delineate the study area in to different agro-ecological zones.

**Data analysis:** Some field data and related laboratory analysis results were subjected to descriptive statistics analysis. Analysis of variance (one-way ANOVA) was employed to determine the presence of significant differences between measured parameters. For means with significant ($p<0.05$) differences, mean comparison was performed using the Duncan's multiple range test (DMRT). For data analysis, computer programs such as Microsoft Office Excel 2007 version 12 and Statistical Package for Social Science version 20 (SPSS[39]) were used.

## RESULTS AND DISCUSSION

**Topographic characteristics of the study area:** Following food and agriculture organization (FAO)[40] landform classifications, a total of six major landforms: Level plain, undulating plain, medium grade hill, medium grade mountain, high grade hill and high grade mountain, were identified in the study area (Fig. 3).

According to the survey results, 74.1, 19.5 and 6.4% of the agricultural lands in Fogera district are found in the plain, hilly and mountainous landforms, respectively. In Farta district, both level landforms and major landforms representing sloppy category have almost equal area coverage (42 and 41%, respectively). Besides that, from the total arable agricultural lands found in Farta district, about 17% are found in ecologically fragile steep landforms (with slope gradient greater than 30%). This finding is in agreement with the report of Gedamu-Gobena[22], who indicated 26% steep landform coverage from the total estimated area in Farta district.

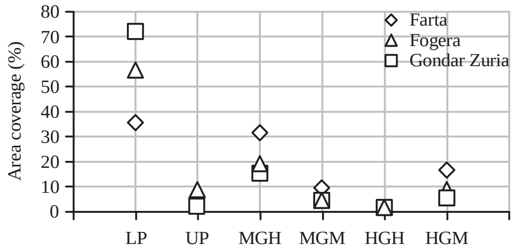


Fig. 3: Percent distribution of agricultural lands on different land forms

Where LP, UP, MGH, MGM, HGH, HGM represent level plain, undulating plain, medium grade hill, medium grade mountain, high grade hill and high grade mountain land forms respectively

Steep land cultivation and further encroachment to these landforms is a major concern in Farta and Gondar Zuria districts. The identified steep landforms are mostly dominated by untreated and shallow soils (locally called Chincha and Borebor) which are being used for the cultivation of common crops growing in the study area. Consequently, these landforms require either making land use change decision to withdraw them from agricultural activities or put in place well designed physical and biological soil and water conservation measures. With regard to conservation structures, it was also observed that massive rehabilitation works are being implemented in the study area on some selected watersheds solely through mass mobilization. As a result, some highly degraded areas have started to revive after just 1 or 2 years of area enclosure.

Similar encroachment and steep slope cultivation activities were also noted in a study conducted in Northern Ethiopia[30,41]. Moreover, the observation related to massive rehabilitation work in the study area is in harmony with the findings of some authors Desta *et al.*[28], Desta *et al.*[31], Bishaw[24] and WFP[26], who reported that further soil degradation in Ethiopia was averted at least from conserved lands. Nevertheless, the intervention scale is not comparable to the longstanding problems these areas have[28-32] although during the past decade, it was possible to rehabilitate about 20 million ha of degraded land at national level (Tekalign Mamo, personal communication).

Plot level slope measurement results (n = 470) reveal that the majority of the agricultural lands (about 59%) are categorized under gently sloping and sloping slope categories (2-10% slope). In addition, agricultural lands having steep slope gradient classes (30-60% slope) are found to be 10%. In general, about 24% of the agricultural lands are found to lie on slope gradient classes which are marginally suitable (14%) and not suitable (10%) for common agricultural activities (slope>15%) unless appropriate conservation measures are employed. The results clearly indicate the pressure the increasing population is putting on the marginal lands that are prone to degradation. Further, this expansion of agriculture into the marginal lands with no adequate conservation and/or management scenarios put in place could be one of the prime causes of the heinous land degradation observed in the study areas.

**Agro-ecology of the study area:** The observed variability in major land forms gave rise to the formation of different agro-ecological zones in the study area. Following the methodology proposed by Hurni[38], the study area is classified into five major agro-ecological zones namely High Wurch (extremely cool highland), Wet Wurch (cool highland), Moist Dega (humid highland), Wet Woynadega (cool sub-humid highland) and Moist Woynadega (sub-humid highland). The altitude requirement to classify an area under one of these three major AEZ names (Wurch, Dega and Woynadega) is, greater than 3200, 2300-3200 and 1500-2300 m.a.s.l, respectively. Similarly, qualifiers (like Wet and Moist) are assigned based on the quantity of precipitation an area is receiving (>1400 and 900-1400 mm, respectively).

Among the identified agro-ecological zones, three zones, Moist Dega, Wet Woynadega and Moist Woynadega comprise about 98.5% of the agricultural lands, five out of the six identified soil types and almost all crops grown in the study area. Conversely, some agro-ecological zones like High Wurch in Farta district and Moist Dega in Fogera district have very small area coverage (0.5% each), which makes their representation on the AEZ map of the respective district difficult (Fig. 4).

In general, the number and area coverage of the identified AEZs in the study area are found to be different from what has been reported by different authors. Chamberlin and Emily[6] tried to put all the identified 11 AEZs on the map of Ethiopia from which the study area was only represented by two AEZs (Moist Woynadega and Moist Dega). On another AEZ map type of the country, which included a total of 33 elaborated agro-ecological zones, the majority of the study area was represented by one agro-ecology (Tepid moist mid highland (M3)) as compared to a small portion of land which was represented by cool moist mid highland (M4)[42].

Apart from this, the indicated agro-ecological classification for Gondar Zuria district was in agreement with the finding by Berhe[43] who reported the prominence of Moist Woynadega agro-ecological zone in the district followed by very small area as Moist Dega. On the other hand, unlike the current finding, Gedamu-Gobena[22] has only identified 2 purely traditional (Dega and Woynadega) agro-ecological zones in Farta district.

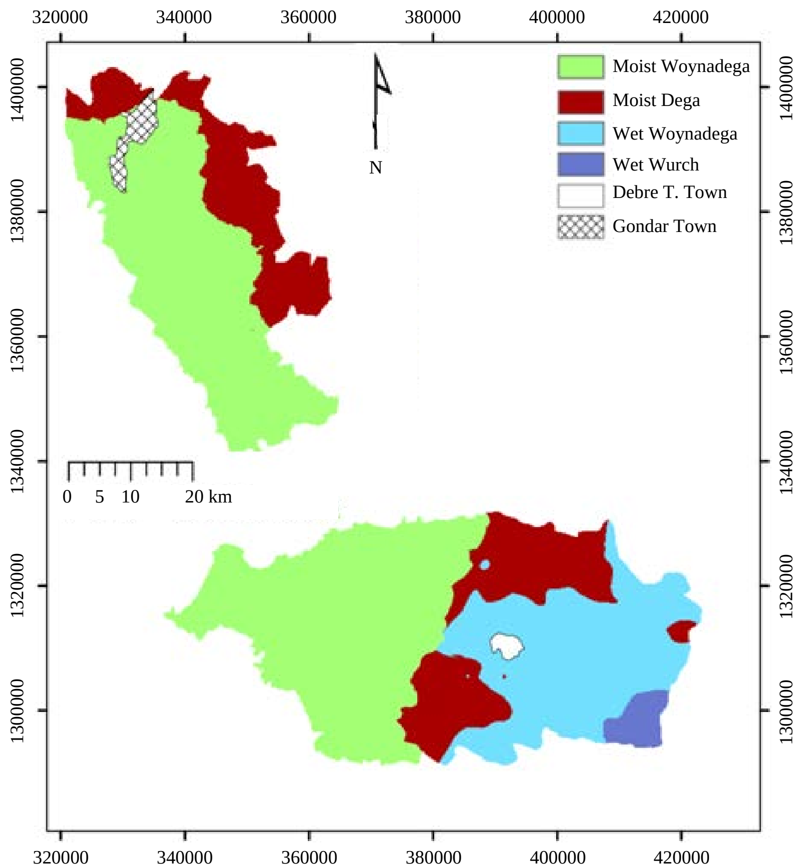


Fig. 4: Major agro-ecological zones identified in the study area

In general, in this study, the possibility of getting more AEZs in a comparatively small geographic area was observed when the observation scale is changed to large. However, small number of meteorological stations (only seven in the study districts having a total area of 3385.17 $km^2$), which could not produce site-specific precipitation data, was considered as a limitation for precisely delineating the different AEZs. Therefore, to better match crops with agro-ecology and devise coping mechanisms for the observed more frequent and extreme climate variability, additional meteorological stations should be established and the current small scale AEZ maps of the country reassessed.

**Variation of selected soil properties with topographic features:** In order to evaluate whether a change in slope gradients have any relationship with soil fertility status, soil samples collected from different slope gradient classes were analyzed and their results were also compared. The ANOVA results for most of the soil properties showed a significant difference ($p<0.01$) among different slope gradient classes (Table 1). However, there was no significant difference ($p>0.05$) between different slope gradient classes and the measured organic C, available P, exchangeable K and extractable B values. Generally, as the slope gradient increased, decreasing trend was observed for clay content, pH, exchangeable $Ca^{2+}$ and $Mg^{2+}$, CEC, available S and extractable micronutrients (Mn, Zn, Fe and Cu). On the other hand, as the slope gradient increased, sand, silt and total N contents also increased.

The first observed trend could be related to the loss of clay and the above listed nutrient elements from the upper slope positions through erosion and their subsequent deposition at the lower slope positions. The indicated comparative increase in the quantity of clay and basic cations could also be the reason for the high CEC and pH values in soils of lower slope gradient classes. On the other hand, significantly higher total N contents on soils with higher slope gradient classes (moderately steep and steep slopes) than soils with lower slope gradient classes might be related to the abundance of grazing lands on the former slope classes.

Table 1: Variation of selected soil properties with slope gradients in the study area

| | | Slope gradient classes (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Analyzed parameters | Range | <2 | 2-5 | 5-10 | 10-15 | 15-30 | 30-60 | Sig. | F |
| Sand (%) | 12.86-64.2 | 24.43 | 26.14 | 31.72 | 34.44 | 36.39 | 36.36 | 28.79 | 0.000 |
| Silt (%) | 21.88-62.3 | 31.02 | 33.01 | 35.13 | 35.86 | 35.80 | 36.59 | 8.37 | 0.000 |
| Clay (%) | 4.38 – 65.1 | 44.55 | 40.84 | 33.15 | 29.70 | 27.81 | 27.03 | 28.84 | 0.000 |
| pH ($H_2O$) 1:2 | 4.9-7.9 | 6.41 | 6.49 | 6.14 | 6.17 | 6.18 | 6.29 | 8.873 | 0.000 |
| OC (%) | 0-5.53 | 1.53 | 1.71 | 1.98 | 1.81 | 1.89 | 1.99 | 1.429 | 0.214 |
| TN (%) | 0-0.51 | 0.12 | 0.15 | 0.19 | 0.18 | 0.19 | 0.20 | 5.358 | 0.000 |
| Av.P (mg $kg^{-1}$) | 1-150 | 11.29 | 15.18 | 20.89 | 22.85 | 23.96 | 22.00 | 2.227 | 0.051 |
| Exc. K ($cmol_c$ $kg^{-1}$) | 0.1-2.9 | 0.99 | 0.98 | 0.95 | 0.96 | 0.94 | 0.91 | 0.175 | 0.972 |
| Exc. Ca ($cmol_c$ $kg^{-1}$) | 2.9-75.6 | 28.41 | 28.92 | 20.42 | 20.82 | 20.74 | 20.45 | 14.583 | 0.000 |
| Exc. Mg($cmol_c$ $kg^{-1}$) | 0.9-25.1 | 12.97 | 11.93 | 7.98 | 7.80 | 8.23 | 8.19 | 16.393 | 0.000 |
| Av. S (mg $kg^{-1}$) | 1-52 | 12.29 | 12.00 | 11.50 | 9.58 | 10.07 | 8.96 | 3.788 | 0.002 |
| Ext. Fe (mg $kg^{-1}$) | 38-613 | 214.18 | 226.49 | 193.55 | 161.52 | 155.87 | 146.99 | 12.896 | 0.000 |
| Ext. Mn (mg $kg^{-1}$) | 16-301 | 150.67 | 149.43 | 132.60 | 104.58 | 85.26 | 70.60 | 25.148 | 0.000 |
| Ext. Cu (mg $kg^{-1}$) | 0.3-9.7 | 5.05 | 3.88 | 2.84 | 2.34 | 2.09 | 2.07 | 33.24 | 0.000 |
| Ext. B (mg $kg^{-1}$) | 0-0.79 | 0.27 | 0.27 | 0.26 | 0.22 | 0.23 | 0.23 | 1.836 | 0.104 |
| Ext. Zn (mg $kg^{-1}$) | 0.4-39.3 | 2.64 | 2.36 | 2.73 | 2.09 | 1.77 | 1.61 | 3.112 | 0.009 |
| CEC ($cmol_c$ $kg^{-1}$) | 13-99.8 | 54.39 | 47.99 | 37.09 | 37.84 | 38.37 | 39.49 | 13.723 | 0.000 |

Exc. and Ext.: Exchangeable and extractable elements, respectively

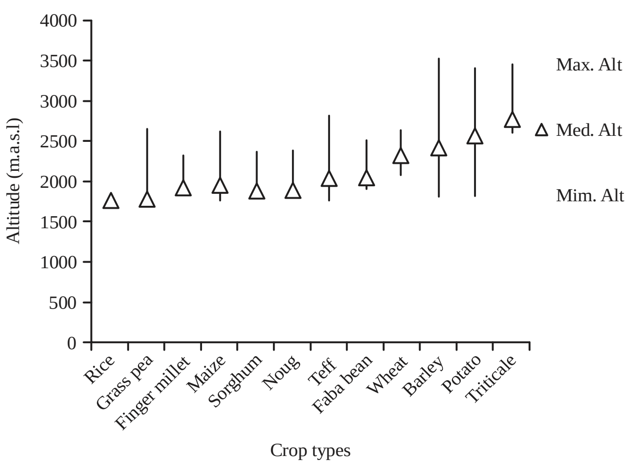


Fig. 5: Distribution of crop types across different altitudes in the study area

The results of this study are in agreement with the findings of some researchers Bezabih *et al.*[44], Selassie *et al.*[27]; and Fanuel[14], who reported that the quantity of clay, pH, exchangeable $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$ and CEC were found to be higher on lower slope gradients than on the medium and upper slope gradient classes. Similarly, the increase in sand and silt content with the slope gradient was also reported in a study conducted in northwestern Ethiopia[27]. However, the indicated trend for total N was different from what has been documented by some other researchers[27,44].

According to critical levels outlined for Ethiopian soils[45], most slope gradient classes are characterized by clay-loam textured soils, with moderately acidic soil reaction and with observed deficiency (low to very low) of some nutrient elements (TN, available P, available S and extractable B). Similarly, optimum (K, Ca, Fe and Cu) and high to very high (Mg and CEC) nutrient quantities were identified in all slope classes regardless of slope gradient differences. The listed soil physicochemical properties observed in each slope gradient classes are found to be similar to the properties observed in the identified six soil types in the study area.

**Crop adaptability to altitudinal variability:** The agricultural lands in the study area are characterized by rugged topography and with highly variable altitudinal values ranging from 1762 m.a.s.l in Fogera district to 3704 m.a.s.l in Farta district (Fig. 5). Among the three districts studied, agriculture is being practiced in a wide range of altitudes in Farta district (1901-3704). Gedamu-Gobena[22] and SGFEDD[34] also reported that the altitude in Farta district varied between 1900-4035 m.a.s.l.

Although the agricultural lands seem to have been expanded to the high-lying areas as well, the majority (71.4%) are concentrated in the 1700-2300 m.a.s.l altitudes. It is only about 28.6% of the agricultural lands that are distributed above 2300 m.a.s.l. These differences in altitude where agriculture, particularly crop production is practiced provide the opportunity for farmers to produce a wide range of crops. In other words, the difference in altitude has resulted in different agro-ecologies that are suitable for a variety of crops.

The most widely cultivated crops in the study area are: Teff (*Eragrostis tef* Zuc. Trotter), finger millet (*Eleusine coracana* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare*), sorghum (*Sorghum biocolor* L.), rice (*Oryza sativa* L.), triticale (*X Triticosecale wittmack*), niger seed (*Guizotia abyssinica*),

Table 2: Major local soil naming approaches used in the study area

| | District distribution | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Farta | | Fogera | | Gondar Zuria | | Study area | |
| Approaches | Number of samples | Percent coverage | Number of samples | Percent coverage | Number of samples | Percent coverage | Number of samples | Percent coverage |
| Color based names | 96 | 61 | 144 | 79 | 104 | 76 | 344 | 72 |
| Other soil property related names | 61 | 39 | 38 | 21 | 32 | 24 | 131 | 28 |
| Total | 157 | 100 | 182 | 100 | 136 | 100 | 475 | 100 |

grass pea (*Lathyrus sativus*), bread wheat (*Triticum aestivum*), chick pea (*Cicer arietinum*), potato (*Solanum tuberosum*) and faba bean (*Vicia faba*). Different researchers, Gedamu-Gobena[22] and Belayneh[7] also reported the predominance of similar crops in the study area. From the listed crops types, rice and triticale are mostly grown in the lower (1760-1890 m.a.s.l) and upper (2625-3467 m.a.s.l) altitudes, respectively as compared to the remaining crops which require comparatively wider altitudinal ranges for their growth and development (Fig. 5). The observed altitude requirement for triticale is in agreement with findings by Minale *et al.*[46] and Gedamu-Gobena[22].

Barley and potato (1800-3500 m.a.s.l) and teff (1800-2800 masl) are some of the major crops that are adapted to wide ranges of altitudes and AEZs. The observed altitudinal variability for barley is in harmony with the findings of Chamberlin and Emily[6], who indicated the increase in importance of barley production with increasing altitude. On the other hand, different researchers Hurni[38] and Gorfu and Ahmed[47] have estimated an altitude of 2300 m.a.s.l as the extreme altitude for teff growth. However, the current 2800 m.a.s.l finding might be due to an increased adaptability of teff to the environment which was presumed unfavorable for its growth.

**Local soil classification system:** Farmers identified a total of six major local soil names which are most frequently used in the study area. The identified local soil names can be broadly classified into two groups based on the approaches followed by the local farmers. These are soil color based names (72%) and names based on other soil properties (28%). From the listed approaches, the latter one is more connected to the observed soil fertility limitations and related management implications (Table 2). The most common color based local soil names identified in the study area are Keyattie, Walka and Yeguassa Afer (Yeguassa Tikur Afer). On the other hand, Chincha, Borebor and Deshen represent soil names classified based on other soil properties (soil depth, fertility status, stoniness, workability, etc).

Majority of the soil types in the study districts (43.4%) have Keyattie soils (Keyattie in Amharic means reddish) (Fig. 6). The color of these soils, according to $\text{Munsell}_{(dry)}$ color chart, ranged from dark reddish brown (5YR 3/3) to light brown (7.5YR 6/3) and was rated by the local farmers to have moderate fertility and adequate soil depth. Walka is another color related local soil name with estimated area coverage of 29.1% (Fig. 6). Walka and Tikur Afer are being used interchangeably both to express black colored soils (Tikur in Amharic language is black). The color of these soils, according to $\text{Munsell}_{(dry),}$ ranged from very dark gray (7.5YR 3/1) to light brown (7.5YR 6/4). Walka soils are known by their high fertility status and sufficient soil depths. However, their sticky natures when wet and related workability problems were mentioned as major constraints to efficiently use these soil types in the study area. In this regard, local farmers tried to further qualify Walka soils based on the level of stickiness they have by adding different prefixes (Moraha, Chilla, tokka).

Local farmers tried to solve the problems in Walka soil management by implementing different practices which include cultivation of their lands during the first few showers of rain when the soil is in moist condition, by late planting of crops and by selecting tolerant crop species to waterlogged conditions. In addition, the extension system has also introduced the broad bed maker (BBM) technology packages and ways of making improved broad bed and furrow systems to drain excess moisture from the field. Similarly, some authors Alemayehu and Hailemariam[48] and Wubie[49] also reported the recent widespread use of Aybar BBM technology package in some areas in Ethiopia having similar Walka soil types.

Yeguassa Afer (also called Yeguassa (Yeterara) Tikur Afer) is another color based local soil name, which is mainly known by its very dark color and its lower soil bulk density. According to $\text{Munsell}_{(dry)}$ color chart, the color of this soil type varies between very dark gray (7.5YR 3/1) to dark gray (7.5YR 4/1). Moreover, according to observation made, one could also easily identify Yeguassa afer from other soil types by the unique sound produced when the land is tapped by foot and this might be related to its lower soil density. Similar

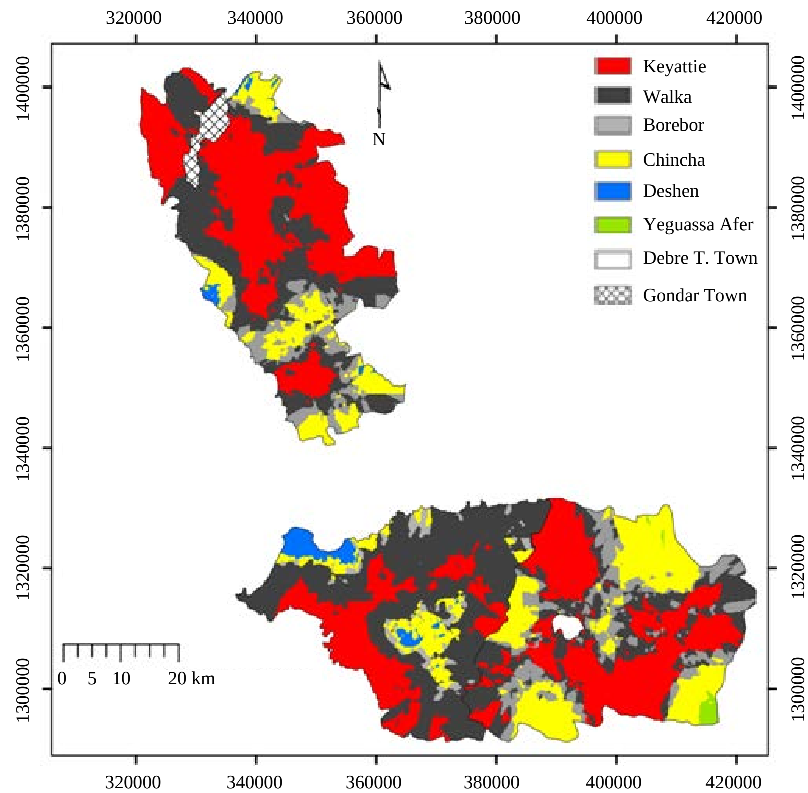


Fig. 6: Spatial distribution of local soil types in the study area

observation was reported by WRB[50] in that the hollow sound when tapped is an indication of the presence of highly porous feralic sub surface horizon in Andosols. Yeguassa Afer has very small area coverage in the study area (0.6%) and it is found in Farta district at the higher peaks of mount Guna.

Borebor, Chincha and Deshen are types of local soil names given by the farmers to express other dominant soil properties irrespective of their colors. Hence, local farmers distinguish Borebor soils from the other soil types by their comparatively lower fertility status and limited soil depths. Borebor soils have 7.2% area coverage and are found widely distributed in different topographic positions of the study area. In some places of the study area Borebor soils are also known by the name Ferefer or Nechatie (which means whitish). Similarly, Chincha (also called Gotagot) is a widely used local soil name in the study area which is characterized by the presence and dominance of small to medium sized stones and rock outcrops. Moreover, shallower soil depth and poor fertility levels were also reported to characterize these soil types. Chincha accounts for about 17.5% of the soils of study area from which majority (about 50%) is found in Farta district. Normally, the presence of stones demonstrates the higher degree of land degradation in the area. The other local soil name in this group is Deshen, which is the result of continuous depositions of alluvial sediments for the last many years. Deshen is the most preferred soil type in the study area due to its comparatively higher fertility level, good workability and sufficient soil depth. The study area coverage by Deshen is about 2.3% and it is found mainly in Fogera and Gondar Zuria districts. Periodical flooding of Rib River and Lake Tana might be the reason for the formation of Deshen soils in the area.

The study result in Farta district was in agreement with Gedamu-Gobena[22], who identified predominating four local soil names (Walka, Keyattie, Borebor (Nechatie) and Chincha). However, in this study one more local soil name. Yeguassa Afer, was also identified.

Generally, farmers' local soil naming approaches were found to base the following major soil properties: Soil color, soil depth, stoniness, fertility status, texture and workability. Similarly, farmers living in different geographic locations were found to follow similar soil properties when classifying their soils[14,21-23,51]. However, from the listed soil properties, soil color was found to be the most predominantly used (72%) criterion in the study area and so is in many different parts of the country[14,17,52,53].

Table 3: Local soil names and their measured soil properties

| Measured parameters | Borebor (N = 34) | Chincha (N = 83) | Deshen (N = 11) | Keyattie (N = 206) | Walka (N = 138) | Yeguassa Afer (N = 3) | F | Sig. |
|---|---|---|---|---|---|---|---|---|
| Altitude (m.a.s.l) | 2306.00 | 2206.00 | 1814.00 | 2159.00 | 1956.00 | 3563.00 | 30.35 | 0.000 |
| Soil depth(cm) | 16.70 | 15.30 | 20.00 | 19.30 | 20.00 | 20.00 | 37.49 | 0.000 |
| Slope (%) | 18.90 | 24.16 | 3.91 | 10.66 | 4.48 | 32.33 | 51.54 | |
| Sand (%) | 38.06 | 35.87 | 25.84 | 31.77 | 25.88 | 48.08 | 29.21 | 0.000 |
| Silt (%) | 36.24 | 36.03 | 38.94 | 35.22 | 32.11 | 38.75 | 11.92 | 0.000 |
| Clay (%) | 25.70 | 28.10 | 35.22 | 33.01 | 42.02 | 13.17 | 29.75 | 0.000 |
| Textural class | L | CL | CL | CL | C | L | | |
| pH ($H_2O$) 1:2 | 6.19 | 6.23 | 6.57 | 6.13 | 6.59 | 5.58 | 16.96 | 0.000 |
| OC (%) | 1.58 | 2.19 | 1.31 | 1.96 | 1.73 | 4.66 | 10.65 | 0.000 |
| TN (%) | 0.17 | 0.21 | 0.09 | 0.19 | 0.16 | 0.44 | 14.44 | 0.000 |
| Av. P(mg kg$^{-1}$) | 24.41 | 19.21 | 16.67 | 26.58 | 14.58 | 19.67 | 1.95 | 0.086 |
| K (cmol$_c$ kg$^{-1}$) | 0.80 | 0.93 | 1.05 | 1.01 | 1.01 | 0.71 | 1.27 | 0.275 |
| Ca (cmol$_c$ kg$^{-1}$) | 19.54 | 20.22 | 26.24 | 20.45 | 32.35 | 10.28 | 29.91 | 0.000 |
| Mg (cmol$_c$ kg$^{-1}$) | 7.40 | 8.22 | 10.37 | 8.71 | 12.21 | 1.95 | 13.52 | 0.000 |
| Mn (mg kg$^{-1}$) | 115.43 | 88.14 | 191.08 | 119.42 | 140.88 | 48 | 12.68 | 0.000 |
| Av. S (mg kg$^{-1}$) | 9.45 | 9.61 | 14.42 | 12.29 | 10.20 | 15.67 | 5.13 | 0.000 |
| Cu (mg kg$^{-1}$) | 1.78 | 2.38 | 3.73 | 2.98 | 3.81 | 0.97 | 16.53 | 0.000 |
| B (mg kg$^{-1}$) | 0.24 | 0.24 | 0.29 | 0.25 | 0.29 | 0.21 | 1.98 | 0.081 |
| Zn (mg kg$^{-1}$) | 2.97 | 1.92 | 2.60 | 2.67 | 2.21 | 2.90 | 1.34 | 0.261 |
| Fe (mg kg$^{-1}$) | 155.29 | 162.39 | 254.56 | 198.33 | 213.66 | 144.70 | 5.98 | 0.000 |
| CEC(cmol$_c$ kg$^{-1}$) | 37.80 | 37.38 | 46.91 | 39.06 | 46.39 | 31.28 | 12.55 | 0.000 |

Table 4: Soil types in relation to physiographic attributes, fertilizer use and crop productivity

| Soil type | Altitude (m.a.s.l±SD) | Slope (%±SD) | Fertilizer use (kg ha$^{-1}$) DAP | Urea | Crop productivity (t ha$^{-1}$) Without fertilizer | With fertilizer | Major grown crops |
|---|---|---|---|---|---|---|---|
| Borebor | 2306±273$^{c}$ | 19±13$^{a}$ | 47.5$^{ab}$ | 65.0$^{d}$ | 0.8$^{e}$ | 2.6$^{h}$ | Teff, barley, wheat, finger-millet, triticale |
| Chincha | 2206±250$^{c}$ | 24±14$^{a}$ | 50.7$^{ab}$ | 44.3$^{cd}$ | 0.9$^{e}$ | 1.8$^{h}$ | Teff, barley, faba bean, maize, wheat |
| Deshen | 1813±37$^{a}$ | 4±0.9$^{b}$ | 54.0$^{ab}$ | 15.7$^{c}$ | 2.5$^{f}$ | 2.9$^{h}$ | Rice, maize, rye, |
| Keyattie | 2159±334$^{bc}$ | 10±9$^{b}$ | 71.5$^{ab}$ | 67.2$^{d}$ | 1.2$^{e}$ | 2.4$^{h}$ | Teff, maize, finger millet, barley, sorghum |
| Walka | 1955±255$^{ab}$ | 4±2$^{b}$ | 79.2$^{a}$ | 76.8$^{d}$ | 1.0$^{e}$ | 2.2$^{h}$ | Grass pea, teff, rice, sorghum, chickpea |
| Yeguassa Afer | 3563±124$^{d}$ | 32±15$^{c}$ | 35.0$^{b}$ | 35c$^{d}$ | 1.0$^{e}$ | 1.7$^{h}$ | Barley, triticale, potato |

The values with the same letters within a column are not significantly different by DMR test (p<0.05). Where, SD represents standard deviation

As per the ratings for Ethiopian soils (EthioSIS[45]), all the identified soil types have moderately acidic pH (5.6-6.5) and very low to low quantities of some nutrient elements (TN, Available P, available S and extractable B) (Table 3). However, despite these similarities, Yeguassa Afer is found to be different from the remaining soil types by its altitude requirements (extreme peak altitude), very high OM (8.03%), high TN (0.44%), low extractable Cu (0.97 mg kg$^{-1}$) and very low extractable Mn (48 mg kg$^{-1}$) values (Table 3).

With regard to fertilizer use, application of almost similar (p>0.05) fertilizer types and rates were observed in all soil types identified (Table 4). Moreover, similar crop productivity irrespective of soil type differences might be related to the observed similar plant nutrient deficiencies in all the soil types which could be among the limitations in exploring the crop's yield potential (Table 4). In general, nutrient mining, low fertilizer application rates, unbalanced fertilization, abandonment of fallowing and removal of crop residue could be some of the reasons for the observed soil fertility problems in the study area.

In relation to this, some authors Taddesse[54], Bishaw[24] and Zelleke *et al*.[55], indicated that land degradation, nutrient mining, recurrent droughts, variable rainfall and crop pest damages are the major reasons for the current low agricultural productivity in Ethiopia.

All in all, some similarities were observed between farmers perceived fertility status of individual soils and the measured soil properties. Some clear similarities were reflected on the farmers' ability to predetermine soil types with shallower soil depths (Chincha and Borebor), soil types that are poor in fertility (Yeguassa Afer) and soils with workability related problems (Walka the most clay rich soil type).

Table 5: Local soil names, farmers perceived properties and their WRB equivalent names

| Local soil name | Fertility status | Workability | Water holding capacity | Soil depth* | Soil color | WRB** equivalent |
|---|---|---|---|---|---|---|
| Borebor | Low | Loose | Low | Shallow | Variable | Cambisols |
| Chincha | Low | Hard | Very low | Shallow | Variable | Leptosols |
| Deshen | Very high | Intermediate | Medium | Deep | Variable | Fluvisols |
| Keyattie | Moderate | Intermediate | Medium | Intermediate | Reddish | Luvisols |
| Walka | High | Hard | High | Deep | Blackish | Vertisols |
| Yeguassa Afer | Low | Extremely loose | High | Intermediate | Strong black | Andosols |

*Local farmers estimate soil depths by the degree by which surface soils are penetrated by local plows, **WRB equivalent soil names were assigned based on FAO[59], Belayneh[7] and Gebregziabher *et al.*[30] reports

Research findings in Tanzania and Ghana also reported the compatibility of results between farmers perceived fertility classes and analyzed nutrient status[51,56]. Moreover, in a study conducted in Rwanda, Rushemuka *et al.*[57] also indicated practicability, rationality and user-friendly nature of farmers' soil knowledge than international classification systems. However, farmers' classification was also found to be usually inconsistent and management oriented[52,58] compared to scientists who focus on diagnostic properties[58], which makes their direct correlation difficult. In general, the list of locally identified soil types, their observed major soil properties and their equivalent reference soil groups names (according to WRB) are presented below (Table 5).

## Traditional soil fertility management practices and fertilizer use

**Crop rotation:** Most farmers (95%) in the study area implement different crop rotation practices that are perceived to be suitable for their specific agro-climatic and crop conditions. The following three specific areas having their own unique crop rotation sequences were identified: Fogera plain (rice-grass pea), Vertisol dominating area of Gondar Zuria (teff-sorghum-chickpea (or grass pea)) and the extreme highland areas of Farta (triticale-potato-barley or triticale-potato). In the remaining majority areas, depending on altitudinal variations and related crop preferences, the following crop rotation sequences are widely used: Teff-wheat-barley-faba bean (or field pea), teff-wheat (barley)-finger millet-chickpea, barley (early maturing)-chickpea (relay cropped)-wheat (teff).

Crop rotation is the main agricultural practice implemented in the study area not only as a means to improve the soil fertility of agricultural lands but also to protect potential weed and pest infestation problems. Similarly, Megersa[20], Karltun *et al.*[17], Fanuel[14] and FAO[5] reported soil productivity improvement and pest control roles of crop rotations. However, in the extreme highlands of Farta district, it was observed that barley native to the area is now being replaced by triticale most probably due to soil acidity and disease problems[7,60] and also suspected soil fertility decline since triticale is known to thrive well under poor soil fertility conditions[22]. Another problem observed in implementing crop rotation especially in some high altitude areas of the study area was the failure of faba bean (field pea) to grow as a sole crop. The farmers' solution in this regard was to implement mixed cropping practices just by sowing faba bean together with other cereals. The probable reason for legume crop failure could be the soil acidity problems in the area[7,60] and suspected plant diseases like chocolate spot (district experts, personal communication). In relation to this, similar crop rotation practices without legume component were also identified in Beseku, Southern Ethiopia, however, the reason in this case was bean thievery directly from the field[17].

**Fallowing:** From about 470 sampling points surveyed, only 12 points (2.4%) were identified as fallow lands. Fallowing is not considered as the alternative soil fertility replenishment mechanism mainly due to high population pressure and related scarcity and fragmentation of farm lands in the study area. The observed abandonment of fallowing was also reported in similar studies conducted in different parts of the country[14,17,21-23,32].

From the identified 12 fallow lands, the majority (67%) were found on hilly and steep topographic features whose measured slope gradient are greater than 16%. Moreover, from those fallow lands which were found in gently sloping categories, some plots were let to fallow not only due to fertility problems but also other socio-economic problems like poverty, ill health and lack of ownership (land, which has been distributed to organized youths) (Example, in Fogera district). Therefore, agricultural plots of the study area which were let to fallow were either highly degraded soils or there existed other socioeconomic reasons hindering their proper use. In this regard, Pound and Jonfa[21] and Fanuel[14] also indicated that lack of oxen and ill health were among the likely reasons for a farm to lie fallow in Wolaita, Southern Ethiopia.

Table 6: Application rates of inorganic fertilizers in the study area (2012-2015)

| Cropping season | Fertilizer use (kg ha$^{-1}$) Total cultivated lands Applied fertilizer DAP | Urea | NPS | Fertilized fields Applied fertilizer DAP | Urea | NPS | Applied nutrient elements N | P | S |
|---|---|---|---|---|---|---|---|---|---|
| 2012/13 | 11.3 | 12.3 | - | 21.0 | 22.8 | - | 14.0 | 4.2 | - |
| 2013/14 | 16.5 | 20.5 | - | 31.0 | 38.4 | - | 23.2 | 6.2 | - |
| 2014/15 | 18.2 | 26.0 | 0.4 | 34.1 | 49.1 | 0.8 | 29.0 | 6.9 | 0.1 |
| 2015/16 | 9.4 | 28.4 | 12.0 | 17.6 | 53.3 | 22.6 | 32.2 | 5.5 | 2.9 |

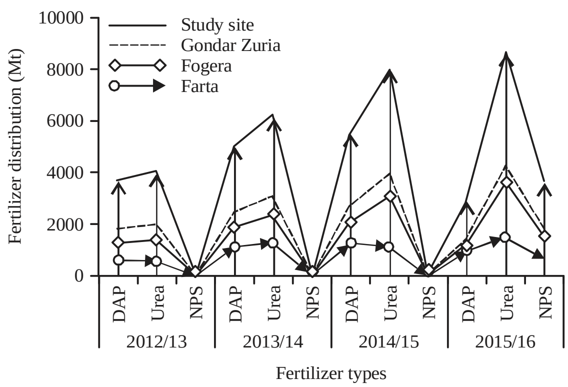


Fig. 7: Fertilizer types and their district base distributions (2012-2015)

**Inorganic fertilizer use:** Inorganic fertilizer is a more widely used (84%) input than organic fertilizer which accounts for only 16% of the fertilizer users. Until recently, di-ammonium phosphate (DAP) and urea were the only inorganic fertilizers which have been used in the study area. However, since the last 2 years, the use of blended or compound NPS fertilizers has become operational as a result of the recent revision made following the digital soil fertility mapping initiative being conducted in the country. In addition, at about the same time, the country has switched to the use of granular urea abandoning, the long used prilled urea.

Information obtained from North and South Gondar zone agricultural development offices indicates a general increase in inorganic fertilizer distribution and use in the study area (Fig. 7). Following this, DAP use was increased from 1853 t in 2012/13 cropping season to 2777 t in 2014/15. However, observed decrease in the quantity of DAP used in 2015/16 cropping season (1435 t) was related to the introduction of new NPS fertilizer, which is supposed to replace further distribution and use of DAP in the country. Thus, the use of NPS fertilizer in the study area was increased from 63 t in 2014/15 to 1840 t in 2015/16 cropping season.

Similarly, the amount of inorganic fertilizer applied on a hectare basis also showed an increasing trend when calculated both for total cultivated land in the study area and based on specific plots which were actually sown using inorganic fertilizers (fertilized fields) (Table 6). For example, when urea use was calculated based on fertilized fields, it has increased from the recent 22.8 kg ha$^{-1}$ in 2012/13 to the current 53.3 kg ha$^{-1}$. The recent decrease in the rate of DAP application was compensated by the distribution and application of the newly introduced NPS fertilizer.

Hence, NPS fertilizer showed a sharp increase from its limited use (0.8 kg ha$^{-1}$) in its first year distribution in Fogera district to its better use (22.6 kg ha$^{-1}$) in all the three districts. This is not without reason. During the past 4 years, many districts in the country were addressed through massive new fertilizer demonstrations in which farmers were encouraged to use the new NPS based compound or blended fertilizers against DAP and compare the yield differences. Since the differences and yield advantages from the new fertilizers were very apparent, farmers did not wait to request the new fertilizers and discontinue using DAP (Tekalign Mamo, personal communication).

Furthermore, conducted field level survey results indicated that from about 279 respondents interviewed, only 55% of them were inorganic fertilizer users. The remaining 45% of the respondents did not use inorganic fertilizers. Suggested reasons for not using inorganic fertilizer were, soaring fertilizer costs, extreme poverty to afford purchasing costs, fear of addiction of their farm lands to applied fertilizers, topographic considerations and crop type selection. Similarly, according to some authors Gedamu-Gobena[22], Yu *et al.*[15], Belachew and Abera[23], Tesfaye *et al.*[16] and Fanuel[14], wealth of individual farmers, crop specialization, high fertilizer costs, low credit availability and untimely delivery of mineral fertilizers were also reported as a major constraints for the observed low to non inorganic fertilizer use.

Table 7: Farmers estimated mean fertilizer application rates per crop types

| | Fertilizer application rates (kg ha$^{-1}$) | |
|---|---|---|
| Crop type | N | P |
| Teff | 38.0 | 12.2 |
| Wheat | 38.0 | 14.2 |
| Rice | 49.0 | 16.2 |
| Maize | 41.0 | 14.4 |
| Finger millet | 24.0 | 10.9 |
| Triticale | 30.5 | 9.6 |
| Barley | 35.0 | 15.1 |
| Mean | 36.50 | 13.2 |

Inorganic fertilizer use in the study area was found to be crop specific. Hence, teff, barley, wheat, maize, triticale, rice, finger millet and to some extent sorghum are the major crop types which are cultivated using variable rates of inorganic fertilizers. With regard to fertilizer application rates, farmers estimated application rates ranged from 20-100 kg ha$^{-1}$ DAP and/or urea fertilizers. The commonly used blanket recommendation, which is 100 kg ha$^{-1}$ DAP and 100 kg ha$^{-1}$ urea, is still in use in the study area. The probable reason for not getting information about NPS fertilizer at the plot level might be related to the accustomed color based identification of fertilizers by farmers (might have similar color with previous fertilizers) or weak on spot extension services in popularizing it. In general, irrespective of their knowledge about blanket recommendation, local farmers' mineral fertilizer application rates are generally lower than the indicated blanket recommendations (Table 7).

Relatively higher fertilizer rate (49 kg ha$^{-1}$ N and 16.2 kg ha$^{-1}$ P) was applied for rice crop (Table 7). However, the applied N rate was lower than the blanket recommendation (64 kg ha$^{-1}$ N and 20 kg ha$^{-1}$ P ) and also from the suggested area specific fertilizer recommendation (60 kg ha$^{-1}$ N and 13.2 kg ha$^{-1}$ P)[61]. Similarly, mineral fertilizer applied for wheat was not only lower than the blanket recommendation but also much lower than the recently identified 72 kg ha$^{-1}$ N and 25 kg ha$^{-1}$ P application rates on highland vertisols of Ethiopia[62]. However, with regard to triticale fertilizer use, there is some similarity between what Gedamu-Gobena[22] estimated (38 kg ha$^{-1}$ N and 11.8 kg ha$^{-1}$ P) and the current survey results (30.5 kg ha$^{-1}$ N and 9.6 kg ha$^{-1}$ P) though, both are below the recommended blanket rates. Generally, based on the farmers' estimate, 37 kg ha$^{-1}$ N and 13.2 kg ha$^{-1}$ P and based on zonal agricultural offices recent estimate, 32.2 kg ha$^{-1}$ N and 5.5 kg ha$^{-1}$ P average fertilizer rates were used for major cereal crops growing in the study area.

In terms of crop productivity, the calculated average productivity for non-fertilized major cereal crops growing in the study area was 1.2 t ha$^{-1}$. By applying variable rates of mineral fertilizers, cereal productivity was found to increase by 1.1 t and reached 2.3 t ha$^{-1}$, which is a similar productivity with the nationally estimated 2.32 t ha$^{-1}$ [63]. Thus, as indicated by Rockstrom *et al.*[64], there is untapped potential for possible yield increase in the study area, if site specific and balanced fertilization strategies are implemented.

Organic fertilizer use in the form of farm-yard manure (FYM) was limited only at the homesteads to grow crops like maize, potato, barley and triticale. From the listed crop types, majority of the FYM (84%) was applied to maize and potato, which are the most commonly cultivated crops at the homesteads. Similar house refuse and manure use for homestead garden crops was also reported as a usual practice implemented by farmers in South Western Ethiopia and Kenya[18,44]. On the other hand, when measured in terms of application rates, the applied FYM amounts varied from 0.4-1.6 t ha$^{-1}$ where 0.92 t ha$^{-1}$ is an average application rate. The applied FYM amount is very small as compared to the recently estimated 3.3 t ha$^{-1}$ average application rate in southern Ethiopia[65]. This low application rates were related to the diversified use FYM is giving to the local community, which include among others, its use as major house fuel source, income source by selling manure cakes and its role in house plastering activities. The results of this study were in agreement with the finding of different researchers Gedamu-Gobena[22], Belayneh[7] and Zelleke *et al.*[55], who reported that animal dung is universally used as fuel source for the rural community and also used as a source of additional income. Generally, very low application rates and highly fragmented application times were the major drawbacks observed in organic fertilizer use in the study area. With regard to application time, FYM application in the study area was not a one occasion activity, rather applications were subdivided in to a number of occasions which are basically dependent on the availability of enough materials.

It is very likely that fertilizer use by farmers will increase in the next few years due to the current initiative of customizing fertilizers by crop and area based on the national soil fertility mapping and new fertilizer demonstrations being carried out in the country.

## CONCLUSION

The abundance and distribution of major landforms are found to cause variability in altitude (1762-3704 m.a.s.l), agro-ecology (five AEZs than usually reported two), soils (six local soil types) and related variability in the growth of different crop types. On the other hand, similar plant nutrient (N, P, S and B) deficiencies, some crop pest related problems and cultivation of ecologically fragile steep landforms were identified as key problems in the study area. Mineral fertilizer use was not only low by the quantity applied but also poor in the number of nutrients it is composed of, both of which negatively influenced the potential crop productivity. Therefore, appropriate soil conservation measures, site specific and balanced mineral fertilizer application and pest control activities are recommended.

## SIGNIFICANCE STATEMENTS

This study discovered the possibility of getting more agro-ecological zones when the scale of the study is changed to a large scale. In other words, the observed higher variability in altitude has resulted in different agro-ecologies that are suitable for the growth of a variety of crops. This study will help the researcher to uncover the critical areas which are unsuitable for agricultural activities and areas with extreme plant nutrients deficiencies that many researchers were not able to explore. Thus, the government may come up with a new land-use policy prohibiting the indiscriminate and unsustainable use of agricultural lands.

## ACKNOWLEDGMENTS

The authors would like to greatly acknowledge the financial support (with a reference number HU/Ad/SA/VP/11/30914/14) provided by the Ethiopian Ministry of Education (MoE) and the Ethiopian Soil Information System (EthioSIS). Authors also would like to thank farmers, development agents and agricultural experts, who in one way or another participated and contributed in this study.

## REFERENCES

1. SIDA., 2003. Ethiopia: Strategic environmental analysis. Swedish International Development Cooperation Agency, Stockholm, Sweden. http://www.sida.se/contentassets/ebfdc500787d46c0a99e122393a338d8/ethiopia--strategic-environmental-analysis_468.pdf
2. Gashaw, T., 2015. The Implication of watershed management for reversing land degradation in Ethiopia. Res. J. Agric. Environ. Manage., 4: 5-12.
3. Mishra, B.B., G. Heluf and K. Kibebew, 2004. Soils of Ethiopia: Perceptions, appraisal and constraints in relation to food security. J. Food Agric. Environ., 2: 269-279.
4. Mohammed, A., P.A.L. Le Roux, C.H. Barker and G. Heluf, 2005. Soils of Jelo micro-catchment in the chercher highlands of eastern Ethiopia: I Morphological and physicochemical properties. Ethiop. J. Nat. Resour., 7: 55-81.
5. FAO., 2016. Ethiopia climate-smart agriculture scoping study. Food and Agriculture Organization, Addis Ababa, Ethiopia. http://www.fao.org/3/a-i5518e.pdf
6. Chamberlin, J. and S. Emily, 2011. Ethiopian agriculture: A dynamic geographic perspective. ESSP II Working Paper 17, International Food Policy Research Institute (IFPRI), Ethiopia. http://essp.ifpri.info/2011/03/22/ethiopian-agriculture-a-dynamic-geographic-perspective/
7. Belayneh, A., 2009. Effect of land use/land cover on selected soil physicochemical properties in the western part of Mount Guna area, south Gondar zone, Amhara National Regional State, Ethiopia. M.Sc. Thesis, Mekele University, Mekelle, Ethiopia.
8. Diwediga, B., K. Wala, F. Folega, M. Dourma, Y.A. Woegan, K. Akpagana and Q.B. Le, 2015. Biophysical and anthropogenous determinants of landscape patterns and degradation of plant communities in Mo hilly basin (Togo). Ecol. Eng., 85: 132-143.
9. Shimelis, G., 2008. The impact of land use change on soil carbon, nitrogen and sulfur stock after grass land conversion to *Pinus patula* and *Eucalyptus grandis*, at Arsi highlands, Ethiopia. M.Sc. Thesis, Mekelle University, Ethiopia.
10. Kiflu, A. and S. Beyene, 2013. Effects of different land use systems on selected soil properties in South Ethiopia. J. Soil Sci. Environ. Manage., 4: 100-107.
11. Ali, A., A. Esayas and S. Beyene, 2010. Characterizing soils of Delbo Wegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. J. Soil Sci. Environ. Manage., 1: 184-199.
12. Abrha, K., 2013. Soil acidity characterization and effects of liming and chemical fertilization on dry matter yield and nutrient uptake of wheat (*Triticum aestivum* L.) on soils of Tsegede District, northern Ethiopia. Ph.D. Thesis, Haramaya University, Haramaya, Ethiopia.
13. Dessalegn, D., S. Beyene, N. Ram, F. Walley and T.S. Gala, 2014. Effects of topography and land use on soil characteristics along the toposequence of Ele watershed in southern Ethiopia. Catena, 115: 47-54.
14. Fanuel, L., 2015. Soil spatial variability analysis, fertility mapping and soil-plant nutrient relations in Wolita zone, Southern region, Ethiopia. Ph.D. Thesis, Haramaya University, Haramaya, Ethiopia.
15. Yu, B., A. Nin-Pratt, J. Funes and S.A. Gemessa, 2011. Cereal production and technology adoption in Ethiopia. IFPRI-ESSP II Discussion Paper 12, International Food Policy Research Institute, Washington, DC. http://www.ifpri.org/publication/cereal-production-and-technology-adoption-ethiopia-0
16. Tesfaye, A., M. Githiri, J. Derera and T. Debele, 2011. Subsistence farmer's experience and perception about the soil and fertilizer use in Western Ethiopia. Ethiop. J. Applied Sci. Technol., 2: 61-74.

17. Karltun, E., M. Lemenih and M. Tolera, 2013. Comparing farmer's perception of soil fertility change with soil properties and crop performance in Beseku, Ethiopia. Land Degrad. Dev., 24: 228-235.
18. Tittonell, P., B. Vanlauwe, P.A. Leffelaar, K.D. Shepherd and K.E. Giller, 2005. Exploring diversity in soil fertility management of smallholder farms in Western Kenya. II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. Agric. Ecosyst. Environ., 110: 166-184.
19. Tan, S.H., 2014. Do land characteristics affect farmers' soil fertility management? J. Integr. Agric., 13: 2546-2557.
20. Megersa, T., 2011. Assessing the role of traditional land management practices in improving cropland productivity: The case of Diga Woreda, Oromia. M.Sc. Thesis, Ambo University, Ethiopia.
21. Pound, B. and E. Jonfa, 2005. Soil fertility practices in Wolaita zone, Southern Ethiopia: Learning from farmers. Policy and Research Series 2, Farm Africa, London. https://www.farmafrica.org/us/downloads/resources/PR2%20Soil%20Fertility%20in%20Wolaita%20%20Southern%20Ethiopia.pdf
22. Gedamu-Gobena, A., 2008. Triticale production in Ethiopia-its impact on food security and poverty alleviation in the Amhara region. Ph.D. Thesis, University of Kassel, Germany.
23. Belachew, T. and Y. Abera, 2010. Assessment of soil fertility status with depth in wheat growing highlands of Southeast Ethiopia. World J. Agric. Sci., 6: 525-531.
24. Bishaw, B., 2009. Deforestation and land degradation in the Ethiopian highlands: A strategy for physical recovery. Ee-JRIF, 1: 5-18.
25. Demelash, M. and K. Stahr, 2010. Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia. J. Soil Sci. Environ. Manage., 1: 164-176.
26. WFP., 2012. WFP-Ethiopia MERET impact evaluation. Case Studies, Annex 16 (Volume III), World Food Program, Rome, Italy.
27. Selassie, Y.G., F. Anemut and S. Addisu, 2015. The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia. Environ. Syst. Res., Vol. 4. 10.1186/s40068-015-0027-0.
28. Desta, L., M. Kassie, S.E. Benin and J. Pender, 2000. Land degradation and strategies for sustainable development in the Ethiopian highlands: Amhara region. Socio-Economic and Policy Research Working Paper 32, ILRI (International Livestock Research Institute), Nairobi, Kenya. http://pdf.usaid.gov/pdf_docs/pnacm308.pdf.
29. ANRS., 2009. Strategic plan for Lake Tana catchment growth corridor (2010-2015). Amhara National Regional State, Bahirdar, (In Amharic).
30. Gebregziabher, G., L.M. Rebelo, A. Notenbaert, K. Ergano and Y. Abebe, 2013. Determinants of adoption of rainwater management technologies among farm households in the Nile River Basin. IWMI Research Report 154, International Water Management Institute, Colombo, Sri Lanka. https://cgspace.cgiar.org/handle/10568/35728
31. Desta, L., V. Carucci, A. Wendem-Agenehu and Y. Abebe, 2005. Community based participatory watershed development: A guideline. Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia.
32. Gala, T.S., M. Pazner and S. Beyene, 2011. Evaluating biophysical attributes of environmentally degraded landscapes in Northern Ethiopia using LANDSAT ETM data and GIS. Ethiop. J. Environ. Stud. Manage., Vol. 4. 10.4314/ejesm.v4i1.1.
33. Deressa, T.T., R.M. Hassan, C. Ringler, T. Alemu and M. Yesuf, 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environ. Change, 19: 248-255.
34. SGFEDD., 2013. Zonal socio-economic survey for the year 2013. South Gondar Zone Finance and Economic Development Department, Debre Tabor.
35. Kassahun, B., 2015. Soil fertility mapping and fertilizer blending. Ethiopian Agricultural Transformation Agency (ATA), Addis Ababa, Ethiopia.
36. Sahlemedhin, S. and B. Taye, 2000. Procedures for soil and plant analysis. Technical Paper No. 74, National Soil Research Center, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia, pp: 89.
37. Mehlich, A., 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal., 15: 1409-1416.
38. Hurni, H., 1998. Agroecological belts of Ethiopia: Explanatory notes on three maps at a scale of 1:1,000,000. Research Report, Soil Conservation Research Program, Addis Ababa. http://library.wur.nl/isric/fulltext/isricu_t4d384c8b_001.pdf
39. SPSS., 2011. IBM SPSS Statistics for Windows, Version 20.0. IBM Corp., Armonk, New York.
40. FAO., 2006. Guidelines for Soil Description. 4th Edn., Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, ISBN-13: 9789251055212, Pages: 97.
41. Samuel, B., P. John and E. Simeon, 2003. Policies for sustainable development in the highlands of Amhara region: Overview of research findings. Proceedings of the Conference on Natural Resources Degradation and Environmental Concerns in the Amhara National Regional state, Ethiopia: Impact on Food Security, July 24-26, 2002, Bahir Dar, Ethiopia.
42. EIAR., 2008. Agro-ecological zones of Ethiopia. Ethiopian Institute of Agricultural Research, GIS Unit, Addis Ababa, Ethiopia.

43. Berhe, K., 2013. Diagnosis and intervention plans for North Gondar zone, Amhara region. Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES). https://lives-ethiopia.wikispaces.com/file/view/North+Gonder-+zonal+report-+final.pdf
44. Bezabih, B., A. Regassa and M. Lemenih, 2014. Soil fertility status as affected by different land use types and topographic positions: A case of delta sub-watershed. J. Biol. Agric. Healthcare, 4: 91-106.
45. ESIS., 2014. Soil fertility status and fertilizer recommendation atlas for Tigray regional state, Addis Ababa, Ethiopia. Ethiopian Soil Information System, Addis Ababa, Ethiopia.
46. Minale, L., A. Alemayehu, T. Tilahun and Y. Belstie, 2006. The influence of seed rate on the grain yield and yield components of triticale (*Triticosecale wittmack*). Proceedings of the 1st Annual Regional Conference on Completed Crop Research Activities, August 14-17, 2006, Bahir Dar, Ethiopia.
47. Gorfu, D. and E. Ahmed, 2011. Crops and agro-ecological zones of Ethiopia. Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia.
48. Alemayehu, J. and F. Hailemariam, 2008. The BBM: Impressions from the field. Field Report Prepared for ILRI (International Livestock Research Institute), Nairobi, Kenya.
49. Wubie, A.A., 2015. Review on vertisol management for the improvement of crop productivity in Ethiopia. J. Biol. Agric. Healthcare, 5: 92-102.
50. WRB., 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Report No. 106, FAO, Rome, Italy, pp: 181.
51. Dawoe, E.K., J. Quashie-Sam, M.E. Isaac and S.K. Oppong, 2012. Exploring farmers' local knowledge and perceptions of soil fertility and management in the Ashanti Region of Ghana. Geoderma, 179-180: 96-103.
52. Tegbaru, B., 2014. Fertility mapping of soils of Abay-Chomen district, Western Oromia, Ethiopia. M.Sc. Thesis, Haramaya University, Ethiopia.
53. Abera, E.T., 2014. Fertility mapping of soils in Alicho Woriro Woreda in silte zone, Southern Ethiopia. M.Sc. Thesis, Haramaya University, Ethiopia.
54. Taddese, G., 2001. Land degradation: A challenge to Ethiopia. Environ. Manage., 27: 815-824.
55. Zelleke, G., G. Agegnehu, D. Abera and S. Rashid, 2010. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system. Working Paper, International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/publications/ethiopianagsectorwp_soil.pdf
56. Kajiru, G.J., J.P. Mrema, B.P. Mbilinyi, F.B. Rwehumbiza, N. Hatibu, J.G. Mowo and H.F. Mahoo, 2005. Assessment of soil fertility status under rainwater harvesting on the Ndala River catchment using local and technical indicators of soil fertility for rice production. Proceedings of the East Africa Integrated River Basin Management Conference, March 7-9, 2005, Sokoine University of Agriculture, Morogoro, Tanzania, pp: 124-133.
57. Rushemuka, N.P., R.A. Bizoza, J.G. Mowo and L. Bock, 2014. Farmer's soil knowledge for effective participatory integrated watershed management in Rwanda: Toward soil-specific fertility management and farmer's judgmental fertilizer use. Agric. Ecosyst. Environ., 183: 145-159.
58. Kauffman, J.J. and M.V. Ramos, 1998. A farmer assisted soil survey and land evaluation in the Peruvian Andes. A Case Study for the San Marcos (Cajamarca) and Quilicas (Huancayo) ILIEA Project Pilot Areas, National Agricultural University-La Monila, Lima and International Soil Reference and Information Center (ISRIC), Wageningen.
59. FAO., 1998. Soil map of Ethiopia. Food and Agriculture Organization, Rome, Italy.
60. Melese, A., 2014. Phosphorus status, adsorption characteristics, kinetics and availability to wheat crop as influenced by applications of various amendments on acid soils of Farta district, Northwestern highlands of Ethiopia. Ph.D. Thesis, Haramaya University, Ethiopia.
61. Gebrekidan, H. and M. Seyoum, 2006. Effects of mineral N and P fertilizers on yield and yield components of flooded lowland rice on vertisols of fogera plain, Ethiopia. J. Agric. Rural Dev. Trop. Subtrop., 107: 161-176.
62. Hailu, H., T. Mamo, R. Keskinen, E. Karltun, H. Gebrekidan and T. Bekele, 2015. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agric. Food Secur., Vol. 4. 10.1186/s40066-015-0038-0.
63. CSA., 2016. Agricultural sample survey 2015/2016, Volume I. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season), Central Statistical Agency, Ethiopia.
64. Rockstrom, J., L. Karlberg, S.P. Wani, J. Barron and N. Hatibu *et al*., 2010. Managing water in rainfed agriculture-the need for a paradigm shift. Agric. Water Manage., 97: 543-550.
65. Laekemariam, F., K. Kibret, T. Mamo and H. Gebrekidan, 2016. Soil-plant nutrient status and their relations in maize-growing fields of Wolaita Zone, Southern Ethiopia. Commun. Soil Sci. Plant Anal., 47: 1343-1356.