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Contents

Soil Survey Research

Soil Fertility Assessment and Mapping of Shashemene District, West Arsi Zone, Oromia, Ethiopia

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Abstract

Soil fertility mapping is the way of assessing soil nutrients on the basis of soil sample test results and preparing their maps at required scale. It is very important information to make efficient land use particularly agricultural crops for managing inputs to soil. Hence, in order to avail information about Shashemene District, the study was carried out to map macro-nutrients phosphorous, potassium; soil organic carbon (SOC) and other soil fertility indicators (pH. Electrical Conductivity (EC), Cation Exchange Capacity (CEC). About 197 soil samples were collected and used to map the whole study site. For every soil parameter analysis, standard laboratory analysis was followed. In order to predict values for unsampled locations the Ordinary Kriging interpolation was used by ArcGIS10.1 software. The validations of maps were also made for each soil parameters. Potassium levels in the study site had three classes medium, high and very high which accounts 7%, 64% and 29% respectively. Shashemene District had five categories of soil pH but the majority of the area were in slightly acidic, neutral, moderately acidic, strongly acidic and very strong acidic which account area share of 42, 25, 24 , 8 and 2%, respectively. Available phosphorus level was categorized as low, medium and high which was 0.20%, 85.97% and 13.84%, respectively. The dominating class was medium phosphorus level, i.e., 5-15ppm. CEC could also be categorized in four classes low (0.02%), medium (59.89%), high (36.55%) and very high (3.54%) of land area. Soil EC ranges were 0.1414 to 0.3727 ds/m, i.e., salt free. Soil OC ranges were from 0 to 9.05% from low to very high categories. The land area coverage of the categories for organic carbon were mainly dominated by medium, very high, high and low with share of 58, 25, 16.99 and 0.01%, respectively.

Key words: Soil fertility mapping, Soil NPK, Kriging, EC, CEC, pH and OC

Introduction

Increasing productivity of any cropping systems depends on an adequate supply of plant nutrients. Although one or more nutrients are applied to most crops, the quantity of nutrients removed in the harvested crop is generally much greater than the quantity added. Continued removal of nutrients, with little or no replacement will increase the potential for the future nutrient related plant stress and yield loss (Tisdale et.al., 1993). Both over dose and under application of chemical fertilizers to soil have negative impact on crop productivity and over dose additionally pollute the environment.

Comprehensive knowledge of soil resources is very important to plan efficient land use system. Soil fertility is the most valuable asset a nation can possess. It should be maintained where it is high, improved where it is low and developed where it is lacking (Shan et.al., 1985). Even though the property of soil fertility is very dynamic, it needs continues assessment and monitoring. In Ethiopia the information presently available on soil fertility is not adequate to meet the requirements of agricultural development programs, and rational fertilizer promotions and recommendations based on limiting nutrients in specific site for a given crop.

Fertilizer application is based on blanket recommendation throughout the country because there is no fertilizer recommendation guideline on soil-test based crop response calibration study. Type and amount of fertilizers to be applied for each crop type at its specific site is not yet assessed. It is essential that the results of soil tests should be calibrated against crop responses from applications of nutrients in question. This information is obtained from field and greenhouse fertility experiments conducted over a wide range of soils (Tisdale et.al., 1993).

Moor (1978) has pointed out that information in soil fertility and on soil responses to management practices is frequently transferred from one area (or soil) to another by analogy, i.e. on the assumption that the two areas are similar (Andrew and Kamprath, 1978).

The map quality, date, and scale also affect the site specific fertilizer application. The soil fertility maps need to manage soil variability should follow the most suitable prediction method by implementing geospatial tools, i.e., ordinary kriging interpolation often preferred for predicting values of not sampled locations continuously.

Although soil fertility assessment and mapping in Shashemene District was initiated as response of where and how to use the soil test based crop response studies results, it has more advantage than this to give information about soil fertility status of the district for different users. Therefore, the objectives of the study were to identify and classify major soil nutrient status of the study area, to map soil fertility parameters, and to avail information on fertilizer recommendation.

Materials and Methods

Description of the study area

The study was carried out in Shashemene District at 253 kilometers far from Finfinne/Addis Ababa to south. The geographical location of Shashemene District ranges from 7^0 04'50" to 7^0 22'45" N and 38^0 23'00" to 38^0 48'00" E. Its total area coverage is 76787.86 hectares and its map is indicated in Figure 1.

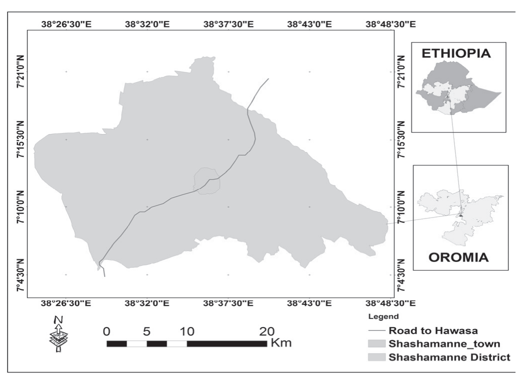

Figure 1. Location map of Shashemene District

Soils

According to Davidson (1980), soil is defined as a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics. In Shashemene District, even though about nine soil types were observed in the district, it was mainly dominated by Vitric Andosols, Eutric Vertisols, Mollic Andosols, Haplic Luvisols, Haplic Luvisols and Lithic Leptosols which accounted for about 29.06%, 20.81%, 18.55%, 16.55% ,7.67% and 5.67% of the area, respectively.

Climate

Climate of the area includes the combination of temperature and rainfall at different extent, which further may be subdivided to evapotranspiration, relative humidity, sunshine hours, etc. In this study only the major two factors rainfall and temperature were used to describe the area from rainfall data of 1983-2005. The average trends of monthly rainfall of Shashemene are shown in Figure 2. Annual total rainfall distributions within and near Shashemene District is indicated in Figure 3. The maximum amounts of rainfalls were recorded at Wendogenet (1111.30mm) but at Shashemene (862.56mm).

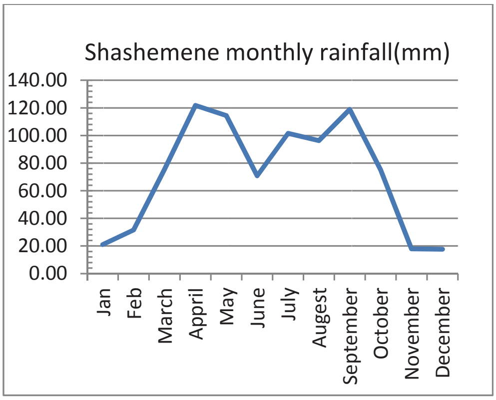

Figure 2. Monthly rainfall of Shashemene

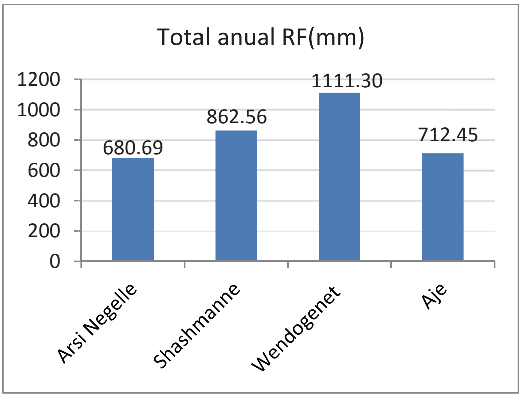

Figure 3. Total annual rainfall of different stations

Topography

Topography is one of the factors influencing the characteristics of soil in a given area. Both slope and elevation of the study area were generated from digital elevation model by using ArcGIS10.1 spatial analyst of surface analysis. The topography of the study area is generally characterized by gently undulating terrain. From the slope classes gently sloping, sloping, level/flat sumed up to more than 80% of the area coverage. Slope categories of the district are indicated in Table1. Elevation of the district varied between 1683 to 2742masl.

Table 1. Slope classes of Shashemene District

No	Slope (%)	Name	Area (ha)	Area (%)
1	0 - 2	Level/Flat	13489.26	17.33
2	2 - 5	Gently Sloping	26828.65	34.46
3	5 - 10	Sloping	21223.88	27.26
4	10 - 15	Strongly Sloping	7288.50	9.36
5	15 - 30	Moderately Steep	7295.74	9.37
6	30 - 60	Steep	1525.09	1.96
7	> 60	Very steep	200.71	0.26

Land use/land cover

The total area of the district has different land use/land cover components such as cultivated lands (77.8%), forests (4.8%), settlements (3.2%), private farm (6.6%), bushes (2.6%), rugged scattered bushes (2.9%) and grazing land (0.3%). The farming system of Shashemene District is mainly crop rotation (maize, wheat, teff, potato).

Selecting of uniform sampling area

Soil conditions are influenced by many environmental facters which could be aggravated accordingly through interventions of human beings and natural disasters. It is important to investigate the relationship of soil forming factors and others factors. In this study as much as possible it was attempted to comperhensively investigate different factors such as topographic, land use, climate and soils of the area at required scale.

The influencing facters were collected from different sources and prepared for further spatial analysis in order to produce spatial layers/features of the study area. These factors were compared to each other and areas which have almost similar characterisitics were grouped into the same category by using GIS overlay analysis. These categories were used as mapping unints and soil samples were collected from these units. The distict was divided into 150 units as indicated in Figure 4.

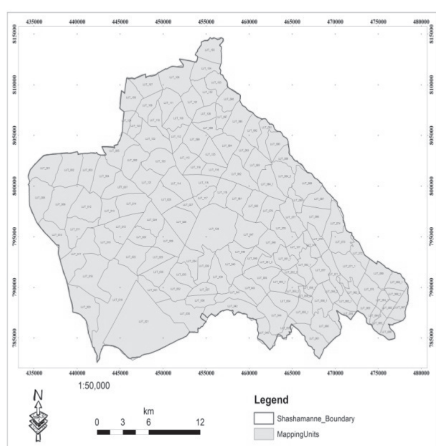

Figure 4. Mapping units

Soil sampling

A composite sample was taken after 15-20 subsamples were augured from each mapping unit or uniform sampling area. The Auger sampling depth was 0-20cm. The sub-samples were collected properly to represent the mapping units and mixed in a bucket to be homogenized. Then 1kg of the composite sample was taken by quartering to laboratory.

Soil analysis

As soon as soil samples were prepared and being ready for analysis, their physical and chemical analyses were conducted in Zeway Soil Research Center laboratory. The analysis was done for texture, EC, CEC, pH-water, nitrogen, phosphorous, potassium and organic carbon and etc. The methods of analysis for each parameter are presented in Table 2.

Table 2. Methods used in analysis of soil parameters

No	Soil parameters	Methods followed
1	pH	pH-meter
2	EC	EC-meter
3	CEC	By Ammonium Acetete
4	Avail. P	Olsen et al (1954)

Soil rating

Based on Booker tropical soil manual (1991) the result of analysis of individual parameters of soils were classified into different categories, i.e., low, medium and high with respect of availability and content of each nutrients.

Map preparation

After database of samples were prepared, both statistical evaluation and geospatial evaluations were undertaken. Then at the end of the study, fertility map was prepared for phosphorous, potassium and pH. The results of data analysis obtained from laboratory and data collected from field during field survey were interpreted and classified into different fertility levels or classes based on the fertility standards. Finally, based on the interpreted data, soil fertility maps were prepared for each required parameters.

Validation of the map

In order to confirm the map of each soil parameters, about sixty five soil samples were collected from different locations of soil parameters rate (low, medium, high, etc.) categorized in the first map. These samples were analyzed at laboratory for P, pH, OC, CEC, K, EC and texture. Then the results were cross validated with the first soil samples results and readjustments were done.

Results and Discussion

Soil parameters

For the whole district mainly six parameters were summarized statistically and overviewed to map their spatial patterns. The parameters were soil pH, EC, available phosphorous, CEC, OC and potassium for the total soil samples of 197. The total samples were collected from agricultural land hence the result mainly represents cultivated lands. The statistical summary of the parameters are as indicated in Table 3.

Table 3. Summary results of soil parameters

No	parameter	pH	EC	CEC	AV.P	K	OC
1	Minimum	4.20	0.14	13.00	1.08	0.32	0.00
2	Maximum	7.65	0.45	63.00	40.16	3.30	9.05
3	Mean	6.23	0.23	26.42	11.82	1.29	3.03
4	Standard Deviation	0.65	0.08	11.99	7.06	0.69	2.10

Spatial distribution of soil parameters

According to Olsen method, available phosphorus in the soil for the study area ranged from 1.08 to 40.16 ppm (Table 3). The classification of phosphorus was made according to Booker (1991) that was on the basis of its suitability for agricultural production and it has three classes as indicated in Table 4.1. Available phosphorus level in Shashemene District was categorized as low, medium and high which accounted for about 0.20%, 85.97% and 13.84%, respectively. The dominating class was medium (5-15ppm) of available phosphorus and accounted more than 85.97% of the area where as the least dominant was low less than 1% of the area. The map of available phosphorus for the Shashemene District is illustrated in Figure 5a.

Soil electrical conductivity (EC) is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms which influence key soil processes. Soils containing excess salts occur naturally in arid and semiarid climates. Salt levels can increase as a result of cropping, irrigation, and land management. Although EC does not provide a direct measurement of specific ions or salt compounds, it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia. In case of Shashemene District soil EC ranged between 0.1414 to 0.3727 dS/m. The result was in the category of salt free according to Booker tropical soil manual (1991) classification. The three equal interval classification of Shashemene soil EC is indicated in Table 4.2 and its spatial pattern is illustrated in Figure 5b.

Soil organic carbon is the main constituent of soil organic matter. Soil organic matter is formed by the biological, chemical and physical decay of organic materials that enter the soil system from sources above ground (e.g. leaf fall, crop residues, animal wastes and remains) or below ground (e.g. roots, soil biota). The elemental composition of soil organic matter varies, with values in the order of 50 per cent carbon (Broadbent 1953), 40 % oxygen and 3 % nitrogen, as well as smaller amounts of phosphorus, potassium, calcium, magnesium and other elements as micronutrients. In the case of Shashemene District, soil OC ranged from 0 to 9.05% from low to very high as categories of Booker Tropical Soil Manual (1991).The land area coverage of the categories were mainly dominated by medium, very high, high and low with share of 58%, 25%, 16.99% and 0.01% as shown in Table 4.3. The spatial patterns of OC of Shashemene District are illustrated in Figure 5c.

The soil pH of Shashemene District ranged from 4.2 to 7.65 from extremely acidic to slightly alkaline. The pH rate classification was done based on Booker Tropical Soil Manual (1991). Shashemene District had about five categories of soil pH but the majority of the area was in slightly acidic, neutral, moderately acidic, strongly acidic and very strong acidic which accounted area share of 42%, 25%, 24% , 8% and 2%, respectively. The area coverage and percentage share of each categories of soil pH are illustrated in Table 4.4. The spatial patterns of the soil pH of Shashemene District were shown in Figure 5d. The categories with strong acidic conditions prevailed at high altitude parts of the district.

The results of laboratory analysis indicated greater values of potassium in the study site than the plant growth limiting ranges of soil potassium level, which ranged from 0.32 to 3.30 meq/100g of soil. In the some context (Gourley, 1999) stated the critical values for K that begin to limit plant growth are around 80 to 200ppm. In the case of this study, the status of potassium level in the surface soil of Shashemene was more than the values which limit the growth of maize in the study area. According to Booker Tropical Soil Manual (1991) the soil potassium level of Shashemene District had three classes medium, high and very high which accounted 7%, 64% and 28%, respectively as indicated in Table 4.5. Its spatial patter varied as indicated in Figure 5e).

Measurements of the cation exchange capacity (CEC) showed significant soil properties in particular its ability to retain the cation because of their mobility in the soil. The Shashemene District soil CEC could be categorized into four classes low, medium, high and very high which accounted 0.02%, 59.89%, and 36.55% and 3.54% land area share as indicated in Table 4.6. The spatial patterns of Cation Exchange capacity is indicated in Figure 5.

Table 4. Classifications of P, EC, OC, pH, K, and CEC of Shashemene soils

Table 4.1	**Available phosphorous (ppm)**	**Area (ha)**	**Area (%)**	**Class rate**
	< 5	279.3	0.2	Low
	5.0 - 15.0	121716.6	85.97	Medium
	> 15	19588.73	13.84	High
Table 4.2	**EC(ds/m)**	**Area(ha)**		
	0.1414 - 0.2185	35566.72	45.49	
	0.2185 - 0.2956	23970.77	30.66	
	0.2956 - 0.3727	18645.1	23.85	
Table 4.3	**OC (%)**	**Area(ha)**		
	< 1	18.08	0.01	Low
	1 - 3	45291.04	58	Medium
	3 - 5	13321.42	16.99	High
	> 5	19231.66	25	Very High
Table 4.4	**pH ranges**	**Area(ha)**		
	4.5 - 5.1	1280.08	2	Very strong Acidic
	5.1 -.5.6	6191.69	8	strongly Acidic
	5.6 - 6.1	18505.84	24	Moderately Acidic
	6.1 -6.6	32575.82	42	Slightly Acidic
	6.6 -7.3	19308.83	25	Neutral
Table 4.5	**Potassium (meq/100g of soil)**	**Area (ha)**		
	0.3 - 0.6	5656.10691	7	Medium
	0.6 - 1.2	50077.97052	64	High
	> 1.2	22128.18511	29	Very High
Table 4.6	**CEC (meq/100g of soil)**	**Area(ha)**		
	13 -15	14.31	0.02	Low
	15 - 25	46823.14	59.89	Medium
	25 - 40	28578.95	36.55	High
	> 40	2769.73	3.54	Very High

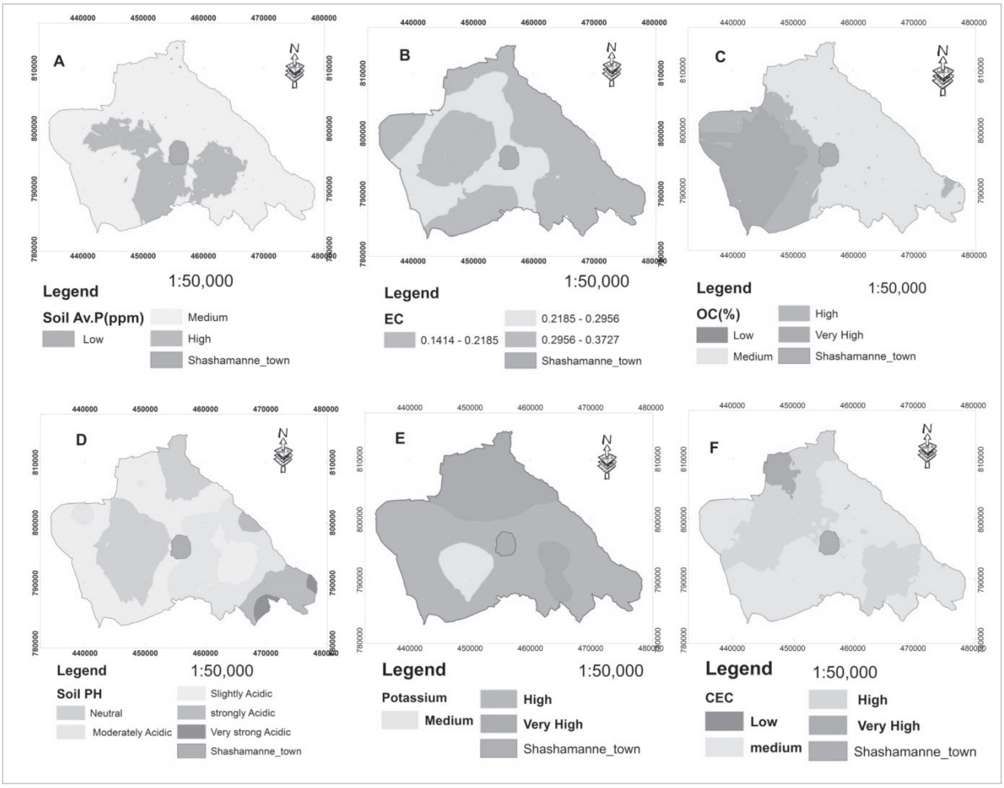

Figure 4. Maps of soil avail. P, EC, OC, pH, K and CEC of Shashemene District

Conclusion and Recommendation

The study was done to assess and map soil fertility status of Shashemene District. Six parameters were summarized and mapped to indicate soil fertility status of the district. The results revealed that available phosphorus level was categorized as low, medium and high with 0.20, 85.97 and 13.84%, respectively but the dominating class was medium (5 -15ppm). Soil EC range was from 0.1414 to 0.3727 dS/m, i.e., totally salt free. Soil OC ranged from 0 to 9.05% from low to very high. The soil potassium level in the study site had three classes, medium, high, and very high accounted for 7, 64 and 29%, respectively. Soil pH of the district had about five categories but the majority of the areas were in slightly acidic, neutral, moderately acidic, strongly acidic and very strong acidic accounted area share of 42, 25, 24, 8 and 2%, respectively. CEC had four classes, low, medium, high and very high which accounted 0.02, 59.89, 36.55 and 3.54 land area share, respectively.

The study should be continued for the different districts, in order to determine the soil fertility status and provide soil test based soil fertility information. The soil fertility map could be used in the study site by development agents to guide farmers as fertilizer application with more validation test of soil parameters at laboratories and also independently. The result could also be extrapolated to watersheds having similar morphologies and agro-climatic zones. During using the outputs/maps, giving consideration for apparent environmental factors is important to compromise the real conditions.

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Phosphorous Requirement Mapping for Maize in Shashemene District, West Arsi Zone, Oromia, Ethiopia

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Abstract

Fertilizer requirement mapping is the way of determining fertilizer demanded by specific crop production type on the basis of soil sample testing results. It is very important method for modern precise agriculture to increase fertilizer use efficiency and environmental friendly. Hence, in order to make efficient fertilizer application for maize in Shashemene District, the study was carried out to map phosphorous requirement for maize variety BH-660. Starting from soil sample collection, laboratory analysis and interpretation and mapping standard methods and tools were used. The total soil samples used for the maize potential areas were 147 and P_c *was 35ppm* P_f *is 1.14. Based on these phosphorous reqquirement was calculated by subtracting* P_o *from* P_C *of the study area. Then the map of phosphorous requirement in ppm was predicted for the whole unknown locations by using ordinary Kriging interpolation of ArcGIS10.1 software. The output ranged from 12.5 to 32.5ppm for the whole area with average of 22.66ppm. Therefore in order to apply phosphorous fertilizer in Shashemene District for maize very efficient rate is just using the map, otherwise using the mean rate (22.66ppm) is suitable. The farmers, development agents, researchers and other stakeholders could use the output directly or by validating with additional soil samples results.*

Key words: Fertilizer requirement, maize, ordinary kriging, phosphorous requirement, Soil P, and P critical

Itroduction

Agriculture is one of the world's most important activities supporting human life. It is in a continuous dynamics, i.e., changing from ancient archaic system to the present precision agriculture. Precision farming can be defined as the gathering of information dealing with spatial and temporal variation within a field and then using that information to manage inputs and practices (Robert *et al*., 2009). In other words it is variable rate technology which is based on the crop productivity differences across a field and varying the inputs to a specific area of a field based on the nutrition or fertility in the soil. The aim of variable rate technology is to maximize the return in each part of a field by adjusting the rate of applying fertilizer to optimize productivity. It has a positive effect on the agricultural development and environmental-friendly application of fertilizers. Therefore variable rate fertilization (VRF) is an important part of variable rate technology in precision agriculture.

Even though Ethiopia faces a wide range of soil fertility issues beyond chemical fertilizer use, it has historically been the major focus for extension workers, researchers, policymakers, and donors. The fertilizer recommendation was blanket, which is not site specific and soil test based but based on out dated very general rate over the whole country (IFPRI, 2010). In response to this, Oromia Bureau of Agriculture and Oromia Agricultural Research Institute (IQQO) has started site specific calibration studies before a decade by its four soil research centers. At the end of calibration work it is known that every soil research centers of IQQO initiate for further verification activities of the study area. Next to this the problem is "how do farmers use the output or verified rate?" This demands farmers to bring their soil samples to the laboratories to get recommended rate to their farm land. This approach is not feasible for fragmented farming system which is characterized by diversified owners and culture. To solve this problem, application of geospatial tools is very mandatory to give comprehensive/general recommendation at district, kebele, mapping units and farm levels. These can be done through manipulation of past recorded research outputs like fertility assessment, calibrations, suitability mapping and validation in harmonized way.

Snoeck (*et al*, 2010) reported from Ghana, in mapping cocoa fertilizer requirements, the soil diagnostic method was used to determine the fertilizer formulae for each of the 397 land units. Then, a fuzzy classification method was used to reduce the number of fertilizer formulae to 32. Six of the fertilizer formulae covered 52%, whilst 12 and 16 of the formulae covered 80% and 90%, respectively, of the cocoa growing areas.

In Ethiopia for more than a decade there were site-specific calibration studies to shift blanket rate of fertilizer recommendation. In progress the requirements of some crops have already known, even though most of the research sites were different and concerned to soil variability spatially. After words there should be critical observation of spatial variability of soils going to be studied at different scales. Hence this activity is needed to integrate the environmental factors in comprehensive manner through application of Geographical Information Systems (GIS) and Remote Sensing tools. The comparison of geostastistical equations can also be useful in solving the problem of interpolation biasness. Therefore the study was designed with the following objectives: to prepare maps of suitable rate of fertilizers for different crops on the basis of their requirement/critical level developed through calibration and verified for the area, to prepare phosphorous requirement map for maize in Shashemene District maize growing areas, and to provide the map at kebele level for development agents to guide farmers.

Materials and Methods

Description of the study area

The study was conducted in Shashemene District on maize potential kebeles, 253 kilometers far from Finfinne/Addis Ababa to south. The geographical location of Shashemene District ranges from 7^0 04’50” to 7^0 22’45” N and 38^0 23'00" to 38^0 48'00" E. Its total area coverage is 76787.86 hectares and its map is indicated in Figure 1.

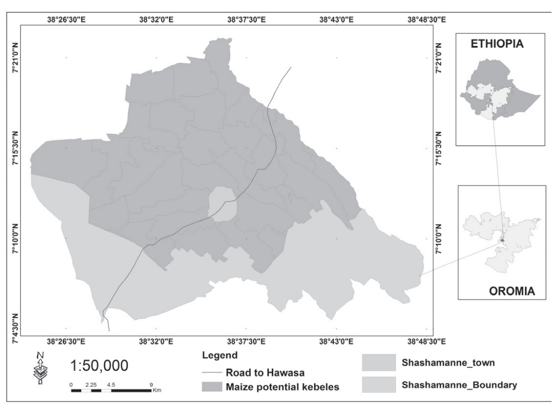

Figure 5. Location map of the study area

In Shashemene District, even though about nine soil types were observed, it is mainly dominated by Vitric Andosols, Eutric Vertisols, Mollic Andosols, Haplic Luvisols, Haplic Luvisols and Lithic Leptosols accounte about 29.06%, 20.81%, 18.55%, 16.55% ,7.67% and 5.67% of the area, respectively.

The climate of the area included the combination of temperature and rainfall at different extent, which further might be subdivided to evapotranspiration, relative humidity, sunshine hours and etc. In this study only the major two factors rainfall and temperature were used to describe the area from rainfall data of 1983-2005. The average trend of monthly rainfall of Shashemene is shown in Figure 2.

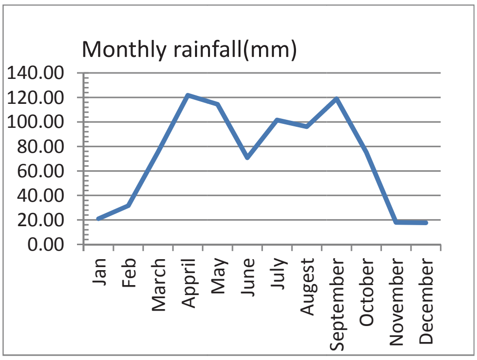

Figure 2. Monthly rainfall of Shashemene

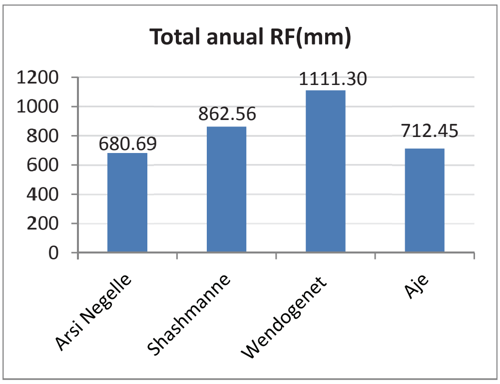

Figure 3. Total annual rainfall of different stations

Topography is one of the factors influencing the characteristics of soil in the given area. Both slope and Elevation of the study area are generated from digital elevation model by using ArcGIS10.1 spatial analyst of surface analysis. The topography of the study area is generally characterized by gently undulating terrain. From the slope classes gently sloping, sloping, Level/Flat sum up to more than 89% of area coverage. Slope categories of the maize potential areas of the district are indicated in table 1. Elevation of the District varies between 1683 m to 2742 m above sea level.

Table 5. Slope classes of maize potential areas of Shashemene District

No	Slope (%)	Name	Area ha	Area (%)
1	0 - 2 %	Level/Flat	9705.7	19.7
2	2 - 5 %	Gently Sloping	20596.0	41.8
3	5 - 10 %	Sloping	13839.8	28.1
4	10 - 15 %	Strongly Sloping	3209.1	6.5
5	15 - 30 %	Moderately Steep	1830.0	3.7
6	30 - 60 %	Steep	125.5	0.3
7	> 60 %	Very Steep	0.7	0.0

The land use/land cover of the district included cultivated lands (77.8%), forests (4.8%), settlements (3.2%), private farm (6.6%), bushes (2.6%), rugged scattered bushes (2.9%) and grazing land (0.3%). The farming system of Shashemene District is mainly crop rotation (maize, wheat, teff, potato).

Likewise, the topography of the area such as slope, elevation, aspect and contours were generated from DEM of SRTM 30m resolution. The drainage condition such as drainage density, stream order was also generated from the same images.

Methodology

Data collection

Soil data

The results of soil fertility assessment and mapping were used as base map. Some of the soil parameters of fertility mapping were used as original phosphorous. More than 147 random soil samples were collected and analyzed to know its phosphorous level.

Crop data

The result of calibration study which was conducted in the district and verified for more application was used and the P-critical values determined for maize in Shashemene District. These data were used to determine fertilizer requirements of the crop.

Determination of fertilizer requirement

The stastistical and spatial variability of the soil parameters, available phosphorous, was analyzed by using statistical tools and geospatial tools of ArcGIS software, respectively. Then based on the variability of available soil phosphorous and crop P-critical level developed through calibration study as well as verified for the study area, crop phosphorous requirement was calculated as the following equation;

The X requirement is calculated from (X_c-X_o) where; X_c is critical nutrient in soil for crop at study area and X_o is initial soil nutrient in soil usually in ppm.

In the case of Shashemene District, phosphorus requirement is calculated from (P_c-P_o) where; P_c is critical phosphorus for maize and P_o is initial soil phosphorus level in ppm. This method was used first in USA by Nelson and Anderson (1977), in Ethiopia by Taye Bekele *et al.* (2000) for wheat and Yesuf Assen *et al.* (2005) for teff.

Map preparation

The mapping of phosphorus requirement was made by applying ordinary Krigging method in spatial analysis tool of ArcGIS software at different landscapes and scales needed. The results of the map were confirmed or validated by collecting more additional random soil samples.

Particularly, based on P
Pc = 35 and the values of every location soil phosphorous (Po) were used to calculate fertilizer requirement and finally, by using ordinary Kriging interpolation, the unknown area were also predicted from 147 sample points.

Results and Discussion

Soil samples

The total number of soil samples used to determine available phosphorous for maize potential kebeles were 147. The values of laboratory analysis by Olsen method had the following statistics as shown in Table 4 as well as the frequency distribution of available soil phosphorous results and phosphorous requirement (ppm) din Figure 3. Available phosphorous values ranged from 1.08 to 40.16ppm.

Table 3. Statistical values of available phosphorous and phosphorous requirement (ppm)

Statistical parameter	Soil initial P (ppm)	Phosphorous Requirement (ppm)	Remarks
Minimum	1.08	-5.16	More than Pc
Maximum	40.16	33.92	Highest (PR)
Mean	12.34	22.66	Average PR (ppm)
Standard Deviation	7.41	7.40	

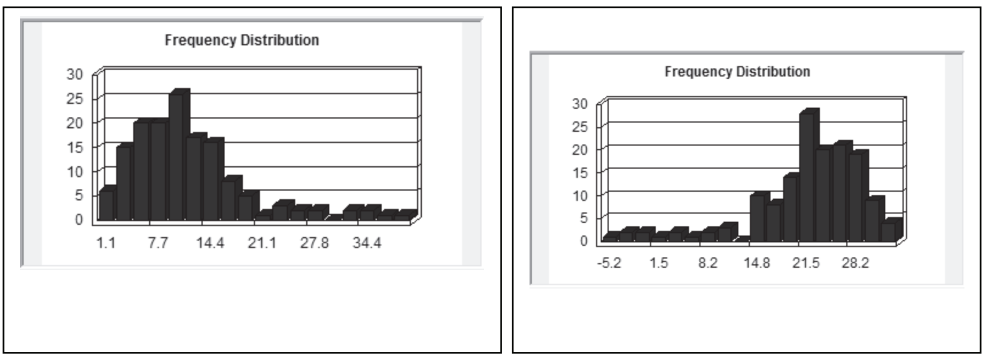

Figure 4. Frequency distribution of initial soil phosphorous and phosphorous requirement for maize

Phosphorus requirement map

Phosphorus (P) is one of the essential nutrients needed for plant growth, and it is the second most important nutrient needed for major crops after nitrogen. Because farming is a business, making any decision to purchase nutrients needs to be based on economic benefits (Charles *et al*., 2009). The fertilizer which is source of phosphorus and mostly used in Ethiopia is DAP. This fertilizer is more expensive than urea for efficient application for each crop production. In this study, maize phosphorus critical level was determined and phosphorous requirement was mapped. The critical phosphorous level for maze was 35ppm in maize potential kebeles of Shashemene District.

The map of phosphorous requirement for maize in Shashemene District was predicted for unknown values of locations by using ordinary Kriging interpolation. The rates of phosphorous requirement were classified into different categories of defined interval which was equal to 2.5ppm and more than 90% land area of the maize potential kebeles required in the range of 17.5 to 30ppm phosphorous requirement for maize. Only 6.39% of the land areas required less than 17.5ppm and only 2.45% required more than 30ppm for maize production in the district. The values and their respective area share of phosphorous requirement rate categories are shown in Table 4. The map of maize phosphorous requirement in maize potential kebeles of the district is illustrated in Figure 5. According to their locations the users could identify more relative rate of application for maize.

Table 4. Phosphorous requirement (ppm) for maize in Shashemene District

No	Phosphorous requirement (ppm)	Area (hectares)	Area (%)
1	12.5 - 15	521.99	1.06
2	15 -17.5	2630.22	5.33
3	17.5 -20	9442.72	19.15
4	20 - 22.5	11368.28	23.05
5	22.5 - 25	9734.65	19.74
6	25 - 27.5	10691.03	21.68
7	27.5 - 30	3715.63	7.53
8	30 - 32.5	1208.26	2.45

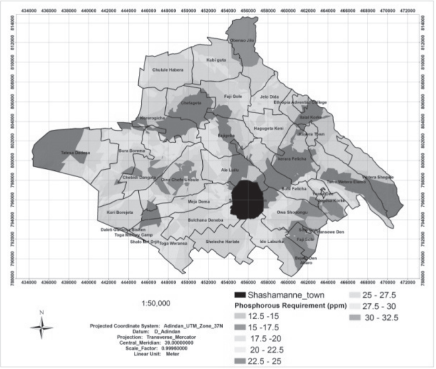

Figure 5. Map of phosphorous requirement for maze in Shashemene District

Conclusion and Recommendation

The study was conducted in Shashemene District for fertilizer requirement mapping of maize particularly phosphorous for maize potential kebeles of the district. The total soil samples used for the maize potential areas were 147 and P_c was 35ppm P_f is 1.14. Based on these data, phosphorous requirement was calculated by subtracting Po from P_C of the study area. Then the map of phosphorous requirement was predicted for the whole unknown locations. The output ranged from 12.5 to 32.5ppm for the maize potential kebeles and with average of 22.66ppm. Therefore in order to apply phosphorous fertilizer in the district for maize, very efficient rate could just using the map, otherwise using the mean rate (22.66ppm) which could be suitable.

The output/map can be used by farmers, development agents and other stakeholders in the study area for maize production. The user could add or reduce rate based on the apparent conditions of their particular farm. For different crops it is research gap to be done in the future in the same manner as has been done for maize. Since the properties of soils are very dynamic the output needs to be validated in regular basis.

Acknowledgment

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Soil Fertility Management Research

Soil Test-based Crop Response Study for Phosphorus on Maize in Shashemene District of West Arsi Zone, Oromia, Ethiopia

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Abstract

Site specific soil-test based crop response phosphorus fertilizer calibration experiment was conducted in Shashemene District on maize during 2010-2012 cropping seasons. This calibration study was conducted on 12 farmers fields using four levels of N (0, 46, 92 and 138 kg/ha) and four levels of P_2O_5 (0, 23, 46, and 96 kg/ha) that designed in a factorial combination plus two levels of potassium as satellite treatments to investigate the response of potassium. These 12 sites (farmers fields) were selected from 33 farm land composite samples collected and analyzed based on the high, low & medium levels of soil available phosphorus. The experiment was laid out in randomized complete block design with two replications having an objective to determine phosphorus critical (Pc), phosphorus requirement (Pf) factor and economical N fertilizer level for maize on major soil type of maize growing area of Shashemene District. Intensive composite soil samples were also collected after 21 days of planting for available P analysis, which were used for phosphorus critical level (P_C) determination using Cate-Nelson diagram method. Economic nitrogen level identified was 46kg N/ha. Accordingly the determined P critical and P requirement factor for maize in Shashemene District for maize growing area were 35 and 1.14, respectively.

Key words: P- critical, P- requirement factor, partial budget, minimum rate of return

Introduction

The population of Ethiopia is currently growing at a faster rate and demands an increased proportion of agricultural products. On the other hand, growth in food production is not in equal footings with population pressure (CSA, 2015); because, the annual net loss of nutrients is estimated to be at least 40 kg N, 6.6 kg P and 33.2 kg K/ha (Scoones and Toulmin, 1999). Continuous cropping, high proportions of cereals (monocropping) in the cropping system, and application of suboptimal levels of mineral fertilizers aggravate the decline in soil fertility (Tanner *et al*., 1991; Hailu *et al*., 1991; Workneh and Mwangi, 1992). Therefore, to satisfy this faster increasing demand for agricultural product necessitate strengthening food production capability of the country by wisely exploiting its existing human and natural resources that requires identification of the proper fertilizer types to use.

Experiments have been carried out on farm land to determine soil P and N optimum with the basic assumption that fertilizer recommendations typically depend on crop response experiments in which spatial variability has been minimized for every independent variable affecting crop yield except for the nutrient in question (Kastens et al., 2003).

Profitable crop production requires adequate and balanced levels of phosphorus (P) and other nutrients, which demand careful planning because of decreasing grain yield and escalating fertilizer prices. So, sound soil test based calibration study is essential for successful fertilizer program and crop production. It is essential that the results of soil tests could be calibrated or correlated against crop responses from applications of plant nutrients in question as it is the ultimate measure of fertilization program. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for each crop (Sonon and Zhang, 2008). Therefore, calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety. That means, fertilizer recommendations on soil test based for economic crop production should be both location and situation specific and can be modified with changes in soil test value as well as input-output ratios. Based on this concept, soil test based calibration studies have been made on maize in Shashemene District since 2010 with the objectives to determine and evaluate P fertilizer requirement for maize based on soil test and crop response, and to give quantitative guidelines and recommendations of P fertilizer for maize in the district.

Materials and Methods

Descriptions of the study area

The study area, Shashemene District is found in West Arsi Zone of Oromia at about 253 km south of Finfinne/Addis Ababa. The total area coverage of the district is 76787.86 hectares, which is geographical located between 7^0 04’50” to 7^0 22’45” N and 38^0 23'00" to 38^0 48'00" (Figure 1). The area is characterized by semi-arid to mid-high land and highland (mountain) agro-ecological zone (AEZ) having altitude range of 1683 to 2742masl. Meteorological data of the area for 11 years (from 1983-2005) were collected from the National Meteorological Service Agency and monthly means of the meteorological data were calculated. Based on these data, the area is found to have long term average annual rainfall of 862.56 mm and minimum and maximum temperature of 11.97 and 26.33 ^oC, respectively.

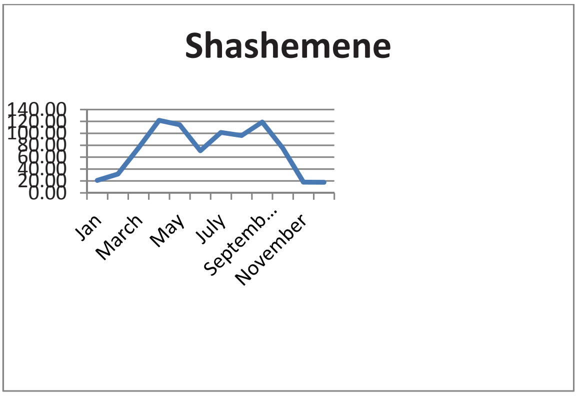

Figure 1. Annual rainfall distribution

Land use/land cover

The major land use observed in the study areas were grouped into cultivated land mostly for annual crop which have double cropping practices per year in some area (77.8%), settlement area (3.2%) and forest land (4.8%), bushes (2.6%) while the rest are mountain and grazing area. Seasonally water-logged grass land used for grazing with patches of farm land at flat floor of the land position of the area and intensively cultivated land with patches of grass land used for grazing at relatively sloping area. Patch of plantation *Eucalyptus* tree also found as homegardens.

Soil characteristics

According to FAO classification the soil of the area were grouped into 10 soil type, whereas the dominant soil types are four Vertic Andosols (29.06%), Eutric Vertisols (20.81%), Mollic Andosols (18.55%) and Haplic Luvisols (16.55%). The soils were acidic to neutral in reaction with pH varying from 4.5 to 7.65. The organic carbon content varied from 0.78% to 9.05%. Texture of the surface soil varied from sandy loam, sandy clay loam to loam with clay percent varying from 10 to 28%. Cation exchange capacities (CEC) of the soils were low to high ranging from 6.4 to 63 meq/100gm soil. The soils were low to high in P (ranging from 1.08 to 40.16ppm) and medium to high in K (from 158 to 678 kg/ha); though these soils were considered to be deficient in nitrogen and humus, but moderate in phosphorus and potassium contents.

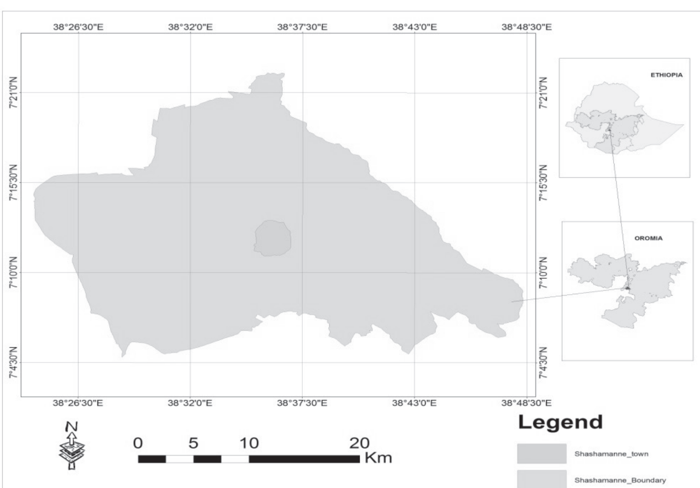

Figure 2. Location map of Shashemene District

Methodology

The study was conducted on farmers' field across the district of maize growing area. Composite soil samples were taken in zigzag method from 33 farmers' fields and analyzed for soil texture, soil pH, OC, total N, available P, available K, and CEC in order to identify the level of the required parameters in the soil to select farm land for actual experiment.

Table 1. Description of treatments

Treatment # (T1-T6) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T7-T12) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T13-T16) *($N:P_2O_5:K_2O$ kg ha^{-1})*
T1 *(0:0:0)*	T7 *(46:46:0)*	T13 *(138:0:0)*
T2 *(0:23:0)*	T8 *(46:92:0)*	T14 *(138:23:0)*
T3 *(0:46:0)*	T9 *(92:0:0)*	T15 *(138:46:0)*
T4 *(0:92:0)*	T10 *(92:23:0)*	T16 *(138:92:0)*
T5 *(46:0:0)*	T11 *(92:46:0)*	T17 *(92:23:60)*
T6 *(46:23:0)*	T12 *(92:92:0)*	T18 *(138:92:60)*

Gross plot size: 5m x 8m Harvested area: 3m x 3m

Land preparation was done using oxen plow. Then, amount of seed and fertilizer per plot were weighed, maize seeds planted in row, and after bund application of fertilizer it was incorporated by the local plow during planting. After three weeks of planting, composite soil samples were collected at 0-15cm depth using auger for each treatment and replications separately, and the samples were subjected to laboratory analysis using Olsen method. Intensive sampling after three weeks of planting was with the assumption of the availability of applied phosphorus fertilizer was more or less in 21 days. With continuous field management, all field agronomic data and post harvest data were collected including date of emergency, date of tasseling, number of tillers/plant, number of cobs/plant, maturity date, bio-mass and grain yield.

Composite soil samples collected before fertilizer application and three weeks (21 days) after planting from each treatment and analyzed by Olsen method for available P were used to calculate P required per hectare to raise the soil test by 1 mg kg^{-1} (1 part per million), and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level. On the other hand, for the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. This was achieved by overlay of a clear plastic sheet having a pair of perpendicular lines drawn on it to produce four quadrants, roughly of the same relative size. The overlay was then positioned on the graph in such a way that the maximum number of points fall in the positive quadrants while the lowest number fall in the negative quadrants. The vertical line defines the responsive and non-responsive ranges. The optimum is indicated by the point where the vertical line crosses the x-axis. Data from 12 sites and all treatments with their replications were used for such analysis**.**

On the other hand, economic analysis was performed to investigate the economic feasibility of the treatments. Partial budget, dominance, marginal and sensitivity analyses were used. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers expect from the same treatment. Average yields also adjusted reducing by 10% because conversion of yield from small plot to hectare will overestimate the actual yield. The average open market price (Birr kg^{-1}) of maize and market prices of N and P fertilizers were used for analysis. For a treatment to be considered a worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% (CIMMT, 1988), which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis.

Finally, phosphorus requirement factor was calculated, which is the amount of P in kg needed to raise the soil P by 1ppm. Phosphorus requirement enables to determine the quantity of P required per hectare to raise the soil test by 1 ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level. It was calculated using available P values in samples collected from unfertilized and fertilized plots; i.e.,

Pr = $\frac{kg\ P\ applied}{\Delta\ soil\ P}$ Hence, rate of P fertilizer to be applied = (Critical P conc.- initial P values) × P requirement factor.

Soil laboratory analysis

For laboratory analysis, soil samples were air dried, ground and sieved through 2 mm size sieve, then analyzed as follows. The pH of soil samples was determined potentiometrically in the supernatant of 1:2.5 soils to liquid ratio by using pH meter (for both pH H_2O and KCl). Electrical conductivity (EC) of soils was measured from 1:2.5 soils to water before pH measurement using electrical conductivity meter (USDA Soil Survey Staff, 1982). the EC readings obtained from the conductivity meter at room temperature were corrected to EC at 25^{o}C using appropriate correction factor. Soil particle size distribution was determined by the Bouyoucos hydrometer method using sodium hexametaphosphate as dispersing agent (FAO, 1984).

Cation exchange capacity (CEC) of the soil was analyzed from distillation of ammonium saturated samples following the modified kjeldhal procedures (Hesse, 1971). Total nitrogen of the soil was determined by Kjeldahl method. The procedure was based on the principle that the organic matter is oxidized by treating soils with concentrated sulfuric acid, nitrogen in the organic nitrogenous compounds being converted into ammonium sulphate during the oxidation. Available potassium of the soil was determined by flame photometer through extraction of samples by Morgan's solution. For available phosphorus determination Olsen method was used, the sample was extracted with sodium bicarbonate solution at pH 8.5. Phosphate in the extract was determined colorimetrically with the blue ammonium molybdate method with ascorbic acid as reducing agent. Similarly the Walkley-Black procedure was used for organic carbon determination (Walkley and Black, 1934). In the procedure soil organic matter was oxidized under standard conditions with potassium dichromate in sulfuric acid solution.

Data management and analysis

All agronomic and soil data which were collected across locations were properly managed using the EXCEL computer software. The collected data were subjected to the analysis of variance using SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

Results and Discussion

Statistical analysis showed that increasing order of agronomic parameter, mean grain yield and plant height with increase of NP fertilization from 0 to the highest required level for both nutrients (Tables 2, 3 and 4). The mean highest grain yield (7534 kg ha^{-1}) and the lowest mean grain yield (4579 kg ha^{-1}) were obtained by the application of the highest rate of phosphorus and nitrogen and the control, respectively (Table 2). Hence, the soil of the area indicated the responsiveness to the application of fertilizer phosphorus and nitrogen. Similarly to previous research reports by Desta (1978), Mesfin (1980) and Asnake and Tekalign (1991), most of the treatments significantly produce mean grain yield as compared to the control and also showed a significant mean grain yield differences between some treatments.

Table 2. Response of maize grain yield to P and N fertilizer application on Vitric and Mollic Andosols

Fertilizer	P level				
	Treatment	0	23	46	92
N level	0	4579 ^{f}	4705 ^{f}	4989 ^{f}	4832 ^{f}
	46	6186 ^{e}	6139 ^{e}	6106 ^{e}	6621^{bcde}
	92	6541 ^{cde}	7164 ^{abc}	7140 ^{abc}	7306 ^{a}
	138	6500de	6916 ^{abcd}	7233^{ab}	7534 ^{a}
LSD (0.05)		623.6			
C.V %		18.2			

***CV (%)** = Coefficient of variations **LSD = Least Significance Difference

Table 3. Effect of N applied on grain yield of maize in Shashemene District

	Agronomic parameter	
N (kg/ha)	Pt Ht (cm)	Gyld(kg/ha)
0	223.86^{c}	4776^{c}
46	247.20^{b}	6262.7b
92	253.35^{ba}	7037.7a
138	255.77^{a}	7045.7a
LSD < 0.05	8.28	325

*Pt Ht = (plant height cm) ** Gyld = Grain yield (kg/ha)

Table 4. Effect of P applied on grain yield of maize in Shashemene District

	Agronomic parameter	
P (kg/ha)	Pt Ht (cm)	Gyld (kg/ha)
0	240.33a	5951.40a
23	241.33a	6227.73a
46	247.33a	6366.74a
92	251.31a	6572.7a
LSD < 0.05	NS	NS

*Pt Ht = (plant height cm) ** Gyld = Grain yield(kg/ha)

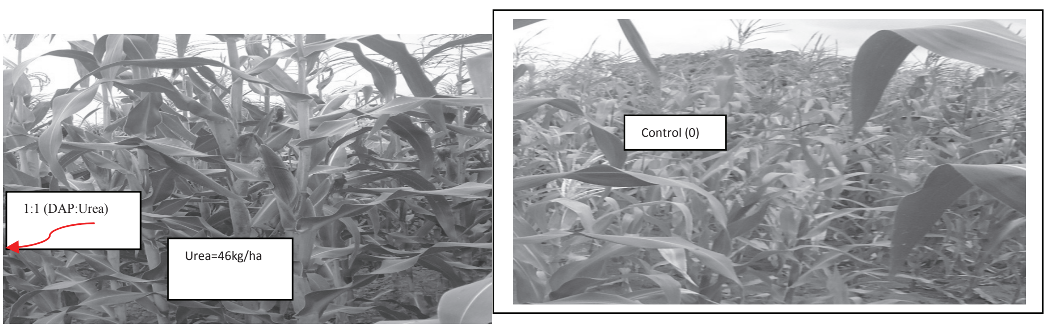

Figure 3. Maize with P fertilizer levels

Determination of optimum nitrogen fertilizer application for maize

Optimum yield can be gained in the presence of all available essential nutrients at balanced and optimum level where phosphorus and nitrogen are the most deficient essential nutrient in the country. Therefore determination of optimum nitrogen fertilization level during P fertilizer calibration is the most important procedure. Hence, determination of optimum nitrogen fertilization level was done by partial economic analysis procedure, which was 46 kg N/ha for maize on Vitric Andisol, and Mollic Andisol for Shashemene District.

Determination of P critical for maize

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. Then, by moving the two perpendicular lines vertically and horizontally until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). Finally, the point where the vertical line crosses the X-axis was defined as "critical" soil test levels. Hence, P critical value for maize in Shashemene District for maize growing area on Vitric Andosol and Mollic Andisol and Haplic Luvisol soil was 35ppm (Figure 3). Similarly, Mesfin Kebede and Tekalign Tadesse

(2012) reported that at Chefe Donsa, Ude and Akaki, highest yield of durum wheat was obtained at soil tests P raised to 6.91, 7.39 and 7.40 ppm, respectively.

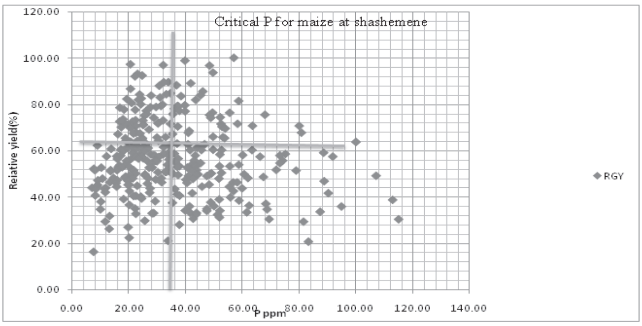

Figure 3. Relative yield vs P Olsen plot chart for P critical determination

Determination of phosphorus correction factor (Pf)

Calculated phosphorus requirement factor (Pr), which is the amount of P in kg needed to raise the soil test P by 1ppm for maize production at Shashamane area was 1.14**.** This Phosphorus requirement factor enables to determine the quantity of P required per hectare to raise the soil test by 1 ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Table 5).

Table 5. Determination of P requirement factor (Pf) for maize, Shashemene District

Fertilizer treatment kg P ha^{-1}	Olsen - P (ppm)		P increase Over control	*P requirements factor kg P^{-1} (ppm) □ P
	Range	Average		
0	7.2- 43.5	20.6	0	0
10	10.8 - 56.9	32.4	11.8	0.85
20	12 - 81.6	39.2	18.6	1.08
40	9.0 - 95.0	47.3	26.7	1.50
Mean			**19**	**1.14**

Conclusion and Recommendation

Mean grain yield data indicated that the increment of grain yield parallel to the increment of fertilizer NP application level verified the responsiveness of the soil to application of fertilizer phosphorus and nitrogen. Site specific soil test-based crop response fertilizer recommendation study in Shashemene District on maize resulted in determination of optimum nitrogen, P critical and P requirement for specific area. Accordingly, optimum nitrogen rate (46 kg N/ha), critical P (Pc) concentrations (35 ppm) and P (Pf) requirement factors (1.14) were determined for maize in Shashemene District, which could be extrapolated to similar soil types and AEZ in Oromia. Therefore, verifying the determined Pc and Pf before disseminating the recommendation should be the prerequisite.

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Soil Test-based Crop Response Study for Phosphorus on Maize in Bedele District of Illubabor Zone, West Oromia, Ethiopia

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Abstract

Understanding soil fertility status and plant nutrients requirement of a given area has vital role in enhancing crop production on sustainable basis. In view of this, on-farm study was conducted in Bedele District of Illubabor Zone of Oromia during the main cropping seasons of 2011 to 2013. The aims of the study were to determine P-critical value and P- requirement factor for P-fertilizer recommendation of hybrid maize (BH-660) for the district. Factorial combinations of four levels of N (0, 46, 92 and 138 kg N/ha) and four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and two satellite K (30 and 60kg/ha K_2O) in the first year to determine N rate and K response. Moreove, single factor of four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and 92 kg N/ha in the second and third years to determine P-critical value and P-requirement factor were laid out in randomized complete block design with two replications. The results of the study revealed that the soil pH (H_2O) values were extremely acidic to strongly acidic ranged from 4.43 to 5.42, very low available P from 1.82 to 4.78ppm. The maximum mean grain yield (5031 kg ha^{-1}) was obtained from the application of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}, whereas the lowest(1439 kg ha^{-1}) was from the control plot. However, fertilizer combinations of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}as compared with 92 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} showed no significant difference on maize grain yield. Therefore, 92 kg N ha^{-1} was selected as N fertilizer recommended for the area. The study also showed that P-critical value (6ppm) and P- requirement factor (23.55) were determined for phosphorus fertilizer recommended for the area. The validity of critical value was verified by conducting verification trials; accordingly, the economic evaluation showed that soil test based recommendation yielded in 2.23 Birr for every birr invested. Thus, farmers in the area might be advised to use soil test based crop response fertilizer recommendation to increase the productivity of maize. Similarly, a considerable soil acidity and low fertility of the soil are threatening agricultural production in the area and require emphasis for both proper soil acidity and soil fertility management practices together.

Key words: Maize (BH-660), Nitrogen, Phosphorus, P critical and P requirement

Introduction

Agriculture is the predominant economic sector in the majority of the developing countries in the world (Ahmed, 2002). People are dependent on soils and, conversely, good soils are dependent on people and the uses they make of the land (Brady and Weil, 2002). Crop yields in the developed world are high and agricultural soils have high fertility status due to intensive use of fertilizers (Mengel and Kirkby, 1996). This implies that using chemical fertilizer plays significant role in increasing food production to meet the demand of the growing population. On the other hand, sub-Saharan Africa is characterized by diverse agricultural systems that are typically low input based subsistence farming systems (Bekunda *et al*., 1997). These soils have been sustaining agricultural production for centuries; as a result, their native fertility has been extremely low (Wong *et al.,* 1991). Soil fertility replenishment has, therefore, been singled out as necessary, but not sufficient condition for sustainable development in Africa (Sanchez and Leakey, 1997).

Soil fertility depletion presents a major challenge to bring about increased and sustainable productivity to feed the ever increasing population of the country. The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, has posed a serious threat to agricultural production (FAO, 2006). The secret of ensuring food security for the ever increasing world population is strongly linked to the productivity of soils (Wakene, 2001). Quinenes *et al.* (1992) also stated that unless something is done to restore soil fertility first, other efforts to increase crop production would end up with little success. Kelsa *et al. (*1992) reported that using chemical fertilizers can increase yield under Ethiopia.

In Ethiopia, maize is first in productivity and second in area coverage after *teff* (CSA, 2010). Research results in high potential maize growing areas are on average 7000-8000 kg ha^{-1}. However, yield levels obtained by smallscale farmers remained stagnant despite the availability of improved varieties even in high maize growing potential areas of western Oromia (Benti, 1993). One of the main causes for this discrepancy is the low use of external inputs, leading to negative balances for N, P and K (Rhodes *et al.*, 1996).

Understanding soil fertility status and plant nutrients requirement of a given area has vital role in enhancing crop production and productivity on sustainable basis. Nevertheless, little information is available in Oromia in general and Illubabor Zone in particular on essential plant nutrients requirement for maize production. The prevailing blanket fertilizer rate recommendation throughout the country on all soil types and agro-ecological zones justifies the existence of little information on the fertility status of Ethiopia's soils. This calls for site-specific soil fertility assessment to determine rate of nutrient application to increase crop productivity thereby feeding the rapidly growing population. Therefore the objectives of the study were to assess and determine P critical value and requirement factor, and give quantitative guidelines and recommendations of P fertilizer for maize production in the district.

Materials and Methods

Treatments, experimental designs and procedures

On-farm study was conducted in the district during the main cropping seasons of 2011 to 2013 to determine P-critical value and P-requirement factor for P-fertilizer recommendation of hybrid maize (BH-660) for the district. The treatments of the experiment were factorial combinations of four levels of N (0, 46, 92 and 138 kg N/ha) and four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and two satellite K (30kg/ha K_2O and 60kg/ha K_2O) in the first year to determine N rate. Moreover, single factor of four levels of P (0, 23, 46 and 92 kg P/ha) and 92 kg N/ha in the second and third years to determine P-critical value and P-requirement factor were laid out in randomized complete block design with two replications. The experimental fields were prepared by using oxen plow in accordance with conventional farming practices followed by the farming community in the area where, the fields were plowed four times. The gross plot size was 5m x8m with net plot 4 m x 6 m. DAP and TSP fertilizers were applied at planting. Nitrogin was applied in split application, half at planting and 35 days after planting in the form of urea. During the different growth stages of the crop, all the necessary field management practices were carried out as per the practices followed by the farming community. All agronomic and soil data were properly managed using EXCEL computer software. Grain yield was analyzed using SAS computer package version 9.1 and economic analysis was based on CIMMYT, 1988)

Agronomic data collection

Date of planting, days to 50% (tasseling, silking and maturity), plant height, number of cobs per plant, ear length, number of seed rows per cob, number of seeds per row, grain yield and thousand-seed weight.

Soil sampling and analysis

Composite surface soil samples (0-20cm depth) were collected from each experimental site before planting to determine pH (H_2O) and available P (Olsen method). Similarly, after 21-35 days of planting, intensive composite soil samples were collected from each experimental plot to determine available P.

Determination of critical P concentration

Critical P value was determined following the Cate-Nelson graphical method where soil P values were put on the X-axis and the relative yield values on the Y-axis (yield x 100/maximum yield). The Cate-Nelson graphical method is based on dividing the Y-X scatter diagram into four quadrants and maximizing the number of points in the positive quadrants. The positions of the lines on the overlay with respect to the axes of the graph were transferred to the graph by making marks on the edges of the graph. The two intersecting lines were then drawn lightly on the graph. The point where the vertical line crosses the X-axis is defined as 'critical soil test level'.

Determination of P requirement factor

Phosphorus requirement factor was calculated using available P values in samples collected from unfertilized and fertilized plots. It also determined by the relation between each fertilizer rate and averaged corresponding soil test P value for each fertilizer rates.

Results and Discussion

Soil pH and available phosphorus

The pH (H_2O) of the soil samples collected before planting was ranged from 4.43 to 5.42 (Table 1). Accordingly, the soils were extremely to strongly acidic in reaction (FAO, 2008). Continuous cultivation and long-term application of inorganic fertilizers lower soil pH and aggravate the losses of basic cations from highly weathered soils (Mokwunye *et al*. 1996). The result showed that soil pH affects maize production which is less than the maize requirement proposed (FAO, 2006). Available Phosphorus (Olsen method) collected before planting was ranged from 1.82 to 4.78ppm (Table 1). The available P contents of the soil were very low (Olsen *et al.,* 1954). The low contents of available P observed in the soil of the study areas are in agreement with previously reported results (Mesfin, 1998; Yihenew, 2002; Dagne, 2012) who reported that the Ethiopian agricultural soils particularly the Nitisols and other acid soils have low available P content due to their inherently low P content, high P fixation capacity, crop harvest and soil erosion.

Table 6. Initial soil phosphorus and pH

Site	Available P (ppm)	pH (H_2O)
Site 1	2.36	5.16
Site 2	3.58	5.31
Site 3	4.78	4.85
Site 4	4.23	5.01
Site 5	2.98	4.89
Site 6	4.73	4.43
Site 7	2.12	5.08
Site 8	1.98	5.42
Site 9	1.82	5.16
Site 10	2.51	4.84
Average	**3.11**	

Nitrogen fertilizer determination

The main effects of both N and P were highly significant ($P \leq 0.01$) and interaction effects were significant ($P \leq 0.05$) on grain yield of maize. These results agree with (Orkaido, 2004) who reported that N and P highly significant main effects and significant interaction effect on grain yield. The maximum mean grain yield (5031kg ha^{-1}) was resulted from the application of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}, whereas the lowest(1439kg ha^{-1}) was from the control plot (Table 2). However, fertilizer combinations of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} as compared with 92 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} showed no significant difference on maize grain yield. Therefore, 92 kg N ha^{-1} was selected as N fertilizer recommended for the area. Satellite potassium fertilizer did not show significant difference on yield.

Means with the same letter are not significantly different at $P \leq 0.05$; LSD =Least Significant Difference, CV= Coefficient of Variance

Table 7. The interaction effect of N and P fertilizers on yield of maize (kg ha^{-1})

	N (kg N ha^{-1})				
P (kg P_2O_5 ha^{-1})	0	46	92	138	Mean
0	1438.8g	2422.8defg	2582.4def	2803.7de	2311.925
23	2017.4efg	3179.6dc	3941.4bc	4228.2ab	3341.65
46	1795.6fg	3904.8bc	4469.8ab	4871.8ab	3760.5
92	1793.8fg	4037.6bc	4238.7ab	5030.6a	3775.175
Mean	1761.4	3386.2	3808.075	4233.575	
LSD	991.73				
CV (%)	48.33				

Phosphorus critical value and requirement factor

The study also showed that P-critical value (6ppm) (Figure 1) and P- requirement factor (23.55) (Table 8) were determined for phosphorus fertilizer recommended for the area.

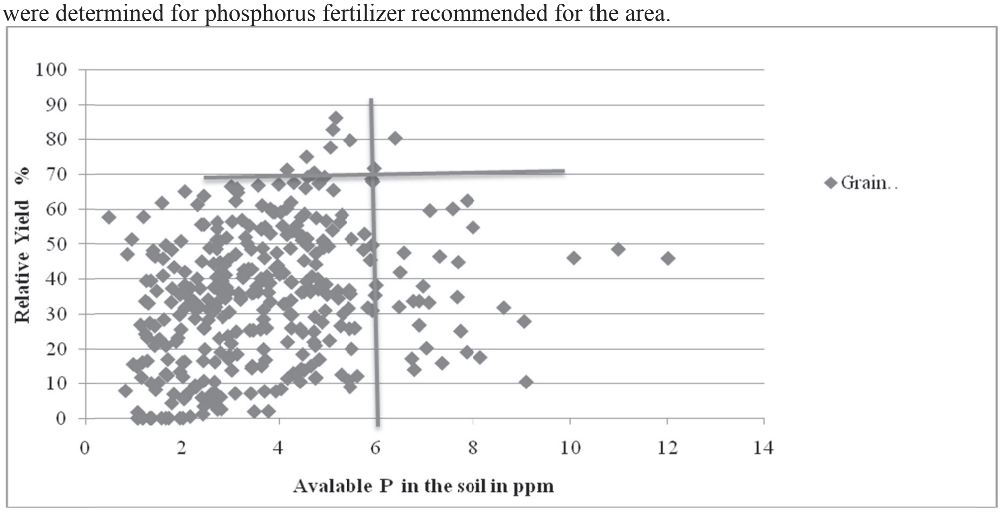

Figure 1. Phosphorus critical value for maize in Bedele District

Table. 3. Phosphorus requirement factor for maize in Bedele District

Fertilizer P applied (kg P/ha)	Olsen P (ppm) Mean	P- increase over the control	P- requirement factor (Pr)*
0	3.11	-	
10	3.61	0.5	20.00
20	3.92	0.81	24.69
40	4.65	1.54	25.97
Average			**23.55**

Verification of phosphorus critical value and requirement factor

There were significant differences ($P \leq 0.05$) among the treatments in maize grain yield. The maximum mean grain yield (5601 kg ha^{-1}) was obtained from the application of STBCRFR, whereas the lowest (2511kg ha^{-1}) was from the control plot (Table 4).

Table 4. Verification of phosphorus critical value and requirement factor

Treatment	**Yield (kg ha^{-1})**
Soil test based	5601.0[a*]
Blanket (Framers practices)	3600.0[b]
Control	2511.4[c]
LSD (5%)	741.03
CV (%)	30.43

*Means with the same letter are not significantly different at $p < 0.05$; LSD = Least Significant Difference, CV = Coefficient of Variance

Economic evaluation of maize production with soil test-based crop response P fertilizer calibration

The partial budget presented in Table 5 showed that the least total variable cost (TVC) was recorded by control treatment (without fertilizer), while the highest net benefit (NB) was obtained from STBCRFR (7323 Birr ha^{-1}), which gave 75.5% higher NB than Blanket (farmers practices) fertilizer application. The analysis of marginal rate of return (MRR), on the other hand, revealed that the rate of return per unit cost of production was highest from STBCRFR (% MRR = 223). This showed that it would yield 2.23 Birr for every Birr invested.

Table 9. Marginal rate of return analysis

Treatment	Partial budget with dominance				
	Yield (kg ha^{-1})	GFB (Birr ha^{-1})	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Dominance
Control	2511.40	10045.60	10550.00	504.40	
Blanket (100 DAP and 100 kg urea/ha)	3600.00	14400.00	12604.00	1796.00	Un dominated
STBCR FR	5601.00	22404.00	15081.18	7322.82	Un dominated
	Marginal rate of return (MRR %)				
			Incremental		
	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Cost	benefit	MRR (%)
Control	10550.00	504.40			
Blanket(FramersPractices)	12604.00	1796.00	2054.00	1291.60	62.88
STBCR FR	15081.18	7322.82	2477.18	5526.82	223.11

GFB = Gross field benefit; TVC = Total variable cost; NB = net benefit; MRR = Marginal rate of return

Conclusion and Recommendation

Sustaining soil fertility in intensive cropping systems for higher yields of better quality can be achieved through application of balanced external inputs or fertilizers. Thus, information on soil fertility status and crop response to different soil fertility management is very important to come up with profitable and sustainable crop production.

The results of the study revealed that the soil pH of the sites were extremely to strongly acidic in reaction based on the pH (H_2O) values and ranged from 4.43 to 5.42. The available P contents of the soil were very low ranged from 1.82 to 4.78ppm. The study also showed that P-critical value (6ppm) and P-requirement factor (23.56) were determined for phosphorus fertilizer recommended for the area. The economic evaluation showed that STBCRFR would yield 2.23 Birr for every Birr invested. Thus, farmers in Bedele District might be advised to use soil test based crop response fertilizer recommendation to increase the productivityand production of maize in the areas.

Acknowledgment
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Abstract

The secret of ensuring food security for the ever increasing population is strongly linked to the productivity of soils. In view of this, on-farm study was conducted in Mana District of Jimma Zone of Oromia, during the main cropping seasons of 2011 to 2013. The objectives of the study were to determine P-critical value and P- requirement factor for P-fertilizer recommendation of hybrid maize (BH-660) for the district. Factorial combination of four levels of N (0, 46, 92 and 138 kg N/ha) and four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and two satellite K (30 and 60kg/ha K_2O) in the first year to determine N rate and K response .Single factor of four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and 92 kg N/ha in the second and third years to determine P-critical value and P- requirement factor were laid out in randomized complete block design with two replications. The results of the study revealed that the soil pH (H_2O) values were extremely acidic to strongly acidic ranged from 3.94 to 5.11, Very low available P (Olsen method) from 0.91 to 1.68ppm. The mean maximum grain yield (4200 kg ha^{-1}) was resulted from the application of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}, whereas the lowest (1401 kg ha^{-1}) was from the control plot. However, fertilizer combination of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}as compared with 92 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} showed no significant difference on maize grain yield. Therefore, 92 kg N ha^{-1} was selected as N fertilizer recommended for the area. The study also showed that P-critical value (5.5 ppm) and P- requirement factor (13.89) were determined for phosphorus fertilizer recommended for the area. The economic evaluation showed that soil test based fertilizer recommendation gave yield with 1.95 B*irr for every birr invested. Similarly, a considerable soil acidity and low fertility of the soil are threatening the agricultural production in the area and require both proper soil acidity and soil fertility management practices together.*

Key words: Maize (BH-660), Nitrogen, Phosphorus, P critical and P requirement

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Results and Discussion

Soil pH and available phosphorus

The pH (H_2O) of the soil samples collected before planting were ranged from 3.94-5.11 (Table 1). Accordingly, the soils were extremely to strongly acidic in reaction (FAO, 2008). Continuous cultivation and long-term application of inorganic fertilizers lower soil pH and aggravate the losses of basic cations from highly weathered soils (Mokwunye *et al*. 1996). The result showed that soil pH affects maize production which is less than the maize requirement proposed (FAO, 2006). Available phosphorus (Olsen method) collected before planting were ranged from 0.91 to 1.68 ppm (Table 1). The available P contents of the soil were very low (Olsen *et al.,* 1954). The low contents of available P observed in the soil of the study areas are in agreement with the results reported (Mesfin, 1998; Yihenew, 2002; Dagne, 2012) who reported that the Ethiopian agricultural soils particularly the Nitisols and other acid soils have low available P content due to their inherently low P content, high P fixation capacity, crop harvest and soil erosion.

Table 10. Initial soil Phosphorus and pH

Site	Available P (ppm)	pH (H_2O)
Site 1	0.97	4.49
Site 2	1.28	4.5
Site 3	1.04	4.35
Site 4	1.15	3.94
Site 5	1.22	4.66
Site 6	1.48	4.69
Site 7	0.91	4.35
Site 8	1.68	5.11
Site 9	1.45	4.52
Site 10	0.92	4.68
Average	**1.21**	

Nitrogen fertilizer determination

The main effects of both N and P were highly significant ($P \leq 0.01$) and interaction effects were significant ($P \leq 0.05$) for grain yield of maize. These results agree with (Orkaido, 2004) who reported that N and P showed highly significant main effects and significant interaction effect on grain yield. The mean maximum grain yield (4200 kg ha^{-1}) was obtained from the application of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}, whereas the lowest (1401 kg ha^{-1}) was from the control plot (Table 2). However, fertilizer combinations of 138 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}as compared with 92 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} showed no significant difference on maize grain yield. Therefore, 92 kg N ha^{-1} was selected as N fertilizer recommended for the area. Satellite potassium fertilizer did not show significant difference on yield.

Phosphorus critical value and requirement factor

The study also showed that P-critical value 5.5 ppm (Figure 1) and P- requirement factor 13.89 (Table 11) were determined for phosphorus fertilizer recommended for the area.

Table 12. The interaction effect of N and P fertilizers on yield of maize (kg ha^{-1})

	N (kg ha^{-1})				
P_2O_5 (kg ha^{-1})	0	46	92	138	Mean
0	1401.0h	2143.8fg	2933.8edc	3187.8edc	2416.6
23	1862.6hg	2608.5ef	3399.0dc	3594.9abc	2866.25
46	1906.5hg	2658.4ef	3488.5bc	4162.1ab	3053.875
92	1780.6hg	2716.3edf	3516.0abc	4200.4a	3053.325
Mean	1737.675	2531.75	3334.325	3786.3	
LSD	685.3				
CV (%)	38.70				

Means with the same letter are not significantly different at p<0.05; LSD = Least Significant Difference; CV = Coefficient of Variance

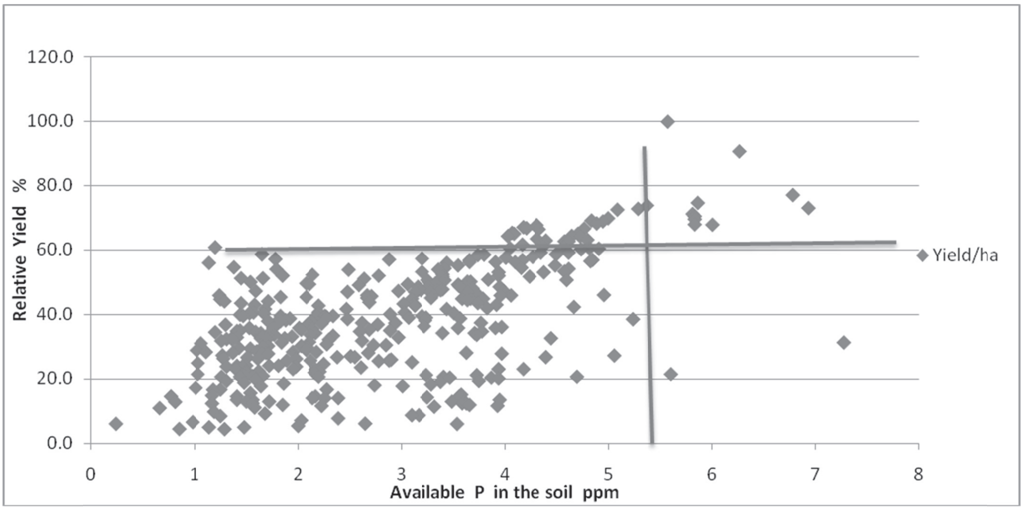

Figure 1. Phosphorus critical value for maize in Mana District

Table. 3. Phosphorus requirement factor for maize in Mana District

Fertilizer P applied (kg P/ha)	Olsen P (ppm)	P increase over the control	P requirement factor (Pr)*
	Mean		
0	1.21	-	
10	2.11	0.9	11.11
20	2.86	1.65	12.12
40	3.38	2.17	18.43
Average			**13.89**

Verification of Phosphorus Critical value and Requirement Factor

There were significant differences ($P \leq 0.05$) among the treatments in maize grain yield. The mean maximum grain yield (4909 kg ha^{-1}) was resulted from the application of soil test based fertilizer recommeendation, whereas the lowest (1970 kg ha^{-1}) was from the control plot (Table 4).

Table. 4. Verification of phosphorus critical value and requirement factor

Treatment	**Yield (kg ha^{-1})**
STBCRFR	4909.0[a]
Blanket (Framers Practices)	3281.0[b]
Control	1970.0[c]
LSD(5%)	400.67
CV(%)	18.96

Means with the same letter are not significantly different at $p< 0.05$; LSD = Least Significant Difference; CV = Coefficient of Variance

Economic evaluation of maize production with soil test-based crop response P fertilizer calibration
he partial budget presented in Table 5 showed that the least total variable cost (TVC) was recorded by control treatment (without fertilizer), while the highest net benefit (NB) was obtained from soil test based (4826 Birr ha^{-1}), which gave 89% higher NB than Blanket fertilizers application. The analysis of marginal rate of return (MRR), on the other hand, revealed that the rate of return per unit cost of production was highest from soil test based (% MRR = 1957). This showed that it would yield 1.95 Ethiopian Birr for every Birr invested.

Table 13. Marginal rate of return analysis

Partial budget with dominance

Treatments	Yield (kg ha^{-1})	GFB (Birr ha^{-1})	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Dominance
1. Control	1970.00	7880.00	10550.00	2670.00	
2. Blanket (Farmers practices)	3281.00	13124.00	12604.00	520.00	Un dominated
3. STBCRFR	4909.00	19636.00	14810.20	4825.80	Un dominated

Marginal rate of return (MRR %)

Treatment	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Incremental cost	Incremental benefit	MRR (%)
1. Control	10550.00	2670			
2. Blanket (Framers Practices)	12604.00	520	2054		
3. STBCRFR	14810.20	4825.8	2206.2	4305.8	195.17

Blanket (100 DAP and 100 urea kg/ha); GFB = Gross field benefit; TVC = Total variable cost; NB = Net benefit; MRR = Marginal rate of return

Conclusion and Recommendation

Sustaining soil fertility in intensive cropping systems for higher yields of better quality can be achieved through application of balanced external inputs or fertilizers; and information on soil fertility status and crop response to different soil fertility management is very important to come up with profitable and sustainable crop production.

The results of the study revealed that the soil pH of the sites were extremely to strongly acidic in reaction based on the pH (H_2O) values and ranged from 3.94-5.11. The available P content of the soil were very low ranged from 1.82 to 4.78ppm. The study showed that P-critical value (5.5 ppm) and P- requirement factor (13.89) were determined for phosphorus fertilizer recommended for the area. The economic evaluation showed that soil test based fertilizer recommendation gave yield of 1.95 Birr for every birr invested. Thus, farmers in the district might be advised to use soil test based crop response fertilizer recommendation to increase the productivity of maize.

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Soil Test-based Crop Response Study for Phosphorus on Bread Wheat in Lume District of East Shewa Zone, Oromia, Ethiopia

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Abstract

Nutrient management is indispensable for crop production and productivity increments on different soil types. Therefore soil nutrient calibration study is pertinent to increase efficient use of inorganic fertilizer like DAP and urea. Based on this understanding site specific soil test based crop response studies for P on bread wheat was conducted from 2010-2012 cropping seasons in Lume District. The objective of the experiment was to determine economically optimum N, phosphorus critical (Pc) and Phosphorus requirement factor. The experimental treatments were developed by factorial combination of four levels of N (0, 46, 92 and 138 kg ha^{-1}) and P (0, 23, 46 and 92 kg ha^{-1}) that laid out in randomized complete block design with two replications. After 21 days of sowing, intensive composite soil samples were collected from each plot for the determination of available P. Plant height, biomass and grain yield were collected. Application of N indicated that significant difference in plant height, biomass and grain yield of bread wheat. However the application of P was not significant on plant height, straw yield and grain yield in the district whereas the interaction effect of N and P application on grain yield, plant height and straw yield was significant. Furthermore, the study revealed that phosphorus critical (Pc) point for bread wheat was 19, and phosphorus requirement factor were also 4.92. Economical N rate was 46 kg N ha^{-1}

Key words: Calibration, P-critical, P- requirement factor

Introduction

The population of Ethiopia is currently growing at a faster rate and demands an increased proportion of agricultural production. On the other hand, growth in food production is not in equal footings with population pressure (CSA, 2015). Strengthening food production capability of the country by wisely exploiting its existing human and natural resources is critical option to avert the existing situation. But, Ethiopia is one of the sub-Saharan African countries where severe soil nutrient depletion restrains agricultural crop production and economic growth. The annual net loss of nutrients is estimated to be at least 40 N, 6.6 P and 33.2 K kg/ha (Scoones and Toulmin, 1999). Continuous cropping, high proportions of cereals in the cropping system, and application of suboptimal levels of mineral fertilizers aggravate the decline in soil fertility (Tanner *et al*., 1991; Hailu *et al*., 1991; Workneh and Mwangi, 1992). Hence, identification of proper fertilizer types is beneficial at the macroeconomic level by improving the efficiency of fertilizer procurement and resource allocation.

Therefore, profitable crop production requires adequate levels of phosphorus (P) and other nutrients. For this careful planning is required because of volatile grain and fertilizer prices. So, sound soil test calibration is essential for successful fertilizer program and crop production. It is essential that the results of soil tests could be calibrated or correlated against crop responses from applications of plant nutrients in question as it is the ultimate measure of fertilization program. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for each crop (Sonon and Zhang, 2008). Hence, calibration is a vital tool to attain the objective while calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety. That means, fertilizer recommendations on soil test based for economic crop production should be both location and situation specific and can be modified with changes in soil test value as well as input-output ratios.

Therefore, this field experiment was conducted with the basic assumption that fertilizer recommendations typically depend on crop response in which spatial variability has been minimized for every independent variable affecting crop yield except for the nutrient in question (Kastens et al., 2003). The objectives of the study were to determine and evaluate P fertilizer requirement for bread wheat based on soil test crop response, and to give quantitative guidelines and recommendations of P and N fertilizers for bread wheat in the district.

Materials and Methods

Descriptions of the study area

The study was conducted in Lume District, East Shewa Zone of Oromia. Geographically the district is located between 8^0 24’300” to 8^0 49’30” North and 39^0 01'00" to 39^0 17'00" East with total area coverage of 67514.73 hectares (Figure 1). The Elevation ranges from 1590 to 2512masl, whereas the average elevation is 1909masl.

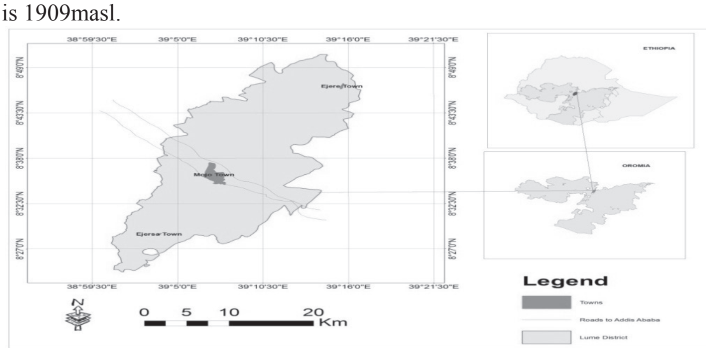

Figure 6. Location map of Lume District

Climate

Climate influences the physical and cultural environments, the types of vegetation, animals reared and crops to be grown, the land use patterns and ultimately the economy. So, Lume District is generally characterized by semi-arid and sub-humid climate based on the moisture index classification of climate (Lemma, 1996). The long term average seasonal (June-September) rainfall which influences the rain-fed agricultural practices of the year ranged from 571.86 to 920.44mm. The average minimum monthly rainfall of 2.70mm was recorded at Modjo station in December and average maximum monthly rainfall of 276.07mm at the same station in July. The mean monthly rainfalls of five stations within and nearest to the study area were calculated from the 10 years data from 1999 to 2009, which was collected from National Meteorological agency (Figure 2). On other hand, the maximum mean monthly temperature of 32.13^{o}C is recorded at Koka dam station in April whereas the lowest mean minimum monthly temperature of 6.86^{o}C was recorded at Chefe-Donsa station in December. Hence, crops growth is influenced by total daily mean heat accumulated, which is related to the daily mean temperature (White *et al.,* 2001). Mean monthly minimum and maximum temperature of four stations within and nearest to Lume District are shown in Figure 3.

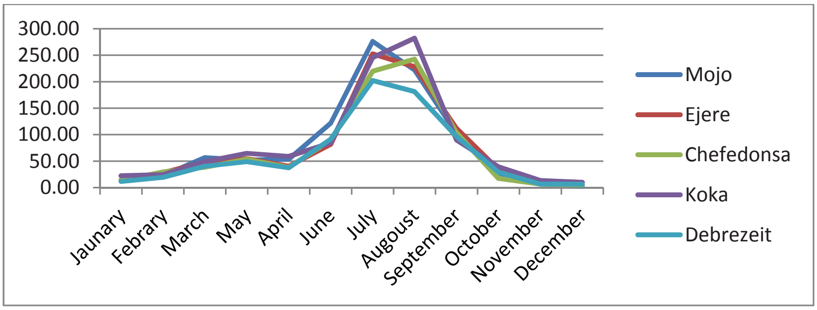

Figure 2. Monthly rainfall of five stations with in and nearest the district

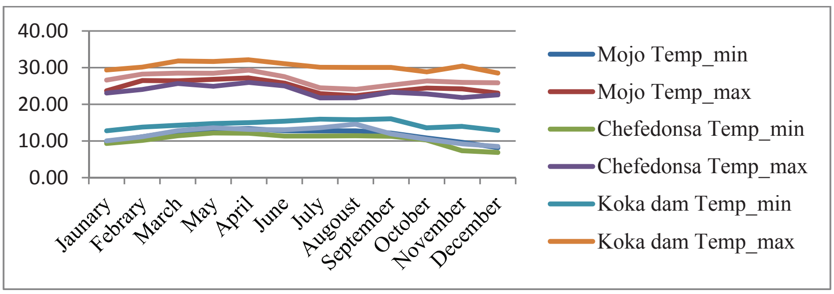

Figure 3. Monthly minimum and maximum temperature

Soil

Soil is defined as a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics (Davidson, 1980). According to FAO soil classification the soils of Lume District were grouped into seven soil types which is mainly dominated by Eutric Vertisol (44.84%), Mollic Andosols (21.69%) and Luvic Phaeozems (14.76%).

Land use/land cover

The farming system of the study area is sedentary mixed agriculture. Crop rotation is one of the systems of soil fertility management. Chemical fertilizer application is another system to increase crop production per unit area. The major crop types in the area are teff, chickpea and wheat. These crops are scaled up by development agents and farmers on the basis of their economic benefits. This indicates that no crop type mainly dominate the area for long year as the past historical farming systems with less inputs and market assessment and prediction. Generally, major land uses of the study area are grouped into four that include agricultural land (93.13%), plantation forest (2.76%), settlements (2.34%) and flower farms (1.77%).

Methodology

The study was conducted on farmers' fields across the district. Composite soil samples were collected from 24 farmers' field and analyzed for soil texture, soil pH, OC, total N, available P, available K, and CEC to identify the level of required parameters in the soil to select farm land for actual experiment. Based on the level of P content a total of 10 farm lands were selected. The experiment was laid out in randomized complete block design with two replications. Four levels of P_2O_5 (0, 23, 46, and 96 kg//ha) and four levels of N (0, 46, 92 and 138 kg/ha) considered in factorial combination plus two levels of potassium as satellite treatments to investigate the response of potassium (Table 1). Replications were folded to minimize soil heterogeneity within each replication.

Table 1. Description of treatments

Treatment # (T1-T6) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T7-T12) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T13-T18) *($N:P_2O_5:K_2O$ kg ha^{-1})*
T1 *(0:0:0)*	T7 *(46:46:0)*	T13 *(138:0:0)*
T2 *(0:23:0)*	T8 *(46:92:0)*	T14 *(138:23:0)*
T3 *(0:46:0)*	T9 *(92:0:0)*	T15 *(138:46:0)*
T4 *(0:92:0)*	T10 *(92:23:0)*	T16 *(138:92:0)*
T5 *(46:0:0)*	T11 *(92:46:0)*	
T6 *(46:23:0)*	T12 *(92:92:0)*	

Gross plot size: 5m x 8m Harvested area: 3m x 3m

Land preparation was done using oxen plow and required seed and fertilizer per plot were broadcast (total DAP and half urea). After 21 days of planting, composite soil samples were taken at 0-15cm depth using auger for each treatment and replications separately, and the samples were subjected to laboratory analysis using Olsen method. Intensive sampling after 21 days of planting with the assumption that P might be available to plant within the given day. With continuous field management, all field agronomic data and post harvest data were collected including date of emergency, date of flowering, number of tiller, maturity date, plant height, biomass and grain yield. Based on soil available P laboratory analysis result of pre-planting and post planting soil composite samples (available P values in samples collected from unfertilized and fertilized plots) data, p requirement factor was calculated that enables one to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1} (1 part per million), and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level.
Hence:

Pr = kg P applied/change in soil P

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. Hence soil and yield data from 10 sites of all treatments with their replications were used for such analysis**.** This was achieved by overlay of a clear plastic sheet having a pair of perpendicular lines drawn on it to produce four quadrants, roughly of the same relative size. The overlay was then positioned on the graph in such a way that the maximum number of points fell in the positive quadrants while the lowest number fell in the negative quadrants. The vertical line defines the responsive and non-responsive ranges, whereas the optimum is indicated by the point where the vertical line crosses the x-axis.

On the other hand, economic analysis was performed to investigate the economic feasibility of the treatments. Partial budget, dominance, marginal and sensitivity analyses were used. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers will expect from the same treatment. The average grain yield also adjusted by reducing 10% to minimize the over estimation of yield when yield of small plot converted to hectare basis. The average open market price (Birr kg^{-1}) of bread wheat, urea (N) and DAP (P) fertilizers were used for analysis. For a treatment to be considered worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% (CIMMYT, 1988), which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis. Finally, using phosphorus requirement factor, phosphorus critical level and initial P values (soil P value from composite soil sample before fertilization) rate of P fertilizer to be applied was calculated as follows:

Rate of P fertilizer to be applied = (Critical P conc. - initial P values) × P requirement factor.

Data management and analysis

All agronomic and soil data which were collected across locations was properly managed using the EXCEL computer software. The collected data was subjected to the analysis of variance using the SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

Results and Discussion

Bread wheat study results indicated that most of the treatments significantly produce mean grain yield as compared to the control. Except treatments with zero level of nitrogen fertilizer, all the rest produced significant mean grain yield as compared to the control (Table 2). Mean grain yield ranged from 1945 kg/ha (Control) to 4218 kg/ha (92 P_2O_5 kg/ha). This result signifies that the existence of positive interaction of P and N fertilizers for the production of bread wheat, and the responsiveness to the application of high level fertilizer phosphorus. Similarly, previous research findings reported by Desta (1978), Mesfin (1980) and Asnake and Tekalign (1991) supported this result. According to Mesfin and Tekalign (2012), at Chefe Donsa, Ude and Akaki, highest yield of durum wheat was obtainedd at soil tests P raised to 6.91, 7.39 and 7.40 ppm, respectively.

The results also indicated that consistently increment and significantly difference of all required bread wheat agronomic parameter (plant height, straw yield and grain yield) as compared to zero as well as between levels, with the increment level of fertilizer N applications. This significant difference on agronomic parameter with required N fertilizer levels signifies very low soil capacity to supply crop with N nutrient. Conversely, the increment of the level of fertilizer P did not indicate significant difference between all levels for all agronomic parameter. This might be because of initial (unfertilized soil) P level of the soil. But the Correlation coefficient between agronomic parameters (plant height, straw yield and grain yield) on bread wheat was significant at $p< 0.05$ (Table 3).

Table 2. Response of bread wheat grain yield to NP fertilizers application on Eutric Vertisol

Fertilizer	P level				
	Trt	0	23	46	92
N level	0	1945.28 ^{f}	1946.32^{f}	1957.15^{f}	2009.44^{f}
	46	2962.86 ^{d}	3188.2 ^{dc}	3163.627^{d}	3181.87^{d}
	92	3657.58 ^{bc}	3885.98^{ba}	3766.98^{ba}	4024.49^{ab}
	138	4045.17 ^{ab}	4087.67^{ab}	4217.67^{a}	4205.39^{a}
LSD (0.05)		466.94			
CV (%)		23.1			

N = nitrogen ; P= phosphorus; LSD= Least Significance Difference ; CV = coefficient of variation.

Table 3. Correlation coefficient between plant height, straw yield and grain yield on bread wheat in Lume District

	Correlation coefficient		
	pt ht (cm)	Syld (kg/ha)	Gyld (kg/ha)
plant height ht(cm)	1.00	0.245(<.0001)	0.746(<.0001)
Straw yield (kg/ha)	0.245(< .0001)	1.00	0.278(<.0001)
Grain yield (kg/ha)	0.746(<.0001)	0.278(<.0001)	1.00

*Pt Ht = (plant height cm); Syld = Straw yield (kg/ha); Gyld = Grain yield (kg/ha)

Determination of optimum nitrogen fertilizer application for bread wheat

Optimum yield can be gained in the presence of all available essential nutrients at balanced and optimum level where phosphorus and nitrogen are the most deficient essential nutrient in the country. Therefore, determination of optimum nitrogen fertilization level during P fertilizer calibration is the most important procedure. Hence, determination of optimum nitrogen fertilization level was done by partial economic analysis procedure, which was 46 kg N/ha for bread wheat on Eutric Vertisols for the district.

Determination of P critical for bread wheat

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. Then, by moving the two perpendicular line vertically and horizontally, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). Finally, the point where the vertical line crosses the X-axis was defined (taken) as ‘critical soil test levels. Hence, P critical value for bread wheat in Lume District on vertisols soil was 19 ppm (Figure 3).

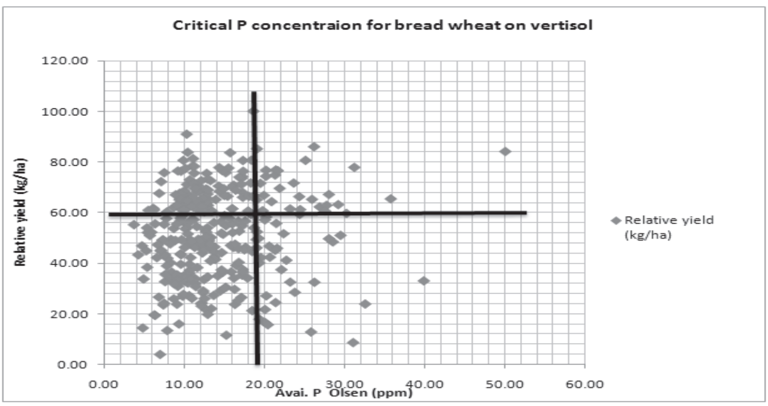

Figure 3. Relative yield Vs P Olsen plot chart for P critical determination

Determination of phosphorus correction factor (Pf)

Calculated phosphorus requirement factor (Pr), which is the amount of P in kg needed to raise the soil test P by 1ppm for bread wheat production in Lume District was 4.92. This phosphorus requirement factor enables to determine the quantity of P required per hectare to raise the soil test by 1ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Table 4).

Table 4. Determination of P requirement factor (Pf) for bread wheat, Lume District

Fertilizer treatment kg P ha^{-1}	Olsen - P (ppm)		P increase Over control	*P requirements factor= kg P □ P^{-1} (ppm)
	Range	Average		
0	3.83-23.25	10.93		
10	5.36-39.88	13.64	2.71	3.69
20	4.84-31.08	14.62	3.69	5.42
40	6.45-50	18	7.07	5.66
Mean olsen				**4.92**

Conclusion and Recommendation

In phosphorus calibration study conducted on bread wheat in Lume District, optimum nitrogen rate (46 kg N/ha), critical P (Pc) concentrations (19 ppm) and P (Pf) requirement factors (4.92) were determined for bread wheat growing areas on Eutric Vertisols. Farther verification of the result on farm land should be made before disseminating the recommendations to the users.

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Soil Test-based Crop Response Study for Phosphorus on Teff in Lume District of East Shewa Zone, Oromia, Ethiopia

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Abstract

Nutrient management is fundamental for crop production and productivity increments on different soil types. Accordingly, soil test based teff response P fertilizer calibration study was carried out from 2010-2012 cropping season in Lume District on Eutric Vertisol, because soil nutrient calibration study is pertinent to increase the use efficiency of inorganic fertilizers like DAP and urea. The objective of the experiment was to determine economically optimum N, and to determine phosphorus critical (Pc) and phosphorus requirement factor for teff in the district. The experiment was contained factorial combination of four levels of N (0, 46, 92 and 138 kg ha^{-1}) and P (0, 23, 46 and 92 kg ha^{-1}) laid out in randomized complete block design with two replications. After 21 days intensive soil samples were collected from each plot for the determination of available P. Plant height, biomass and grain yield were collected. Application of N indicated significant difference in plant height, grain and biomass yield. However application of P was not significant on plant height, straw yield and grain yield. The interaction effect of N and P application was also not significant to grain yield, plant height and straw yield. The study revealed that phosphorus critical (Pc) point for teff was 13, and phosphorus requirement factor was also 3.65. The result showed that 46 kg Nha^{-1} was economical.

Key words: Calibration, P- critical, P- requirement factor

Introduction

Ethiopia is one of the sub-Saharan African countries where severe soil nutrient depletion restrains crop production and economic growth. The annual net loss of nutrients is estimated to be at least 40 N, 6.6 P and 33.2 K kg/ha (Scoones and Toulmin, 1999). Continuous cropping, high proportions of cereals in the cropping system, and application of suboptimal levels of mineral fertilizers aggravate the decline in soil fertility (Tanner *et al*., 1991; Hailu *et al*., 1991; Workneh and Mwangi, 1992). Strengthening food production capability of the country by wisely exploiting its existing human and natural resources is critical option to avert the existing situation. Thus, identification of the proper fertilizer types is one of the beneficial means at the macroeconomic level that improves the efficiency of fertilizer procurement and resource allocation. It is generally understood that crop response to fertilizer inevitably declines, if nutrient applications are continually unbalanced.

Crop production can be profitable if and only if adequate and balanced levels of phosphorus (P) and other nutrients are used. At the present volatile grain and fertilizer prices, sound soil test calibration is essential for successful fertilizer program and crop production. It is essential that the results of soil tests could be calibrated or correlated against crop responses from applications of plant nutrients in question as it is the ultimate measure of fertilization program. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for each crop (Sonon and Zhang, 2008). Therefore, calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety. That means, fertilizer recommendations on soil test based for economic crop production should be both location and situation specific and can be modified with changes in soil test value as well as input-output ratios. Based on this concept, soil test calibration study was conducted on teff in Lume District with the objectives to determine and evaluate P fertilizer requirement based on soil test crop response, and to give quantitative guidelines and recommendations of P fertilizer for teff in the district.

Materials and Methods

Descriptions of the study area

The study was conducted in Lume District of East Shewa Zone, Oromia. Geographically the district is located between 8^0 24’300” to 8^0 49’30” North and 39^0 01'00" to 39^0 17'00" East with total area coverage 67514.73 hectares and the average elevation is 1909masl (Figure 1).

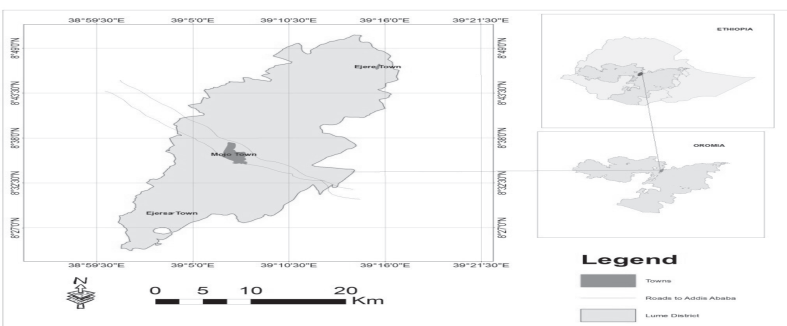

Figure 7. Location map of Lume District

Climate

Lume District is generally characterized by semi-arid and sub-humid climate based on the moisture index classification of climate (Lemma, 1996). The long term average seasonal (June-September) rainfall which influences the rain-fed agriculture ranged from 571.86 to 920.44mm. The average minimum monthly rainfall of 2.70mm was recorded at Modjo station in December and average maximum monthly rainfall of 276.07mm recorded at the same station in July. The mean monthly rainfall of five stations within and nearest to the study area was calculated from 20 year data of National Meteorological agency (Figure 2). The mean maximum monthly temperature of 32.13°C was recorded at Koka dam station in April and the lowest mean minimum monthly temperature of 6.86°C was recorded at Chefe-Donsa station in December. Hence, crop growth is influenced by total daily mean heat accumulated, which is related to the daily mean temperature (White *et al.,* 2001). The mean monthly minimum and maximum temperature of four stations within and nearest to Lume district are shown in Figure 3.

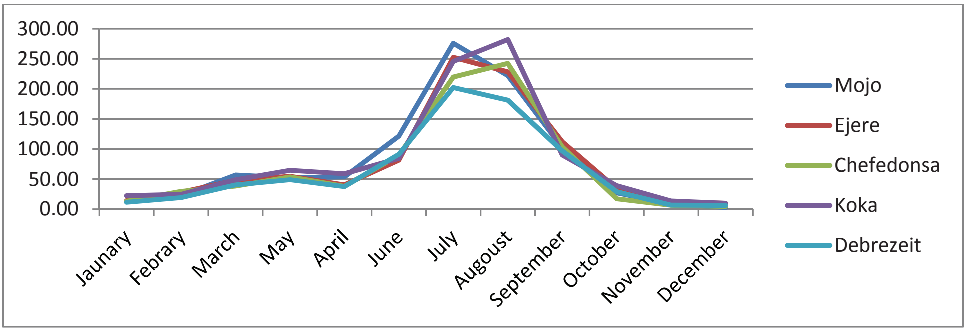

Figure 2. Monthly rainfall of five stations within and nearest the district

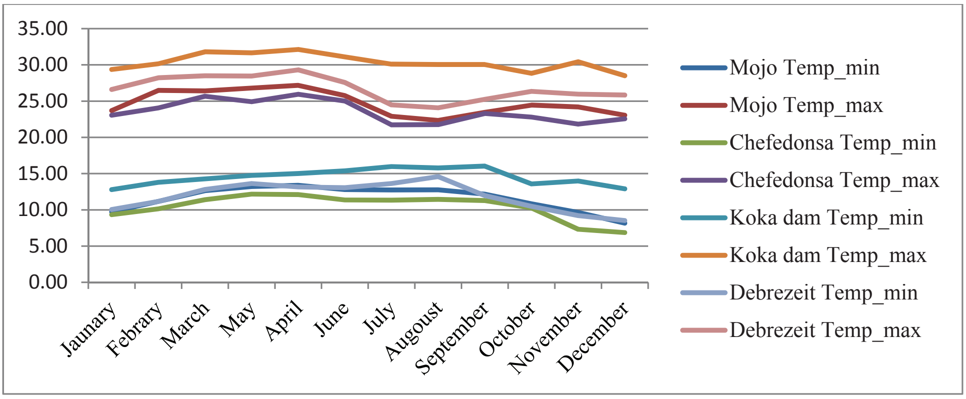

Figure 3. Monthly minimum and maximum temperature of the five stations

Soil

Soil is defined as a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics (Davidson, 1980). According to FAO soil classification the soils of Lume District were grouped into seven soil types which are mainly dominated by Eutric Vertisol (44.84%), Mollic Andosols (21.69%) and Luvic Phaeozems (14.76%).

Land Use/land cover

The farming system of the study area is sedentary mixed agriculture and crop rotation is one of the systems of soil fertility management. Chemical fertilizer application is another system to increase crop production per unit area. The major crop types in the area are teff, chickpea and wheat. These crops are scaled up by development agents and farmers on the basis of their economic benefits. This indicates that no crop type mainly dominate the area for long year as the past historical farming systems with less inputs and market assessment and prediction. Generally, major land use of the project area is grouped into four that includes agricultural land (93.13%), plantation forest (2.76%), settlements (2.34%) and flower farms (1.77%).

Methodology

The study was conducted on farmers' field across the district. Composite soil samples were collected from 20 farmers' field and analyzed for texture, pH, OC, total N, available P, available K, and CEC in order to identify the level of the required parameters in the soil to select farm land for actual experiment. Based on the level of P content a total of 10 farm lands were selected. The experiment was laid out in randomized complete block design with two replications. The treatment considered were four levels of P_2O_5 (0, 23, 46 and 96 kg/ha) and four levels of N (0, 46, 92 and 138 kg/ha) in factorial combination and two levels of potassium as satellite treatments to investigate the response of potassium (Table 1). Replications were folded to minimize soil heterogeneity within each replication.

Table 1. Description of treatments

Treatment # (T1-T6) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T7-T12) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T13-T18) *($N:P_2O_5:K_2O$ kg ha^{-1})*
T1 *(0:0:0)*	T7 *(46:46:0)*	T13 *(138:0:0)*
T2 *(0:23:0)*	T8 *(46:92:0)*	T14 *(138:23:0)*
T3 *(0:46:0)*	T9 *(92:0:0)*	T15 *(138:46:0)*
T4 *(0:92:0)*	T10 *(92:23:0)*	T16 *(138:92:0)*
T5 *(46:0:0)*	T11 *(92:46:0)*	
T6 *(46:23:0)*	T12 *(92:92:0)*	

Gross plot size: 5m x 8m   Harvested area: 3m x 3m

Land preparation was done using oxen plow. Teff seeds and fertilizers (total DAP and half urea) were broadcast. After 21 days of sowing, composite soil samples were taken at 0-15cm depth using auger for each treatment and replications separately, and the samples were subjected to laboratory analysis using Olsen method. With continuous field management, all field agronomic data and post harvest data were collected including date of emergency, date of flowering, maturity date, height, grain and biomass yield. Based on P laboratory analysis result of pre-planting and post planting soil samples (available P values in samples collected from unfertilized and fertilized plots) data P requirement factor was calculated that enables one to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1} (1 part per million), and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level.

Hence,
Pr = kg P applied per change in soil P

For determination of critical P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. This was achieved by overlay of a clear plastic sheet having a pair of perpendicular lines drawn on it to produce four quadrants, roughly of the same relative size. The overlay was then positioned on the graph in such a way that the maximum number of points fell in the positive quadrants while the lowest number fell in the negative quadrants. The vertical line defines the responsive and non-responsive ranges while the optimum is indicated by the point where the vertical line crosses the x-axis. Data from 10 sites for each crop and all treatments with their replications were used for such analysis**.**

Eonomic analysis was performed to investigate the economic feasibility of the treatments. Partial budget, dominance, marginal and sensitivity analyses were used. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers will expect from the same treatment. The average yield also adjusted reducing by 10% to minimize over estimation of grain while converting yield of small plot to hectare base. The average open market price (Birr kg^{-1}) of teff, prices of urea (N) and DAP (P) fertilizers were used for analysis. For a treatment to be considered a worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% (CIMMT, 1988), which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis.

Finally, using phosphorus requirement factor, phosphorus critical level and initial P values (soil P value from soil sample before fertilization) rate of P fertilizer to be applied was calculated as follows:

Rate of P fertilizer to be applied = (Critical P conc. - initial P values) × P requirement factor.

Data collection

During field experiment the agronomic data collected were planting date, emergence date, plant height, maturity date, grain and bio-mass yield.

All agronomic and soil data which were collected across locations were properly managed using the EXCEL computer software. The collected data were subjected to the analysis of variance using SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

Results and Discussion

Teff calibration study results indicated that most of the treatments significantly different compared to the control (Table 2). Accordingly, the mean grain yield ranged from 773 kg/ha (control) to 1392 kg/ha (138, 92 N-P_2O_5 kg/ha). This result signifies that the existence of positive interaction of P and N fertilizers for teff yield, and the responsiveness to the application of high level fertilizer phosphorus. But low mean grain yield of teff while the experiment duration was late starting of rain from normal rainy season that highly enhanced weed infestation.

The results also indicated that consistently increment and significantly difference of all required teff agronomic parameter (plant height, straw yield and grain yield) as compared to zero as well as between levels, with the increment level of fertilizer N applications. This significant difference on agronomic parameter with required N fertilizer levels signifies very low soil capacity to supply crop with N nutrient. However, the increment of fertilizer P level was significan for grain yield, but did not result in significant difference among levels for other agronomic parameter (Tables 3 and 4). These might be because of initial (unfertilized soil) P level of the soil. But correlation between agronomic parameter (plant height, straw yield and grain yield) on teff were significant at $p<0.05$ (Table 5).

Table 2. Response of teff grain yield to NP fertilizers application on Eutric Vertisol

Fertilizer	P level				
N level	Trt	0	23	46	92
	0	772.74[c]	827.79[c]	782.95[c]	798.89[c]
	46	909.54[bc]	1155.97 [ba]	1193.18[a]	1393.62[a]
	92	914.99[bc]	1199.43[a]	1244.85[a]	1305.1 [a]
	138	814.45[c]	1154.86[ba]	1245.34[a]	1392.20[a]
	LSD (0.05)	269.99			
	CV (%)	23			

Table 3. Effect of P applied on plant height, straw yield and grain yield of teff in Lume District

	Agronomic parameter		
P (kg/ha)	pt Ht (cm)	Syld (kg/ha)	Gyld (kg/ha)
0	86.84b	1071.91b	846.91c
23	90.41ba	1214.42ba	1084.52b
46	89.70ba	1330.05a	1116.58ba
92	91.49a	1367.68a	1227.47a
LSD < 0.05	3.59	158.45	134.81

*Pt Ht = Plant height; Syld = Straw yield; Gyld = Grain yield; LSD = Least Significance Difference

Table 4: Effect of N applied on plant height, straw yield and grain yield of teff in Lume District

N (kg/ha)	Agronomic parameter		
	Pt ht (cm)	Syld (kg/ha)	Gyld (kg/ha)
0	82.42a	881.35a	786.47a
46	88.74b	1216.48b	1164.71b
92	92.94c	1426.98c	1166.10b
138	94.12c	1449.25c	1151.74b
LSD < 0.05	3.6	158.8	135.1

*Pt Ht = Plant height; Syld = Straw yield; Gyld = Grain yield; LSD = Least Significance Difference

Table 5: Correlation coefficient between plant height, straw yield and grain yield of teff in Lume District

	Correlation coefficient		
	Pt ht (cm)	Syld (kg/ha)	Gyld (kg/ha)
plant height ht(cm)	1.00	0.48(<.0001)	0.521(<.0001)
Straw yield (kg/ha)	0.48(< .0001)	1.00	0.513(<.0001)
Grain yield (kg/ha)	0.521(<.0001)	0.513(<.0001)	1.00

*Pt Ht = plant height; Syld = Straw yield; Gyld = Grain yield

Figure 4. Teff response in experimental field

Determination of optimum nitrogen fertilizer application for teff

Optimum yield can be gained in the presence of all available essential nutrients at balanced and optimum level where phosphorus and nitrogen are the most deficient essential nutrient in Lume District. Therefore, determination of optimum nitrogen fertilizer level during P calibration is the most important procedure. Hence, determination of optimum nitrogen fertilization level was done by partial economic analysis procedure, which was 46 kg N/ha for teff on Eutric Vertisols soil of the district.

Determination of P critical for teff

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. Then, by moving the two perpendicular line vertically and horizontally, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). Finally, the point where the vertical line crosses the X-axis was defined (taken) as 'critical soil test levels. Hence, P critical value for teff at Lume area on vertisols soil were 13ppm (Figure 4)

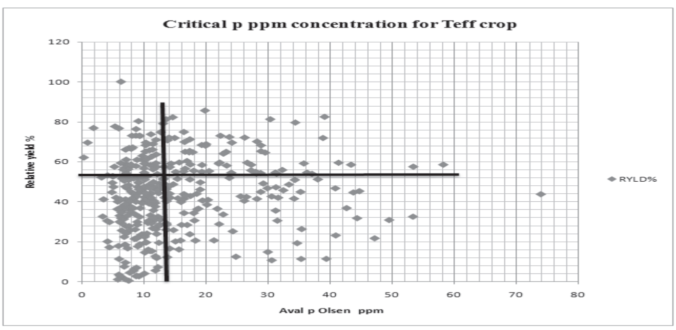

Figure 4. Relative yield vs P Olsen plot chart for P critical determination

Determination of phosphorus correction factor (Pf)

Calculated phosphorus requirement factor (Pr), which is the amount of P in kg needed to raise the soil test P by 1ppm for teff production in the district was 3.65. This phosphorus requirement factor enables to determine the quantity of P required per hectare to raise the soil test by 1ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Table 4).

Table 4. Determination of P requirement factor (Pf) for teff, Lume District

Fertilizer treatment (kg P ha^{-1})	Olsen - P (ppm)		P increase Over control	*P requirements factor = kg P □ P^{-1}(ppm)
	Range	Average		
0	3.25-49.46	10	0	0
10	0.19-35.16	13.1	2.9	3.45
20	1.78-73.92	15.43	5.43	3.68
40	4.82-58.12	20.45	10.45	3.83
Mean for olsen				**3.65**

Conclusion and Recommendation

Based on site specific soil test based crop response phosphorus calibration study conducted on teff, optimum nitrogen rate (46 kg N/ha), critical P (Pc) concentrations (13 ppm) and P (Pf) requirement factors (3.65) were determined for Lume District teff growing area on Eutric Vertisols. Farther verification of the result on farm land should be prerequisite before disseminating the recommendation to users.

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Soil Test-based Crop Response Study for Phosphorus on Teff in Chora District of Illubabor Zone, Southwest Oromia, Ethiopia

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Abstract

Soil fertility depletion presents a major challenge to bring about increased and sustainable productivity to feed the ever increasing population of the country. In view of this, on-farm experiment was conducted in Chora District of Illubabor Zone of Oromia, during the main cropping seasons of 2010 to 2013. The objectives of the study were to determine P-critical value and P- requirement factor for P-fertilizer recommendation of local variety "Darardimesa" for the district. Factorial combinations of four levels of N (0, 46, 92 and 138 kg N/ha) and four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and two satellite K (30 and 60kg/ha K_2O) in the first year to determine N rate and k response .Single factor of four levels of P (0, 23, 46 and 92 kg P/ha) and 46 kg N/ha in the second and third years to determine P-critical value and P-requirement factor were laid out in randomized complete block design with two replications. The results of the study revealed that the soil pH (H_2O) values were strongly acidic ranged from 4.70 to 5.18, very low available P (Olsen method) from 0.28 to 1.05ppm. The mean maximum grain yield (1156 kg ha^{-1}) was obtained from the application of 46 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}, whereas the lowest (1053 kg ha^{-1}) was from the control plot. Therefore, 46 kg N ha^{-1} was selected as N fertilizer recommended for the area. The study also showed that P-critical value 4.0 ppm and P- requirement factor 11.71 were determined for phosphorus fertilizer recommended for the district. The economic evaluation showed that soil test based gave yield of 1.37 Birr for every Birr invested. Similarly, considerable soil acidity and low fertility of the soil are threatening the agricultural production in the area and requiring for both proper soil acidity and soil fertility management practices for sustainable increasing of productivity and production of teff in the areas.

Key words: Maize (BH-660), Nitrogen, Phosphorus, P critical and P requirement

Introduction

Agriculture is the predominant economic sector in the majority of the developing countries in the world (Ahmed, 2002). People are dependent on soils and, conversely, good soils are dependent on people and the uses they make of the land (Brady and Weil, 2002). Crop yields in the developed world are high and agricultural soils have high fertility status due to intensive use of fertilizers (Mengel and Kirkby, 1996). This implies that using chemical fertilizer plays significant role in increasing food production to meet the demand of the growing population. On the other hand, sub-Saharan Africa is characterized by diverse agricultural systems that are typically low input based subsistence farming systems (Bekunda *et al*., 1997). These soils have been sustaining agricultural production for centuries; as a result, their native fertility has been extremely low (Wong *et al.,* 1991). Soil fertility replenishment has, therefore, been singled out as necessary, but not sufficient condition for sustainable development in Africa (Sanchez and Leakey, 1997).

Soil fertility depletion presents a major challenge to bring about increased and sustainable productivity to feed the ever increasing population of the country. The loss of soil fertility from continual nutrient mining by crop removal without adequate replenishment, combined with imbalanced plant nutrition practices, has posed a serious threat to agricultural production (FAO, 2006). The secret of ensuring food security for the ever increasing population is strongly linked to the productivity of soils (Wakene, 2001). Quinenes *et al.* (1992) also stated that unless something is done to restore soil fertility first, other efforts to increase crop production would end up with little success. Kelsa *et al. (*1992) reported that using chemical fertilizers can increase yield under Ethiopian.

In Ethiopia, teff is cultivated on about 3.016 million hectares. This makes it the first among cereals in the country in area coverage. Despite the aforementioned importance and coverage of large area, its productivity is very low. The average national yield of teff is about 1.465 tone ha^{-1} (CSA, 2014). Some of the factors contributing to low yield of teff are low soil fertility and suboptimal use of mineral fertilizers in addition to weeds, erratic rainfall distribution (Fufa, 1998).

Understanding soil fertility status and plant nutrients requirement of a given area has vital role in enhancing crop production and productivity on sustainable basis. Nevertheless, little information is available in Oromia in general and Illubabor Zone in particular on essential plant nutrients requirement for teff production. The prevailing blanket fertilizer rate recommendation throughout the country on all soil types and agro-ecological zones justifies the existence of little information on the fertility status of Ethiopia's soils. This call for site-specific assessment for soil fertility management to determine rate of nutrient application to increase crop productivity to feed the rapidly growing population.Therefore the objectives of the study were to assess and evaluate P critical value and requirement factor; and give quantitative guidelines and recommendations of P fertilizer for maize production in the district.

Materials and Methods

Treatments, experimental designs and procedures

On-farm study was conducted in the district during the main cropping seasons of 2010 to 2013 to determine P-critical value and P- requirement factor for P-fertilizer recommendation of teff local cultivar for the district. The treatments of the experiment were factorial combinations of four levels of N (0, 46, 92 and 138 kg N/ha) and four levels of P (0, 23, 46 and 92 kg P_2O_5/ha) and two satellite K (30 and 60kg/ha K_2O) in the first year to determine N rate and k response. Moreover, single factor of four levels of P (0, 23, 46 and 92 kg P/ha) and 46 kg N/ha in the second and third years to determine P-critical value and P-requirement factor were laid out in randomized complete block design with two replications. The experimental fields were prepared by using oxen plow in accordance with farmers' practices where the fields were plowed four times. The gross plot size was 5m x8m) with 3mx3m net plot. DAP and TSP fertilizers were applied at planting. Nitrogin was applied in split application, half at planting and 35 days after planting. During the different growth stages of the crop, all the necessary field management practices were carried out as per the practices followed by the farming community. All agronomic and soil data were properly managed using EXCEL computer software. Grain yield was analyzed using SAS computer package version 9.1 and economic analysis was based on CIMMYT (1988).

Agronomic data collection

Date of planting, heading, plant height, maturity and grain yield.

Soil sampling and analysis

Composite surface soil samples (0-20cm depth) were collected from each experimental sites before planting to determine pH (H_2O) and available P (Olsen method). Similarly, after 21-35 days of planting, intensive composite soil samples were collected from each experimental plot to determine available P.

Determination of critical P concentration

Critical P value was determined following the Cate-Nelson graphical method where soil P values were put on the X-axis and the relative yield values on the Y-axis (yield x 100/maximum yield). The Cate-Nelson graphical method is based on dividing the Y-X scatter diagram into four quadrants and maximizing the number of points in the positive quadrants. The positions of the lines on the overlay with respect to the axes of the graph were transferred to the graph by making marks on the edges of the graph. The two intersecting lines were then drawn lightly on the graph. The point where the vertical line crosses the X-axis is defined as 'critical soil test level'

Determination of P requirement factor

Phosphorus requirement factor was calculated using available P values in samples collected from unfertilized and fertilized plots. It also determined by the relation between each fertilizer rate and averaged corresponding soil test P value for each fertilizer rates.

Results and Discussion

Soil pH and available phosphorus

The pH (H_2O) of the soil samples collected before planting were ranged from 4.70-5.18 (Table 1). Accordingly, the soils were strongly acidic in reaction (FAO, 2008). Continuous cultivation and long-term application of inorganic fertilizers lower soil pH and aggravate the losses of basic cations from highly weathered soils (Mokwunye *et al*. 1996). The result showed that soil pH affects teff production which was less than teff requirement proposed (FAO, 2006). Available **p**hosphorus values (Olsen method) collected before planting were ranged from 0.28 to 1.05ppm (Table 1). Available P contents of the soil were very low (Olsen *et al.,* 1954). The low contents of available P observed in the soil of the study areas are in agreement with the results reported (Mesfin, 1998; Yihenew, 2002; Dagne, 2012) who reported that the Ethiopian agricultural soils particularly the Nitisols and other acid soils have low available P content due to their inherently low P content, high P fixation capacity, crop harvest and soil erosion.

Table 14. Initial soil phosphorus and pH

Site	Available P (ppm)	pH (H_2O)
Site 1	0.45	4.89
Site 2	0.52	4.99
Site 3	0.98	5.15
Site 4	0.66	5.14
Site 5	0.54	5.18
Site 6	1.05	4.94
Site 7	0.28	5.15
Site 8	0.37	4.84
Site 9	0.54	4.7
Site 10	0.3	4.95
Average	**0.54**	

Nitrogen fertilizer determination

The main effects of both N and P, and interaction effects showed no significant difference on teff grain yield (Table 2). However, (Arif *et al*. (2010) suggested that, nitrogen plays an important role in crop life and it is one of the most important nutrients needed by plants in large quantities. Brady and Weil (2002) also reported that nitrogen is mediates for the utilization of phosphorus, potassium and other elements in plants and the optimal amounts of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Based on this suggestion the lowest rate of nitrogen in this experiment 46 kg N ha^{-1} was selected for recommendation. Satellite potassium fertilizer also did not show significant difference on yield.

Phosphorus critical value and requirement factor

The study also showed that P-critical value 4.0 ppm (Figure 1) and P- requirement factor 11.71 (Table 3) were determined for phosphorus fertilizer recommended for the area.

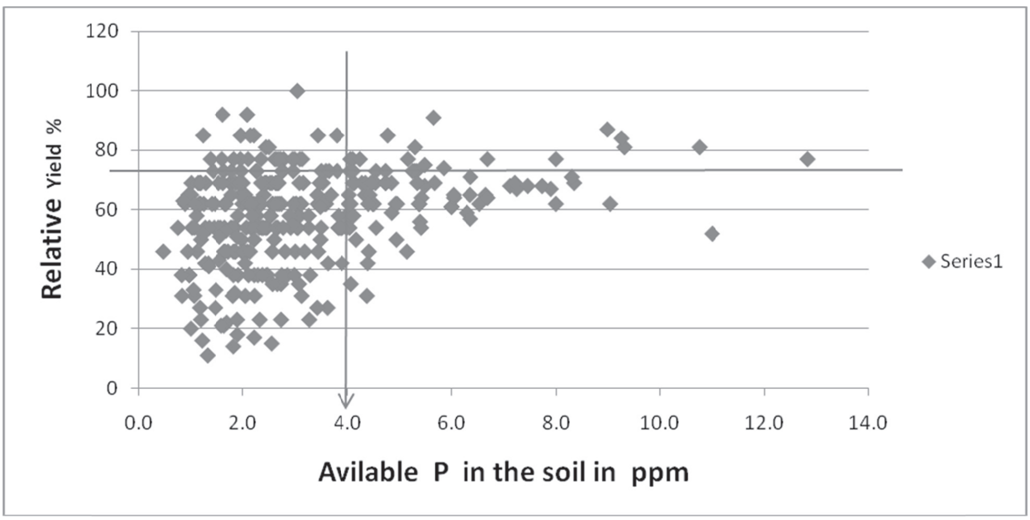

Figure 1. Phosphorus critical value for teff in Chora District

Table 3. Phosphorus requirement factor for teff in Chora District

Fertilizer P applied (kg P/ha)	Olsen P (ppm) Mean	P increase over the control	P requirement factor (Pr)*
0	0.54		
10	2.39	1.85	5.41
20	2.4	1.86	10.75
40	2.65	2.11	18.96
Average			**11.71**

Verification of phosphorus critical value and requirement factor

There were significant differences ($P \leq 0.05$) among the treatments in teff grain yield. The mean maximum grain yield (889 kg ha^{-1}) was resulted from the application of soil test based, whereas the lowest (371 kg ha^{-1}) was from the control plot (Table 4).

Table 4. Verification of phosphorus critical value and requirement factor

Treatment	**Yield (kg ha^{-1})**
STBCRFR	888.57[a]
Blanket (Framers Practices)	696.43[b]
Control	371.43[c]
LSD (5%)	101.63
CV (%)	20.05

Means with the same letter are not significantly different at $p< 0.05$; LSD = Least Significant Difference, CV= Coefficient of Variance

Economic evaluation of maize production with soil test-based crop response P fertilizer calibration

The partial budget presented in Table 5 showed that the least total variable cost (TVC) was recorded by control treatment (without fertilizer), while the highest net benefit (NB) was obtained from soil test based (3919 Birr ha^{-1}), which gave 39.7% higher NB than Blanket (Farmers Practices) fertilizers application. The analysis of marginal rate of return (MRR), on the other hand, revealed that the rate of return per unit cost of production was highest from soil test based (% MRR = 137). This showed that yield of 1.37 Birr for every Birr invested.

Table 5.Marginal rate of return analysis

	Partial budget with dominance				
Treatments	Yield (Kg ha^{-1})	GFB (Birr ha^{-1})	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Dominance
1. Control	371.43	5200.02	5800.00	599.80	
2. Blanket (Framers Practices)	696.43	9750.02	7386.50	2363.52	Un dominated
3. STBCR FR	888.57	12439.98	8521.14	3918.84	Un dominated

	Marginal rate of return (MRR %)				
Treatment	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Incremental cost	Incremental benefit	MRR (%)
1. Control	5800.00	599.80			
2. Blanket (Farmers Practices)	7386.50	2363.52	1586.50	1763.72	111.17
3. STBCR FR	8521.14	3918.84	1134.64	1555.32	137.08

GFB = Gross field benefit; TVC = Total variable cost; NB = Net benefit; MRR = Marginal rate of return

Conclusion and Recommendation

Sustaining soil fertility in intensive cropping systems for higher yields of better quality can be achieved through application of balanced external inputs or fertilizers. Thus, information on soil fertility status and crop response to different soil fertility management is very important to come up with profitable and sustainable crop production. The results of the study revealed that the soil pH of the sites were strongly acidic in reaction based on the pH (H_2O) values and ranged from 4.70-5.18. Available P contents of the soil were very low ranged from 0.28 to 1.05ppm. The interaction effects of N and P were not significant ($P \leq 0.05$) on grain yield of teff , and the lowest rate of nitrogen in the study, 46 kg N ha^{-1} , was selected for recommendation. The study showed that P-critical value (4.0 ppm) and P- requirement factor (11.71) were determined for phosphorus fertilizer recommended for the area. The economic evaluation showed that soil test based yield of 1.37 birr for every birr invested. Thus, farmers in the in the district might be advised to use soil test based crop response fertilizer recommendation to increase the productivity of teff in the areas.

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Soil Test-based Crop Response Phosphorus Calibration Study on Teff in Girar Jarso District of North Shewa Zone, Oromia, Ethiopia

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Abstract

Soil test based crop response phosphorous calibration study was conducted in Girar Jarso District on teff with the objectives to establish site-specific soil test based phosphorus fertilizer recommendation and to give quantitative guideline and recommendation of P fertilizer. The study was conducted on 9 farmers field using four levels of N (0, 46, 92 and 138 kg ha^{1-}) and four levels of P_2O_5 (0, 23, 46, and 92 kg ha^{1-}) that designed in a factorial combination plus two levels of potassium as satellite treatments to investigate the response of potassium. The trial was laid down in a completely randomized block design in two replications. After twenty one days of sowing intensive composite soil samples were collected from each treatment plot by replication and the collected samples were analyzed for available P using Olsen method for the correlation study. Accordingly the determined P critical and P requirement factor for teff in Girar Jarso District were 18ppm and 3.04, respectively. Soil test based P calibration result, farmers' practice in the area and the control were the treatments. Analysis of variance indicated that there was highly significant difference ($P<0.001$) for the treatments tested as fertilizer rates for the district. The highest mean grain yield (1802 kg/ha) was recorded with soil test based P calibration result which was not significantly higher than farmer's practice (1638 kg/ha) and followed by the control for the district. Therefore, it was concluded that for obtaining target yield and profit with sustenance of soil fertility test based fertilizer recommendation was economically feasible for teff production in the study areas.

Key words: Calibration, P- critical, P-requirement factor

Itroduction

The population of Ethiopia is currently growing at a faster rate and demands an increased proportion of agricultural products. On the other hand, growth in food production is not in equal footings with population pressure. The annual net loss of nutrients is estimated to be at least 40 N, 6.6 P and 33.2 K kg/ha (Scoones and Toulmin, 1999). Continuous cropping, high proportions of cereals in the cropping system, and the application of suboptimal levels of mineral fertilizers aggravate the decline in soil fertility (Tanner et al., 1991; Hailu et al., 1991; Workneh and Mwangi, 1992). In addition to this, leaching losses and the losses by runoff water and/or erosion is another out flow for such nutrient elements such as N and K. This could possibly lead to nutrient deficiency in most agricultural soils of the country.

Nitrogen and phosphorus are the most yield limiting nutrients in Ethiopia. The use of chemical fertilizer to overcome these nutrient deficiencies is a practice that is receiving a wide acceptance in the country. The favorable effects of fertilizer have been demonstrated under different set of climatic and soil conditions. Very recently in experiment at Holeta average wheat grain yield of 1447kg ha^{-1} over unfertilized was obtained by applying 60 kg N/ha with phosphorus application (EARO, 2000). Currently however, there are no site-specific fertilizer recommendations for the different soil-crop-climate related conditions.

Sound soil test calibration study is essential for successful fertilizer program and crop production. It is essential that the results of soil tests could be calibrated or correlated against crop responses from applications of nutrients in question as it is the ultimate measure of fertilization program. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for each crop (Sonon and Zhang, 2008). Calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety.

Soil test based fertilizer recommendation plays a vital role in ensuring balanced nutrition to crops. Therefore, fertilizer application schedules should be based on the magnitude of crop response to applied nutrients at different soil fertility levels (Santhi *et.al*. 2002). As in all other parts of the country, fertilizer recommendations in Girar Jarso District are also not based on soil test results. Hence, this study was conducted with the objectives to establish site-specific soil test based phosphorus fertilizer recommendation, and to give quantitative guideline and recommendation of P fertilizer for tef in the district.

Materials and Methods

Description of the study area

The study was conducted in Girar Jarso District of North Shewa Zone, Oromia. It lies between 9^0 64’78’’ to 9^0 98’30’’N and $38^0$60’96’’ to 38^0 87’36’’E and found at about 112km distance north-west of Finfinne/Addis Ababa. The area has altitude ranging from 2400 to 2800masl and humid agro-ecology. Five-year (2010-2014) weather datat collected from Fitche Meteorology Station revealed that the Girar Jarso District had uni-modal rainfall pattern and mean annual rainfall of 1200mm. The rainy season extends from May to September and maximum rain received in June to August. The annual average minimum and maximum air temperatures were 15 and 22^0C, respectively. The soil of the study area is classified as Pellic Vertisols according to the FAO soil classification systems (Mesfin, 1998). The dominant crops in the area were teff, wheat and faba bean. The major land use types are cultivated land and grazing land.

Methodology

Soil test based crop response fertilizer recommendation study was conducted in Girar district of North Shewa Zone Oromia on tef crop during the main cropping season of 2015. These field experiments studies were undertaken in three different phases: soil test based crop response phosphorus calibration study; verification of soil test based phosphorus recommendation study; and demonstration of soil test based phosphorus recommendation study.

Soil test based crop response phosphorus calibration study (Phase I)

Experimental design and field layout

Treatments included in the experiment were 4 rates of N (0, 46, 92 and 138 kg ha^{1-}) and 4 rates of P_2O_5 (0, 23, 46, 92 kg ha^{-1}) in factorial combination with two satellite treatments to investigate the response of potassium. The trials were laid down in completely randomized block design in two replications. Teff local cultivar was used for the study with farmers’ practices for crop management.

Table 1. Description of treatments

Treatment # (T1-T6) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T7-T12) *($N:P_2O_5:K_2O$ kg ha^{-1})*	Treatment # (T13-T16) *($N:P_2O_5:K_2O$ kg ha^{-1})*
T1 *(0:0:0)*	T7 *(46:46:0)*	T13 *(138:0:0)*
T2 *(0:23:0)*	T8 *(46:92:0)*	T14 *(138:23:0)*
T3 *(0:46:0)*	T9 *(92:0:0)*	T15 *(138:46:0)*
T4 *(0:92:0)*	T10 *(92:23:0)*	T16 *(138:92:0)*
T5 *(46:0:0)*	T11 *(92:46:0)*	T17 *(92:23:60)*
T6 *(46:23:0)*	T12 *(92:92:0)*	T18 *(138:92:60)*

Gross plot size: 5m x 8m Harvested area: 3m x 3m

Procedures

Soil samples were collected from 50 farmers' fields from the district following the standard procedures. After soil chemical and physical analyses were completed, nine farmers' fields were selected based on initial phosphorus concentration categories (low, medium and high). The treatments were applied in one block in folded RCB design due to its large number of treatments with large plot size (5m*8m). After twenty one days of planting, intensive composite soil samples were collected from each treatment plot and replication and the collected samples were analyzed for available P using Olsen method for the correlation study. Agronomic data were collected on plant height, heading date, maturity date, biomass and grain yield.

Critical phosphorus

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. This was achieved by overlay of a clear plastic sheet having a pair of perpendicular lines drawn on it to produce four quadrants, roughly of the same relative size. The overlay was then positioned on the graph in such a way that the maximum number of points fell in the positive quadrants while the lowest number fell in the negative quadrants. The vertical line defines the responsive and non-responsive ranges whereas. The optimum is indicated by the point where the vertical line crosses the x-axis.

Phosphorous Requirement factor (Pf)

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1ppm. Phosphorus requirement enables to determine the quantity of P required per hectare to raise the soil test by 1 ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level. It will be calculated using available P values in samples collected from unfertilized and fertilized plots.

$$Pf = \frac{\text{kg P applied}}{\text{change in soil P}}$$

Verification of soil test based phosphorus recommendation (Phase II)

This trial also was undertaken in Girar Jarso District in main cropping season of 2013. Soil test based P calibration result, farmers' practice in the area and control were the treatments used for the trial. The trial was conducted on farmers' fields of plot size 10m x 10m for each treatment.

Procedure

Soil samples were collected from 20 farmers' fields and laboratory analysis was carried for available phosphorus and seven farmers' fields having available phosphorus less than critical phosphorus for the district were selected for the experiment. Then phosphorus fertilizer requirement were calculated for each farmer by using the formula:

Phosphorus fertilizer rate (kg/ha) = (Pc-Pi)*Pf;

Where:
Pc- critical phosphorus = ***18ppm***
Pi- initial available phosphorus;
Pf- phosphorus requirement factor = ***3.04***
Data management and analysis

All agronomic and soil data collected across locations were properly managed using the EXCEL computer software. The collected data were subjected to analysis of variance using SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

Economic analysis

Marginal rate of return **(**MRR) was calculated both farmer practice and soil test based values by using the formula given blow (CIMMYT, 1988):

$$\mathbf{MRR} = \frac{\textbf{Net Income From Fertilized Field} - \textbf{Net Income From Unfertilized Field}}{\textbf{Total Variable Cost From Fertilizer Application}}$$

Total variable cost is a cost incurred due to application of P fertilizer (both but in separate of soil test based P calibration result and farmers' fertilizer rate) with the assumption that the rest of the costs incurred are the same for all treatments. Gross income is obtained by multiplying mean grain yield (kg/ha) of each treatment by the price of one kg of the grain. Net income is calculated by subtracting the total variable cost from the gross income. To use the marginal rate of return (MRR) as basis for fertilizer recommendation, the minimum acceptable rate of return (MARR) was set to 100%.

Results and Discussion

Soil testbased crop response phosphorus calibration study

Critical P-concentration

The Cate-Nelson graphical method was employed to determine the P-critical point. P-values were arranged in the x-axis while the relative grain yield values were on the y-axis. As indicated in Fig 1 below, the P-critical concentration above which the response of crop to the applied P is low or no was 18ppm.

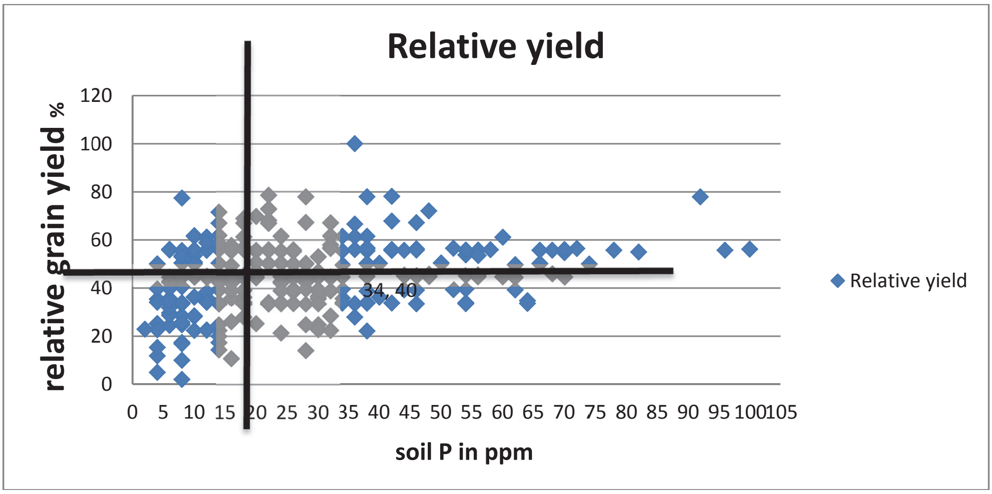


Figure 1. Critical concentration of P in Girar Jarso District

Phosphorus requirement factor (Pf)

It is used to determine the amount of P-required per ha to raise the soil test by 1ppm was calculated using available P-values in the sample collected from unfertilized and fertilized plots.

$$Pf = \frac{\textbf{P applied}}{\textbf{change in soil P}}$$

The calculated mean P-factor for the district was 3.04 (Table 1)

Table 1. P-requirement factor determination for teff

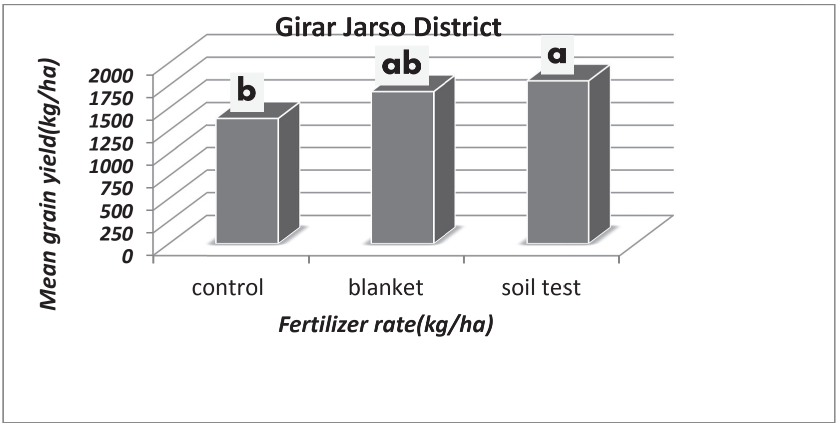
Fertilizer treatments kg P ha^{-1}	**Olsen ppm (average)**	**P- level increase over the control**	**P requirement factor (Pf)**
0	20.75	_	-
10	25	4.25	10/4.25=2.35
20	27	6.25	20/6.25=3.20
40	32	11.25	40/11.25=3.56
Mean			**3.04**

Verification of soil test based phosphorus recommendation study

The finding of soil test based crop response phosphorus calibration study was verified along with farmers' practice and the control on farmers' fields.

Teff grain yield as affected by different fertilizer rates recommendation is presented in Fig 2**.** The result indicated that grian yield was significantly different ($p<0.05$) among the different fertilizer rates. The highest mean grain yield (1802 kg/ha) was obtained with the soil test based calibration treatment which was not significantly higher than the farmer practice (1683 kg/ha) and followed by the control (Figure 2).

Fig 2: Teff grain yield (kg/ha) as affected by different fertilizer rates recommendation



Bar graphs designated by the same letters are not significantly different from each other at p<0.05 (blanket fertilizer rate, 100kg/ha DAP and 100kg/ha urea)

Economical analysis

To estimate the economical significant of the different fertilizer rates, partial budget analysis (CIMMYT, 1988) was employed to calculate the Marginal rate of return (MRR). Since there was no significant difference between farmers' practices and soil test based fertilizer rates, partial budget analysis was done. Farm gate price of 16.50EB (Ethiopian Birr) per kg of tef and 13.86 kg per kg of DAP were used (Table 2**).** These are the actual unit prices during the year 2015 harvesting season (personal observation).

Table 2. Partial budget analysis for teff

No.	Fertilizer rate	Variable Input (kg/ha)	Unit Price	TVC	Output (kg/ha)	unit price(ETB)	Gross income	Net Income	MRR (%)
1	Control	0.00	13.86	0.00	1387.19	16.50	22888.64	22888.64	-
2	Farmer practice	100.00	13.86	1386.00	1637.99	16.50	27026.84	25640.84	199
3	Soil test based P fertilizer .rate	86.48	13.86	1198.612	1801.68	16.50	29727.72	28529.11	471

TVC=total viable costs; MRR=Marginal rate of return

The Marginal Rate of Return (MRR) was found to be range from 471% in soil test based fertilizer rate to 199% in farmer practice as indicated in Table 2. Although, there was no significant difference between farmers' practice and soil test based fertilizer recommendation on grain yield of teff, partial budget analysis indicated that soil test based fertilizer recommendation is economically feasible for teff production in the district.

Conclusion and Recommendation

In Ethiopia, chemical fertilizers are recognized as one of the most important inputs for maintaining soil fertility and maximizing agricultural production and productivity of the country.

In this study, the critical available phosphorus concentration was 18ppm and the P-requirement factor for major soil of the district was 3.04. The established P-requirement factor and the critical P concentration in conjunction with soil P-value can be applied to give site specific P fertilizer recommendation for teff in the district.

Generally, based on this study results, to step up the work in other districts on major crops for developing a system for soil test based fertilizer recommendation, sufficient soil and crop information is very essential. Although, there was no significant difference between farmers' practice and soil test based fertilizer recommendation on grain yield of teff, partial budget analysis indicated that soil test based fertilizer recommendation was economically feasible for teff production in the district.

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Soil and Water Conservation Research

Effect of Surface Management Practices on Soil, Water, and Nutrient Conservation and Yield of Bread Wheat (Triticum aestivum L.) at Sinana On-station, Bale Highlands, Southeast Oromia, Ethiopia

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Abstract

Soil erosion is one of the major problems constraining agricultural production in the highlands of Ethiopia. Accordingly, field experiment was conducted on the effect of surface management practices on soil, water, and nutrient conservation and yield of bread wheat (Triticum Aestivum L.) using Eutric Vertisol of Sinana Agricultural Research Center (SARC) during 2011and 2012 "Meher" cropping seasons (August-December). The objectives were to evaluate the degree to which rainfall, runoff and sediment losses are related in the presence of surface management practices under Bale highland conditions; to investigate soil, water and associated nutrient losses under different surface management practices; and to assess productivity of wheat as affected by surface management practices under the prevailing conditions of Bale highland. The treatments included straw mulch in four levels (0, 2, 4 and 6 t ha^{-1}) and farmyard manure in four levels (0, 2, 4 and 6 t ha^{-1}) were applied in randomized complete block design with three replications. Bread wheat varity Medda Welabu (HAR-1480) was used at 150 kg ha^{-1} seed rate. The results indicated that straw mulching could control the runoff of water loss by 84 to 98% and soil loss by 99.7% as compared to control (zero mulching). The nutrient loss among treatments varied in a range as follows: organic carbon (OC) from 0.07 to 25.37 kg ha^{-1}; total nitrogen (N), 0.001 to 0.25 kg ha^{-1}, for available phosphorus (P), 0.04 to 12.20 kg ha^{-1}, and for exchangeable potassium (K) 0.87 to 299.63 kg ha^{-1}, and for OC with the lowest loss values in all cases from 6 t ha^{-1} straw mulch treatment. Straw mulching reduced losses of OC, P, N and K by 94.6, 91.7, 94.1 and 94.7%, respectively as compared to the control. In general, from this study, 6 t ha^{-1} strawmulch was recommended in controlling soil and water erosion. Further research work by increasing doses of manure with sole and integration of straw mulch is recommended in different soil types with different slopping areas on yield and yield components of bread wheat in the future.

Key words: Straw mulch, farm yard manure, runoff depth, soil loss, grain yield, wheat

Introduction

Soil erosion is second only to population growth as the biggest environmental problem that threatens agriculture in Africa and other parts of the world (Eswaran *et al*., 2001). The problem is becoming increasingly more urgent in developing countries like Ethiopia where majority of the population are dependent on agriculture. According to El-Swaify and Hurni (1996), the Ethiopian highlands that constitute 46% of the total land area with over 95% of the regularly cropped land, constitute one of the most degraded lands in Africa.

The average rate of soil erosion from cultivated land in Ethiopia has been estimated to be 42 t ha^{-1} yr^{-1} (Hurni, 1990; Nebel and Wright, 1993), which is by far in excess of the mean annual soil loss tolerance value of 5 to 11 t ha^{-1} which is generally accepted as permissible rate of soil erosion (Montgomery, 2007) though this value can be as low as 2 t ha^{-1} for particularly sensitive areas (Hudson, 1995).

In addition to accelerated soil erosion and the alarming rate of land degradation, the loss of nutrients with sediments and runoff coupled with low external input of chemical fertilizers is the fundamental cause of low productivity in Ethiopia. The major emphasis was given to mechanical soil and water conservation (SWC) measures in cultivated fields with little attention to soil physico-chemical and biological degradation (Teklu and Selamyihun, 2001). As a result, the desirable outcomes were not achieved and still final solution is problematic and elusive. Site-specific SWC strategies, approaches and technologies must be in place to tackle the problem.

Soil or land management practices to reduce soil loss and runoff to negligible amounts are usually based on bio-physical measures of erosion control (Lal, 1977; Woldeamlak, 2003). As pointed out by Lal (1977), conservation of soil on arable lands requires reducing the direct impact of rain drops, maintaining maximum soil infiltrability, increasing surface storage and decreasing the quantity, velocity and transport capacity of runoff water. These can best be achieved either through the use of surface management such as surface mulches or manuring and nutrient management by providing effective plant cover (Adhikari *et al*., 2003; Lal, 2004; Singh *et al*., 2004). Their applications to the soil provides potential benefits including improving the fertility, structure, water holding capacity, increasing organic matter content and reducing the amount of synthetic fertilizer needed for crop production (Belay *et al*., 2002; Teklu and Hailemariam, 2009). Manuring reduces soil erosion by increasing formation, stability and strength of aggregates due to the addition of organic matter. Grande *et al*. (2005) reported reduction in water runoff by 70–90% and sediment loss by 80–95% due to manuring. Straw mulch for soil and water conservation has been extensively studied in the arid and semi-arid conditions of tropical Africa (Danga *et al*., 2009) and was found to be one of the most effective erosion control measure in agricultural production (Bobe, 2004; Jordan *et al*., 2010; Bruce, 1995; Blanco), and Lal (2008) pointed out that crop residues significantly reduce losses of plant nutrient in runoff.

However, the soils, of Sinana Agricultural research Center, in the study area is Vertisol with poor structure, low infiltration capacity and develop deep cracks in dry seasons. These soils remain devoid of vegetative cover between cropping seasons and are prone to fertile topsoil removal particularly during the onsets of rainfall. At present, no systematic study on effect of manure and crop residue on runoff, soil and nutrient loss, and yield of wheat under agro-climatic conditions of Bale highland has been made. Therefore, the present investigation was undertaken with specific objectives to evaluate the degree to which rainfall, runoff and sediment losses related in the presence of surface management practices; to investigate the soil, water and associated nutrient losses under different surface management practices; and to assess productivity of wheat as affected by surface management practices.

Materials and Methods

Description of the study area

The experiment was conducted at SARC geographically located at 07^0 06' 12'' to 07^0 07' 29'' N and 40^0 12' 40'' to 40^0 13' 52''E coordinate and altitude of 2400masl. The area has bimodal rainfall pattern; receiving rainfall of 346 to 861mm during the "*Belg*" (March to July) and 353 to 894mm during the "*Meher*" (August to December) cropping seasons.

The mean annual maximum and minimum temperature were 21^0C and 9.5^0C, respectively. Topographically, the area consists of gently undulating plain with average slope gradient of 6%. Crop production in the study area is characterized by cereal (wheat and barley) dominated cropping system. Some highland pulses such as field pea, faba bean, and oil crops like mustard and linseed are also grown.

Methodology

Materials required and treatments

The experiment was conducted on twenty-one runoff plots (2m x 8m separated by 2m wide buffer) on Eutric Vertisols of SARC crop field with 6% slope. Each plot was hydrologically isolated from adjacent areas by installing corrugated iron sheets to a depth of 15cm and extending 15cm above the soil surface along the boundaries. Each runoff plot was connected to storage tank through hose of 50mm diameter outlet pipe of polyvinylchloride (PVC) located at extreme lower end of the plot to guide the whole runoff from the plot towards the collecting tanks. Sticking material (gypsum) was used to make the connection between PVC tubes; storage tanks and the border of experimental plot that direct the runoff to the PVC tube watertight (Figure 1). The collecting tanks were covered with lids to prevent direct entry of rainfall and evaporation losses. The design adopted for collecting tanks was that of multi-slot divisor in similar way as suggested by FAO (1993) and Pathak *et al*. (1997). The first collecting tank consisted of divisor plate with three orifices which enabled one third of the overflow, if any, from the first tank to be diverted into the second tank. Daily rainfall amount was recorded using non recording raingauge at 8:00am during measurement period at meteorological station located in the close vicinity of the experimental site.

The experiment had seven treatments: three levels of farmyard manure (FYM) (2, 4 and 6 tha^{-1}), three levels of barley straw mulch (2, 4 and 6 tha^{-1}) and a control without any mulch and FYM which were applied to runoff plots that were laid out in a randomized complete block design with three replications. Agronomic aspects (e.g., time of planting, seed rate, weeding, recommended wheat variety, etc.) were carried out according to research practices and conditions. Bread wheat variety Medda Welabu (HAR-1480) was used for this study. This variety was selected as it is high yielder and most widely grown in the area. The cultivar was planted on August 29, 2011 and August 18, 2012 at recommended seed rate of 150 kg ha^{-1}. Planting was done by uniformly broadcasting seeds over the plots. Urea and triple superphosphate (TSP) were broadcast and incorporated into the soil at the time of planting at rates of 30 kg N and 10 kg P ha^{-1} to all plots.

The applied rate of N was to alleviate temporary adverse effect of N immobilization (Christensen, 1986) and enhance straw decomposition (Schnürer *et al*., 1985), while TSP was meant to supply half of P fertilizer recommended for the area. The following treatments were used wheat straw applied at the rate of Treatment 1: 2 t ha^{-1}, Treatment 2: 4 t ha^{-1}**,** Treatment 3: 6 t ha^{-1}**,** Treatment 4: farmyard manure applied at the rate of 2 t ha^{-1}**,** Treatment 5: farmyard manure applied at the rate of 4 t ha^{-1}**,** Treatment 6: farmyard manure applied at the rate of 6t ha^{-1} and Treatment 7: control without any mulch and FYM. The reason for the use of wheat straw as mulch was local availability.

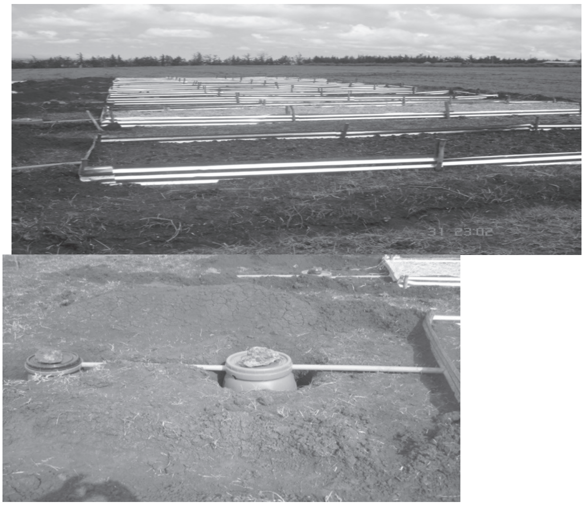

Figure 1. Experimental setup of runoff plots and its collectors at SARC

Cattle manure was collected and heaped for about two months prior to the initiation of the experiment. After removing the outer part of the heap, the manure was air dried at room temperature, properly crushed into smaller size to ensure uniform distribution over the field. On August 04, 2010, the specified rates of 2, 4 and 6 t ha^{-1} were incorporated into the soil to a depth of 20cm by raking. Proper care was taken to ensure uniform distribution over the plots. Straw was air dried weighed and the specified rates of 2, 4 and 6 t ha^{-1} were applied right after planting in the surface of the field uniformly.

Soil samples collection and methods of analysis

Soil samples were collected from each plot at suitable moisture conditions to a depth of 20cm using augur prior to the start of the experiment, after application of manure treatments and after harvest. The samples were taken to the laboratory, air-dried, crushed, and sieved to pass through 2 mm mesh sieve. Physical and chemical properties of the soil were determined following standard procedures. Particle size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH was determined potentio-metrically in the supernatant suspension of 1:2.5 soil: water ratio (Motsara and Roy, 2008); organic carbon content according to Walkley and Black, (1934); available phosphorus by Olsen *et al., (*1954); total nitrogen content by the Kjeldahl method (Motsara and Roy, 2008); exchangeable potassium by Flame photometer (Toth and Prince, 1949). Bulk density was gravimetrically determined from samples taken by core samplers of known volume that were oven dried to constant weight at 105^{0}C.

The clear water was then carefully decanted and the weight of wet sediment per litre of runoff was measured, air dried and kept for further physicochemical analysis except that 2 to 5 grams of wet sediments were oven dried at 105ºC for 24 hours for the determination of moisture correction factor (mcf).

Dry sediment concentration per litre of runoff was determined; the product of the sediment concentration and the total runoff per plot per day was used to determine the daily sediment loss. Finally, the daily sediment losses were summed up to give seasonal soil loss values.

The daily sediment load per liter of runoff was composited for respective runoff plot during the entire season. The same procedures and methods were used to determine texture, OC, N, P, K and pH of the eroded sediments. Sediment bound nutrient losses were calculated by multiplying seasonal soil loss by nutrient concentrations. The total depth of rainwater that was retained *in-situ* under each of the treatments was determined on the basis of runoff producing rainfall and runoff depth.

Agronomic data

At physiological maturity, plant height, number of fertile tillers per plant, spike length and grains per spike were collected on the basis of 10 randomly tagged plants in 5m^2 patch in the middle of erosion plot. Thousand-kernel weight was determined on the basis of weight of 1000 grains randomly sampled from the grain yields of each treatment. To achieve this, grains were counted by electric seed counter and their weights were measured with sensitive balance. The data on grain and biomass yield were collected.

Data analysis

Data collected from the effects of treatments on runoff, soil loss, nutrient loss and agronomical parameters of wheat were subjected to analysis of variance using general linear model procedures of statistical analysis system of computer software (SAS, 2004. Version 9.1.3) and treatment means were compared using the least significant difference at the 5% probability level.

Results and Discussion

Soil properties

Soil physical and chemical properties

Effective and sustainable land resources use and development of improved technologies requires a thorough understanding of the resource (Teklu, 2005). Among other factors, soil texture, organic matter and chemical element content determine the inherent susceptibility of soils to erosive agents (Morgan, 2005). Cognizant of this, pre-treatment soil characterization was done for some of soil physico-chemical properties on the basis of soil samples collected from different locations of each runoff plot.

Soil physical analyses

Textural analysis of the soil of the study area had a textural class of clay with average sand, silt and clay contents of 25, 23 and 52%, respectively. The texture of the surface soil (0-20cm) in the experimental area was homogenously rich in clay (>51%). It forms surface seals and crusts that close the cracks thereby slowing water infiltration rates. These lead to high runoff and soil loss particularly when the surface is not covered with vegetation. The bulk density of surface soil varied from 0.85 to 0.98 g/cm^3 with the mean value of 0.94 g/cm^3. Similar values were reported by Abayneh and Ashenafi (2006) where soil bulk density values of 0.85 to 0.96 g/cm^3 for surface soils and 0.91 to 1.23 g/cm^3 for subsurface horizons were observed for Sinana on-station. The low bulk density value of surface soils might be due to relatively high water retention capacity which is a characteristic feature of Vertisols. The overall bulk density values indicate that the soil is not compacted to inhibit root development. Clay dispersion ratio and dispersion ration were observed to be high. According to the criterion of Middleton (1930) soils having dispersion ratio > 0.15 are structurally weak and easily erodible in nature. So, as per the above criterion, the soils were found to be highly erodible. This might be attributed to poor aggregation due to excessive tillage practices and the concomitant low organic matter content of the soil in the area.

Soil chemical analyses before applications of surface management measures indicated that the nutrient contents of the experimental plots were generally low as compared generally to other findings. The soil had low organic carbon; low to medium total nitrogen in consistent; phosphorus was medium but was low against Abayneh and Ashenafi (2006). The low total N may be associated with the low organic matter content, the loss of N due to the surface runoff, leaching, and crop removal (Deckers*et al.,* 2001; Eylachew, 2001; Fageria and Baligar, 2005). The plant available P was increasing but Abayneh and Ashenafi (2006) reported 0.42 to 3.32ppm for the same area. This increase in available phosphorus with time might be associated with cumulative effect of annual fertilizer application. Based on the soil interpretation guide given by Marx *et al*. (1999), soils of the experimental site had very high exchangeable K.

Runoff depth and soil loss

Total runoff depth and soil loss varied significantly among treatments ($p<0.01$) for both years (2011 and 2012). All straw mulch treatments showed substantial reduction in runoff and soil loss compared to the control treatment. The 6 t ha^{-1} straw mulch resulted in considerably lower runoff depth and soil loss of (0.06 t ha^{-1}, 0.03 t ha^{-1}) than all other treatments followed by 4 t ha^{-1} mulching rate (3.38mm, 1.3mm) and (0.11 t ha^{-1}, 0.14 t ha^{-1}) for 2 t ha^{-1}, respectively. Runoff reduction as compared to the control was 98.78, 91.7 and 65.3% for 6, 4 and 2t/ha mulch rate, respectively for 2012 cropping year. Even though manure application was less effective in reducing runoff and soil loss as compared to straw mulching, there was reduction in reducing runoff and soil loss compared to that of control.

The analysis of variance revealed that total runoff varied significantly among treatments ($p<0.0001$). All straw mulch treatments showed substantial reduction in runoff compared to the control treatment. As indicated in Table 1, the 6 t ha^{-1} straw mulch resulted in considerably lower runoff depths (0.66 mm, 0.50mm) than all other treatments and was followed by 4 t ha^{-1}mulching rate (1.3mm, 3.38mm). Runoff reduction as compared to the control was 98.3, 96.7 and 84.7% for 6, 4 and 2 tha^{-1} mulch rate, respectively. Similar findings were reported in other investigations (Dickey et al., 1994; Edwards et al., 1995; Bobe, 2004; Bhatt and Khera, 2006). This substantial reduction in runoff is attributed to increased infiltration due to detention of flow, and also residues dissipated the energy of raindrops, prevented surface sealing and ultimately reduced the quantity of rainwaters that become runoff. The results further revealed that manure application was less effective in reducing runoff as compared to straw mulching. This suggests that the benefits of manure in reducing runoff cannot be realized under such a short duration experiments and their influence could be seen as residual effect in the subsequent crops. In rainfall simulation experiment, Ramos *et al.* (2006) observed that surface application of 30 tha^{-1} cattle slurry increased runoff volume by up to 30%. Study by Cabrera *et al*. (2009) also revealed an 8% higher runoff in manure treated plots than in control in the first year of manure application. With straw application levels of 2 and 4 t ha^{-1} at 10% slope, Lal (1975) reported that soil loss reduced by 97 and 99.6%, respectively, compared to soil loss from without mulch plots.

Table 1. Effect of surface management on soil loss, runoff, sediment bound and in-situ water conservation

Treatment	**Soil loss t/ha**		**Run off depth(mm)**		**Sediment con(g/l)**		**In-situ water conservation (mm)**
	Yr 2011	**Yr 2012**	**Yr 2011**	**Yr 2012**	**Yr 2011**	**Yr 2012**	**Yr 2012**
Control	9.83a	11.40a	39.74a	40.85a	24.9ba	28.04a	180.26b
FYM 2	6.66b	8.66a	35.26bc	36.17a	18.9b	23.87b	184.93a
FYM 4	9.60a	9.39a	38.43ba	33.28a	25.4ba	28.08a	187.82b
FYM 6	9.51a	9.65a	34.89c	32.15a	27.2a	30.00a	188.95b
STR 2	0.51c	1.38b	6.09d	14.17b	8.4c	9.50c	206.93a
STR 4	0.11c	0.141b	1.30e	3.38b	8.5c	10.21c	217.72a
STR 6	0.03c	0.06 b	0.66e	0.50b	4.8c	5.67d	220.60a
LSD(0.05)	1.69	4.37	3.51	16.16	6.53	2.93	16.16
CV	18.41	42.94	8.85	40.24	21.72	8.64	4.66

Soil loss

The analysis of variance revealed that the effect of different surface management practices on soil loss was highly significant ($p<0.0001$). The mean soil loss from experimental plots is indicated in Table 1. The 6 t/ha strawmulch was significantly more effective in checking soil loss (0.03, 0.06 t/ha^{-1}) than all the other treatments followed by 4 and 2 t ha^{-1} mulching rates implying that the latter could also effectively control soil loss under the prevailing condition of the study area. This substantial reduction in soil loss with mulching is consistent with the finding of Döring *et al.* (2005) who reported more than 97% reduction in soil erosion in rain simulation experiment on potato field of 8% slope with 5 t/ha chopped straw applications. Soil loss due to particle detachment by raindrop impact, erosive power of runoff, sediment transportation by raindrop splash, and surface runoff flow are well recognized (Gajri *et al.,* 2002; Kinnell, 2004). Soil surface cover and roughness reduce the raindrop impact and hence soil loss. The amount and velocity of runoff also affects soil loss by water (Gajri *et al*., 2002). Preserving crop residues on soil surface is a proven and effective method of water erosion control (Lal, 1975; Bobe, 2004; Döring *et al*., 2005; Jordan *et al*., 2010).

The present result indicates that straw mulching is not only reducing the surface runoff but also provided a cover to the soil surface and hence decreased soil detachment by raindrop impact, reduced runoff erosivity, provided more infiltration opportunity, and trapped the sediments carried by surface runoff. As shown in Table 1, even small amounts of straw mulch (2 t ha^{-1}) substantially reduced soil loss and sediment concentration in runoff. This might be attributed to high sediment trapping capacity of the straw mulch. In contrary to the plenty of evidences that farmyard manure incorporation decreases runoff and sediment loss (Gilley and Risse, 2000; Gessel et al., 2004; Ekwue et al., 2009), soil loss from plots that received 4 and 6 t ha^{-1} FYM was not significantly different from that of control. This could be partially attributed to the higher runoff volume and the longer time required for the organic matter in the manure to become incorporated into the soil and impact soil properties. The lack of any significant differences among manure treatments might be due to the relatively short time frame, two months after application. Similar observation was made by Cabrera *et al* (2009) who found insignificant soil loss reduction in the first year of dairy manure application. Sauer *et al*. (1999) ascribed runoff and soil loss from manure treated plots to the time between application and the first rainfall.

Water conservation

Results showed that the effect of treatments on *in-situ* rainwater retention was significant ($p<0.05$). The results demonstrated that *in-situ* soil moisture conservation increased significantly for 6 t ha^{-1} mulch compared to the control treatment. The results indicated that soil moisture storages were increased by 22.4, 20.2, 14.8 for straw 6, 4, 2 t ha^{-1}, while 4.8, 4.2, and 2.2% for FYM 6, 4 and 2 t ha^{-1}, respectively as compared to the control treatment. The results demonstrated that *in-situ* soil moisture conservation increased significantly for 6 t/ha mulch as compared to the control treatment.

Soil moisture storage in the 6 t ha^{-1} mulch treatment was 216.11mm which was 39.15mm higher in comparison to the control. However, the mean soil moisture storage for 4 t ha^{-1} straw mulch was 215.40 mm which similar comparison with that retained at 6 t ha^{-1} straw mulch. The average rainwater depth retained for 6 t ha^{-1} farmyard manure application (181.81mm) was significantly higher than that retained under control treatment (176.96 mm). The results agreed with the findings of Verma and Acharya (2004) who reported 7.2mm more moisture in 0-30cm soil depth in mulched treatments.

Rainfall-runoff-soil loss relationship

It was observed that the heavy storms did not necessarily coincide with higher amounts of runoff or sediment loss. For example, rainfall with magnitude of 21mm that occurred on September 06, 2012 yielded more runoff and soil loss under most of the treatments than did 37.5mm rainfall that occurred.

These results suggest that rainfall-runoff relationship is a complex, dynamic and nonlinear process, which is affected by many and often inter-related physical factors.

The most important cause of such non linearity in runoff and soil loss response to rainfall is represented by the effect of antecedent moisture content, surface cover, infiltration capacity and surface storage. As the interception of rainfall was less on plots without straw mulch, these plots showed higher runoff and consequently, more soil loss than those with straw mulch. This demonstrates that the potential impacts of mulching on hydrological responses are of paramount importance under conditions of the study area. Under all treatments, rainfall and soil loss, rainfall and runoff were positively and significantly correlated with rainfall on event basis. Soil loss was significantly and positively correlated with runoff except under straw 6 t ha^{-1} which was insignificantly correlated. This is logically reasonable due to sediment filtering capacity of straw mulch.

This demonstrates that the potential impacts of mulching on hydrological responses are of paramount importance under conditions of the study area as those plots without mulch got higher runoff and consequently, more soil loss than those with straw mulch. The insignificant correlation between rainfall and soil loss was in line with the reports of Raya *et al.* (2006). The insignificant correlation might be partially attributed to less number of observations and also there might be other soil and rainfall characteristics such as antecedent soil moisture content, rainfall intensity and kinetic energy that govern soil loss and runoff processes.

Sediment bounded nutrient losses

The analysis of variance revealed that the effect of different surface management practices on sediment bound losses of OC, available P, N and K was highly significant ($p<0.0001$). The average values of sediment associated losses of nutrients were in the range of 0.87 to 299.63 kg ha^{-1} for OC, 0.001 to 0.250 kg ha^{-1} for available P, 0.07 to 25.37 kg ha^{-1} for total N and 0.04 to 12.20 kg ha^{-1} for exchangeable K, with the lowest values in all cases from the plot treated with 6 t ha^{-1} straw mulch. Therefore, straw mulching reduced losses of OC, P, N and K by 94.6, 91.7, 94.1 and 94.7%, respectively as compared to the control treatment. The data are in consistent with those measured by Girmay *et al.* (2009) in the northern Ethiopia; Atreya *et al.* (2005). Also, the results of analysis indicated that manure treatments on nutrient losses tended to be lower as compared to the control, but higher nutrient loss as compared to straw mulch. The average values of sediment associated losses of nutrients were in the range of 1.53 to 292.98 kg ha^{-1} for OC, 0.001 to 0.43 kg ha^{-1} for available P, 0.15 to 27.36 kg ha^{-1} for total N and 0.01 to 17.9 kg ha^{-1} for exchangeable K, with the lowest values in all cases from the plot treated with 6 t ha^{-1} straw mulch.

The results also suggested that straw mulching is a potential alternative for reducing nutrient transport with eroded sediment. Runoff reduction due to increased infiltration can have practical implications for removing fine sediments and soluble nutrients in runoff. The reduction in losses of OC, N, available P and K in mulched plots might be caused by increased infiltration of runoff with colloidal particles. Considering N, P and K losses per unit of sediment, nutrient concentration in the straw mulch treatments were modertly higher than those in the control. This could be attributed to the mineralization of wheat straw and the higher clay percentage in the sediment in the straw mulched plots according to the findings of Danga *et al,* (2009). The quantities of P, N, and K lost in the eroded sediments were strongly correlated with OC ($r = 0.90$, 0.93 and 0.98, respectively, $N=7$) suggesting that higher exports of OC is responsible for losses of these nutrients. These are in agreement with findings of Kothyaria *et al.* (2004) from the plot having rain-fed agricultural crop as the land cover.

Effect of surface management practices on bread wheat yield and yield components

The effect of treatments on plant height, number of tillers per plant, spike length, biomass and straw yield was significantly different. However treatments had no significant effect on grains per spike, grain yield and thousand kernel weights for 2011 and number of tillers per plant and grains per spike for 2012. Although not significant, in 2011, the 6 t ha^{-1} FYM gave the highest grain yield (41.95 qt ha^{-1}) whereas the 6 t ha^{-1} straw mulching resulted in the lowest grain (29.42 qt ha^{-1}) and biomass yield (10.7 t ha^{-1}) and in 2012 significantly different the 6 t ha-1 FYM gave the highest grain yield (43.08 qt ha-1) whereas the 6 t ha^{-1} straw mulching resulted in the lowest grain (33.64 qt ha^{-1}) and biomass yield (11.36 t ha^{-1}). Relatively lower yield and yield components under high straw mulching rate of 6 t/ha might be due to less decomposition rate of straw, competition of micro-organisms to decompose straw, less decomposing micro-organisms in the soil, below optimum soil temperature which influenced crop growth and decomposition rate, etc. Similarly Chen et al. (2007) reported in grain yield reduction with 6 t /ha straw mulching by 7% in winter wheat as compared to the control and Rasmussen et al. (1997) also reported 13% reduction. They attributed this reduction to reduced soil temperature. Reduced yields might also be contributed to reduced soil nitrate levels, temporary microbial immobilization of soil nitrogen (N) after straw incorporation into the soil due to the high C/N ratio of straw (Döring*et al.,* 2005; Morgan, 2005; Irshad*et al.*, 2002; Ma *et al*., 1999).

Table 2. Grain yield and some yield parameters of bread wheat as influenced by surface management practices during 2011 and 2012 cropping years

Treatment	**Biomass yield (t/ha)**		**Grain yield (qt/ha)**		**TKW (gm)**	
	Yr 2011	**Yr 2012**	**Yr 2011**	**Yr 2012**	**Yr 2011**	**Yr 2012**
Control	13.6ba	13.77	39.01	41.81ab	42.8	43.42abc
FYM 2	14.5a	13.31	39.59	41.52ab	41.9	41.21c
FYM 4	12.6bac	12.39	41.32	40.98ab	41.4	41.21c
FYM 6	14.3a	14.59a	41.95	43.08a	41.9	42.81abc
STR 2	11.3bc	12.41	33.74	40.65ab	43.8	44.39a
STR 4	12.3bac	11.72b	40.89	37.05bc	44.3	43.83ab
STR 6	10.7c	11.36b	29.42	33.64c	43.6	43.41abc
LSD(0.05)	2.28	2.69	ns	5.77	ns	2.50
CV	10.05	17.974	13.5	12.364	6.2	4.968

TKW = thousand kernel weight

Effect of surface management practices on soil, water, and nutrient conservation

Rate of erosion in Ethiopia varied from 16-300 t ha^{-1} yr^{-1} mainly depending on rainfall intensities, surface cover, topographic and soil conditions. The results of the current study are summarized as follows: the soil of the study area was clay in texture with sand, silt and clay contents of 25, 23 and 52%, respectively.

The bulk density of surface soil (0-20cm) varied from 0.85 to 0.98 g cm^{-3} indicating no compaction to inhibit root development. Chemical analyses showed that the nutrient contents of the experimental plots were generally low. The soil had low organic carbon and low to medium total nitrogen content. The plant available phosphorus was medium. Soils of the experimental site had very high exchangeable K.

The results of the study also suggested that the average runoff and soil loss from control treatments were 40.85mm and 11.40 t ha^{-1}, respectively. The straw mulch reduced runoff and soil loss by at least 98.78 and 95%, respectively. The 6 t ha^{-1} mulch rates retained 220.60 mm of runoff producing rainfall which was 39.8mm higher in comparison to the control. The average values of sediment associated losses of organic carbon and nutrients were in the range of 1.53 to 292.98 kg ha^{-1} for OC, 0.001 to 0.43 kg ha−1 for available P, 0.15 to 27.36 kg ha^{-1} for total N and 0.01 to 17.9 kg ha^{-1} for exchangeable K, with the lowest values in all cases from the 6t/ha^{-1} straw mulch. N and P losses accounted for 84.6 and 1.9%, respectively of the total amounts that were applied as fertilizer in the control, as against 0.23 and 0.01% respectively in the 6 t ha^{-1} straw mulch. The results suggest that straw mulching is a potential alternative for reducing nutrient transport with eroded sediment. Mulching slows runoff, promotes infiltration and enhances soil deposition. Considering N, Pav and K losses per unit of sediment, nutrient concentration in the straw mulch treatments were moderately higher than those in the control. This could be attributed to the mineralization of wheat straw (Danga *et al.,* 2009) and the higher clay percentage in the sediment in the straw mulched plots.

The higher concentration of nutrients in the sediment under straw mulch treatments was compensated for by the lower sediment loss of the treatment. The results of the experiment clearly demonstrated that surface application of straw mulch is more effective in reducing runoff, soil loss and in-situ moisture conservations than farmyard manure. In addition to significantly checking soil losses, the 4 t ha^{-1} straw mulch resulted in grain yield (4.09 t ha^{-1}) that was comparable with the yield obtained (4.31 t ha^{-1}) for 6 t ha^{-1} manure application rate.

Conclusion and Recommendation

The results of this study showed that the 4 t ha^{-1} straw mulch resulted in grain yield (4.09 t ha^{-1}) comparable with the yield obtained (4.31 t ha^{-1}) from 6 t ha^{-1} manure application rate. In addition straw mulch at 6 t ha^{-1} provided better protection of soil and water loss and is a promising practice for sustainable soil nutrient and moisture management in the study area. Hence this rate could be utilized as management practice for soil and water conservation in the future with similar slope gradient and climatic conditions. It is also recommended that further studies to understand straw mulch and farm yard manure decomposition dynamics and factors influencing, and to compare their application rates under similar conditions in medium to long term duration in the future.

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Effects of Level Fanya Juu and Fanya Chin on Grain Yield of Maize in Low Moisture Areas of Daro Labu District of West Hararghe Zone, East Oromia, Ethiopia

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Abstract

The experiment was conducted during 2011 and 2012 cropping seasons in low moisture stress areas of Sororo peasant association (PA) in Daro Labu District, West Hararghe Zone. The objectives were to evaluate effect of level Fanya Juu and Fanya Chin on grain yield of maize and to increase farmers' awareness level and skills on using the technologies for improving productivity. The treatments were level Fanya Juu, Fanya Chin and farmers' practice (flat planting) used as control with testing crop maize (Melkasa-4) arranged in randomized complete block design on three farmers' fields as replications. In the first year (2011) the statistical analysis revealed that there was significant difference (p<0.05) among the treatments on maize grain yield, but no significant in stand count at harvest and number of cobs. In the second year (2012) there was no significant difference among the treatments on maize grain yield, stand count at harvest and also number of cobs per plot. As compared to flat planting, both structures gave better yield (i.e. yield advantage varied from 7.5-87% over farmers' practice) besides decreasing soil erosion & enhancing soil moisture. Therefore this physical conservation structures are recommended for further scale up in low moisture stress areas of Daro Labu Districrt and similar agro-ecologies.

Key words*:* Fanya Juu, Fanya Chin**,** low moisture stress, yield

Introduction

Ethiopian agriculture is mainly rain-fed with only about 5% of the total arable land is under irrigation. Although the average annual rainfall is about 848mm with maximum over 2000mm, it is highly erratic and often falls intensively (Mikael & Teklu, 2006; Regasa *et al.*, 2006). Despite high average annual rainfall & favorable environmental variables for agriculture, the performance of rain-fed crop production of the country is very poor which is attributed to high temporal and spatial variations in rainfall, wide spread nutrient deficiencies and improper soil, water & crop management (Tamirie, 1986; Heluf and Yohannes, 2002; Mikael &Teklu, 2006)

The rates of annual loss of soil due to erosion in Ethiopia are variable. It is from almost zero on lowland grasslands to over 200 t/ha/year on steep slopes of the highlands, i.e., cultivated with erosion promoting crops such as maize or sorghum (Getachew, 1998). Soil and water conservation is required to alleviate both the problems of erosion and drought which are symptoms of two different extremes of rainfall conditions. Since rainfall erosivity, soil erodibility and landform are inherent properties of climate, soil and land respectively, only little can be done to modify their effects appreciably. Therefore, control of soil erosion and runoff water depends on judicious soil and crop management practices (Hudson, 1977; Lal, 1977a, b). The practice of judicial water conservation undoubtedly plays a significant role in increasing agricultural production in arid, semi arid and sub-humid areas where agriculture is hampered by periodic droughts and low soil fertility (Tamirie, 1986; Heluf, 1989; Heluf and Yohannes, 2002).

The efficiency of the physical soil and water conservation techniques depends on the soil type, climate, the crop grown and the cropping methods. Among physical soil and water conservation measures are level Fanya Juu and Fanya Chin. The term Fanya Juu and Fanya Chin originated from Swahili which literally means ‘make upwards’ and ‘make downwards’ respectively, each term referring to the way these are constructed. Fanya Juu is constructed by digging a trench and throwing the soil uphill to form an embankment and can be developed to bench terrace if enough soil moves down slope and lodges above the embankment. Similarly, Fanya Chin is constructed by digging a trench and throwing the soil downhill to form embankment (Amanuel *et al*., 2002).

Despite the significance of the problems of soil erosion and low soil fertility in the Ethiopian semi-arid and arid, research aimed at generating soil and water conservation techniques and farming practices that reduce soil erosion and harvest rain water for use by plants, on cultivated lands, is inadequate. Today, Ethiopia is entering in era of physical and economic water scarcity due to increasing population pressure, degradation of natural environment, increasing livestock pressure, increase in cost of supply, increase in demand for other uses such as industries, construction, lack of efficient and effective water institutions that insures equitable allocation of the nominally accessible water among users (Moges, 2006).

The human population is growing at an alarming rate, which necessitates increased food and fiber production to meet the corresponding growing demand. This is possible only through efficient use of the natural resource base with which the country endowed. Because rainwater is the prime factor that largely determines the level of rain-fed agricultural production, its improved efficiency can substantially augment the countries food security endeavors (Mikael & Teklu, 2006). Many analysts believe that future increases in food supplies and economic prosperity for the rural poor of Ethiopia will mainly come from improved agricultural soil and water management. In light of which researchers, policy makers, NGOs and farmers are increasingly experimenting and promoting various innovative agricultural water management technologies & practices (Regasa *et al.*, 2006).

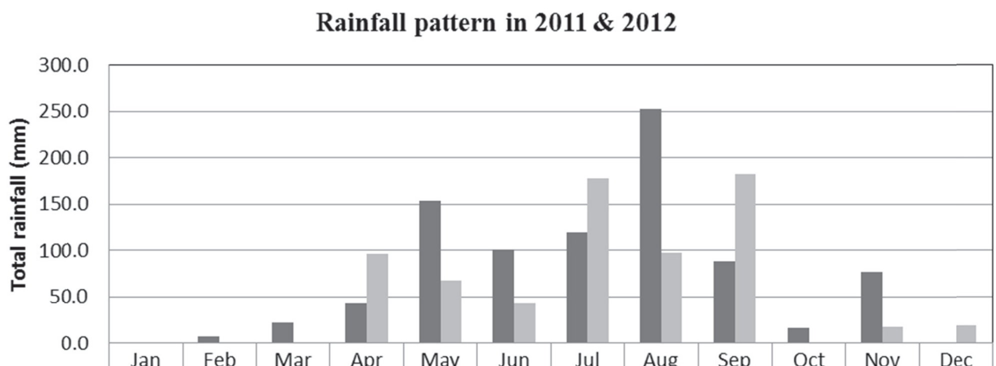
In the study area, moisture deficit is the primary problem, which highly constrains the productivity of smallholder farmers particularly of the mid & lowland parts. Extreme dry spells and recurrent drought are common. Late start, early finish and little in amount are becoming main characteristics of rainfall in the areas. Crops fail at vegetative stages before seed setting, livestock lost in absence of feed and watering due to drought that prevails (Eshetu *et al*., 2010). As a result, population living in the district is food insecure and is under aid by Safety Net programs, United Nations WFP, NGOs like Goal. To cope up with prevailing low moisture stress problem and so that ensure food security of the region, promoting and evaluating different adaptable soil and water management technologies is necessary. The study was, therefore, conducted with objectives of evaluating effects of level Fanya Juu & Fanya Chin on grain yield of maize in low moisture stress areas of Daro Labu District as well as enhancing farmers’ level of awareness/skills towards utilizing those technologies.

Materials and Methods

Description of the study area

The field experiment was conducted in Daro Labu District of West Hararghe Zone of Oromia. It is located 434km to the east of Finfinne/Addis Ababa and 115km from Chiro zonal capital to the south on a gravel road that connects to Arsi and Bale zones. Its latitudinal and longitudinal positions are 40^{0}19.114 North and 08^{0}35.589, East respectively. The area has bimodal type of rainfall distribution with annual rainfall ranging from 900-1300mm (average annual rainfall of 1094mm) and ambient temperature of the district varies from 14 to 26^{o}C with average of 20^{o}C (Mechara metrological station 2009-2014).

The nature of rainfall is very erratic and unpredictable causing tremendous erosion. The altitude range for Daro Labu is 1350 to 2450masl with area coverage of 434,280ha and the predominant production system in the district is mixed crop-livestock production with peculiar sub-systems. The crops grown in the area include from small cereals like teff to tree and fruit crops like coffee, mango and avocado. The major soil type of the area is Nitisol and its texture is sandy loam clay which is reddish in color (Report on farming system of Daro Labu and Boke districts, Mechara Agricultural Research Center (unpublished)). The chart below shows the actual rainfall pattern during the trial period (2011-2012) which was taken from nearby meteorological station (i.e. Mechara station-found at about 10km from the trial site).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	0.0	8.0	22.7	43.2	154.2	100.9	118.6	252.0	88.1	16.9	76.9	0.0
2012	0.0	0.0	0.2	95.6	67.3	43.3	178.3	97.7	182.4	0.0	18.3	19.7

Figure 1. Monthly rainfall pattern in 2011 & 2012 cropping seasons at Mechara meteorological station

Experimental design, data collection and analysis

The study was conducted during the period of 2011-2012 for testing effect of level Fanya Juu and Fanya Chin on grain yield of maize in low moisture stress areas of Daro Labu District. One PA was selected in the district where low moisture stress is the problem. Three farmers were selected on willingness to participate on construction of the structures. Level Fanya Juu & Fanya Chini was constructed with length of 10m, depth of basin 60-70cm top width 1m & with tie 1m between basins on 5% slope of land. Maize variety Melkasa-4 was used to plant on farmers` fields between Fanya Juu & Fanya Chini with plot size of 10mx10m with recommended fertilizer rate and spacing of 75x25cm inter-and intra-row spacing (Figure 2). Farmers practice without structure was used as control. The numbers of farmers were considered as replicates. Data on grain yield stand count at harvest & number of cobs per plot were collected. The collected data were subjected to analysis of variance using SAS statistical software and means were separated using least significant difference test.

Figure 2. Level Fanya Juu and Fanya Chin at initial stage of maize at Sororo Peasant Association in 2012

Results and Discussion

There was significant difference ($p<0.05$) among treatments on grain yield, but number of cobs per plot and stand count at harvest were not significant in the first year (2011) (Figure 3 and Table 1). Significant variations ($P<0.05$) in stand count at harvest and number of cobs were observed during 2012 growing season. There was highly significance difference ($p<0.01$) among treatments on days of maturity during two years of practices and maize planted on Fanya Chin matured earlier as compared to the other structures because crop planted might got sufficient moisture on time of requirement (Table 1).

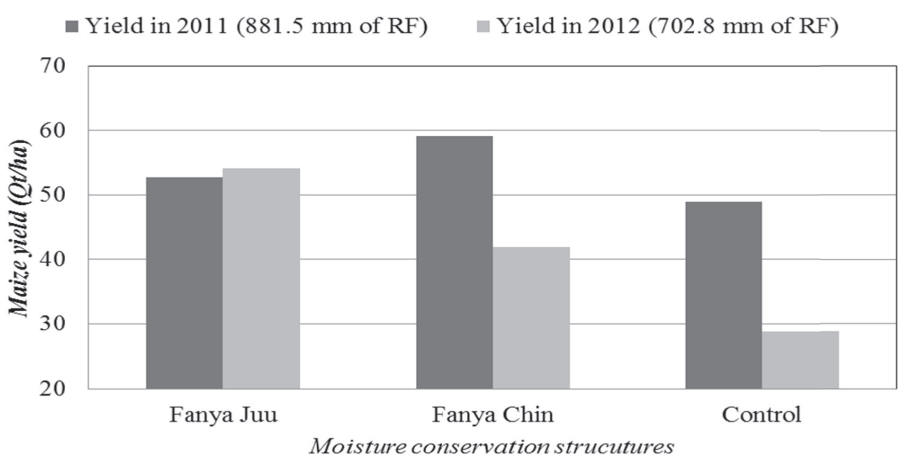


Figure 3. Relationship of moisture conservation structure and yield of Maize in 2011 and 2012

Table 1: Mean grain yield of maize, stand count at harvest (STCH) & number of cobs per plot (NCpt) during 2011-2012 cropping seasons

Treatment	Mean values of parameters during 2011 cropping season					Mean values of parameters during 2012 cropping season				
	STCH	NCpt	Yield (Qt/ha)	Days maturity	Yield advantage (%)	STCH	NCpt	Yield (Qt/ha)	Days to maturity	Yield advantage (%)
Level Fanya Juu	572	660.3	52.7	113.00	7.5	665	655	54.09	114.7	87
Level Fanya Chin	593.7	656.3	59.2	109.33	20.8	709	694	41.9	112	45
Control	649	657.6	49	116.67	-	357	342.6	28.9	117.7	-
Mean	**605**	**658.1**	**53.64**	**113.00**	-	**577**	**564**	**41.64**	**114.8**	-
P-value	0.5108	0.995	0.0137	0.014	-	0.009	0.0029	0.139	<.001	-
LSD (0.05)	ns	ns	5.2	3.702	-	169.03	127.6	ns	0.756	-
CV (%)	12.78	7.92	4.27	1.4	-	13.0	9.9	28.5	0.3	-

As can be observed from Figure 3, the relative importance of the structures in improving soil moisture retention capacity and thus maize yield was more pronounced in 2012 cropping season. This was as a result of the relative reduction of rainfall in the second year, particularly in early growth period of the crop; around months of May to June (Figure 1) which impacted moderate yield reduction for maize planted on control plots and the yield advantage gained by using the two structures was significantly higher (Table 1). Lakew *et al*. (2005) reported that level Fanya Juu was used to retain rainfall and hence, increased soil moisture, water availability to plants, and increased the efficiency of fertilizer application for crop production. Others authors also reported that Fanya Juu technique has been successfully increased crop yields (Motsi *et al*., 2004; Tenge *et al*., 2005). Quantitatively, the crop yield advantage gained by using soil and water conservation structures like Fanya Juu varied in between 22-50% (Abay, 2011; Eriksson, 2011; Liniger *et al.,* 2011). The findings of these reports are in line with that of this study which gave yield advantage of up to 85%. Thus the study verified that, among the treatments considered, planting in the Level Fanya Juu and Fanya Chin produced higher grain yield than farmers' practice.

Conclusion and Recommendation

In general, both structures (Fanya Juu & Fanya Chin) were better than farmers practice in grain yield, stand count at harvest, days of maturity (early matured) and number of cobs per plot. Depending on these results (yield improvement, conserving soil moisture and considered reducing soil erosion) both structures (Level Fanya Juu and Fanya Chin) were recommended with short maturing maize varieties or other annual crops to be further scaled up in low moisture stress areas of Daro Labu District and other similar agro-ecology. This study has limitations that it is not supported by soil moisture and other soil parameter analyses. Hence, it is recommended that repeating the study by including more soil moisture conservation structures by including critical soil parameters such as fertility is very important.

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Effect of Level Bund on Yield of Maize and Sorghum in Low Moisture Areas of Hawi Gudina District, West Hararghe Zone, East Oromia, Ethiopia

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Abstract
The experiment was conducted in 2011-2012 cropping seasons in low moisture stress areas of Dhega Dheba PA of Hawi Gudina District, West Hararghe Zone. The objective was to evaluate effect of level bund on grain yield of maize and sorghum in low moisture stress areas for improving productivity. The treatments were level bund and farmers' practice with maize (melkasa-4) and sorghum (Abshir) on three farmers' fields as replications. Mean grain yield of maize on level bund was 28.5% higher than farmers' practice and also the yield advantage of sorghum on level bund was 51% over farmers practice during first year. During second cropping season, the mean grain yield of maize on level bund was 26.8% higher than farmers' practice and of sorghum was 53% over farmers practice. The yield advantage obtained was more pronounced for sorghum when compared to maize which was attributed to more resistance of sorghum cultivar to moisture deficit as compared to maize. Therefore, appropriate soil and water conservation structures are essential in low moisture deficit areas to increase productivity of suitable crops.

Key words: Level bund, days of maturity, low moisture stress, yield

Introduction

Ethiopian agriculture is mainly rain-fed with only about 5% of the total arable land is under irrigation. Although the average annual rainfall is about 848mm with maximum over 2000mm, it is highly erratic and often falls intensively (Mikael & Teklu, 2006; Regasa *et al*, 2006). Despite the high average annual rainfall (848mm) & favorable environmental variables for agriculture, the performance of rain-fed crop production is very poor which attributed to high temporal and spatial variations in rainfall, wide spread nutrient deficiencies and improper soil, water & crop management (Tamirie, 1986; Heluf and Yohannes, 2002; Mikael & Teklu, 2006). As a result agricultural production is affected and crop yields reduced and persistent crop failure occurs (Keating *et al*., 1992; Miriti *et al*., 2012). Further, the loss of nutrients through plant nutrient mining, removal of crop residues, erosion, leaching or volatilization, and the deterioration of soil physical properties can independently or interactively result in yield reduction (Bielders *et al*., 2002).

Ethiopian arid and semi-arid lands are also experiencing low crop production due to combination of biophysical problems such as low rainfall, surface sealing, unavailability of high quality manure, declining soil fertility due to continuous cultivation and crust formation that reduces soil water availability to crops (Gicheru, 2002; Gitau, 2004). In this area increasing the productivity of smallholder agriculture requires bringing to scale several practical interventions. The key ones are the use of improved seeds of adaptable crops, soil moisture conservation practices and use of fertilizers to realize the benefits from increased productivity and production.

In Hawi Gudina District, where this study was conducted, low moisture stress is the primary problem, which highly constrains the productivity of smallholder farmers particularly of the lowland part (priority problem raised in Research-extension-farmer Linkage Advisory Council (REFLAC) meeting). Extreme dry spells and recurrent drought are very common. Late start, early finish and little in amount are becoming main characteristics of rainfall in the areas. Crops fail at vegetative stages before seed setting, livestock lost in absence of feed and watering due to drought that prevails. As a result, the population living in the districts is food insecure and is under aid by Safety Net Programs, United Nations WFP, NGOs like Goal (Eshetu et al., 2010). To cope up with this prevailing moisture deficit and ensure food security of the region, promoting and evaluating of different adaptable soil and water conservation technologies is important. Therefore, this study was carried out to evaluate the effect of level bund on yield of maize and sorghum in low moisture stress areas of Hawi Gudina District.

Materials and Method

Description of the study area

The field experiment was conducted in Hawi Gudina District of West Hararghe Zone of Oromia. It is located at the distance of 519km and 180km from Finfinne/Addis Ababa and Chiro zonal capital, respectively. The total area of the district is estimated to be 3041.19km^2. The district is situated in-between 7˚52’15’’ to 9˚25’43’’N latitude and 40˚34’13’’ to 41˚9’14”E longitude. The topography of the district is mainly flat lowland with altitudes ranging from 976 to 2077m.a.s.l. Agro-ecologically it is divided in to Kola (83.8%), Weina Dega (12.9%) and Dega (3.3%). Annual rainfall of the district is 500-900mm/year whereas mean minimum and maximum temperatures reach 14˚C and 35˚C, respectively with average of 25˚C. The pattern of rainfall is bimodal and its distribution is mostly uneven. Generally, there are two rainy seasons: the short rainy season ‘Belg’ lasts from mid-February to April whereas the long rainy season ‘kiremt’ is from June to September. The rainfall is erratic, onset is unpredictable, and its distribution and amount are also quite irregular. Consequently most PAs frequently face shortage of rainfall (HGPDO, 2011). According to CSA (2007) the population of the district was estimated to be 55,903 from which 28,780 were males and 27,123 were females. The rural population comprises 98% of the population of the district.

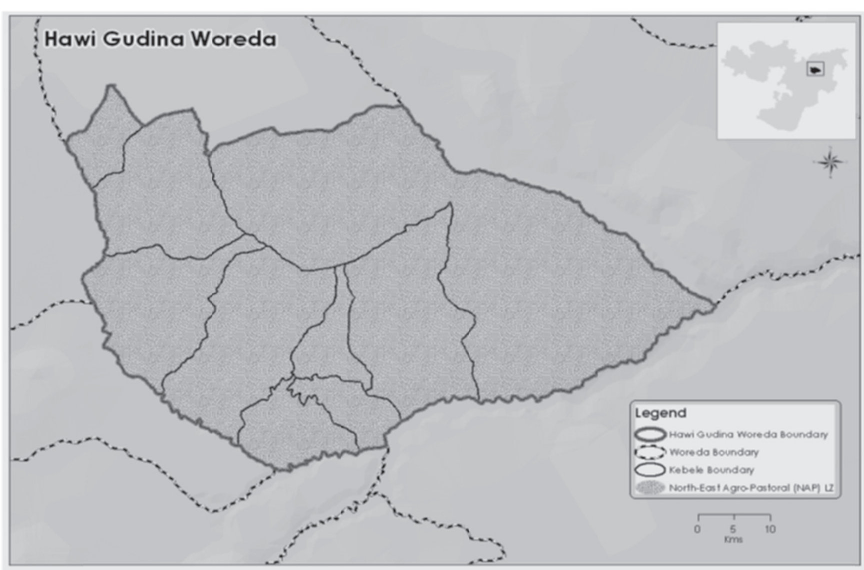

Figure 1. Map of Hawi Gudina District (adapted from Oromia Livelihood Zone Reports)

Experimental design, data collection and analysis

The study was conducted during 2011-2012 cropping seasons for evaluating effect of level bund on grain yield of maize and sorghum in low moisture stress areas of Hawi Gudina District. One PA was selected in the district where moisture deficit is the problem. Three farmers were selected based on willingness who participated on construction of the structures. Level bund was constructed on plot size of 10mx10m with bottom and top width of 75cm and 30cm respectively and 30cm height of embankment on land of <5% slope. After the bund was constructed, early maturing sorghum variety (*Abshir*) and maize (*mekasa-4*) were planted in between bunds and farmers' practice in randomized manner considering every space between counters as block using recommended fertilizers rate and spacing 25x75cm intra- and inter-row spacing for both crops. Data on grain yield, stand count at harvest and number of cobs/heads per plot were collected for both crops and analyzed using descriptive statistics.

Results and Discussion

The study area was affected by severe drought during the study years. As a result, two experimental sites were failed totally. But depending on one location data, some promising result was obtained even though the yield was not to the potential. Mean of maize yield on level bund was 28.5 % higher than farmers' practice. And also the yield advantage of sorghum on level bund was 51% over farmers practice during first year (Table 1). This was because level bund had ability to conserve moisture and decreased soil erosion. The yield of maize was reduced during second year because of prevailing climatic condition (moisture deficit). During second season, the mean yield of maize on level bund had 26.8% higher yield than farmers' practice and that of sorghum was 53% higher than farmers practice (Table 2). The yield advantage obtained was more pronounced for sorghum when compared to maize which was attributed to more resistance of sorghum cultivars to moisture deficit as compared to maize. Similar with this study, the plots with bunds were found more productive than those without such technologies in semi-arid areas. This is apparently due to the moisture conserving benefits of this technology being critical in drier areas (kassie *et al.,* 2007*)*. Also, improved in field water harvesting can increase time required for crop low moisture stress to set in and thus can result in improved crop yield and resulted in positive effects on soil fertility, moisture conservation and agricultural productivity (Alamu and Kidane, 2014)

Table 1. Mean grain yield, stand count at harvest and number of cobs/heads in 2011 cropping season

Practice	Maize (Mekasa-4)					Sorghum (Abshir)				
	Stand count	NO. Cobs /plot	Days of maturity	Yield (Qt/ha)	Yield adv.(%)	Stand count	NO. heads/plot	Days of maturity	Yield (Q/ha)	Yield adv. (%)
Level bund	530	613	114	45	28.57	290	281	112	13	51.1
Farmers practice	600	581	112	35	-	254	230	113	8.6	-

Table 2. Mean grain yield, stand count at harvest and number of cobs/heads in 2012 cropping season

Practice	Maize (Mekasa-4)					Sorghum (Abshir)				
	Stand count	No. Cobs/plot	Days of maturity	Yield	Yield adv	Stand count	No of heads/plot	Days of maturity	Yield (Qt/ha)	Yield adv. (%)

					(%)					
Level bund	153	110	112	8.5	26.8	580	563	120	23.5	53.3
Farmers practice	168	131	115	6.7	-	508	479	119	15.32	-

The grain yield and yield advantage of sorghum and maize was relatively very high in level bund as compared with farmers' practice (without structures). This finding is similar with (ETWWA, 2010) which showed that better water management, coupled with improved soil and crop management can improve agricultural productivity more than double in low moisture stress areas with current low yields.

Conclusion and Recommendation

Depending on parameters collected from crops planted on the structure, mean yields of level bund when compared to farmers' practice was promising for the two crops (maize & sorghum). Conserving soil moisture & decreasing soil erosion is most important feature of the structure, especially in moisture deficit areas to increase productivity and production of small holder farmers. Even if yield was not much better during the two years which was attributed to unfavorable climatic condition of the area, level bund is recommended in low moisture stress areas of the district to integrate with annual crops for improving yield as well as conserving soil moisture and reducing soil erosion. This study had limitations that it was not supported by soil moisture and other soil parameter analysis. Hence, it is also recommended that repeating the study by including other suitable soil moisture conservation structures and including soil parameters is important.

Acknowledgement

We would like to thank Oromia Agricultural Research Institute for financial support and Mechara Agricultural Research Center for the provion of the necessary facility for the research work. We would also like to express our gratitude to Wazir Mohamed for his active participation in conducting this experiment.

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Effects of Negarim and Semi-circular Structures on Growth and Yield of Banana (Musa paradisiacal var. Sapiertum) in Moisture Deficit Area of Daro Labu District, West Hararghe Zone, East Oromia, Ethiopia

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Abstract
The study was conducted for three years (2011/12-2013/14) to evaluate the growth and yield of banana (Robusta) with different water harvesting structures and to overcome moisture deficit by using these structures in Oda Leku PA of Daro Labu District. The water harvesting structures used as treatments were semi-circular bund with and without mulch, Negarim micro-catchment with and without mulch and normal pit with and without mulch used as control. The treatments were laid out in randomized complete block design on three farmers' fields as replications. The statistical analysis revealed there was significant variation ($p<0.05$) among treatments on yield and number of fingers but there were no significant differences among treatments on survival rate, number of suckers, plant height, and area coverage. The mean plant height, area coverage and number of suckers on semi-circular bund with mulch and Negarim micro-catchment with mulch were better than the structures without mulch and control. Both structures are therefore recommended with mulch for banana production in low moisture stress areas and similar agro-ecologies.

Key words: Negarim, semi-circle, survival rate, area coverage, number of sucker

Introduction

Water is the major limiting factor to crop production in semi-arid conditions, yet a substantial amount of it is lost from agricultural fields and adjacent land through runoff. Several innovations have been developed in the past to improve water availability to field crops by harnessing the excess runoff. Degradation of soil and water resources is a worldwide problem that takes many forms (Napier *et al*., 2000). It is especially severe in developing countries where people are struggling to eke out an existence and are more concerned with survival than with conservation.

The drylands of Ethiopia comprise about 70% of the total landmass and 45% of the arable land, including arid, dry semi-arid, moist semi-arid and parts of the sub-moist zone. However, these areas contribute only 10% of the total crop production. About half of the arable land is in the arid and semi-arid regions, and most rural people living in such areas depend on small-scale dry land agriculture. The drylands are characterized by severely fragile natural resource base. Soils are often coarse-textured, sandy, and inherently low in organic matter and water-holding capacity, thereby making them easily susceptible to both wind and water erosion. As a result, crops can suffer from moisture deficit and drought even during normal rainfall seasons. Farm productivity has declined substantially and farmers have found themselves sliding into poverty (Kidane, 1999).

Banana has been cultivated for several years in Ethiopia as a garden plant. In Ethiopia, the major banana producing regions are Southern Nations and Nationalities, Oromia and Amhara regions (MOA, 2011). During the 2010/2011 cropping season about 31, 885.86ha of land was covered with banana and the estimated annual production was about 270, 571.516 tones (CSA, 2011). The actual yields are less than 40 t ha^{-1} $year^{-1}$ (Wairegi *et al*, 2010); whereas, the potential yield of banana is greater than 70 t ha^{-1} $year^{-1}$ (Van Asten, *et al*, 2005). The poor productivity of banana has been attributed to a number of biophysical factors (Gold, 1999). Among these, low moisture stress is the critical problem for banana production particularly in arid and semi arid areas.

Water conservations are methods to increase the amount of water stored in the soil profile by trapping or holding rain where it falls or where there is some small movement as surface run-off. Schemes which are more concerned with catching and storing runoff for later use or at a distance from storage. Some authors have used the terms internal and external catchments. Internal catchments are where the runoff producing areas is within the cropped area and external catchments are runoff areas outside the cropped area.

Although the first reports of Negarim micro-catchments were derived from southern Tunisia (Pacey and Cullis, 1986), the technique was developed in the Negev desert of Israel. Where precipitation is less than crop water requirements, here the strategy includes land treatments to increase runoff onto cropped areas, following for water conservation and the use of drought tolerant crops with suitable management practices. And where precipitation is equal to crop water requirement, here the strategy is local conservation of precipitation, maximizing storages within soil profile and storage of excess runoff for subsequent use. Thus, Negarim and semi-circular micro-catchment is the well known in-situ water conservation systems. The weakness of using these approaches is that the main feature of rainfall in semi-arid regions is very erratic and completely unpredictable. There can be wide variations of moisture shortage and surplus both within and between seasons.

In West Hararghe Zone, moisture deficit is the primary problem, which highly constrains the productivity of small holder farmers particularly of mid and lowland parts of the districts (priority problem raised in REFLAC, 2009/10 meeting). Extreme dry spells and recurrent drought is common phenomena; late start, early finish and little in amount is becoming main characteristic of rain fall in the areas (Eshetu *et al*., 2010). Hence, there is a need to introduce in-situ moisture conservation to the target area for banana productivity and production. Therefore, the study was initiated with the objective of evaluating in-situ moisture conservation structures on growth and yield of banana and to overcome moisture deficit using structures to the target area.

Materials and Methods

Description of the study area

The field experiment was conducted in Daro Labu District of West Hararghe Zone of Oromia. It is located 434km to the east of Finfinne/Addis Ababa and 115km from Chiro zonal capital to the south on gravel road that connects to Arsi and Bale zones. Its latitudinal and longitudinal positions are 40^{0}19.114N and 08^{0}35.589E, respectively. The area has bimodal type of rainfall distribution with annual rainfall ranging from 900-1300mm (average annual rainfall of 1094mm) and ambient temperature of the district varies from 14 to 26^{o}C with average of 20^{o}C (Mechara metrological station, 2009-2014).

The nature of rainfall is very erratic and unpredictable causing tremendous erosion. The altitude range for Daro Labu District is 1350 to 2450masl with area coverage of 434,280ha and the predominant production system in the district is mixed crop-livestock production with peculiar sub-systems. The crops grown in the area include from small cereals like teff to tree and fruit crops like coffee, mango and avocado. The major soil type of the area is sandy loam clay which is reddish in color (Report on farming system of Daro Labu and Boke districts, Mechara Agricultural Research Center unpublished).

Experimental design

The study was conducted to evaluate the growth and production of banana (Robusta) using in-situ water harvesting structure and to overcome prevailing moisture stress problem of Daro Labu District on farmers' fields at Oda Leku PA for three years (2010/11-2013/14). The experiment was designed in RCBD and planted on three farmers' field used as replications. The semi-circular structure was constructed with 2.5m diameter and 1.25m of radius and negarim was constructed with 1.25m length for each side. For all treatments spacing between two banana seedlings and between rows was 2.5m arranged in staggered manner to control erosion as well as for conserving moisture on plot area of 5mx7.5m. Two banana suckers per treatment per farmer were planted (total 12 suckers per farmer).

Data collection and analysis

Data for growth parameters such as survival rate (per 6 months), plant height and area coverage (at 1 9/12 year), and number of sucker (at 2 years) were recorded. The matured bunch was harvested for determination of bunch yield. Number of fingers per hand and bunch weight was measured and yield was calculated to t/ha. The data recorded throughout the growing periods were averaged over every harvest in the cropping seasons for data analysis and computation. Analysis of variance was performed using the GLM procedure of SAS statistical software Version 9.0. Effects were considered significant in all statistical calculations with $p< 0.05$. Means were separated using Least Significant Difference test.

Results and Discussion

The statistical analysis revealed that there was significant difference ($p<0.05$) among treatments on yield and number of fingers. But there were no significant differences among treatments on survival rate, plant height, area coverage, and number of suckers. Higher yield that ranged from 14.57 to 22.53 t/ha and number of fingers per bunch were recorded on both structures (negarim and semi circular bund) with mulch and normal pit with mulch (Table 1).

Table 1. The mean value of yield and other growth parameters of banana (2011/12-2013/14)

Treatment	Mean value of collected parameters					
	SR	**PHT**	**AC**	**NS**	**Yield* (t/ha)**	**Average no of fingers/bunch**
Semi-circle without mulch	98.33	0.80	1.066	5.00	2.667[b]	19[b]
Semi-circle with mulch	100	1.7833	1.7833	7.66	14.571[a]	79[a]
Normal pit without mulch	100	1.26	1.433	4.66	-	-
Normal pit with mulch	100	0.9333	1.166	7.00	14.933[a]	71[a]
Negarim without mulch	100	0.936	1.1933	5.00	12.693[ab]	72[a]
Negarim with mulch	100	1.566	1.7833	7.667	22.523[a]	101[a]
Mean	99.72	1.21	1.35	6.166	13.50	68.1
LSD 0.05	2.1	0.88	0.80	4.66	11.67	51.05
CV (%)	1.18	39.81	32.6	41.55	47.60	39.8

N.B: Means with the same letter in column are not significantly different
*=represents yield taken from one plant per pit (not include ratoon plant).
SR=survival rate, PHT=plant height, AC=area coverage, NS = number of sucker

However, there was no yield recorded from normal pit without mulch (local check) during the experimental period signaling that the banana production in the study area was highly limited by insufficient soil moisture, thus impacting the yield potential of the improved varieties used for production (i.e. up to 45 t ha^{-1} under research farms) (Tekle *et al.,* 2014). It is reported that banana production is greatly affected by environmental stresses such as drought (Turner, 1998). Banana is sensitive to soil water deficits, expanding tissues such as emerging leaves and growing fruit are among the first to be affected. As soil begins to dry, stomata close and leaves remain highly hydrated, probably through root pressure. Productivity is affected because of early closure of stomata (Turner, 1998). In addition to moisture conservation structure, surface management (grass mulch) is used to protect the soil surface from rain, wind and sun and also increase soil moisture by allowing more water to sink into the ground and by reducing evaporation (FAO, 2005). According to the above findings, the constructed structure had resulted in greater bunch yield and number of fingers than the local check. This finding has thus validated the potential of moisture conservation structures with soil surface management for increased fruit crop production like banana where inadequate availability of moisture is the most limiting. Therefore, it could be suggested that use of in-situ moisture conservation structure had brought a proportional yield increment than the normal pit without mulch.

Conclusion and Recommendation

Integrating in-situ moisture conservation structures to crop production could make an important contribution to increase agricultural productivity and production where there is high moisture deficit. To this end, use of appropriate soil and water conservation technologies such as negarim and semi-circular micro-catchment could be some of the alternatives to improve productivity of smallholder farmers. The findings of current study showed that moisture conservation structures with mulch such as negarim and semi circular micro catchment are advisable and could be appropriate for banana production in the study area even though further testing is required to put the recommendation on strong basis and evidences.

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We would like to thank Oromia Agricultural Research Institute for financial support and Mechara Agricultural Research Center for the provion of the necessary facility for the research work. We would also like to express our gratitude to Wazir Mohamed for his active participation in conducting this experiment.

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Sustainable Rangeland Managemnt Research

Spatial Variability of Soil Physico-Chemical Properties in Termite Mounds and Adjacent Control Soils in Yabello and Miyo Districts of Borena Zone, South Oromia, Ethiopia

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Abstract

This study was conducted in Yabello and Miyo districts of Borana Zone. The objective of the study was to examine the soil texture and macronutrient distribution in termite mounds in relation to adjacent soils. Standard procedures were used to analyse the soil parameters. One way ANOVA was used to compare results among control soil, external termite mound and internal termite mound materials. The study revealed that termites had produced more different soil texture and some nutrient content than the surrounding soils. Internal termite mounds at both study sites were enriched with clay in relation to external and control soil. SOM and CEC contents of control soils were higher at Boku Luboma. SOM content of external termite mound at Did-Yabello site was lower in relation to external and control soil. The termite mound at Did-Yabello had higher CEC content in relation to the surrounding soil. Exchangeable Ca content of termite mound did not show significant difference in relation to control soils. Termite activities enriched mounds with exchangeable potassium content. To design proper termite management techniques, without ecological damages and make use of ecological services provided by termites, termite species in Borana rangeland should be identified. There is no trend of termite mound use as soil amendment in Borana. In the future, amount of termite materials to be incorporated into soil to increase crop yield and socio-economic factors that affect use of termite materials as soil amendment should be studied in detail.

Key words: Termite mound, soil physico-chemical properties, Borana

Introduction

It is recognized that termites are important component of agro-ecosystems, particularly in developing countries where they are an alternative to high priced inputs. Mound-building termites are recognized as "ecosystem engineers" because they promote soil transformation by disturbance processes (Dangerfield et al., 1998). They collect particles from different soil depths and deposit them in mounds, so that contents of organic carbon, clay and nutrients, pH and microbial population are higher in termite mounds than in the adjacent soils unmodified by termites (Black and Okwakol, 1997). The accumulated material is redistributed by erosion causing changes in soil micro-structure and fertility (Black and Okwakol, 1997; Shaefer, 2001). Given the major problems in the soil crusting and nutrient depletion, termites associated with proper management techniques can play a vital role. Termites contribute to the rehabilitation of crusted soils, by opening up voids on the sealed surface leading to improved infiltration capacity, and consequently improved water availability.

Although termites are the most important soil fauna in the semi-arid tropics (Lobry and Conacher, 1990), they are often regarded as pest because they attack roots, and above ground plants, and stored food supplies (Iroko, 1996; Wood, 1996). As a result, termite research, in agro-ecosystems, has historically concentrated on the pest management aspects. However, of more than 2500 species (Pearce and Waite, 1994), relatively few are agricultural pests. Furthermore, pest activity is only a part of the termites' potential role in agro-ecosystems (Lee, 1990; Anderson, 1994).

In Borana rangeland, both mound building and moundless termites are abundant and widely distributed (Barnett et al*.,* 1987), and termite mounds are conspicuous features of Borana landscape. Their materials can be differentiated from the adjacent soil by its different physico-chemical properties that impact soil processes. Usually high concentration of organic matter and mineral nutrients are found in termite mound than in other soils. Consequently, subsistence farmers in Africa commonly spread termite mound materials in their fields to improve soil conditions and increase plant nutrient availability (Watson, 1977; Nyamapfene, 1986). They also promote nutrient availability, nutrient cycling and soil physical properties (Anderson, 1994).

However, according to Gauchan et al., (1998), research on termite in Ethiopia has been concentrated on only the pest management aspects. Thus, generally in the study area, the impact of mound-building termites on soil ecology in general and macronutrient distribution in particular were not yet studied. This study was conducted to examine the soil texture and macronutrient distribution in termite mounds in relation to adjacent soils, and to analyze termite impact on soil physico-chemical properties in Borana rangelands.

Materials and Methods

Description of the study area

The study was conducted in Did Yabello and Boku Luboma districts of Borana Zone. The rainfall is bi-modal. There are four seasons in the year: Ganna, long rainy season (March-May); Bona, dry season (December-February); Hagaya, short rainy season (September-November); and Adoolessa, cool dry season (June-August) (Coppock, 1994). The study area comprises important cultural landscapes that have been utilized for centuries. The study area is also confronted with the problem of bush encroachments in the native savannah grass lands.

Site selection, sampling of soils and mound materials

The study sites, Did-Yabello and Boku Luboma were selected because of widespread termite mounds in the area. In each location, replications of three termite mounds were systematically selected on a uniform slope. Internal mound and external mounds were sampled separately after destruction of termite mound. The externals (walls) of the termite mounds were sampled after scratching and removing the outer surface of mound materials. The internal mound (chamber) with thin structure was sampled separately.

In order to evaluate some physico-chemical composition of termite mounds in relation to soils, a total of six adjacent (control) soils, three in each location were sampled for this study. The control soil was sampled at soil depth of 0-25cm and 0-23cm for Did-Yabello and Boku Luboma sites respectively in a relatively unaffected area at reasonable distance from mounds. Control soils were considered to be the reference soils without significant termite activity; not mean that necessarily that termite activity ever occurred in it. Termite mound and its corresponding control soils were located on comparative slope gradients in order to remove further differences that can be introduced due to topographic effects. Thus, any difference in soil physico-chemical properties between termite mound materials and adjacent soil was attributed to the effects of mound-building termites.

Physical and chemical analysis of soils and mound materials

The soil samples were air dried and ground, mixed well and passed through 2 mm sieve for analysis. Particle size analyses were performed using the Bouyocous hydrometer method. The USDA particle size classes, sand (2.0-0.05mm), silt (0.05-0.002mm) and clay (<0.002mm), were followed for assigning textural classes.

Soil pH (H_2O) was measured using pH-meter in 1:2.5 soil water ratio. Determination of organic carbon content was carried out following the Walkley and Black wet digestion procedure (Walkley and Black, 1934) and the percent soil organic matter (SOM) was calculated by multiplying the percent organic carbon by factor of 1.724 (Brady, 1990) and total nitrogen was determined by the Kjeldhal method (Jackson, 1958). Available phosphorus analysis was undertaken according to the method described by Olsen *et al*. (1954). Exchangeable bases (Ca, Mg, and K) were analyzed after extraction using 1M ammonium acetate method at pH 7.0. Exchangeable Ca and Mg in the extracts were read using atomic absorption spectrophotometer where as exchangeable K was read by Flame photometer.

After displacement of the exchangeable base forming cations using 1M ammonium acetate, the samples were washed using ethanol and the ammonium on the saturated exchange sites were subsequently replaced by the addition of Na from NaCl solution. Cation exchange capacity (CEC) was thereafter estimated titrimetrically by distillation of ammonium that was displaced by sodium (Chapman, 1965).

Data analysis

The soil physico-chemical data were analyzed using SAS software (SAS, 2002, Version 9). One way ANOVA was used to compare soil physico-chemical properties among control soil, internal termite mound and external termite mound. Differences were considered significant only when $p<0.05$.

Results and Discussion

Particle size distribution

The textural class of the control soil was sandy loam for Did-Yabello site and loam for Boku Luboma site. Particle size distribution in termite mound, internal and external, in relation to the control soil was affected by termites. Clay particles were significantly higher in the internal mound at both study sites (34.6 % ± 3.8 % clay particles at Did Yabello and 49.2% ± 1.4 % at Boku Luboma). At Did Yabello site the silt content was significantly lower for internal mound whereas silt content of Yabello site did not show difference at $p <0.05$. The sand content of internal termite mound was significantly lower for both sites ($p<0.05$) (Table 1).

Table 15. Soil particle distribution of termite mound

Parameters	Part of Termite mound	District	
		Did Yabello	Boku Luboma
Clay (%)	Internal mound	34.6 ± 3.82[a*]	49.2 ± 1.4[a]
	External mound	22.9 ± 5.20[b]	40.4 ± 0.7[b]
	Control soil	13.3 ± 1.9[b]	21.7 ± 1.9[c]
LSD		10.645	3.4706
Silt (%)	Internal mound	12.9 ± 1.4[a]	25.8 ± 1.4[a]
	External mound	11.7 ± 10.0[a]	29.6 ± 1.9[b]
	Control soil	6.7 ± 0.7[a]	31.7 ± 0.7[b]
LSD		12.934	2.7539
Sand (%)	Internal mound	52.5± 4.33[a]	25.0 ± 00[a]
	External mound	65.4 ± 5.1[b]	30.0 ± 2.5[b]
	Control soil	80.0 ± 2.5[c]	46.7 ± 1.4[c]
LSD		3.7783	4.4304

*Means followed by different letters within column and district differ significantly at $p<0.05$

As evidenced from this study soil termite mound was relatively enriched with clay in relation to the surrounding soil (control soil). This difference could be attributed to the preferential selection by termites during establishment of mound (Harry et al., 2001). Manuwa (2009) observed similar trend in the clay content of termite mound in relation to the surrounding soil. In contradiction to this trend Ackerman et al. (2007) found slightly lower clay and higher silt and sand in thier study which implies that in the presence of high clay materials (76% clay) termites collect and transport more silt and sand proportions to their mound in relation to the control soil. The increase in clay content by termite activity can be crucial in improving soil physico-chemical properties in soil in general and sandy-sandy loam soil in particular. This study showed that clay materials plaid a key role in the construction of termite mound.

Soil pH

The pH values of external and internal mound were not significantly different in relation to the surrounding soil for both districts. The result is in agreement with study conducted by Brossard et al. (2007).

Soil organic matter, total nitrogen and available phosphorus

The soil organic matter (SOM) content of external mound was significantly lower than internal and control soil at Did Yabello site but differed significantly for control soil (higher SOM) for Boku Luboma site. The decrease in SOM in termite mounds in relation to the control soil at Boku Luboma could be attributed to termite SOM depletion potential with other soil microorganisms (Dahlsjo et al., 2014). Some researchers argue that the low SOM content in termite mound could be due to low SOM in the soil from subsoil used for mound construction (Contour-Ansel et al., 2000). Higher SOM for control soil was obtained by Jouquet et al. (2015) in relation to the termite mound. In contrary to this study higher SOM content in termite mound in relation to the surrounding soil was obtained by Ackerman et al. (2007), in which the feeding habit and materials used for construction of the termite mound contributed to the elevated SOM.

Internal termite mound at Did Yabello site had significantly higher total nitrogen content than external termite mound and control soil (Table 2). The high amount of total nitrogen in the termite mound might be due to the mineralization of soil organic matter by termites. Ackerman et al. (2007) obtained higher total N content in termite mound.

The Available P contents of internal and external termite mound were non-significant for Did Yabello and Boku Luboma sites. These results are consistent with the study conducted by Ackerman et al. (2007). Although the feeding habit of termite and materials used for construction of mound could have significant impact on phosphorus sorption affecting availability.

Table 16. Soil chemical properties of termite mound

Parameters	Part of termite mound	District	
		Did Yabello	Boku Luboma
Total N (%)	Internal mound	0.056 ± 0.004[a*]	0.078 ± 0.014[a]
	External mound	0.034 ± 0.007[b]	0.081 ± 0.025[a]
	Control soil	0.040 ±0.04[b]	0.096 ± 0.059[a]
LSD		0.0135	0.0995
OM (%)	Internal mound	0.79 ± 0.06[a]	2.05 ± 0.14[a]
	External mound	0.46 ± 0.07[b]	1.61± 0.17[a]
	Control soil	0.76 ±0.11[a]	2.55 ± 00[b]
LSD		0.2857	0.4762
Exch. K (meq/100 g soil)	Internal mound	1.50 ± 0.50[a]	2.44 ± 0.32[a]
	External mound	0.89 ± 0.31[b]	1.60 ± 0.49[b]
	Control soil	0.53 ± 0.14[b]	1.09 ± 0.29[b]
LSD		0.5715	0.7571

CEC (meq/100 g soil)	Internal mound	10.65 ± 0.50[a]	8.29 ± 1.90[a]
	External mound	8.91 ± 0.30[a]	6.86 ± 0.99[a]
	Control soil	3.24 ± 3.12[b]	12.03 ± 1.3[b]
LSD		4.2836	3.4307
Ex. Ca (meq/100 g soil)	Internal mound	6.17 ± 1.66[a]	34.58 ± 3.98[a]
	External mound	5.79 ± 0.56[a]	43.45 ± 2.30[a]
	Control soil	7.50 ± 1.74[a]	39.83 ± 6.9[a]
LSD		2.606	12.752
Exch. Mg (meq/100 g soil)	Internal mound	1.28 ± 0.17[a]	7.95 ± 0.97[a]
	External mound	1.78 ± 0.18[b]	10.95 ± 2.78[a]
	Control soil	1.31 ± 0.10[a]	3.52 ± 0.4[b]
LSD		0.3357	3.1442

*Means followed by different letters within column and district differ significantly at $p<0.05$

Exchangeable cations and cation exchang capacity

The internal termite mound had significantly higher exchangeable K (Exch. K) in relation to external termite mound and control soil at both sites (Table 2). This result is consistent with study conducted by Jouquet et al. (2004). According to the rating by Jones (2003), the exchangeable potassium content of the study area was medium (0.53 ± 0.14 ppm) for control soil and very high (1.50 ± 0.50ppm) for internal termite mound at Did-Yabello site. Exch. K at Boku Luboma was rated as very high.

The Exchangeable calcium (Exch. Ca) contents of termite mounds were non significant in relation to the adjacent soil. Research conducted by Jouquet et al. (2004) revealed that non-significant level of Exch. Ca in termite mound in relation to adjacent soil which is consistent with this study. Brossard et al. (2007) obtained higher Exch. Ca in their study which was assumed to be caused by transportation of mineral soil from deep sub soils. The Exch. Ca is rated as medium for Did Yabello and very high for Boku Luboma site according to Jones (2003) ratings.

Exchangeable magnesium (Exch. Mg) content of Did Yabello external termite mound was significantly higher than internal termite mound and control soil. Exch. Mg content of control soil was significantly lower at Boku Luboma site ($p<0.05$) (Table 4) when compared with internal and external mound which is in agreement with study conducted by Jouquet et al. (2004). The differences in trends of the exchangeable cation could be attributed to soil types.

Control soil at Did Yabello had significantly lower CEC content than internal and external termite mound but higher at Boku Luboma site. The difference in CEC between control soil and termite mound could be due to change in clay type as termites work on soil which is explained by different researchers (Mujinya et al., 2013; Jouquet et al., 2015). Termites either decrease or increase clay's chemically active surface area which affect the soil's CEC content. Higher CEC for control soil is also obtained by Jouquet et al. (2016). Termite mounds with high CEC can be used to improve low CEC soils which further support plant growth and act as nutrient storage media.

Conclusion and Recommendation

Termites are beneficial insect groups in natural ecosystems. They rework soils; modify spatial soil composition through relocation of soil separates during mound construction. They select, transport and manipulate soil particles in doing so they bring about change in soil physico-chemical properties. Termites produced soils that had more different soil texture and some nutrient contents than the surrounding soil. Termite mounds (internal and external mound) were enriched with clay soil in both sites in relation to the surrounding soil. The clay content in sandy and sandy loam soil can be improved by incorporating the termite mound materials into soil which in turn improves soil physico-chemical properties. Termite mound materials in both sites were enriched with Exch. K and Exch. Mg. The other soil properties studied did not show similar trend in both sites (Boku Luboma and Did Yabello). Termite mound (internal mound) of Did Yabello site was enriched with total N but that of Boku Luboma was non-significant in relation to adjacent soil. The SOM content of external termite mound at Did Yabello decreased in relation to internal mound and control. Cation exchange capacity of soil was improved by termite activity at Did Yabello site, in contradiction to this CEC of Boku Luboma was reduced.

Termite species have effect on the physico-chemical properties of soil; therefore, species of termite in Borana rangelands need to be identified. This helps to design proper termite management techniques without ecological damages so that one can make use of ecological services provided by termites. There is no trend of termite mound use as soil amendment in Borana. In the future, amount of termite mound materials that should be incorporated into soil to increase crop yield and socio-economic factors that influence the use of termite materials as soil amendment should be studied in details.

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The Impacts of Mound-building Termites on Micro-nutrients and Soil Hydraulic Properties in Parts of Borana Lowland, South Oromia, Ethiopia

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Abstract

The condition of soil is unfavorable when its physical, chemical and biological features have negative impact on environment. Knowledge on soil hydraulic properties and micro-nutrient content for soils affected by termite mound and adjacent unaffected soil would give a clue on the impact of mound building termite for plant establishment. The objective of the current study was to determine the impact of termite mounds on micronutrients and soil hydraulic properties of Borana rangelands. Infiltration rate for adjacent soil profile 106.47mm/hr (Moderately rapid) and for termite mound profile 142.13mm/hr (rapid) infiltration rate were observed while the packing density up to 1.80t m^{-3} (high) for external part of termite mound which was greater than 1.36t m^{-3}(low) for adjacent soil profile. There was also higher concentration of manganese (Mn) and zinc (Zn) contents on external part of termite mound for fine textured soil and no difference in copper (Cu) and Iron (Fe) contents between termite mound material and adjacent soil. Generally, termite mounds had positive impact on soil hydraulic properties of soil in order to support plant establishments.

Key words: Termite mound, hydraulic properties, micronutrients

Introduction

In Borana lowlands, both mound building and moundless termites are abundant and widely distributed (Barnett *et al.,* 1987). Termite mound materials can be differentiated from the adjacent soil by its different physico-chemical properties that impact some soil processes. Usually high concentration of organic matter and mineral nutrients are found in termite mound than in the surrounding soils. Consequently, subsistence farmers in Africa commonly spread termite mound materials in their fields to improve soil conditions and increase plant nutrient availability (Watson, 1997). They also promote nutrient availability, nutrient cycling and soil physical properties (Anderson, 1994; Lavelle *et al*., 1994).

However, Amsalu (2009) reviewed that research on termites in Ethiopia has been concentrated only on the pest management aspects. He studied the effects of mound-building termites on macronutrients and some physical properties and found that termite biogenic structures are rich in macronutrients specifically in available phosphorus and basic cations. In spite of relatively rich in macronutrients, highly visible in many of the Borana rangelands mounds are bare of vegetation, creating a marked visual patchiness to the landscape (personal observation). What properties of the mounds at our study site constrain vegetation establishment instead? Only a handful of studies exist describing macronutrients properties of termite mounds in Yabello and Dire Districts of Borana Zone (Amsalu, 2009). No studies on the hydraulic and micronutrients properties of termite mounds were found for the zone. With this understanding, the objective of the current study was to determine the impact of termite mounds on micronutrients and soil hydraulic properties of Borana rangelands.

Materials and Methods

Description of the study area

The study was conducted in Borana Zone of South Oromia, 577km away from Finfinne/Addis Ababa. Borana Zone has thirteen districts, with its capital Yabello town. The Borana rangelands are characterized by arid and semi-arid climate, with pockets of sub-humid land. The vegetation is patchy, due to widely varying soils, temporally and spatially variable rainfalls and differences in the land use history (Gemedo, 2004). The plateau is divided into four major seasons: *Ganna* (March-May), the long rainy season; *Adoolessa* (June-August), the cool dry season; *Hagayya* (September-November), the short rainy season; and *Bona* (December-February) (Coppock, 1994). The average annual rainfall ranges between 350 and 900mm, with a considerable inter-annual variability of 21 to 68% (Kamara, 2001). Rainfall is bimodal, 60% of the rainfall occurs between March and May (main rainy season) followed by a minor peak between September and November (short rainy season) (Coppock, 1994).

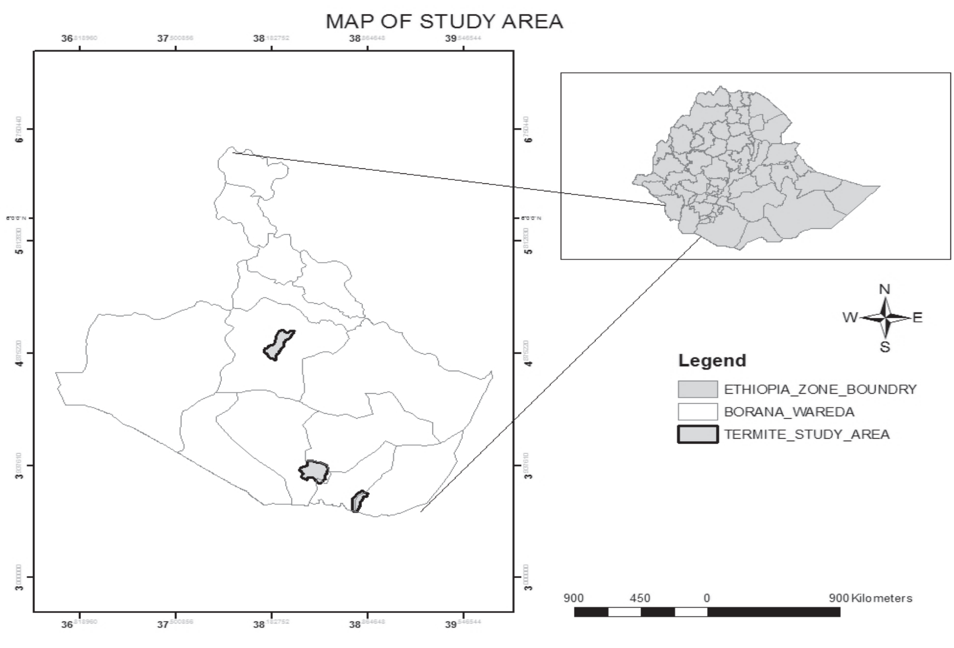


Figure 1. Study area map

Site selection, sampling of soils and mound materials

The study was conducted in two districts of Borana Zone. Specific districts and sites were selected considering the widespread of termite mounds and agricultural expansion. In each location, replications of three termite mounds were purposively selected on a uniform slope. To test whether high concentration of nutrients are found where new building materials are deposited such as on the top of the mounds and termite mound materials has been collected from the top and bottom parts of mounds. Samples were collected after scratching and removing the outer surface of mound materials.

Besides, in order to evaluate micronutrients composition of termite mounds in relation to the surrounding soils, a total of six soil profiles were sampled for this study. The profiles have been opened in a relatively unaffected area by termite mound at reasonable distance from mounds and considered to be the reference soils without significant termite activity not mean necessarily that termite activity never occurred in it. Termite mound and its corresponding soil profile were located on comparative slope gradients in order to avoid further differences that can be introduced due to topographic effects. Under this condition, any difference in soil micronutrients properties between termite mound materials and adjacent soil profile can be attributed to the effects of mound-building termites.

Before collecting soil samples, all soil profiles were described in accordance with the FAO (2006) guidelines for soil profile description. In all cases depth of sampling and number of sample per profile/pit were depended on soil depth and their horizon formations. For bulk density determination, mound materials and adjacent soil profile samples were collected using core sampler.

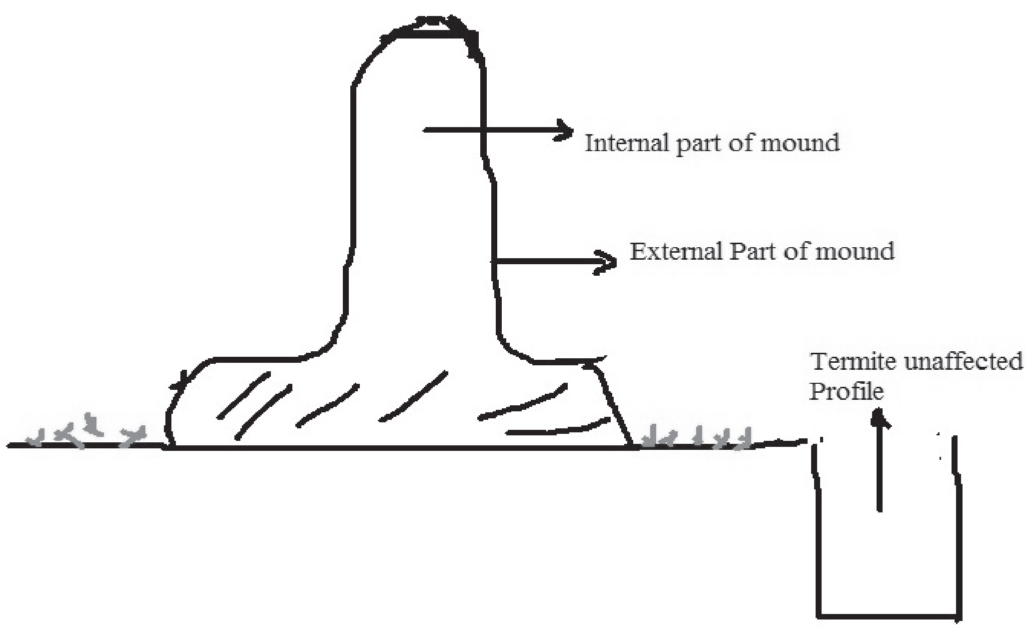


Figure 2. Sketch of sampling protocol from termite mound, termite unmodified soil profile

Physico-chemical analysis of soils and mound materials

The soil samples were air dried and ground, mixed well and passed through 2mm sieve for analysis. Parameters were analyzed following standard procedures as described in MoNRDEP (1990) at J.J soil laboratory and Holeta Agricultural Research Center soil laboratory. Soil compaction was measured using bulk density. Available micronutrients (Fe, Mn, Zn, and Cu) were extracted with DTPA as described by Lindsay (1979). Infiltration rate was determined in the field using ring infiltrometer. R-commander statistical package software version 2.15.5 was used to analyze the data.

Soil hydraulic property

The condition of soil is unfavorable when its physical, chemical and biological features have negative impact on environment. Information on soil hydraulic properties is very crucial in understanding plant-water relationship in the soil. Several hydraulic parameters were used under different circumstances for water management activities. Different hydraulic properties were more commonly selected than the others depending on difference on application of water management or water movement in soil. Soil hydraulic properties can be obtained directly from laboratory or field measurement.

Selection of soil hydraulic properties

Soils under termite mound and adjacent soil profile were sampled to determine critical soil hydraulic properties which were selected for measurement based on environmental soil condition assessment criteria under this activity. Soil infiltration rate indicates the movement of water into and through the soil profile; and soil compaction which is a mechanical stress of soil destroying the soil structure, reducing or eliminating its permeability to water, heat and air.

Infiltration rate

Infiltration is the downward entry of water into the soil. Infiltration rate is the velocity at which water enters to the soil, i.e., the volume of water passing through a unit cross sectional area per unit time. In relation to soil function, infiltration is the pointer of soil`s ability to allow water movement through and into soil profile such as storage, plant growth and habitat as function of soil. Infiltration rate is affected by inherent properties of soil such as soil texture (percentage of sand, silt and clay) and clay mineralogy as well as the dynamic properties like reflection of climate, landscape position, management practice and initial water content of soil affect the additional intake of water in it (USDA NRCS, 2008).

Cumulative infiltration is the total amount of water that enters the soil in a given time. Cumulative infiltration is important parameter in evaluating the infiltration characteristics of the soil. The relationship between the cumulative infiltration and elapsed time for design purpose can be expressed as the following equation Panda (2007).

$$Y = at^n \quad \text{(1.1)}$$

$$Y = at^n + b \text{ When } t \neq 0 \quad \text{(1.2)}$$

Where, Y = cumulative infiltration in time t, (cm)

t = elapsed time or infiltration opportunity time, (min) and a, b, n are characteristics constant (range between 0 and 1)

The infiltration rate can be obtained by differentiating the equation as

Dy/dt =ant^{n-1} ……………………………………………. (1.3)

A ring infiltrometer of 30cm diameter was used to measure final infiltration rate. To protect the disturbance of soil surface and soil structure the ring infiltrometer was inserted in the depth of about 10cm. The ring was filled with water at the depth of about 12-16cm water level and manually measured for 150min using T-ruler in both termite mound and adjacent soil. As different soil has different infiltration rate it is important to classify infiltration rate into different classes (Panda, 2007).

Table 1. Classification of infiltration rates

Class	Rate (cm/hr)
Very rapid	>25.4
Rapid	12.7-25.4
Moderately rapid	6.3-12.7
Moderate	2.0-6.3
Moderately slow	0.5-2.0
Slow	0.1-0.5
Very slow	<0.1

Soil compaction

Soil compaction is generally defined as the process by which a mass of soil consisting of solid particles, air, and water is reduced in volume by mechanical means thereby increasing dry density or bulk density (Shroff and Shah, 2003). As bulk density increases, there is frequently a corresponding increase in soil mechanical strength, resulting from the closer packing orders of the soil particles.

Primarily, compaction occurs under natural condition in soils with little organic and inorganic colloid contents as well as compaction may also be caused by loss of water content, dry out, by precipitation or long term stagnation of water over the surface of soil.

In the process of compaction air is forced out of the soil`s three-phase medium, while the soil volume is reduced. Compaction is a mechanical stress destroying soil structures, reducing or eliminating the penetration of water, heat and air to the soil (Birkås, 2008). This stress of soil caused by direct or indirect consequences of damage type to the soil, is a risk factor for both environmental and crop production.

Bulk density is an indicator of soil compaction and soil health which influence key soil processes and productivity by affecting infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity. Soil bulk density (Db) is the ratio of mass of dry solids to bulk volume of soil. An increase in Db indicates that movement of air and water within the soil has been reduced, and that the soil may be less favorable for plant growth or be more likely to erode (Miller et al., 2001).

Soil bulk density affected by inherent soil properties such as soil texture which cannot be changed and also it is dependent on soil organic matter, the density of soil mineral (sand, silt, and clay) and their packing arrangement.

The effect of compaction in relation to bulk density, texture and pore space can be suggested by growth-limiting bulk density (GLBD).

According to Birkås (2008), soil is in unfavorable condition if its degree of compactness equals at least 95%, its bulk density equals 1.60-1.70g cm^{-3} and its pore volume drops below 40%.

By integrating the bulk density, structure, organic matter content of mineral fraction and clay content (RANST et al., 1995), to find packing density in order to provide a single measure of soil compactness which is defined as

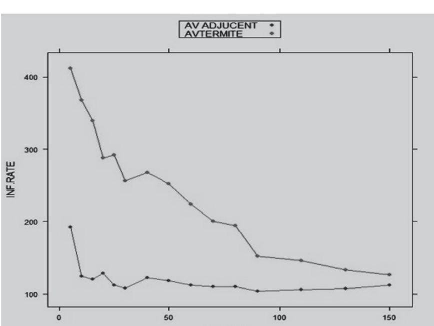
$$PD = Db + 0.009C \text{ --- } (1.4)$$

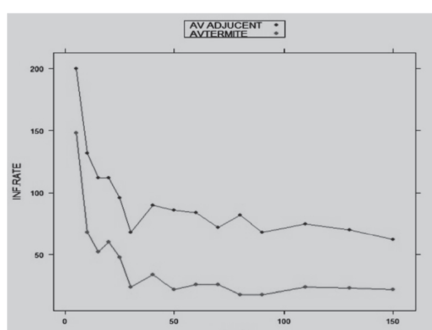
Where, PD = packing density in t m^{-3}; Db = actual bulk density in t m^{-3}; C is clay content (%). There are three classes of packing density recognized; low: <1.40t m^{-3}, medium 1.40-1.75t m^{-3}, and high: > 1.75t m^{-3}. The packing density can be determined in situation where the actual bulk density is known by incorporating the clay% which is a useful parameter for spatial interpretations that require a measure of the compacted state of soil.

Results and Discussion

Infiltration rate

The infiltration rate is given for Tilo Maddo and Boku Luboma sites in respect to termite mound and adjacent soil profiles respectively (Figure 3a and b) while Figure 4 shows the combined average infiltration curves of both sites in order to evaluate the total difference of infiltration rate of termite profile vs adjacent soil profile. The infiltration curve for termite profile had high starting value and gradually decreased while for adjacent soil profile the curve had high initial values with gradually decrease value until it attained a constant value.





(a) **(b)**

Figure 3. Basic infiltration rate for Tilo Maddo site (a) and Boku Luboma site (b)

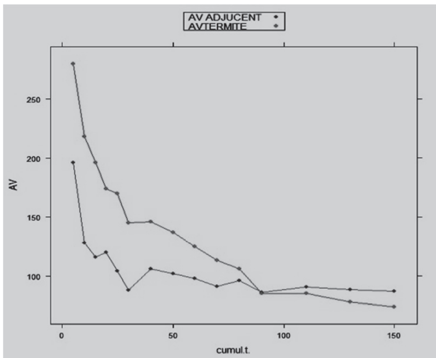


Figure 4. Average basic intake rate for Tilo Maddo and Boku Luboma sites

Generally, using the R-commander statistical package independent sample t-test (Welch Two Sample t-test), there was significant difference between the two means of infiltration rate at the bottom of termite mound and adjacent soil profiles at $p<0.05$ level. The p-value = 0.044 with the mean for adjacent soil profile 106.47mm/hr (Moderately rapid) and at bottom of termite mound 142.13mm/hr (rapid) infiltration rate have been observed. Due to the heterogeneity of soil the highest infiltration rate 412mm/hr (very rapid) in Tilo maddo site and 18mm/hr (Moderately slow) for Boku Luboma sites were recorded. The activities of termite created tunnels and galleries at the beneath of termite mound could be the reason for higher infiltration than that of adjacent soil profile (Mando et al., 1996). From model that quantifies the relationship between overland flow and macro pore infiltration in vadose zone which was developed by Ruan and Illangasekare (1998), concluded infiltration is highly sensitive to macro porosity, or the number of macro pores, suggesting that increased macro porosity caused by termites will increase infiltration. Léonard and Rajot (2001) also indicated that the increase of infiltration as runoff interception process, whereby an increased number of macro pores intercepting runoff which resulted from termite activities led to increase in infiltration. The influence of different termite species activity and its variation over time and space for particular site is important to consider as different species have different surface macro pores diameter which correspond to infiltration (Léonard and Rajot, 2001).

Compaction rate

For crop establishment, the correlations of soil bulk density, texture and pore space are important indicators of soil compaction which can be expressed by growth-limiting bulk density (GLBD). Sandy soils have large continuous pores than clay soils which have small pores and water movement in such soils is slow.

Although different species of termites do not have specific particle size requirements for the construction of their mound, most termites preferentially select clay and silt particles (Lee and Wood, 1971). Investigation of soil under termite mounds led to the conclusion that in general termites have the potential to modify soil morphology up to 6.1m below mounds not including potentially greater depths away from these mounds (Watson, 1962).

Table 2. Textural class of soil samples from external part of mound and adjacent soil profile

Boku luboma site					Did-Yabello site				
Field No	**%clay**	**%silt**	**%sand**	**Textural class**	**Field no**	**%clay**	**%silt**	**%sand**	**Textural class**
MBM1Ext	40	30	30	clay loam	DYM1Exit	18.75	21.25	60	sandy loam
MBM2Exit	41.25	31.25	27.5	clay	DYM2Exit	28.75	1.25	70	sandy clay loam
MBM2Exit	40	27.5	32.5	Clay	DYM3Exit	21.25	12.5	66.25	sandy clay loam
MBP1A	20	32.5	47.5	loam	DYP1A	15	7.5	77.5	sandy loam
MBP2A	21.25	31.25	47.5	loam	DYP2A	11.25	6.25	82.5	loamy sand
MBP3A	23.75	31.25	45	loam	DYP3A	13.75	6.25	80	sandy loam

As cohesive soils have lower bulk density than non-cohesive soil, soil samples taken from Did-Yabello site exhibited higher dry density than Bokuluboma site which is the result of inherited soil properties. However, the textural class between adjacent soil profile (Horizon A) and mound external part was significantly different. This is the result of soil used to built termite mound are finer textured than the top soil profile horizon of adjacent soil.

Table 3. Bulk density

Parameter	Site	**Treatment**	**Mean**	**p-value**	**Significance ($p<0.05$)**
Bulk Density	Did-Yabello	Adjacent Soil Profile A Horizon	1.54 g/cm^3	0.547	Ns
		Termite External Mound Part	1.59 g/cm^3		
Bulk Density	Bokuluboma	Adjacent Soil Profile A Horizon	1.05 g/cm^3	0.24	Ns
		Termite External Mound Part	1.17 g/cm^3		
Bulk Density	Did-Yabello	Total Termite Mound Profile	1.44 g/cm^3	0.034	S
		Adjacent Soil Profile	1.54 g/cm^3		
Bulk Density	Bokuluboma	Total Termite Mound Profile	1.02 g/cm^3	0.233	Ns
		Adjacent Soil Profile	1.08 g/cm^3		

Packing density (PD) of termite mound external part was not significantly different with A horizon of adjacent soil profile for Did-Yabello site while the packing density for Bokuluboma site was significantly different at p<0.05l with p-value = 0.042. This difference could arise from the clay content of termite mound that created by termite selection of fine textured soil in their construction (Table 2). The external part of the mound was more compacted than the top horizon of adjacent soil profile according to the range given by RANST et al., (1995), the mean for Did yabello site 1.66 t m^{-3} (medium) and 1.80 t m^{-3} (high) packing density even if there was no difference statistically. However, for the fine textured Bokuluboma site, the mean of PD for external part of the mound 1.540 t m^{-3} (medium range) and for adjacent soil profile 1.246 t m^{-3} (low) and it had significant difference. Those results indicated that the external part of termite mound was more compacted than that of normal adjacent soil.

Micro-nutrients

ANOVA-Tukey Contrasts result of multiple comparisons of mean showed that there was no significant differences among means of internal part of termite mound, external part of termite mound and adjacent top layer of profile (A horizon) in copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) contents at $p<0.05$ for Did-Yabello site. From Bartlett test of homogeneity of variances, results indicated that there was significant difference in soil bulk density among internal part of termite mound, external part of termite mound and adjacent top layer of profile (A horizon) at $p<0.05$ for this site.

For Bokuluboma site, using one-way ANOVA-Tukey Contrasts of multiple comparisons of mean, copper (Cu) and iron(Fe) contents were not significantly different at $p<0.05$, while the means of manganese (Mn) and zinc (Zn) contents showed that there was significant difference at p<0.05l with Pr(>F)- value = 0.0246, Pr(>F)- value = 0.0221, respectively for between internal part of termite mound, external part of termite mound and adjacent top layer of profile (A horizon). By using Bartlett test of homogeneity of variances, there was no significant variation in SD for manganese (Mn) and zinc (Zn) content while for copper (Cu) and iron(Fe) contents there were significant variation in SD with p-value = 1.599e-07, p-value = 0.005858 respectively at $p<0.05$ for Bokuluboma site.

Conclusion and Recommendation

The information on soil hydraulic properties is crucial in understanding the soil-plant-water relationship. For infiltration rate due to biological activities of termite, there was more rapid rate than the adjacent termite unaffected soil profile which was moderately rapid. This indicates that as a result of preferential flow of water in fine textured soil from which the termite mound is built may offer higher moisture retention capacity than that of adjacent soil for the establishment of plants.

In relation to soil compaction rate, the external termite mound is less workable than that of termite unaffected adjacent soil profile due to its high packing density even if the rate of compactness depends on soil inherent properties and selection of soil by termite to build the mound. While in comparison of total profile depth under termite mound and adjacent termite unaffected soil, there was no difference in compactness. Generally, the termite mound had positive impact on soil hydraulic properties of soil in order to support plant establishments.

Micro-nutrients also depend on heterogeneity nature of soils. In soils with sandy to medium textured soils, there was no change in micro-nutrient contents among internal part of termite mound, external part of termite mound and adjacent top layer of profile (A horizon) for copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) availability at Did-Yabello site. For fine textured soil (Bokuluboma site), copper (Cu) and iron (Fe) contents showed no difference, while manganese (Mn) and zinc (Zn) contents were higher in external part than that of internal and termite unaffected top horizon.

It is important that identifying termite species in order to investigate further ecological function of termite that are abundant to the study area. Additionally it is important to study best agronomic management practices to use the positive impact of termite mound hydraulic properties.

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Irrigation and Water Harvesting Research

Evaluation and Demonstration of Rooftop Water Harvesting Combined with Low-cost Drip Irrigation System in Moisture Deficit Areas of Daro Labu District, West Hararghe Zone, East Oromia, Ethiopia

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Abstract
The efficient use of water is a key to crop production in semi-arid and arid areas of Ethiopia. For smallholder farmers, low-cost drip irrigation systems provide means of maximizing returns on their cropland by increasing the agricultural productivity per unit of land; and through increasing cropping intensity during the dry season. The experiment was conducted in 2011/12- 2013/14 cropping seasons in moisture deficit areas of Sororo PAs in Daro Labu District, West Hararghe Zone. The objectives of the study was to evaluate and demonstrate rooftop water harvesting technologies in combination with low-cost drip irrigation in moisture deficit areas and to increase productivity of farmers' using harvested water with water saving low-cost drip irrigation technologies. It also aimed to improve farmers' awareness, knowledge and skill on utilizing water harvesting and water saving technologies. One farmer, who actively participated and had house with corrugated iron sheet roof was selected. On the roof, side collectors and gutters were tied and appropriate site was selected to place plastic tank for storage. The collected water during rainy season was stored in the two plastic tankers (total 8000 liters) for using during off season for high value crop tomato (Cochoro variety) during three years of practice. The plastic tank and gutters were purchased from nearby suppliers and low cost drip set which operates with gravity installed at 1m height above the ground to supply water for the crop was obtained from Daro Labu District agriculture office. The plot area on which tomato was cultivated varied depending on rainfall amount and variability during the three years practice. The marketable yield obtained varied from 5.24 to 39.06 t/ha with average value of 25.76 t/ha and corresponding gross income varied from 78, 600 to 313, 405 Birr per hectare. Further, farmers' field day was organized to assess their feeling towards the technology and they rated it was good and important to be utilized in moisture deficit areas both for supplementary and complementary irrigation with careful planning for wise use of harvested water for increased production.

Key words*:* low-cost, drip irrigation, productivity, water use efficiency

Introduction

It is well known that the pressure on land is increasing continuously due to population growth, causing more and more use of marginal lands for agriculture. Agriculture is only possible when there is availability of water. Water harvesting during rainy seasons can increase water availability. Currently, the terminology 'water harvesting' is used to indicate the collection of any kind of water for domestic, agricultural, or other purposes.

Water is harvested and directed either directly onto cropped fields, or into various types of natural or man-made storage structures. A large variety of storage technologies are used in Eastern and Southern Africa and many of these are described and illustrated in Ngigi (2003), Mati (2006), and Aulachew *et* *al.* (2006). For water harvesting structures to be successful, the local communities must participate in the planning and construction of the structures and accept responsibility for their operation and management. A major reason for the low and inconsistent rate of growth in agricultural production is as a result of high uncertainty and unpredictable rainfall, combined with low soil fertility (FAO, 2003). Even in years of 'average' rainfall, a shortfall during critical periods of crop growth often leads to widespread crop failure. Therefore, water storage is absolutely crucial for stabilizing and increasing crop yields (FAO, 2003). The harvested water can be stored in many ways: large and small dams, aquifers, on-farm storage tanks, and in the root zone of crops itself.

To increase agricultural production and improve living standards in dry lands of Ethiopia, greater priority must be given to enhancing efficiency of water collection and utilization (Hillel, 2001; Sandra, *et al.*, 2001; Hune and Paul, 2002). Using drip irrigation, thus, can achieve 90-95% efficiency by reducing evaporation and deep percolation (Bresler, 1990; Brouwer, 1990; Baker, *et al.*, 1993). In addition to this desirable feature of drip irrigation, uniform distribution of water is possible and it is one of the most important parameters in design, management and adoption of the system. Ideally, well designed drip system applies nearly equal amount of water to each plant, meets its water requirement and is economically feasible (Clark, 1990; Fekadu and Teshome, 1997; Mizyed and Kruse, 2008). Thus, it is often promoted as a technology that can conserve water, increase crop production, and improve crop quality (Frederick and Troeh, 1980; Jensen, 1983; Michael, 1997; Hacham, 2001; Isaya, 2001).

As amount and availability of rainwater in time in a given area is the prime factor that largely determines the performance of rain-fed agriculture, its improved efficiency can substantially augment the countries food security endeavors (Michael & Teklu, 2006). In line with with this, demonstration of water harvesting from rootop was initiated to tackle the problem of moisture deficit in the district which is resulted from low rainfall amount, high rainfall variability in space and time and decreasing reliability from time to time.

Harvesting water from roof-top catchment and then utilizing the collected water for irrigation combining with water saving irrigation systems like low-cost family drip sets are among the primary options to cope with low moisture stress existing in midlands and lowlands of West Hararghe Zone. This is because development of other water resources like ground water development, diversions from rivers, construction of large dams will not be easy or costly to develop in these areas. In addition, the housing condition of population of the region, which allows collecting of runoff from corrugated iron sheet roof and the current farmers' practice in tanker and hand-dug pond, is the potential. Therefore, this study was carried out to evaluate and demonstrate rooftop water harvesting technologies with low-cost drip irrigation for increased productivity and to improve farmers' level of awareness, knowledge and skill on using the technologies in the district in dry seasons.

Materials and Method

Description of the study area

The field experiment was conducted in Daro Labu District of West Hararghe Zone, Oromia. It is located at distance of 434 km to the east of Finfinne/Addis Ababa and 115 km from Chiro zonal capital to the south on a gravel road that connects to Arsi and Bale zones. Its latitudinal and longitudinal positions are 40^{0}19.114 North and 08^{0}35.589 East, respectively. The area has bimodal type of rainfall distribution with annual rainfall ranging from 900-1300mm (average annual rainfall of 1094mm) and ambient temperature of the district varies from 14 to 26^{o}C with average of 20^{o}C (Mechara metrological station 2009-2014).

The nature of rainfall is very erratic and unpredictable causing tremendous erosion. The altitude range for the district is 1350 to 2450m.a.s.l with area coverage of 434,280ha and the predominant production system is mixed crop-livestock production with peculiar sub-systems. The crops grown in the area includes from small cereals like teff to tree and fruit crops like coffee, mango and avocado. The major soil type of the area is Nitisol with texture of sandy loam clay which is reddish in color (Report on farming system of Daro Labu and Boke districts, Mechara Agricultural Research Center unpublished).

Experimental design

The evaluation and demonstration of rooftop water harvesting for tomato was made at Sororo PA of Daro Labu District on-farm, for three years (2011/12-2013/14) on one farmer as a demonstration, who actively participated and had house with corrugated iron sheet roof. On the roof, side collectors and gutters were tied and appropriate site was selected to place plastic tank storage. The collected water during rainy season was stored in the two tankers (8000 liters total) for using during off-season for high value crop, tomato (Cochoro variety) during three years practice. The plastic tank and gutters were purchased from nearby suppliers and low-cost drip set which operates with gravity installed at 1m height above the ground using barrel to supply water for tomato was obtained from Daro Labu District agriculture office. The land on which tomato seedlings transplanted was prepared and the study plots used where 16m^2, 72m^2 and 42 m^2 respectively during three years of practice (Table 1). Data on fruit yield, total selling price, water productivity and farmers' perception towards the technologies were recorded. Mini-field day was arranged during the second year of practice which involved 18 participants (5 female & 10 male farmers with 3 DAs) (Figure 1). Tomato production from rooftop water harvesting is showed in Figure 2.

Figure 1. While installing drip lines and discussion with farmers to assess their perception towards the technologies

Figure 2. Rooftop water harvesting and use of drip irrigation for tomato production on farmer's field, Sororo kebele, Daro Lab District, West Hararghe Zone

Results and Discussion

Table 1. Summarized data of evaluation and demonstration of rooftop water harvesting with drip irrigation system for tomato production in Daro Labu District

Year	Variety	Planting area (m^2)	Total amount of water (m^3/ha)	Yield (t/ha)	Water use efficiency (kg/m^3)	Gross Income (Birr/ha)
2011/12	Cochoro	4mx4m	5000	39.06	7.82	312,500
2012/13	"	7mx8m	1111	32.99	29.70	313,405
2013/14	"	6mx7m	1904.8	5.24	2.75	78,600
Average			**2671.9**	**25.76**	**13.4**	**234,835**

As indicated in Table 1, the yield was better during the first (39.06 t ha^{-1}) & second (32.99 t ha^{-1}) years due to favorable climate, but it was too much decreased in the third year (5.24 t ha^{-1}) which was the result of harsh climatic condition that favored tomato disease (*Fusarium* wilt). Gross income gained from sell of produced tomato using low-cost drip irrigation system also varied with the yield and was from 78, 600 to 312, 500 Birr/ha. The use of highest water level (5,000 m^3) relatively gave maximum fruit yield; but, the highest water use efficiency (WUE) was recorded at the lowest water amount used (1,111 m^3). The least WUE (2.75 kg/m^3) was recorded during the third year due to the lowest economical yield gained. The overall mean yield of tomato gained and WUE during three cropping seasons were 25.76 t/ha and 13.4 kg/m^3 respectively, with corresponding average gross income of 234,835 Birr (Table 1). As compared to average yield of tomato which varied from 6.5-24 t ha^{-1} (Gemachis *et al.,* 2012) in Ethiopia, the yield obtained from low-cost drip irrigation system by using harvested water from rooftop where rainfall amount was found not sufficient to meet the crop requirement was promising. The increase in fruit yield is justified by the more efficient drip irrigation system where the limited amount of water is supplied effectively to root zone.

Studies revealed that, drip irrigation increased the yield of tomato and water use efficiency (WUE) by 19 and 20% (Fekadu and Teshome, 1997) as compared to furrow irrigation; and others found it significantly reduced irrigation water requirement of a crop as it supply water only to root zone (Bogle, 1986; Raina *et al*., 1998). It was also reported that use of harvested water from rooftop for irrigating vegetables by low-cost drip irrigation systems like bucket/drum kits increased farmers gross income in Kenya that they gained over 18,000 USD/ha (Ngigi, no date).

Conclusion and Recommendation

Water saving irrigation technologies need to be tested under local environment and particular agricultural production systems. Drip irrigation was found increased fruit yield of tomato and improved WUE due to consumption of less water. Generally, practicing rain water harvesting and using the collected water as supplementary or as complementary irrigation for double cropping is the better way of increasing agricultural crop production in moisture deficit areas of West Hararghe Zone as low rainfall amount, high variability in space and time and decrease in reliability is the major impediment to the productivity of rural poor in these areas.

In this study, water harvesting technology combined with water saving drip irrigation system was found effective in moisture deficit areas like Daro Labu District and similar agro ecologies; especially for producing high value crops (onion, tomato, etc) which have high return per unit of land and per drop of water during off season or to supplement rain-fed crops. But, it needs careful planning for wise use of harvested water, i.e., increasing water use efficiency to ensure increased production.

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Evaluation of Low-cost Drip Irrigation Technology for Tomato Production at Adami Tulu Center, Mid-Rift Valley of Oromia, Ethiopia

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Abstract

Evaluation of low-cost drip irrigation technology was carried out under condition of Adami Tulu Agricultural Research Center, on-station to compare its performance with furrow irrigation systems for increased tomato productions. Four improved tomato verities were used. The trials were replicated four times in randomized complete block design. There was difference in some parameters of tomato under the two irrigation systems. Some tomato varieties performed well under drip while others well under furrow irrigation. But, the overall effect showed that drip irrigation system performed relatively better than furrow irrigation system. There was non-significant difference in tomato yield between the irrigation systems, 44.09 t/ha for drip as compared to 43.38 t/ha in furrow irrigation. However, drip irrigation used less water than furrow irrigation system, and gave much higher water use efficiencies. It was concluded that low cost drip systems achieved water saving of more than 25.9% as compared to surface irrigation systems. In this study, Fetan and Cochoro performed significantly higher yield than both Chali and Melkashola under drip irrigation system. This technology requires further evaluation under farmers' conditions.

Key words: surface irrigation; low cost drip irrigation, tomato and water use efficiencies

Introduction

Huge proportion of the population (more than 85%) in Ethiopia is engaged in less productive agricultural activities. This low productive rain-fed small-holder agriculture is the main source of food supply in the country. With this regard, unreliable distribution of rainfall represents critical constraint to enough food production and is the major cause for food insecurity in the country. Under these conditions, irrigation is necessary to sustain food production. Irrigation implies the application of suitable water to crops in right amount and time with the right methods. Irrigation reduces the risk of expensive inputs being wasted by crop failure resulting from moisture stress (FAO, 1997). Therefore, effort to improving water productivity, careful application to promote growth and yield and enhance the economic efficiency of crop production is vital. Selection of the appropriate irrigation method can increase water use efficiency and reduce the demand on fresh water (Gawad *et al*., 2005).

Reports showed, that low cost drip irrigation (LCDI) is in use in over 80 countries worldwide, and the demand is growing fast. In Africa, it is used in Kenya, Tanzania, Malawi, Zambia and Uganda (Isaya, 2001). In India, resource-poor farmers have used LCDI systems with reported success (Isaya, 2001). Micro-irrigation systems have been found to be superior in terms of water and nutrient saving and higher productivity of many crops (Fekuda and Teshome, 1998). Micro-irrigation system was found to result in 30 to 70% water savings in various orchard crops and vegetables along with 10 to 60% increases in yield as compared to conventional methods of irrigation (Baye, 2011). It is wise to make efficient use of water and bring more area under irrigation through limited water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practices (Zaman *et al*., 2001).

Drip irrigation has superiority over traditional irrigation methods in terms of yield and economics (Pawar *et al*., 2002). Conventional drip irrigation systems typically cost US$ 5,000 -10,000 per hectare, or much more, installed in East Africa (Isaya, 2001). Experiences from Arba Minch University showed that single low-cost drip irrigation system of 60-70 birr initial cost can supply family with fresh vegetable for home consumption from 7.5m^2 area of land (Fassil *et al*., 2004). Reports from other country showed coupling of LCDI technologies with water harvesting technologies allows better control and management of limited water resources and resulted in much higher returns to farmers.

Small-scale LCDI systems that can be easily afforded and managed by poor farmers contribute significantly to ensuring food self-sufficiency at household level. Thus alternative methods such as low-cost smallholder irrigation technologies are vital and attractive. The present study was, therefore, conducted to evaluate low-cost drip irrigation technology for tomato production under Adami Tulu condition, on-station.

Material and Methods

Description of the study area

The experiment was conducted at the experimental site of Adami Tulu Agricultural Research Centre. It lies at 7° 9'N latitude and 38° 7'E longitude; and altitude of about 1650masl. The rainfall is bimodal and unevenly distributed with average annual rainfall of 760 mm. The minor and main rainfall periods are from February to April and July to September, respectively. The soil is loam with sand, silt and clay in proportion of 44, 34 and 22%, respectively and pH of the soil is 7.88 (Teshome *et al*., 2012).

Materials used

Material used for the experiment was bucket with the temporary water storage (water source) near to the plot to fill the bucket. The water was lifted manually by labor to fill the bucket. Woods for pillars of bucket at 0.8 heights from the point where the blind hose was situated to maintain the 92.4% distribution uniformity were used. The blind hose (16&4.5mm diameter) with 0.8-1mm diameter micro tube, plastic bottles, mesh filter (locally known as 'shash') were also used. Partial flume was used for furrow irrigation system water measurement. Tomato which is most economical crops in the area was used for the experiment.

Experimental methodology

The study was conducted during off season (2013/14 cropping season). The experiment had two factors, two irrigation types (micro tube drip and furrow irrigation) and four tomato varieties (Chali, Melkashola, Fetan and Cochoro) that were combined in factorial giving a total of eight treatments. The treatment was installed on well prepared fields of 360m^2 areas to grow tomato varieties. The seeds of selected released tomato varieties were sown on nursery bed. The seedlings were then transplanted on well prepared experimental plots. The recommended fertilizer rates, 200 kg ha^{-1} DAP and 100 kg ha^{-1} urea, were applied at time of sowing and two weeks after transplanting (Desalegne, 2002). Other agronomic and crop protection practices (weeding, watering and pesticides) were adopted uniformly as per recommendation for tomato production.

Depending on the recommended plant spacing, single lateral line was used for single row of tomato varieties. The spacing between lateral lines and emitters is 1m and 0.5m, respectively. In one bucket there were four mesh covered plastic bottle (filter) that attached with 4.5mm diameter blind hose to convey pure water into four laterals (Figure 1).

Figure 1. Low-cost bucket drip irrigation system mounted 0.8 m above the ground on a stand constructed from wood, January 2014

Water was delivered to the varieties through micro tubes/emitters in blind hose of 16mm diameter. Varieties were planted next to the holes, so that the soil around the plant was kept wet without wasting any water. Irrigation with low cost drip system was applied in shorter duration (daily or every other day) to maintain high level of soil moisture and met the crop water requirement which was lost between irrigation hence the interval of bucket filling depended on crop water requirement.

Water Productivity (WP)

Water productivity was determined by dividing beneficial fruit yield by total applied irrigation water and is expressed as follows (Ali *et al.,* 2007):

WP = BY/Wa, where BY is beneficial yield (kg ha^{-1}) and Wa is total irrigation applied water (m^3 ha^{-1}).

Data analysis

Irrigation method and tomato varieties were used as independent variables and parameters of tomato as dependent variables. The effects of irrigation system and variety on parameters of tomato were tested by two way analysis of variances. The parameters of tomato were subjected to analysis of variance using the general liner model procedure of the statistical analysis system (SAS, version 9.0). Where significant difference ($p<0.05$) due to irrigation system and variety for assessed parameter observed, mean separation for each parameter was made using least significant difference.

Results and Discussion

Results of the analysis of variance showed significant difference for most of the characters between the irrigation systems.

Yield and yield related parameters under drip irrigation

Statistical analysis showed significant difference for yield among tomato varieties. Significant differences in tomato single fruit weight were also observed among varieties under drip irrigation system at $p \leq 0.05$ (Table 1) that ranged from 61.35 (Melkashola) to 100.75gram (Fetan). This is in agreement with the finding of Muhamed *et al*. (2013) who reported a wide range of difference (6.18 - 74.91 gram) of tomato fruit weight. But, no significant variations among the varieties for fruit width and length were observed. Significantly higher yield (45.1 t/ha) was resulted from Cochoro while the lower (43.1t/ha) was fromr Melkashola (Table 1). Similarly, Regassa *et al*. (2012) reported that the yields of these varieties were between the range of 30-45 t/ha.

Growth traits under drip irrigation

Comparing the plant height under drip irrigation system for selected tomato varieties, a wide range of difference was observed (46.3 to 58.2cm). Similarly, Meseret *et al*. (2012) and Jiregna (2013) reported a wide range of differences in plant height of these tomato varieties; i.e., 40.2 to 107cm and from 57.74-68.04 cm, respectively. Melkashola was the tallest (60.2cm) while Fetan was the shortest (47.05cm). Cochoro and Chali were in between the two. Significant differences for number of branch were also observed among some varieties. It ranged 5.02-8.12 with highest number for Fetan and lower for Cochoro (Table 2). This is in agreement with Jiregna (2013) who reported a wide range of differences for number of branches per plant for these tomato varieties (4.72-9.3).

Table1. Tomato yield and other yield related parameters under drip irrigation method

Variety	Fruit weight (gr)	Fruit width (cm)	Fruit length (cm)	Fruit yield (t/ha)
Chali	81.25b	5.24a	5.26a	43.35b
Melka shola	61.35c	4.48a	5.77a	43.07b
Fetan	100.75a	4.90a	5.05a	44.87a
Cochoro	67.75c	5.2a	5.27a	45.07a
Mean	77.77	4.96	5.34	44.09
LSD 0.05	8.67	Ns	Ns	3.71
CV%	6.97	11.72	13.02	0.52

Significant differences for most yields were indicated with number of fruits and number of clusters per plant for Fetan and other varieties. Number of fruits per plant was ranging from 18 to 36. Many authors Jiregna (2013) and Chernet *et al*. (2013) found number of fruits per plant of tomato varieties in the range of 8.10-36.12 and 4-97, respectively. Lower number of fruits per plant (18.22) and cluster per plant (6.12) was recorded from Fetan, while the others gave more or less similar values of number of fruits and number of clustesr (Table 2). But comparing of yields among Fetan, Melkashola and Chali, significantly higher yield was obtained from Fetan than the other two. That might be due to higher single fruit weight recorded under Fetan than the other (Tables 1&2). Thus, in this study, Fetan and Cochoro performed significantly higher yield than both Chali and Melkashola under drip irrigation system.

Table 2. Tomato growth parameters under drip irrigation method

Variety	Plant height (cm)	No of Branch/plant	No fruit per plant	No of cluster per plant
Chali	51.90ab	7.45a	31.15a	8.15a
Welka shola	58.2a	5.80b	35.03a	8.37a
Fetan	46.30b	8.12a	18.22b	6.12b
Cochoro	52.45ab	5.02c	35.57a	8.61a
Mean	52.21	6.59	29.99	7.81
LSD 0.05	10.02	0.67	1.48	1.46
CV%	11.99	6.39	3.09	11.67

Yield and other parameters of tomato varieties under furrow irrigation

Results of the analysis of variance revealed significant difference for some of the characters among the tomato varieties. Significant variation in tomato single fruit weight was observed between Chali and other varieties under furrow irrigation system at $p \leq 0.05$. Like that of drip irrigation, significantly lower tomato single fruit weight (60gram) was recorded from Melkashola while the highest was recorded under Fetan (88.5gram). This is in agreement with the finding of Shushay *et al*., (2014) who reported a wide range of difference (40.4-86.4 gram).Comparing the yield which is the most important parameter, significantly different yield was observed among some varieties. Similar to drip system Cochoro perform better than the others (Table 3).

Table 3. Tomato yield and other yield related parameters under furrow irrigation method

Variety	Fruit weight (gr)	Fruit width (cm)	Fruit length (cm)	Fruit yield (t/ha)
Chali	76.5b	4.51a	5.35a	42.77c
Melka shola	60.00d	4.25a	5.35a	42.30c
Fetan	88.50a	4.64a	5.27a	43.70b
Cochoro	66.25c	4.10a	5.00a	44.75a
Mean	72.81	4.37	5.24	43.38
LSD 0.05	2.97	Ns	Ns	6.37
CV%	2.55	13.37	10.87	0.92

Growth traits of tomato varieties under furrow irrigation

A wide range of difference was observed for plant height (59.37 to 95.12cm) among varities which is in agreement with reports of other authors Meseret *et al*. (2012) (40.2 to 107cm) , Jiregna (2013) (57.74-68.04cm) and Chernet *et al.* (2013) (4-97cm*)*. Similar to drip system highest plant height was recorded for Melkashola compared to others. Melkashola was the tallest (95.5cm) while Fetan was the shortest (59.5cm) (Table 4). Even though no significant differences for number of branch and number of fruits per plant of varieties were observed, number of branches varied from 6.02-7.87 while number of fruits per plant varied between 21and 34.5 (Table 4). Jiregna (2013) reported number of branches ranged between 4.72 and 9.3, while number of fruits per plant ranged between 8.10 and 36.12. This was similar with that of drip irrigation systm in this study. A wide range of difference was observed for number of clusters per plant (5.91 to 15.05) which was in line with finding of Shushay *et al., (*2014).

Table 4. Tomato growth parameters under furrow irrigation

Variety	Plant height(cm)	No of branch/plant	No of fruit per plant	Number of cluster
Chali	75.06b	7.00a	32.25a	7.50c
Melka shola	95.12a	6.02a	33.03a	11.04b
Fetan	59.37c	7.87a	21.01a	5.91d
Cochoro	72.31b	6.25a	34.50a	15.05a
Mean	75.47	6.78	30.19	9.87
LSD 0.05	6.78	1.04	4.83	0.69
CV%	5.62	9.57	10.00	4.39

Comparison of yield and yield related parameters of tomato under two irrigation systems

There was observed difference in parameters of tomato under the two irrigation systems. Mean single fruit weight and fruit width were significantly affected by the two irrigation systems. Higher fruit weight and fruit width were recorded under drip than furrow irrigation system, but fruit length was not significantly differed (Table 5). Yield which is the most important parameters was not significantly affected under the two irrigation systems. Howevr, relatively higher mean yield of tomato (44.09t/ha) was obtained under drip irrigationcompared to furrow irrigation (43.38t/ha) (Table 5). In line with results of this study, Shah (2011) and Satyendra *et al. (*2013) reported that yield of tomato under drip system was found higher by 44% and 47% respectively as compared to the surface irrigation method. So considering the yield, as the most parameter for comparison between the two systems, all tomato varieties showed better yield under drip than furrow irrigation system (Tables 1 &3).

Other vegetative traits such as plant height and number of clusters per plant also showed significant difference between the two irrigation systems; whereas higher plant height and number of clusters per plant were recorded in furrow irrigation system, but no significant difference between the two irrigation systems, other vegetative traits like number of fruits per plant and number of branches per plant also showed better results under furrow irrigation system (Table 6). This might be due to more water consumption and more wetting pattern under furrow irrigation than drip irrigation system. So from the present study the main factor for yield difference between the two irrigation system was the fruit size which determined by single fruit weight and width. It was Cochoro variety which performed well under both systems with mean average yield of 44.92t/ha.

Table 5. Comparison of tomato yield and other yield related parameters under two irrigation systems

Irrigation system	Fruit weight (gr)	Fruit width (cm)	Fruit length (cm)	Fruit yield (t/ha)
Drip	77.77a	4.96a	5.34a	44.09a
furrow	72.81b	4.37b	5.24a	43.38a
Mean	75.29	4.67	5.28	43.73
LSD 0.05	3.23	0.42	NS	NS
CV%	5.88	12.36	11.37	0.89

Means followed by the same letter in a column were not significantly different at p ≤ 0.05; CV = coefficient of variation

Table 6. Comparison of tomato growth parameters under two irrigation systems

Irrigation system	Plant height (cm)	No fruit/plant	No of branch/plant	No. cluster/plant
Drip	52.21b	29.99a	6.59a	7.81b
Furrow	75.47a	30.19a	6.78a	9.87a
Mean	63.84	30.09	6.69	8.84
LSD0.05	4.98	NS	NS	1.36
CV%	10.70	7.97	9.49	21.10

Means followed by the same letter in a column were not significantly different at p ≤ 0.05; CV= coefficient of variation

Pearson correlation coefficient of yield showed that it had a positive correlation with all characters except for fruit length and plant height (Table 7). This is in agreement with the finding of Regassa *et al.* (2012). Number of fruits per plant showed negative correlation with single fruit weight. This might be due to the variety which had highest number of fruits per cluster also had relatively small size of fruits. Positive association of plant height, number of fruits per plant and number of clusters per plant was found. Similar results were also reported (Regassa *et al*., 2012). In generally, association of characters indicated that fruit yield per plant, number of fruits per plant, number of fruit clusters per plant were the most important parameters which contributed more for higher yield per hectare for most varieties except for Fetan which was mainly governed by single fruit weight.

Table 7. Pearson correlation coefficient of fruit yield (t ha^{-1}) with other characters of tomato variety

Parameter	Fruit weight (gr)	Fruit length(cm)	fruit Width (cm)	Plant height (cm)	No of branch per plant	No of Fruit per plant	No of Cluster per plant	Yield t ha^{-1}
Fruit weight	1	-0.08	0.30	-0.54*	0.76	-0.81 *	-0.54*	0.31
Fruit length		1	0.07	0.10	-0.13	0.08	-0.08	-0.29
Fruit width			1	-0.44	0.24	-0.16	-0.33	0.23
Plant height				1	-0.27	0.35	0.49*	-0.59*
No of branch per plant					1	-0.70*	-0.32	0..01
No of fruit per plant						1	0.57*	0.21
No of cluster per plant							1	0.025
Yield(ton ha^{-1})								1

* *Significant at $p< 0.05$*

Estimation of installation cost and water use efficiency of low cost drip irrigation

Results of the study revealed that approximately 87.78 and 118.5 $m^3$of irrigation water was applied to tomato using drip and surface irrigation systems, respectively during the entire crop growing period. The mean tomato yield was recorded as 44.09 and 43.38 t ha^{-1}, respectively for drip and surface irrigation methods. Drip irrigation showed a saving of 25.9% water and 1.6% higher yield as compared to surface irrigation (Table 8). Water saving of drip system was also reported by Satyendra *et al.* (2013) which was up to 39% as compared to the surface system. Similarly Shah (2011) reported that 44% yield increment and 79 % water saving under drip irrigation in tomato production higher than furrow irrigation system. In this study, water use efficiency was recorded to be 22.1 and 13.5 kgm^{-3} for drip and surface method, respectively. Similarly, Satyendra *et al.* (2013) found that the drip system almost double the water productivity value by 13.1kg m^{-3} for tomato production.

Table 8.Yield obtained and total irrigation water used (m^3) for 1ha of land under two irrigation methods

Crop	Yield t ha^{-1}				Estimated cost for drip	Estimated cost for furrow	Water supplied (m^3)		
	furrow	drip	Increase (%)	Unit cost/kg	Total cost (Birr)	Total cost (Birr)	furrow	drip	Water saving (%)
Tomato	43.38	44.09	1.6	10	440900	43380	3291.7	2438.3	25.9

Investment of 4160 Birr was estimated for installation of drip system for 0.036 ha of tomato production. Grand total of about 8022 Birr was spent for different items during this study (Table 9). On the other hand, converting the yield obtained under low cost drip irrigation system into Birr which was about 19400 Birr, there was a promising result. Estimate of about 7900 Birr was gained during the first year.

Table 9. Summary of cost or the two irrigation system for (0.036ha) area of land

Description	Cost in for two irrigation systems (Birr)	
	Drip	furrow
Labour expense	2520	2520
Material expense	4159.68	-
Agricultural input expense	646.55	646.55
Fuel	696	696
Grand Total	**8022.23**	**3862.55**

.

Conclusion and Recommendation

The study indicated that low cost drip irrigation system had significant effects on some parameters of tomato as compared to furrow irrigation system. Less amount of irrigation water demand was observed under drip irrigation. Drip irrigation used less water than furrow irrigation systems thus giving much higher water use efficiency. It was concluded that low cost drip systems achieved water saving of more than 25.9 % when compared to furrow irrigation system. From the present study, using low-cost drip irrigation for tomato production could be profitable and alternative option especially for smallholder poor farmers. This technology requires further evaluation under farmers' conditions for better acceptance.

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Assessment of Surface and Ground Water Quality for Smallscale Irrigation in East Shewa Zone of Oromia, Ethiopia

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Abstract

Irrigation with poor quality waters may bring undesirable chemicals to soil in excessive quantities affecting its fertility. The seasonal variation in surface and ground water quality of different districts in East Shea Zone was evaluated for two years (2013/14 to 2014/15). The objective was to assess the suitability of water for irrigation purpose .In this study water samples were collected from river, pond, lake and ground water and analyzed for ten parameters of physical and chemical properties. The analyzed water quality parameters showed seasonal variation and high concentration in dry season compared to wet season due to dilution effects. Electrical conductivity, pH, ionic composition, sodium adsorption ratio (SAR) & total dissolved solids (TDS) were calculated using the standard equations. Analysis showed a wide range of electrical conductivities that varied from 332-2627.5 µS/cm and salinity ranged between 197.9-1681.6mg/L. The SAR in the study area ranged between 1.42 and 22.09 in most irrigation water sources. Considering SAR as important parameter of suitability for irrigation, most of the results are under usual range compared to the irrigation water standards, except for some samples collected from undergroundwater sources. The mean pH values of almost all water sources were between 7.58 and 8.19 which could be categorized as normal range for irrigation purpose. The results concluded that water quality at some of the locations was above permissible limit for irrigation and requires proper monitoring to preserve and maintain its quality for agricultural purpose. Since water quality alone would not sufficient enough to evaluate potential salinity hazard of irrigation water, consideration should also be given to crop, soil, climate, agronomic and irrigation management practices. Therefore the present study serves only as preliminary baseline information for future research needs.

Key words: Irrigation water, salinity, permissible limits, seasonal variation, ionic composition

Introduction

Water quality is becoming priority concern both from supply point of view and with respect to the environmental impacts. Definition of water quality depends on the desired use of water (; Kirda, 1997; Jain *et al.,* 2009). Therefore, different uses require different criteria of water quality as well as standard methods for reporting and comparing results of water analysis (Singh *et al*., 2004). Water quality for agricultural purposes is determined on the basis of the effect of water on the quality and yield of the crops, as well as the effect on soil characteristics (Ayers and Wecot, 1985).

There is increasing need to use waters of mid Rift Valley of Oromia for agricultural purpose; but, there is little information whether these water bodies are chemically suitable for agricultural purpose. Utilization of water bodies without information on the chemical composition could be threat and cause degradation of the environment (Zinabu and Elias, 1989). The importance of water quality becomes more significant in arid and semi arid climates due to lack of natural leaching of deposited salts and high rate of evaporation (Qayyum, 1970). All irrigation water whether diverted from surface streams or pumped from wells, carry certain chemical substances in solution, dissolved originating from weathering of the rocks and soil, and dissolving of lime, gypsum and other salt sources as water passes over or percolates through them (Wilcox,1955). The amount and types of these dissolved constituents determine the quality of water for irrigation use. Thus, evaluation of water bodies for their suitability, particularly with regard to their chemical compositions, is critical.

Although, information on major ions and nutrients are available for Ethiopian rift valley (Kassahun and Amha,1984; Elizabeth *et al*., 1994), this information is mostly from short-time studies and does not reveal a full picture of the chemical composition of different irrigation water source in mid rift valley of Oromia over extended period of time. Quality of irrigation water is not constant over seasons. Salt concentration of rivers, lakes and manmade reservoirs may increase toward the end of summer. Relative change of the concentration depends on storage volume of the reservoirs. Salt concentration change is 10-20 % in large bodies of water, whereas as high as 100% in small ponds, lakes and reservoirs (Kirda, 1997). Deep ground water wells show the least fluctuations in salt concentration, while shallow wells may show considerable changes. Thus, quality of irrigation water must be assessed considering its seasonal fluctuations in salt concentration.

Therefore, knowledge of the chemical composition and quality–related issues of water bodies for irrigation purpose is paramount importance. In this study, water bodies, river, lakes and ground water of mid rift valley of Oromia were assessed during dry and wet seasons for two consecutive years. Therefore, the objective of the study was to assess irrigation water quality of surface and ground water and to provide information on future proper use of water for irrigation purpose and management interventions.

Materials and Methods

Description of the study area

The study was conducted in Fentale, Adama, Lume, Dugda and Adami Tulu Jido kombolcha districts of East Shewa Zone in mid rift valley of Oromia. These districts were selected based on some salinity indictors on irrigated farm and yield reduction reported by farmers during problem identification. The area is found within the mid rift valley (situated at 7°09''N to 8°45'N and 38°32'E to 39°17'E). The mid rift valley has erratic, unreliable and low rainfall, averaging between 500 and 900mm per annum (ATARC, 1998).The annual mean maximum temperature varies between 24.2 and 30.5^{0}C and mean minimum temperature between 10.4 and 16.8^{0}C (Hengsduk *et al*., 2011).The water bodies studied here were Awash River at different district lining between Lume and Fentalle, Koka and Zeway Lake and ground water in East Shewa. Before collecting water samples, sampling areas were classified based on source of water for irrigation; this is required to determine the effect of the sources of water for irrigation on the buildup of soil salinity and other problems in the area.

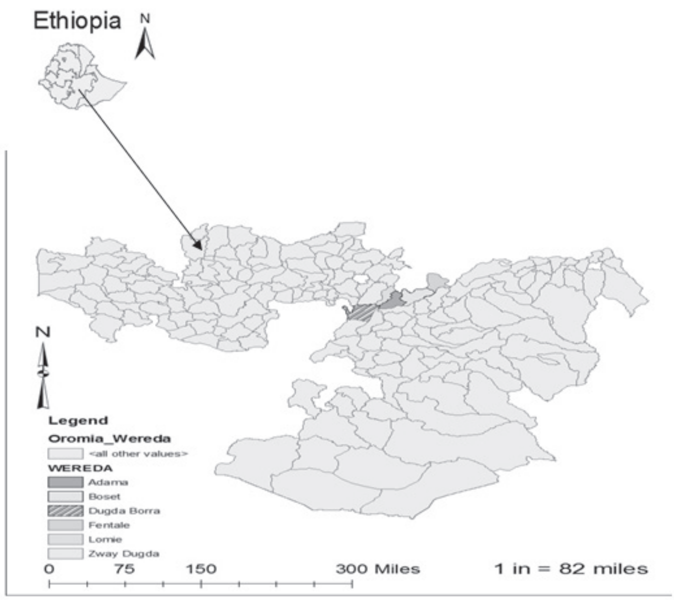

Figure 1. Location map of the study area

Water sampling

As part of the study on seasonal changes in the irrigation water quality, the chemical composition of water bodies were determined during wet and dry seasons between 2013/14 and 2014/15 years. River, lakes and ground water were used as sampling points. At each sampling point, two liters of water sample were taken using labeled and clean polyethylene bottle every quarter. Methods of sampling were varied depending on different sources of water. Samples from rivers were taken from the fastest flowing part at mid-way along the width of the river while samples from lakes were taken from where it was assumed to be a central part of them. Sample from deep well was taken after some minutes of pumping (Kirda, 1997). All samples collected from water bodies were from surface layer except for deep well, which was at 13meters depth of well. Irrigation water samples were transported immediately after collection and reserved in the refrigerator. Samples brought to the laboratory were analyzed without delay to prevent biological transformation.

Methods of analysis

The samples were analyzed for pH, electrical conductivity (Ec), carbonate ($CO3^{2-}$), bicarbonate ($HCO3^{-}$) , chloride (Cl^{-}), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^{+}). The pH and Ec were read on a pH-meter and conductivity- meter, respectively. CO_3^{2-} and HCO_3^{-} were determined by the titration method. Ca^{2+} and Mg^{2+} were determined by the EDTA titration method while Na^{+} was determined by Flame photometry. The Cl^{-} was determined by barium sulfate turbidimetric or gravimetric method (American Public Health Association, American Water Works Association and Water Pollution Control Federation, 1986) depending on concentrations in the samples. Then sodium adsorption ratio (SAR), important empirical measure of the suitability of water for irrigation, was calculated as:

$$SAR = \frac{Na^{2+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$ (Richards, 1954 cited in (Ayers and Westcot, 1985)

The TDS values displayed by the conductivity/TDS meter were calculated from the specific conductance of the water samples and could be approximated by the following equation
TDS = ke EC (Lloyd and Heathcote, 1985), Where TDS is expressed in milligrams per liter and EC is the electrical conductivity in microsiemens per centimeter at 25°C (specific conductance).

Table 1. The permissible limits for classifying the suitability of irrigation water

Some of Irrigation water quality parameters	permissible limits in irrigation water	source
SAR	0-15	Ayers and Westcot, 1985
Ec (µS/cm)	0-3000	
TDS (mg/L)	0-2000	
pH	6.5-8.4	
Na^{+}(meq/L)	0-40	
Ca^{+2}(meq/L)	0-20	
Mg^{+}(meq/L)	0-5	
$CO3^{=}$+ $HCO3^{-}$(meq/L)	0-10	
Cl^{-}(meq/L)	0-30	

Statistical analysis

Descriptive statistics, mean and range were used to describe the irrigation water quality parameters.

Results and Discussion

Salinity and conductivity of water sources

Salinity and conductivity of river

Awash River at different sampling points showed wide range of salinity and conductivity measures that varied from 212.48 to 277.9 mg/L and 332µS/cm and 434.2µS/cm, respectively (Table 2). The averages for Awash River at different sites were under usual range for irrigation in terms of TDS and EC (Ayers and Westcot, 1985), and could be regarded as suitable for irrigation.

Salinity and conductivity of ground water

The irrigation water samples collected from ground water showed wide range of salinity and conductivity measures that varied from 801.3 to 1681.6 mg/L and 1252µS/cm to 2627.5µS/cm, respectively (Table 3). Irrigation water samples collected from underground water of two peasant associations (Tuchi-sumayan &Korke Adi) which are found in Dugda District showed that the areas were under increasing water quality problem (Table 3). The chemistry of these underground waters might be influenced by leaching and accumulation of dissolved salts. Unless management practices may be done, using underground water for irrigation purpose in the two PAs will result in severe salinity problem in the very near future. Hence, these areas need special attention.

Table 2.Mean values of conductivity (µS/cm), salinity (mg/L) and pH of river in the study area .Values in brackets are permissible limits in irrigation water. N represents sample size

Site	Water source	N	EC (µS/cm) (0-3000)		TDS (mg/L) (0-2000)		pH (6.0-8.5)	
			range	mean	range	mean	range	mean
Gidara	Awash river	8	170-453.7	344.7	108.8-290.4	220.6	7.83-8.08	7.94
Diresede	Awash river	8	176.6-469.5	332	103.46-290.5	212.48	7.94-8.34	8.03
Fateledy	Awash river	6	253-424.2	370	161.9-271.5	236.8	7.69-8.0	7.87
Ilala	Awash river	8	155-570	379.8	99.2-289.9	243.1	7.93-8.24	8.06
waktiyo	Awash river	8	238.5-454.5	346.1	152.6-290.9	221.5	7.88-8.17	8.01
Kobolito	Awash river	8	192.7-457	372.85	174.4-292.5	238.6	7.55-7.93	7.58
Lume	Awash river	8	175-753.5	434.2	112-482.24	277.9	7.62-8.27	7.93

pH of irrigation water sources

The mean pH values of Awash River at different sampling sites was about 7.9 (Table 2); and categorized under usual ranges for irrigation purpose (Ayers and Westcot, 1985). The same is true for ground water at different sampling sites, which was about 7.87 (Table 3). The mean pH values of Zeway and Koka lakes were about 8.0 (Table 4), with high value indication at Zeway Lake. But there was large fluctuation over the study period. This suggests that the suitability of water sources for irrigation, with respect to their pH values, is seasonally variable.

Table 3.Mean values of conductivity (µS/cm), salinity (mg/L) and pH of ground water in the study area.Values in brackets are permissible limits in irrigation water. N represents sample size

Site	Water source	N	EC (µS/cm) (0-3000)		TDS (mg/L) (0-2000)		pH (6.0-8.5)	
			range	mean	range	mean	range	mean
wenjii	Ground water	6	1203-1389.5	1285.1	769.7-889.3	822.5	7.64-8.25	7.86
Tuchisumayan	Ground water	8	1825.5-2330	2050	1168-1491	1312	7.73-8.16	7.95
Shubigamo	Ground water	8	1196-1335	1252	765.4-854.4	801.3	7.61-8.18	7.89
Korke Adi	Ground water	6	2379-2970	2627.5	1522.5-1900.8	1681.6	7.32-8.08	7.78

Salinity and conductivity of lake

The irrigation water samples collected from Zeway and Koka lakes at different sites showed wide range of salinity and conductivity measures that varied from 197.9 to 606.3 mg/L and 308.3µS/cm to 947.35µS/cm, respectively (Table 4). The mean values of salinity and conductivity of these lakes at different sites are under usual range for irrigation in terms of the TDS and EC (Ayers and Westcot, 1985). Therefore, these lakes could be regarded as suitable for irrigation purpose. The concentrations of both salinity and conductivity of water samples from lakes were found in decreasing order (Zeway Lake at Kore Adi site > Zeway Lake at Wayu Gebrel > Zeway Lake at municipal > Koka Lake). The high mean value of both salinity and conductivity for Zeway Lake at Korke Adi site might be influenced by saline surface runoff and accumulation of dissolved salts from agricultural lands and roads. The lake is under great pressure at this site from the surrounding huge number of cattle for grazing and drinking. So, further investigation on soil is needed in this site to know the source of salt.
Study on the seasonal variation of salinity of lake showed that the salinity values of irrigation water from Zeway and Koka lakes at different sites varied during the wet and dry seasons. Seasonal analyses of electrical conductivities of irrigation water samples showed that wet seasons were lower than the dry seasons. The lower limit under the range indicated the laboratory result in wet season while upper limit showed in dry season (Table 5).The reason for this might be due to the dilution effect of non-saline surface runoff and less evaporation rate during the wet seasons.

Table 4. Mean values of conductivity (µS/cm), salinity (mg/L) and pH of lake in the study area .Values in brackets are permissible limits in irrigation water. N represents sample size

Site	Water source	N	EC (µS/cm) (0-3000)		TDS (mg/L) (0-2000)		pH (6.0-8.5)	
			range	mean	range	mean	range	mean
Batigarma ma	Koka lake	8	209.35-425	308.3	133.9-272	197.9	7.65-8.19	8.01
Korke Adi	Lake(ziwa y)	8	600-1359	947.35	384-869.8	606.3	7.79-8.45	8.04
Wayu gebrel	Lake (ziway)	8	649.5-995	836.5	415.7-636.8	535.4	7.39-8.31	7.78
Ziway	lake	8	380-549.5	466.85	243.2-351.7	220.6	7.76-8.74	8.19

Ionic composition of water bodies

Ionic composition of river

Irrigation water sample analysis of Awash River at different sites showed that ionic compositions varied during wet and dry seasons. The ionic compositions of samples taken from all sites showed wet seasons were lower than the dry seasons. The lower limit under the range indicated the laboratory result in wet season while upper limit showed in dry season (Table 6). Moreover, the variations were observed between the two consecutive years of the study period (Table 5). The analysis of water samples of later year showed higher ionic composition than the first year. The reason for this might be due to the accumulation of dissolved salt as result of evaptransparation and long dry spell during the second year of study period.

Na^+ was the most dominant cation with range 1.57 to 2.41 meq/L at all sampling sites of Awash River and CO_3^{2-}+ HCO_3^- (total alkalinity) was the major anions with range of 2.64 to 3.44 meq/L (Table 7). It was interesting to note that none of the cations and anions was found in concentration higher than the permissible limits in any sampling sites of Awash River (Ayers and Westcot, 1985). The concentrations of cations of water samples from Awash River at different sampling sites were found in a decreasing order for both cation and anion (Na^+ >Ca^{2+}>Mg^{2+}) and anion (CO_3^{2-}+ HCO_3^-) >Cl^-. The total alkalinities in the study area were mainly due to HCO_3^-, while carbonate was not detected in most sampling sites of Awash River. The rivers of the study area are originated from the highlands which flow with most dilute waters (waters of very low ionic content), hence it has low ionic composition. However, evaporative concentrations and the addition of saline thermal waters, that obtains the solutes from rocks through which they pass, may sometimes lead to higher concentration of solutes in the rivers (Telford, 1998).

Sodium adsorption ratio (SAR) of water bodies

Sodium adsorption ratio (SAR) of river

The sodium adsorption ratios (SAR) of river at sampling sites showed variation ranging from 1.56 to 1.97 (Table 6). Although the amount and combination of many substances define the suitability of water for irrigation and the potential for the plant toxicity, SAR is the most important determinant. Hence by considering SAR as an indicator of suitability of water for irrigation, water samples taken from Awash River at different sampling sites could be considered suitable for irrigation (Ayers and Westcot, 1985).

Sodium adsorption ratio (SAR) of ground water

The sodium adsorption ratios (SAR) of ground water irrigation sampled from well showed variation from 5.62 to 22.09 (Table 6). The ground water irrigation samples taken from Tuchi-sumayan, Korke Adi and shubi-gamo PAs' were high and regarded as unsuitable for continuous use of irrigation based on their SAR values (Table 7) according to classification standard stated for irrigation water quality by Ayers and Westcot (1985).

Table 5. Mean comparison of seasonal variations of water quality parameters over two consecutive years of study period

Site (PA)	Year	source	Parameters									
			N	Na^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)	($CO_3^= + HCO_3^-$) (meq/L)	Cl^- (meq/L)	PH	SAR	EC (µS/cm)	TDS (mg/L)
				mean	mean	mean	mean	mean	Mean	mean	Mean	mean
Gidara	2006	Awash river	4	1.3	1.04	0.81	2.45	0.49	7.9	1.36	296.7	189.89
	2007	Awash river	4	1.84	1.36	0.8	2.82	0.63	7.97	1.77	392.7	251.33
Diresede	2006	Awash river	4	1.53	1.23	0.79	2.71	0.48	7.97	1.52	269.9	172.74
	2007	Awash river	4	2.44	1.59	0.65	2.9	0.88	8.08	2.31	394.1	252.22
Fateledy	2006	Awash river	3	1.6	1.19	0.97	3.21	0.51	7.8	1.54	279.4	178.82
	2007	Awash river	3	2.69	1.6	0.88	3.37	0.88	7.94	2.41	460.6	294.78
Ilala	2006	Awash river	4	1.48	1.34	0.97	2.87	0.47	7.99	1.38	367	234.88
	2007	Awash river	4	2.84	1.59	1.04	2.89	0.78	8.13	2.48	392.6	251.26
waktiyo	2006	Awash river	4	1.45	1.23	0.73	2.94	0.57	7.9	1.47	265.1	169.66
	2007	Awash river	4	2.25	1.39	1.2	3.02	0.77	8.11	1.98	427	273.28
wenjii	2006	Ground water	3	5.14	1.44	0.81	12.17	1.02	7.79	4.85	1205.2	771.33
	2007	Ground water	3	10	3.9	1	11.83	1.14	7.93	6.39	1365	873.6
Kobolito	2006	A.river	4	1.09	1.4	0.58	3.14	0.46	7.53	1.09	338.7	216.77
	2007	A.river	4	2.34	1.71	0.85	3.26	0.84	7.64	2.07	407	260.48
Batigarmama	2006	Koka Lake	4	0.87	1.22	0.76	2.69	0.49	7.95	0.88	234.6	150.14
	2007	Koka Lake	4	2.12	1.67	0.68	2.89	0.77	8.06	1.96	382	244.48
Lume	2006	Awash river	4	1.69	2.1	0.91	3.43	1.2	7.89	1.38	456.7	292.29
	2007	Awash river	4	3.13	2.07	1	3.45	1.25	7.96	2.53	411.7	263.49
Tuchisumayan	2006	Ground water	4	22.22	0.87	1.3	15.01	2	7.92	**21.37**	1783.3	1141.31
	2007	Ground water	4	22.37	0.94	0.98	15.24	1.46	7.98	22.82	**2316.7**	1482.69
Shubigamo	2006	Ground water	4	14.64	0.78	1.22	11.43	0.73	7.81	14.66	1250	800
	2007	Ground water	4	11.97	0.55	0.82	11.51	0.5	7.98	14.49	1254	802.56
Korke Adi	2006	Lake	4	7.43	0.99	0.8	8.02	1.03	7.99	7.86	868	555.52
		Ground water	3	25.81	1.62	0.8	16.55	1.95	7.83	23.47	1980	1267.2
	2007	Lake	4	10.93	1.82	1.34	8.08	1.17	8.09	8.7	1026.7	657.09
		Ground water	3	25.96	2.25	1.25	18.12	1.2	7.74	19.64	**3275**	2096
Wayu gebrel	2006	Lake	4	5.07	1.29	1.27	6.73	0.9	7.8	4.49	816.7	522.69
	2007	Lake	4	5.16	1.69	1.34	6.85	0.6	7.76	4.19	856.3	548.03
Ziway	2006	Lake	4	2.58	0.84	1	3.76	0.87	7.98	2.69	460	189.89
	2007	Lake	4	2.93	1.26	0.89	3.85	0.57	8.4	2.82	473.7	251.33

Table 6. Mean concentration (meq/L) of major ions, sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) in mid rift valley irrigation water source. N is sample size. Vvalues in brackets are permissible limits in irrigation water. Values in bold and under line are above permissible limits in irrigation water

Site	Water source	N	Na^{+} (0-40)		Ca^{+2} (0-20)		Mg^{+2} (0-5)		$CO3^{=}$+ $HCO3^{-}$ (0-10)		Cl^{-} (0-30)		SAR (0-15)	
			range	mean	range	mean	range	mean	range	mean	range	mean	range	mean
Gidara	Awash river	8	0.75-2.43	1.57	0.84-1.51	1.2	0.43-1.09	0.81	1.51-3.59	2.64	0.24-0.7	0.56	0.95-2.11	1.565
Diresede	Awash river	8	0.77-3.03	1.98	1.03-1.76	1.41	0.37-1.11	0.72	1.45-4.02	2.84	0.42-0.94	0.68	1.05-2.49	1.91
Fateledy	Awash river	6	1.03-2.16	2.15	1.29-1.92	1.39	0.48-1.28	0.93	2.41-4.27	3.29	0.43-1.01	0.69	1.09-2.48	1.97
Ilala	Awash river	8	0.74-3.17	2.16	1.30-1.75	1.46	0.32-1.86	1.01	1.46-4.37	2.88	0.22-1.03	0.63	0.83-2.31	1.93
waktiyo	Awash river	8	0.87-2.95	1.85	1.0-1.64	1.31	0.51-1.58	0.96	1.92-4.03	2.98	0.36-0.95	0.67	1-2.27	1.72
Kobolito	Awash river	8	0.68-2.56	1.72	1.17-1.76	1.55	0.37-1.12	0.72	2.16-4.32	3.2	0.55-0.86	0.65	0.78-2.07	1.58
Lume	Awash river	8	1.18-3.74	2.41	1.2-2.73	2.08	0.4-1.32	0.96	1.35-3.81	3.44	0.55-0.86	1.23	1.36-2.62	1.95

Table 7. Mean concentration (meq/L) of major ions, sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) in mid rift valley irrigation water source. N is sample size. Values in brackets are permissible limits in irrigation water[2]. Values in bold and under line are above permissible limits in irrigation water

Site	Water source	N	Na^{+} (0-40)		Ca^{+2} (0-20)		Mg^{+2} (0-5)		$CO3^{=}$+ $HCO3^{-}$ (0-10)		Cl^{-} (0-30)		SAR (0-15)	
			range	mean	range	mean	range	mean	range	mean	range	mean	range	mean
Wenjii	Ground water	6	3.65-9.52	7.57	1.13-3.49	2.67	0.68-1.16	0.91	11.06-13.5	12	0.81-1.19	1.08	3.73-6.23	5.62
Tuchisu mayan	Ground water	8	17.35-27.18	22.29	0.64-1.18	0.91	0.78-1.8	1.14	14.13-16.32	**15.13**	1.28-2.19	1.73	20.5-22.31	**22.09**
Shubiga mo	Ground water	8	10.13-19.51	13.31	0.41-0.93	0.66	0.48-1.39	1.02	10.68-12.75	**11.47**	0.38-0.85	0.62	15.2-18.09	**14.57**
Korke Adi	G round water	6	14.51-35.4	9.18	0.75-2.72	1.41	0.26-1.68	1.07	15.86-20.64	8.05	0.62-1.28	1.1	20.47-23.5	**21.55**

Table 8. Mean concentration (meq/L) of major ions, sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) in mid rift valley irrigation water source. N is sample size. Values in brackets are permissible limits in irrigation water. Values in bold and under line are above permissible limits in irrigation water

Site	Water source	N	Na^{+} (0-40)		Ca^{+2} (0-20)		Mg^{+2} (0-5)		$CO3^{=}$+ $HCO3^{-}$ (0-10)		Cl^{-} (0-30)		SAR (0-15)	
			range	mean	range	mean	range	mean	range	mean	range	mean	range	mean
Batigarmama	Koka lake	8	0.59-1.2	1.5	1.18-1.7	1.44	0.42-1.12	0.72	1.56-3.76	2.79	0.37-0.96	0.63	0.66-2.02	1.42
Korke Adi	Lake(ziway)	8	5.8-11.5	8.28	0.9-1.61	1.94	0.21-1.6	1.03	5.16-11.17	8	0.76-1.57	1.55	8.26-8.48	8.28
Wayu gebrel	Lake(ziway)	8	2.94-7.0	5.12	1.17-1.9	1.49	0.83-1.91	1.31	5.00-8.25	6.79	0.5-1.1	0.75	2.89-5.11	4.34
Ziway	Lake	8	2.2-3.16	2.75	0.94-1.33	1.05	0.71-1.26	0.94	3.19-4.30	3.81	0.56-.98	0.72	2.43-2.77	2.75

Ionic composition of ground water

Na^+ and CO_3^{2-}+HCO_3^- (total alkalinity) were the most dominant cation and anion ranging 9.18 to 22.29 meq/L and 8.05 to 15.13 meq/L in all ground water irrigation used as sampling points respectively (Table 8). Total alkalinity from the two PAs of Dugda District was higher than the permissible limits for irrigation (Table 7), while in the rest of study sites they were in the range of permissible limits to be used for irrigation (Ayers and Westcot, 1985). In these PAs it was also possible to note that the composition of Ca^{+2} and Mg^{+2} were lower as compared to other sites, while composition of Na^+ was higher. The lower in calcium and magnesium composition might be due to precipitation as carbonates when the water was decreasing by transpiration and evaporation.The concentrations of cations of water samples from ground water of Wenji and korke Adi were in decreasing order as $Na^+ > Ca^{2+} > Mg^{2+}$, while it was in decreasing order as $Na^+ > Mg^{2+} > Ca^{2+}$ in Tuchisumaya and Shubigamo sites (Table 7). Similarly, the concentrations of anions were found in the decreasing order of (CO_3^{2-}+ HCO_3^-) >Cl^- in all ground water irrigation used as sampling points.

Although, the concentrations of Na^+ were in usual ranges for irrigation water in the study sites there were indications for potential sodium hazards; especially for PAs' in the Dugda District, and special attention should be given for irrigation water source used from underground.

Ionic composition of lake

Similar to river and ground water irrigation sources mentioned above, Na^+ was the most dominant cation with range 1.50 to 8.28 meq/L at all sites of lake water irrigation sampling points and CO_3^{2-} + HCO_3^- was the major anions with range of 2.79 to 8.0 meq/L (Table 8). Similar to Awash River the lakes of the study areas are originated from the highlands which flow most dilute waters (waters of very low ionic content), and has low ionic composition compare to ground water source.

Concentrations of chloride

Concentrations of Cl^- in all the water samples were lower than the permissible limits in irrigation waters (Table 6, 7&8) (Ayers and Westcot, 1985).

Sodium adsorption ratio (SAR) of lake

Sodium adsorption ratio (SAR) in lake showed variation from 1.42 to 8.28 (Table 8). Similar to water samples taken from Awash River at different sites water samples taken from all the lakes could also be considered as suitable for irrigation (Ayers and Westcot, 1985). In general, sodicity and salinity classes of water samples collected from different sites and water bodies are showed in Table 9.

Table 9. Sodicity and salinity class of water samples collected from different sites and water bodies

Site	Water source	SAR	Sodicity Class	Ec(µS/cm)	Salinity Class
Gidara	Awash river	1.565	Low (S1)	344.7	Medium (C2)
Diresede	Awash river	1.915	Low (S1)	332	Medium (C2)
Fateledy	Awash river	1.975	Low (S1)	370	Medium (C2)
Ilala	Awash river	1.93	Low (S1)	379.8	Medium (C2)
waktiyo	Awash river	1.725	Low (S1)	346.05	Medium (C2)
Kobolito	Aawsh river	1.58	Low (S1)	372.85	Medium (C2)
Lume	Awash river	1.955	Low (S1)	434.2	Medium (C2)
Wenjii	Ground water	5.62	Low (S1)	1285.1	High (C3)
Tuchisumayan	Ground water	**22.095**	**High(S3)**	**2050**	**High (C3)**
Shubigamo	Ground water	14.58	Medium (S2)	1252	Medium (C2)
Korke Adi	Ground water	**21.555**	**High(S3)**	**2627.5**	**Very High (C4)**
Batigarmama	Koka lake	1.42	Low (S1)	308.3	Medium (C2)
Korke Adi	Lake(ziway)	8.28	Low (S1)	947.35	High (C3)
Wayu gebrel	Lake(ziway)	4.34	Low (S1)	836.5	High (C3)
Ziway	Lake	2.755	Low (S1)	466.85	Medium (C2)

Conclusion and Recommendation

Water analysis results of samples collected from different irrigation water source of mid rift valley of Oromia indicated that water from Awash River in different districts could be suitable for irrigation purpose. Zeway Lake and Koka dam could also be suitable for irrigation based on almost all aspects of chemical compositions. Irrigation waters containing high concentration of Na^+ require special concern because of sodium's effects on soil, and the so-called sodium hazard, which is expressed in terms of SAR. Based on SAR values water samples taken from two PAs (Korke Adi and Tuchi-sumayan) of Dugda District were unsuitable for irrigation purpose. This unsuitability of irrigation water also intensified by high total alkalinity ($CO3^{=}$+ $HCO3^-$), which were above permissible limits for irrigation.

The Cl^- which is one of the toxic ions for irrigated crop was below the permissible limits and this information would be important for irrigation use. The water quality of samples from the study areas showed that about 60% of the samples fell in the C2-S1 category (medium salinity with low sodicity hazard), 20% of the samples fell in the category C3-S1 (high salinity with low sodicity hazard), 6.66% of the samples fell in the category C2-S2 (medium salinity with medium sodicity hazard), 6.66% of the samples fell in the category C3-S3 (high salinity with high sodicity hazard), and 6.66% of the samples fell in the category C4-S3 (very high salinity with high sodicity hazard). It was irrigation water from underground which fell in the category of very high in salinity and high in sodicity hazards.

Although this study dealt with the suitability of the irrigation waters of mid rift valley of Oromia in light of their chemical composition only, it is not possible to classify different qualities of irrigation water with cut boundaries, and therefore one must consider plant, soil, climatic conditions as well as existing agronomic and irrigation practices in deciding the usefulness of the water for irrigation. Even these water bodies that were assumed to be suitable for irrigation could develop problems over long term use. Hence, the results given here should only be taken as preliminary study. It is evident that the waters from the different areas of East Shewa Zone have been assumed to be unsuitable for irrigation. Here, it could be acceptable for irrigation when evaluated in combination with other factors mentioned above, or when certain management options are applied. Therefore, future study should focus on soil type and tolerance of crops to be used. This study output can be used by planers, managers, investors and agriculturalists as basic preliminary information.

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Agro-forestry Research

Evaluation of Two Moringa species for Adaptability and Growth Performance under Bako Condition, East Wollega Zone, West Oromia, Ethiopia

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Abstract

Experiment on Moringa species adaptability was conducted at Bako Agricultural Research Center, on-station, for three consecutive years (2010/11-2013/14). The objective of the study was to assess the growth performance and adaptation of Moringa species to the area depending on their early growth patterns and survival. Two different Moring species (Moringa oleifera and Moringa stenopetala) were compared using randomized complete block design with three replications. Results showed that there was significant difference in height growth, but non-significant difference in root collar diameter, diameter at breast height and survival between the two Moringa species. The study results showed that there was highly significant difference in root collar diameter measured at one month and significant difference diameter at breast height at one year age of establishment performance of the species. This could be due to environmental factors and inherent genetic potentials of the species which generally govern tree growth. The height growth of Moringa oleifera (4.01m) was higher than Moringa stenopetala (2.40m). There was significant difference between Moringa stenopetala (0.84 cm) and Moringa oleifera (0.66 cm) regarding root collar diameter development at the first assessment (after one month age), but both species were not significantly different at increased age of the species. Both species Moringa stenopetala and Moringa oleifera, showed good survival rates with mean values of 97.33 and 100%, respectively. Based on the results of three years growth data, the performance of Moring oleifera species was promising and hence both ould be considered for further technology specific and on-farm agro-forestry practices around Bako.

Key words: diameter at breast height, genetic potentials, *Moringa oleifera*, *Moringa stenopetala*, root collar diameter

Introduction

Moringa species is a tropical plant belonging to the family *Moringaceae* that grows throughout the tropics. The genus *Moringa* consists of 13 species (NRC, 2006) of which only *Moringa oleifera* has been accorded research and development attention. It is represented by 13 species, out of which five species, *Moringa stenopetala, Moringa oleifera, Moringa longituba, Moringa rivae* and *Moringa ruspoliana* are found in Ethiopia (www.geocites.com). Among the five species *Moringa stenopetala* is often referred to as the African *Moringa* tree because it is native only to southern Ethiopia and northern Kenya (Mark, 1998). Northeast tropical Africa is a center of endemism plus diversity for the genus (Mark, 1998). *Moringa oleifera* is native to sub-Himalayan tracts of northern India and is commonly referred to as “horseradish tree” or “drumstick tree” (Jahn, 1991). *Moringa* is multipurpose tree of significant economic importance, as it has vital nutritional, industrial, and medicinal applications (Jahn, 1991; NRC, 2006).

Generally, different tree species respond differently to the different environments (Rocheleau et.al, 1988). Because every tree species has its own range of biotic and abiotic factors in which it performs with its maximum capacity (FAO, 1974; EVAN, 1992). Similarly different sites may have different qualities. Thus, whenever one plans to plant a tree species in any form, he has to match the requirements of a species with the site condition. This adaptation of *Moringa species* was initiated to assess their performance and adaptation to Bako condition, and to make use of them for agroforestry practices in Bako area as well as in similar agro-ecology. Therefore, the objective of this study was to identify the best adaptable, compatible, productive, disease and pest tolerant *Moringa species* for Bako area, and other similar agro-ecology.

Materials and Methods

Description of the study area

The trial was conducted at Bako Agricultural Research Center, on-station, which is located at 9^{o}07' N latitude and 37^{o}05' E longitude (Figure 1). The area is mid-altitude, sub-humid tropical climate with unimodal rainfall pattern (Figure 2), experiencing average annual rainfall of 1270mm and average annual temperature of 20^{o}C (maximum, 27^{o}C and minimum, 13^{o}C). The altitude at Bako Meteorological station is about 1650 masl. The soil is dominantly reddish brown Nitisol, with pH of 5-6, and clay dominated in texture (Legesse *et al*, 1987; Abebe, 1998).

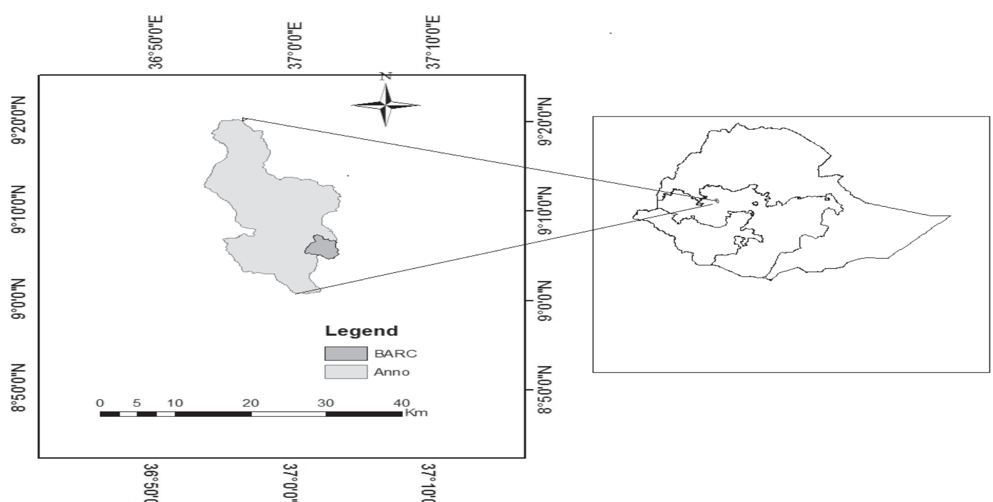

Figure 1. Location of the study area

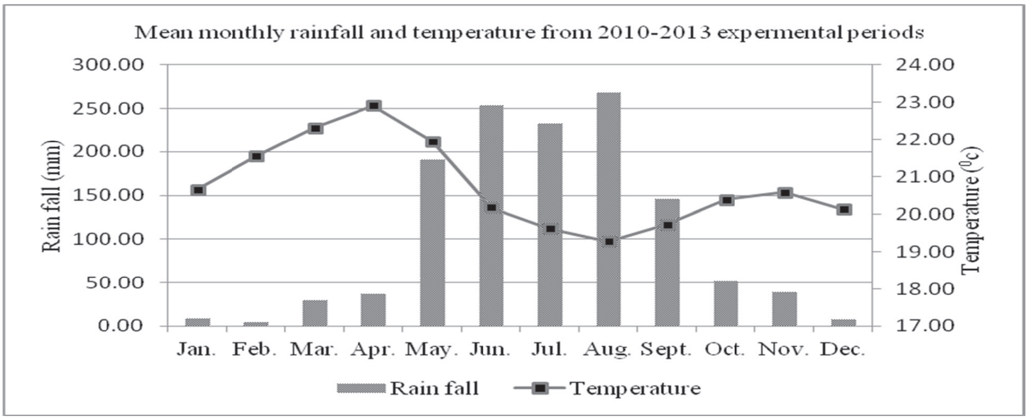

Figure 2. Mean monthly rainfall and temperature during experimental period of Bako area

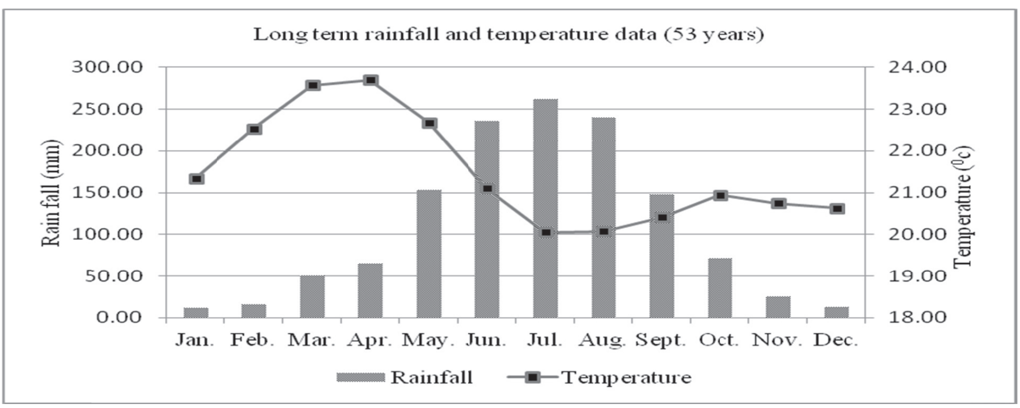

Figure 3. Long-term mean monthly rainfall and temperature of Bako area, based on 1996-2013 meteorological data at Bako Agricultural Research Center

Treatments and experimental design

The treatments were 2 different tree species (Table 1).

Table 17. *Moringa* species and their seed source

Tree species	Family	Seed source
1. *Moringa oleifera* Lam.	Moringaceae	MARC, Ethiopia
2. *Moringa stenopetala* (Bak.f.) Cuf.	Moringaceae	FRC, Ethiopia

FRC= Forestry Research Center MARC = Melkassa Agricultural Research Center

Seedlings of the trees were raised at Bako tree nursery using polyethylene tubes of 10cm diameter and 15 cm long in April 2010, and out-planted during the rainy season in the end of June of the same year. The experiment was laid out in randomized complete block design with three replications. The block was folded to accommodate the two treatments within fairly uniform field conditions. The block lies from West to East with distance of 3m between the species, and 2m between plots within block. The spacing between trees was 1.5 m x 1.5 m, and the plot area was 144 m^2 (12 m x 12 m) with a total of 81 trees per plot.

Data collection and analysis

Height, root collar diameter, diameter at breast height and survival rate were the four growth and adaptation parameters that were measured for the three years at interval of 2 months. Survival count was made for the whole trees in a plot (81 trees per plot), while the trees in the middle (25 trees per plot) were taken as sample for height and root collar diameter measurement so as to minimize the border effect. Height growth was determined by using measuring tapes, and root collar diameter by caliper. Analysis of variance was made for plot-mean data, and F-test was used to test the significance of differences between species using SAS computer software. Treatment means that showed significant difference by F-test were separated by least significant difference.

Results and Discussion

Summary of results for height and root collar diameter are presented in Table 2. The diameter at breast height and survival are presented in Table 3. And also the trend observed for each species in height, diameter at breast height and survival rate over three years is indicated in Figures 3, 5 and 6 respectively and root collar diameter over a month indicated in Figure 4.

Height growth

Statistical analysis revealed that there was marked difference in height growth between the *Moringa* species. At the age of two years after establishment *Moringa oleifera* (4.01 m) was higher than *Moringa stenopetala* (2.40 m). M*oringa oleifera* and *Moringa stenopetala* showed fastest growth with the annual height growth rate of 2.69 m and 1.23 m, respectively. As the result in Table 2 showed, *Moringa oleifera* out-smarted *Moringa stenopetala* in height. On other other hand, the performance of both species was significantly different because the growth performance is mainly depending up on the characteristics of the species that has towards the specific agro-ecology. This could be due to either their superior genetic potential or the environmental requirements of these species.

There was also significant interaction between tree species and tree age as clearly shown in Table 2. At the early age of establishment, the variation in height growth between *Moringa stenopetala* (0.56 m) and *Moringa oleifera* (0.28 m) was minimal but at increased age *Moringa oleifera* attained higher mean height than *Moringa stenopetala*, but the difference became evident with time as the tree age increased.

Root collar diameter development

Growth in root collar diameter also differed significantly between the two tree species. The difference in growth of root collar diameter between *Moringa stenopetala* (0.84 cm) and *Moringa oleifera* (0.66 cm) was significant at the age of one month after establishment with respective six month root collar growth rates of 4.22 and 4.09 cm. But both species were not significantly different as age increased; *Moringa stenopetala* and *Moringa oleifera* considerably increased the average root collar diameter of the latter - otherwise higher difference couldn't have been noticed between the two species. Results indicated that tree species having greatest root collar diameter were those which grew tallest. Height growth and root collar diameter development were well correlated (r = 0.976, p = 0.0009). Similarly, smaller root collar diameter was recorded for shorter species.

Table 2. Height and root collar diameter of two *Moringa* species over three years

	Height (m)				**Root collar diameter (cm)**			
Moringa species	Assess.1	2011	2012	2013	Assess.1	Assess.2	Assess.3	Assess.4
Moringa oleifera	0.28b	2.97a	4.01a	3.97a	0.66b	2.18a	3.75a	4.75a
Moringa stenopetala	0.56a	1.79b	2.40b	2.63b	0.84a	2.16a	4.14a	5.06a
Mean	0.42	2.39	3.21	3.30	0.75	2.17	3.94	4.903
LSD (5%)	0.09	0.31	0.99	1.12	0.06	0.44	1.19	0.80
SE	0.0147	0.052	0.164	0.184	0.009	0.073	0.195	0.131
CV (%)	6.05	3.76	23.84	9.66	2.14	5.84	8.59	4.63
P value	0.0056	0.0038	0.0202	0.0356	0.0051	0.8867	0.294	0.240

Means followed by different small letters within column are significantly different at p< 0.05

SE=Standard error of the mean; CV=Coefficient of variation; P =Probability; Assess. =Assessment;

LSD = Least Significant Difference

Assess.1 = Assessment seedling height and root collar diameter measured after one month.

Assess.2 = Assessment seedling root collar diameter measured after three months.

Assess.3 = Assessment seedling root collar diameter measured after five months.

Assess.4 = Assessment seedling root collar diameter measured after seven months.

Diameter at breast height

Growth in diameter at breast height also differed significantly for the two *Moringa* species. The difference in growth of diameter at breast height (1.3 m) above the ground between *Moringa stenopetala* (1.52 cm) and *Moringa oleifera* (2.97 cm) was highly significant at the age of one year diameter at breast height growth. But diameter at breast height growth was non-significantydifferent for both species at the age of the species above one year old. As showed in Table 3 both *Moringa* species had good performance in diameter at breast height. From both species *Moringa oleifera* showed high diameter at breast height within three years data records. So, this helped for the species to provide seed within one year after planting and also this species had good stand in the field, but *Moringa stenopetala* has not yet given any seeds until the completion duration of the study.

Tree survival percent

There were not significant differences between the species in survival rate. At assessment seedling survival measured after one month *Moringa stenopetala* and *Moringa oleifera* at the assessment seedling survival measured after one month 100 and 100% respectively. However, at the age of three years after establishment *Moringa oleifera* and *Moringa stenopetala* showed relatively better survival with mean values of 100 and 97.3%, respectively, but survival rate with mean of both species was not significantly different. Tree survival was not strongly correlated with height growth (r = 0.637, p >0.05), root collar diameter (r =0.4035, p >0.05) and diameter at breast height (r = 0.693, p >0.05). This means those trees with highest height, diameter at breast height and root collar diameter growths could not attain highest survival, and vice versa.

Table 3. Diameter at breast height and survival count of two *Moringa* species over three years, Bako Research Center

	Diameter at breast height (cm)			**Survival (%)**			
***Moringa* species**	2011	2012	2013	Assess.1	2011	2012	2013
Moringa oleifera	2.97a	4.22a	4.92a	100.0a	100.0a	100.0a	100.0a
Moringa stenopetala	1.52b	2.58a	3.31a	100.0a	97.33a	97.33a	97.33a
Mean	2.25	3.40	4.11	100.0	98.7	98.7	98.7
LSD (5%)	0.71	1.95	2.61	0.00	11.47	11.47	11.47
SE	0.117	0.320	0.429	0.000	1.89	1.89	1.89
CV (%)	8.99	16.3	18.1	0.000	3.3	3.3	3.3
P value	0.0127	0.0679	0.1183	NS	0.4226	0.4226	0.4226

Means followed by different small letters within column are significantly different at p< 0.05

SE= Standard error of the mean; CV= Coefficient of variation; P = Probability; Assess. = Assessment LSD = Least Significant Difference, NS= Non-significant Difference.

Assess.1 = Assessment seedling survival measured after one month;

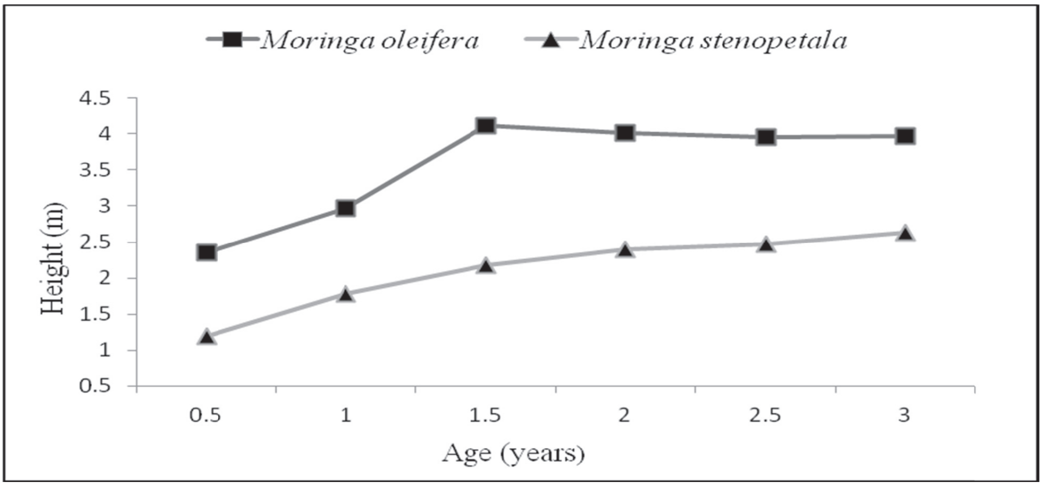

Figure 3. Height growth as function of *Moringa* species age

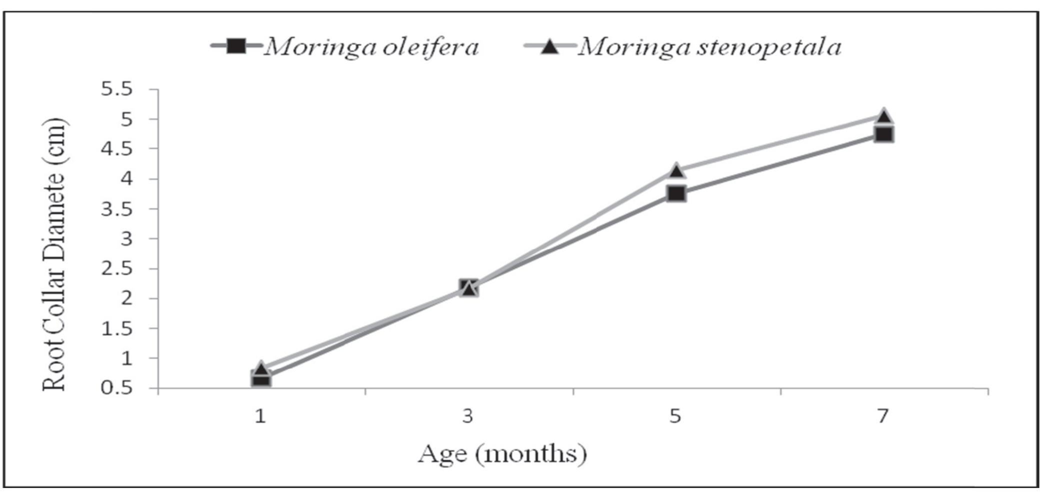

Figure 4. Root collar diameter growth as function of *Moringa* species months

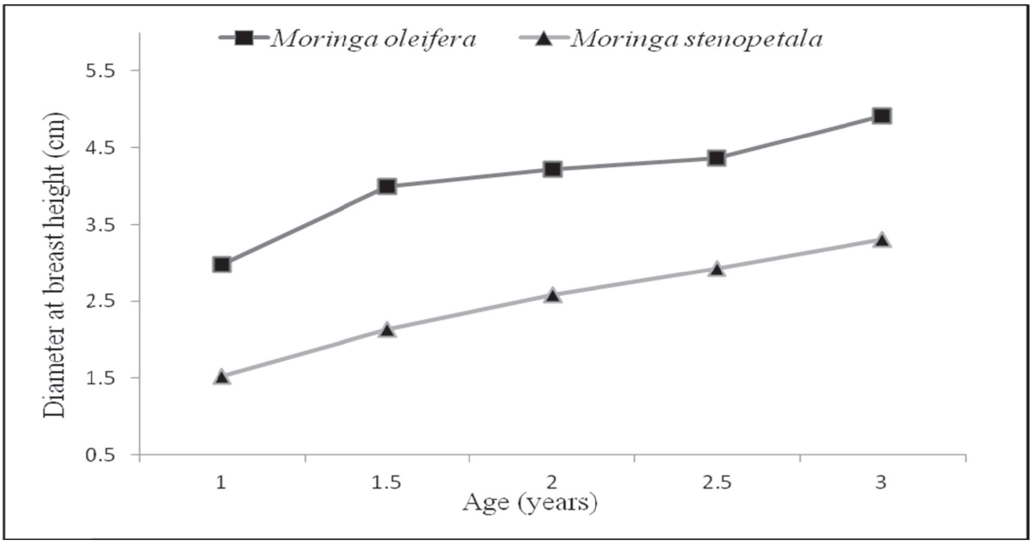

Figure 5. Diameter at breast height (DBH) growth as function of *Moringa* species age

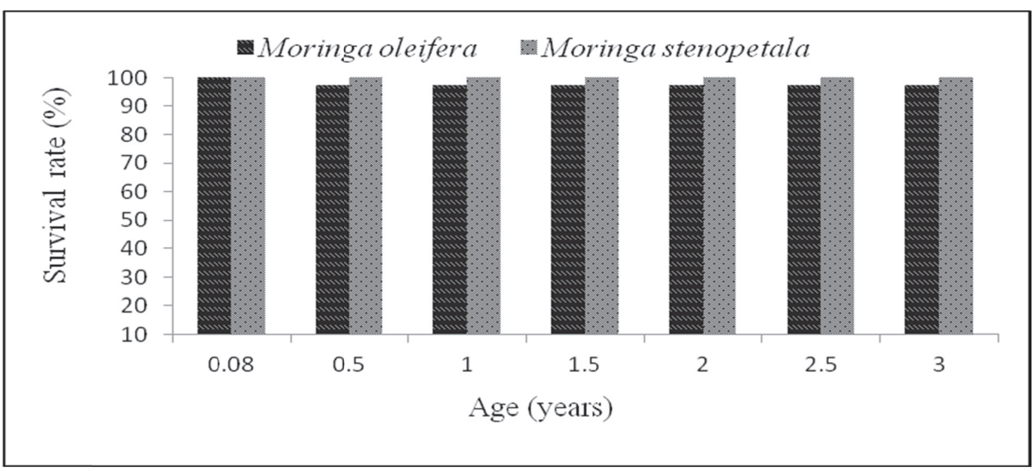

Figure 6. Survival as function of *Moringa* species age

Conclusion and Recommendation

Moringa oleifera was the most vigorous in height growth and root collar diameter showing promising performance under Bako conditions. Both species are multipurpose tree of significant economic importance, i.e., vital nutritional, industrial, and medicinal applications. To make use of the potentials of both *Moringa* species to the maximum, further technology specific (i.e., silvicultural, nutritional value, utilization and other management studies) and on-farm agroforestry practices should be carried out on these moringa species in the area.

For the immediate use, however, it is possible to recommend the following species for Bako area and for sites with similar agro-ecological conditions with Bako *Moringa* species for boundary planting, homestead/homegarden and woodlots establishment as source of provision of both direct (food, feed, wood, medicinal and water purification) and indirect potential benefits (soil and water conservation, shade and shelter, salinity control, etc) for the society and their domestic animals (NRC, 2006). So it should be given due attention by all concerned bodies and considering priority *Moringa* species to alleviate malnutrition, climate change mitigation and reduce poverty by demonstration, multiplication and scaling-up of both *Moringa* species.

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Adaptation and Growth Performance of Multipurpose Trees under Haro Sebu Condition, Kellem Wollega Zone, West Oromia, Ethiopia

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Abstract

This study was conducted to evaluate adaptability and growth performance of five tree species at Haro Sebu Agricultural Research Center, on-station, for four years (2011-2014). Seedlings of the species Grevillea robusta, Casuarina equisetifolia, Moringa stenopetala, Cordia africana and Mellitia ferrugenia were out-planted on plot of 12mx12m for each species based on their recommended spacing between and within row. Growth parameters, diameter (root collar diameter and diameter at breast height), height and survival rate were measured and recorded at interval of 3 months. As a result, height growth performances showed significant difference (p<0.000) for Grevillea robusta, Casuarina equisetifolia and M. stenopetala. Similarly, root collar diameter revealed that there were highly significant differences (p<0.000) among the species. High mean value of root collar diameter was recorded for Grevillea robusta, Casuarina equisetifolia while it was low for Cordia africana and Mellitia ferrugenia. The basal area of the species showed high mean value for Grevillea robusta followed by Casuarina equisetifolia while Cordia africana had low mean value. The survival rate also showed that Moringa stenopetala was higher (84.72%) followed by Grevillea robusta (81.81%), Casuarina equisetifolia (73.86%), and Mellitia ferrugenia (73.33%), while survival of Cordia africana was the lowest (40%). Thus, poor survival and growth performance were observed on Cordia africana that might be explained as response to the specific site condition of the study area. Generally, these findings may help forest managers (stakeholder) to properly allocate species into the site that grow and adapt well. Further testing of provenances of the best performing species is recommended to select the most adaptable ones for such areas for future forest plantation establishment at wider scale on which success of forest plantations depend.

Introduction

Vegetation cover of the country in general and that of Oromia in particular has been decreasing from time to time at faster rate than one can imagine. The reduction in vegetation leads most productive area of the land to severe degradation. Land degradation is the process that lowers the current and/or potential capability of land to produce goods such as crops, livestock or timber, or to provide services such as unpolluted water (Muya et al, 1997). The failurity of the land to give such goods will have a direct negative effect on ecological, economical and soil value of the area.

The causative agents for land degradation are both biotic and abiotic, of which destruction of natural vegetation mainly forest by natural as well as man-made is the major priority problem in most developing countries like Ethiopia. As the land is degraded the biological composition will decrease and hence, reduction in economic growth, change in micro and macro climate, loss of valuable species, which in turn leads to the occurrence of wood and food insecurity become the periodical problem in the country.

Starting from some time ago, the reduction in land productivity due to land degradation touches the attention of many people from different fields of profession. Land degradation in the Ethiopian highlands (i.e. areas above 1500masl) has been a concern for many years (Lakew et al, 2000). To overcome this problem, research, bureau of environmental protection, responsible NGOs and other related professionals in collaboration with the local people have been trying to develop strategies for the rehabilitation purpose.

Some rehabilitation practices in many parts of the country for more than decades have been area closure, reforestation, enrichment planting and others.

All the above mentioned approaches have their own limitations like in area closure method there should be soil seed bank which can regenerate after the area is closed against any external interference. In reforestation program, the soil should have some fertility in order to support the planted tree for initial growth and likewise enrichment planting is practical in areas where the biological entities are less disturbed.

But in areas where there is no soil seed bank, lack of soil fertility for initial plant growth and highly disturbed that mean under severe degradation, the rehabilitation strategies listed might not be as such practical. So, such area needs special concern to develop land modification as an alternate method through fertilization and put in practical to rehabilitate.

There is a large gap between demand and supply of forest, agricultural commodities and other basic necessities in the country, such an imbalance between demand and supply of is imposing more pressure on the existing forest land through encroachment, overgrazing and unplanned legal and illegal felling.

Similarly, in the particular area the forest coverage are degraded, so to cope up with such challenges developing tree species for agro-forestry and forestry activities through evaluating their adaptability and growth performance as well as selecting best performed tree species to the area are the best alternative option.

Materials and Methods

Description of the study site

The study was conducted at Haro-Sebu Agricultural Research Center from 2011-2014, on-station which is located in Kellem Wollega Zone of Oromia. It is found at 550km away from Finfinne/Addis Ababa, 89 and 110 km from the nearby towns, Dambi Dollo and Ghimbi, respectively. The elevation of the center is 1300-2000masl, average temperature 23-34^{0}c, rainfall 1000-1300mm and is conducive for agricultural production system under rain-fed in the present climatic conditions.

Methodology

Seeds of the species (*Moringa stenopetala, Grevillea robusta, Casuarina equisetifolia, Cordia africana* and *Mellitia ferrugenia*) that used for the experiment were obtained from Forestry Research Centre. Seedlings were raised directly into polythene tubes at Haro-Sebu Agricultural Research Center on-station with the recommendation of nursery activities. One to two seeds were put in polythene tubes and the weak ones were removed out (transplanted to other polythene tubes) sometime after emergence. Seedlings were out-planted by complete block design on plot size of 12mx12m for each species. Spacings between rows and within rows were based on recommendation of each species. In order to fit the given objectives, data were collected on the following parameters, date of sowing, date of emergence, date of planting, growth parameters diameter (root collar diameter, RCD and diameter at breast height,DBH), height and survival rate. RCD were collected only up to the tree reaches 1.3 meters in height whereas height and survival were up to the end of the period of the activity by interval of 3 months. Finally, data collected were analyzed using statistical package (SAS and Minitab).

Results and Discussion

Average survival rates of the five species under this study revealed that *M. stenopetala* was highest (84.72%) followed by *G. robusta* (81.81%), *C. equisetifolia* (73.86%) and *M.ferrugenia* (73.33%), but survival of *Cordia africana* was the lowest (40%), (Figure 1 and Table 1).

The poor survival and growth performance observed on *Cordia africana* might be explained as response to the specific site condition of the study area. Soil and below ground competition are also other factors that influence the growth and survival rate (Casper and Jackson, 1997).

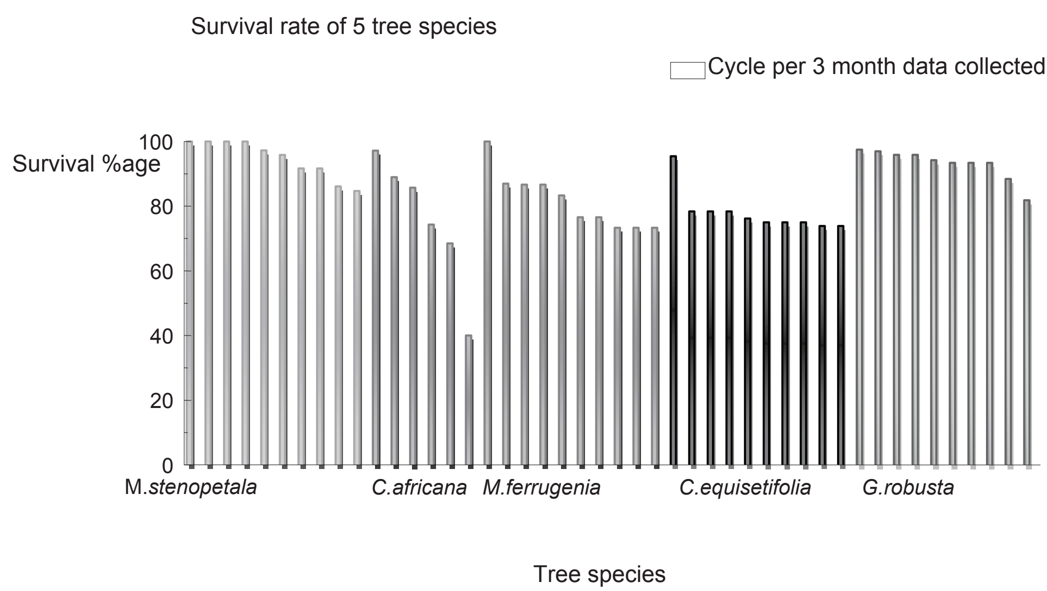

Figure 1. Sequence of Survival (%) for *Moringa stenopetala*, *Cordia africana*, *Mellitia ferrugenia*, *Causuarina equisetifolia*, *Gravillea robusta* through sequential periods from March 2011 to June 2014. Most of *Cordia africana* were died after the six cycles due to specific site problem.

Table 1. Mean survival rate (%) of *Moringa stenopetala*, *Cordia africana, Mellitia ferrugenia*, *Causuarina equisetifolia* and *Gravillea robusta* through sequential periods from March 2011 to June 2014

Tree Species	Survival rate (%)
Casuarina equisetifolia	73.86
Cordia africana	40
Grevillea robusta	81.81
Mellitia ferrugenia	73.33
`Moringa stenopetala	84.72

Height and diameter growth

Statistical analysis revealed that there were highly significant differences in height among the species ($p<0.000$). *Grevillea robusta*, *Casuarina equisetifolia* and *M. stenopetala* were the species that attained the highest mean height values, while *Cordia africana* and *Mellitia ferrugenia* had the lowest height (Figure 2).

Similarly, the root collar diameter revealed that there were highly significant differences ($p<0.000$) among the species and the basal area of the species showed high mean value on *Grevillea robusta* followed by *Casuarina equisetifolia,* but *Cordia africana* had low mean value (Figure 2).

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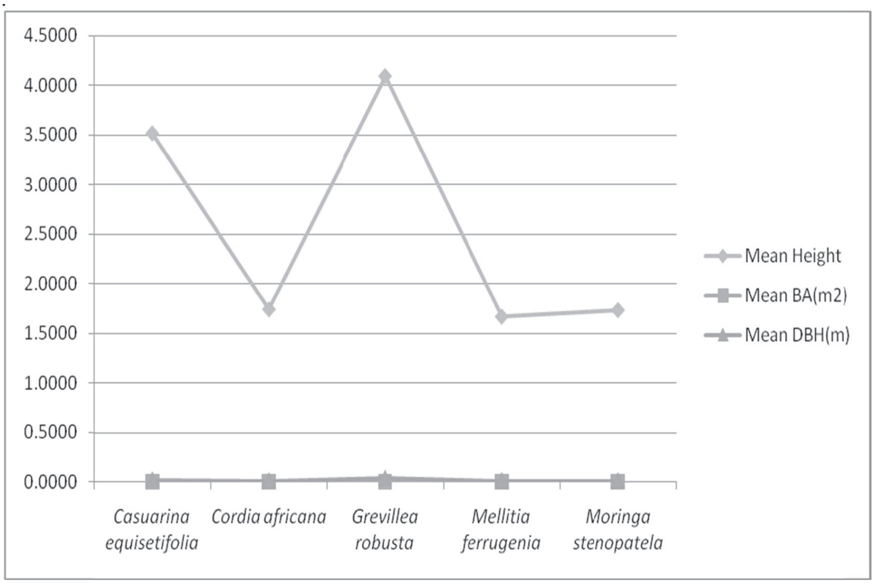

Figure 2. Growth of mean height (m), mean Basal area (BA (m^2)), mean diameter at breast height (DBH (m)) for *Moringa stenopetala*, *Grevillea robusta*, *Casuarina equisetifolia*, *Cordia africana* and *Mellitia ferrugenia*

Relative growth rate

The analysis of variance for relative height and diameter growth rates for the selected species showed highly significant differences. The comparisons between the height and diameter at breast height averages for the species showed that *Grevillea robusta* had the highest average height followed by *Casuarina equisetifolia and Moringa stenopetala*. Similarly, the basal area of the selected species showed highly significant differences ($p<0.000$) among the species. The highest mean basal area was recorded by *Grevillea robusta* followed by *Casuarina equisetifolia and moringa stenopetala,* while the lowest mean basal areas were recorded from *Cordia africana* and *Mellitia ferrugenia* (Table 3).

Results on the growth performance also showed that *Grevillea robusta*, *Casuarina equisetifolia*, *Moringa stenopetala* were higher than the other species. Thus, increase their importance for soil conservation in the area, since trees with fast growth habit can shorten establishment period and protect the soil from excessive soil erosion. Similarly, Raebild et al. (2003) also stated that apart from indicating productivity, height may also be seen as a measure of the adaptability of trees to the environment as tall trees usually better adapted to the site than short trees (Cossalter, 1987). *M. stenopetala* could also play a great importance in the rehabilitation process especially during periods of drought or in areas where nutrient resources are not available. Several similar studies also showed that fast growth of seedling is an important indicator in terms of determining the situation of growth response especially in the first growing period and it is commonly assumed that the early fast growth rates of tropical trees reflect productivity status of the trees (Baris and Ertenkin, 2010).

Table 2. Mean height, diameter at breast height, basal area and survival rate of *Moringa stenopetala, Grevillea robusta, Casuarina equisetifolia, Cordia africana* and *Mellitia ferrugenia*

Tree species	Mean Ht(m)	Mean DBH(m)	BA(m^2)	Survival Rate
C.equisetifolia	3.513^{b}	0.02035^{b}	4.23E-04^{c}	73.86
C.africana	1.744^{cd}	0.01099^{cd}	1.15E-04de	40
G.robusta	4.088^{a}	0.03552^{a}	1.20E-03^{a}	81.81
M.ferrugenia	1.670^{cd}	0.01276^{cd}	1.55E-04^{cde}	73.33
M.stenopetala	1.736^{d}	0.01162^{c}	1.27E-04^{d}	84.72

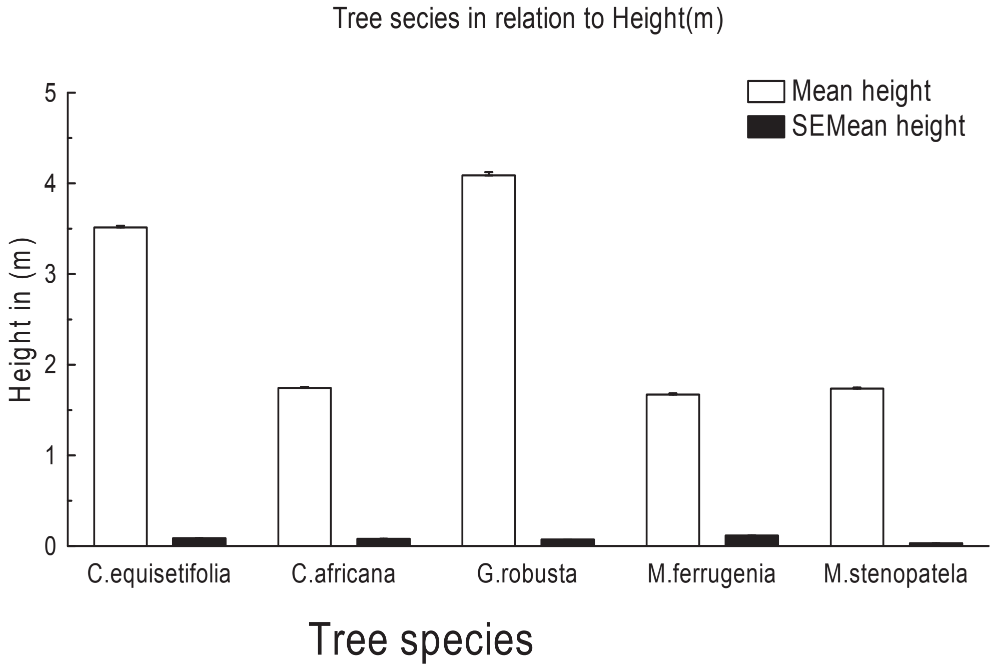

Figure 3.Growth of height for *Moringa stenopetala, Grevillea robusta, Casuarina equisetifolia, Cordia africana* and *Mellitia ferrugenia*

Conclusion and Recommendation

The result revealed that the survival rate of *Moringa stenopetala* was the highest followed by *Grevillea robusta* and *Casuarina equisetifolia*. While *Mellitia ferrugenia* and *Cordia africana* showed poor survival rate. Poor survival and growth performance might be explained as response to the site condition and termite problems of the study area. *Grevillea robusta*, *Casuarina equisetifolia* and *M. stenopetala* were the species attained the highest mean heights, while *Cordia africana* and *Mellitia ferrugenia* species had the lowest values.

The comparisons between the height and diameter at breast height averages for the species showed that *Grevillea robusta* had the highest average height followed by *Casuarina equisetifolia* and *Moringa stenopetala*.

Generally, results on the growth performance showed that *Grevillea robusta*, *Casuarina equisetifolia* and *Moringa stenopetala* had better performance than *Mellitia ferruginea* and *Cordia africana*. Therefore planting of these better performing tree species and increase their promotion as agro-forestry practices were recommended as important for soil conservation, timber production, shading, and in general multifunction purposes in the area.

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Early Survival Evaluation of Different Agro-forestry Trees and Shrubs under Moisture Conservation Structures at Hawi Gudina District, West Hararghe Zone, East Oromia, Ethiopia

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Abstract

The ever-increasing demand for biomass energy in developing countries like Ethiopia seeks urgent attention. Tree growth depends on genetic potential of the species and environmental conditions. Thus, this study was conducted at Hawi Gudina District during 2010-2013 to evaluate early survival of different agro-forestry trees/shrubs (Melia azedarach, Moringa oleifera, Leucaena leucocephala, Grevilia robusta and Sesbania sesban) for their adaptability under three different moisture conservation structures. The main effect of moisture conservation structures was not significant. But highly significant variations among species in survival rate (P<0.01) were recorded at all three years of age. Among the species tested, Moringa oliefera and Melia azedarach showed superior performance with survival rate of 100% followed by Sesbania sesban with value of 88.9%. Though there was no significant difference in survival of trees/shrubs with respect to different planting methods, the mean survival of seedlings planted in half-moon (80%) was higher than in normal pit (73.33%) and trench (60%) in three years after establishment. Similarly, species planted in half-moon had relatively higher diameter and height size followed by trench micro catchment. Moringa oliefera, Melia azedarach and Sesbania sesban with half-moon planting method offered much promise for future use in agro-forestry practices in the area and similar agro-ecologies.

Key words: Half-moon, Normal pit, Trench, Moisture, Survival rate

Introduction

In Ethiopia, rapid deforestation caused by escalating demand for fuel wood and expansion of land for agriculture has brought an ever increasing pressure on native woodland species (Mebrate *et al*., 2004). Some reports indicate that the remaining forest and woodland cover in Ethiopia is estimated to be diminishing annually at rate of 160,000 to 200,000 ha (Anonymous, 1994). If no remedial action is taken, this will cause severe impact on agricultural productivity leading to poverty of energy and environmental degradation. Indigenous tree and shrub species play considerable role in addressing such multi-faceted demands in mixed crop-livestock production systems (Betre *et al*., 2000). They have the ability to fit into farming systems to use as source of manure, soil conservation, fuel wood, farm implements and others like shade and shelter (Kahsay *et al*., 2001). Before introducing any species to a given agro-ecology, there is always a need for a well conducted field trial for matching of the species to a particular site (Zobel and Jabret, 1984; Abebe *et al*., 2000; Mebrate *et al*., 2004). The most reliable information is based on trial planting in the proposed plantation area (Saville *et al*., 1996). The first trial should be species screening trial that will test the survival and early growth performance of the species in one to three years (Eldridge *et al*., 1994). The objective of conducting this trial was, therefore, to select the best performing multipurpose agro-forestry trees/shrubs species with suitable planting methods in low moisture stress areas of Hawi Gudina District.

Materials and Methods

Description of the study site

Hawi Gudina District is located at distance of 519 km and 180 km from finfinne/Addis Ababa and Chiro zonal capital, respectively. The district is situated between 7˚52`15`` and 9˚25`43``N and 40˚34`13`` and 41˚9'14" E. The topography of the district is mainly flat lowland with altitudes ranging from 976 to 2077masl. Agro-ecologically it is divided into Kola (83.8%), Weina Dega (12.9%) and Dega (3.3%). Annual rainfall of the district is between 500-900mm/year whereas mean minimum and maximum temperatures reach 14˚C to 35˚C, respectively with average of 25˚C. The pattern of rainfall is bimodal and its distribution is mostly uneven. Generally, there are two rainy seasons: the short rainy season 'Belg' lasts from mid-February to April whereas the long rainy season 'kiremt' is from June to September. The rainfall is erratic, onset is unpredictable, and its distribution and amount are also quite irregular.

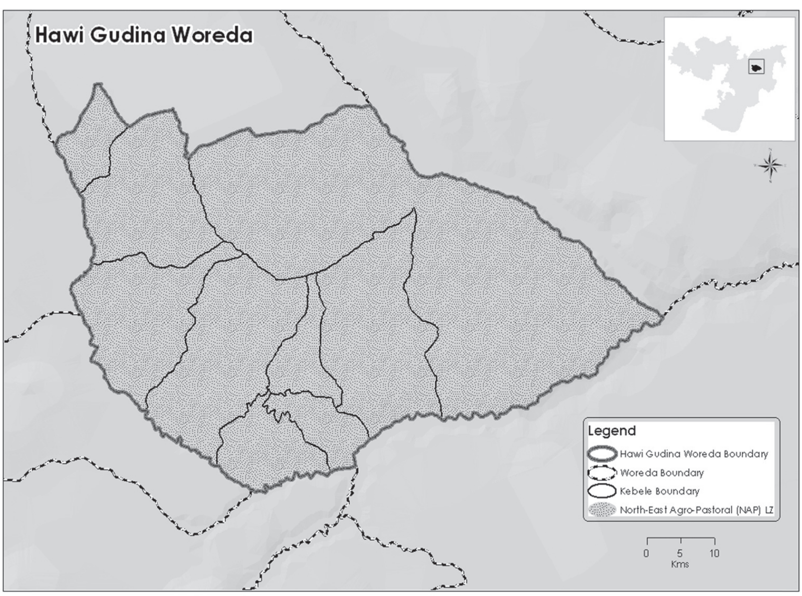

Figure 1. Map of Hawi Gudina District (adapted from Oromia Livelihood Zone Reports)

Seed source, nursery and field management

Seeds of the species were obtained from local mother trees/shrubs. Seedlings were raised in polythene tubes of size 10cm diameter and 15cm length at Mechara nursery site in medium of 2 parts forest soil, 1 part local soil and 1 parts sand soil. The out planting site was cleared of bushes and the moisture conservation structures (planting methods) were prepared before planting the seedlings. Planting holes of size (40cm width by 40cm depth) were dug and seedlings were out-planted manually in July, 2010. The plantation site was fenced and thorough management was carried out until all necessary data were taken.

Experimental design and layout

The experiment was laid out in factorial randomized complete block design with three replications. Each plot contained three plants with 3m spacing between plants. Space between replications was 1m and space between plots and blocks was 1.5m. Structures used: *Half-moon* (semicircular micro basin) was prepared with diameter of 1.5 m, space across the slope 0.5 m, ridge around periphery 30cm high and 60cm wide, down the slope in staggered manner 2m apart. *Trench* was prepared with depth of 50 cm, width 50cm, and space across the slope 0.5 m, along the slope in staggered manner 2m apart and *normal pit* was prepared with diameter 40cm and depth 40cm.

Data collection and analysis

Data for survival count, above ground tree height and diameter at breast height (DBH) were collected. Survival rate was calculated as the proportion of surviving trees to total number of trees of the same species planted at the begining,whearas height and DBH were analysed as the mean of surviving trees of the same species. Plot means for three variables were calculated to two decimal places and subjected to unbalanced analysis of variance (ANOVA) using Genstat stastical tool since the treatments are not equally replicated in each blocks. Treatment comparisons of means were made at 5% level of siginificance using least siginificunt difference test (Steel and Torrie,1980), independantly and dependantly. Independant analyses were excuted for trees/shrubs and then combined analysis was done to observe if there were significant variation among species in relation to planting techniques.

Results and Discussion

The analysis of variance revealed that interaction of tree/shrubs survival with planting methods was insignificant at 1, 2 and 3 years of age after transplanting. The main effect of moisture conservation structures was also not significant (Table 2). But highly significant variations among species in survival rate ($P<0.01$) was recorded at all three years of age. *Moringa oliefera*, *Melia azedarach* and *Sesbania sesban* showed good performance among tested trees/shrubs species, while *Leucaena leucocephala* performed least among tested species. The survival trend for three species showed declining trend except *Moringa oliefera* and *Melia azedarach* which maintained their survival rate for all the assessment period (Table 1).

Table 1. Mean survival rate (%) of species planted in Hawi Gudina District

Tree,shrub	Stage (age) of seedling after out-planting		
	Year 1	Year 2	Year 3
Moringa oliefera	100^{a}	100^{a}	100^{a}
Melia azedarach	100^{a}	100^{a}	100^{a}
Grevilia robusta	100^{a}	88.9^{a}	55.9^{b}
Sesbania sesban	100^{a}	100^{a}	88.9^{a}
Lucena leucocephala	22.22^{b}	11.11^{b}	11.11^{c}
CV (%)	24.33	26.57	42.84
P-value	<0.0001	<0.0001	<0.0001

NB: *Means in columns with the same letters are not significantly different using LSD*

Although there was no significant difference in survival rate of trees/shrubs with respect to different planting methods during the study periods, the mean survival of seedlings planted in half-moon (80%) was higher than in normal pit (73.33%) and trench (60%) after three years of establishment (Table 2).

Table 2. Mean survival rate of the tree/shrubs species in different planting methods at three ages

Panting method	Mean survival rate (%) of trees/shrubs at different ages		
	Year 1	Year 2	Year 3
Half moon	93.33[a]	86.67[a]	80[a]
Normal pit	80[a]	73.33[a]	73.33[a]
Trench	80[a]	80[a]	60[a]
P-value	0.577	0.727	0.281
CV (%)	44.22	50.63	62.43

The effects of DBH and height of trees/shrubs planted in different planting methods is presented in Tables 3 and 4. Among the species tested, *Luecenea lucenophela* demonstrated the highest height growth (3.25 m) while *Grevilia robusta* showed the least (2.22 m) at age of three years (Table 4). Variations were also recorded among the species in DBH in which *Moringa oleifera* demonstrated the highest diameter (2.84 cm) while *Grevilia robusta* showed the least (1.33cm) three years after establishment (Table 3). The variation in growth parameters are attributed to the type/nature of species. With respect to planting methods, species planted in half-moon relatively had higher DBH and plant height followed by trench micro-catchment.

Table 3. Diameter at breast height of tree/shrubs species in different planting methods after three years of establishment

Planting method	Trees/shrubs					**Mean**
	Moringa oliefera	*Melia azedarach*	*Grevilia robusta*	*Sesbania sesban*	*Luecenea lucenophala*	
Half Moon	2.97	3.07	-	2.47	-	**2.84**
Normal pit	2.65	1.44	1.17	1.98	2.53	**1.95**
Trench	2.89	2.39	1.48	1.3	-	**2.02**
Mean	**2.84**	**2.30**	**1.33**	**1.92**	**2.53**	

Table 4. Plant height of tree/shrubs species in different planting methods after three years

Planting method	Trees/shrubs					**Mean**
	Moringa oliefera	*Melia azedarach*	*Grevilia robusta*	*Sesbania sesban*	*Luecenea lucenophala*	
Half Moon	2.96	3.2	-	3.23	-	**3.13**
Normal pit	2.19	1.93	1.99	3.2	3.25	**2.51**
Trench	2.83	3.13	2.44	2.9	-	**2.83**
Mean	**2.66**	**2.75**	**2.22**	**3.11**	**3.25**	

The species tested showed highly significant survival rate differences among each other. The choice of adaptive species may, therefore, be decisive for success or failure of future planting. Natural selection tended to produce populations that are well adapted to the conditions in which they evolved. Whether or not a tree/shrub species has a natural distribution within which environmental conditions vary, it will probably show genetic variation. It had been reported that 80% survival rate in plantation development (Evans, 1996) is acceptable. The survival that recorded in this experiment for *M. oliefera, M. azedarach, S. sesban* and *G. robusta* by far exceeded this survival threshhold rate, although the remaining species were far below the acceptable survival threshold. *M. oliefera* had comparable survival rate to *M. azedarach* and *S. sesban*. In addition, half-moon micro catchment was promising and suitable planting method for these species since it relatively increased survival and other growth parameters compared to trench and normal pit.

Conclusion and Recommendation

Three years after establishment, the result revealed that survival rate of trees for the interaction was not significant, strongly indicating it was not influenced by the combined treatments (tree species and structures). The objective of managing multipurpose trees/shrubs for low moisture stress areas is to provide the best adapted species with most useful planting methods which give various services. With their good survival and outstanding height and diameter growth, *Moringa oliefera*, *Melia azedarach* and *Sesbania sesban* planted in half-moon were the most promising among the species tested at Hawi Gudina District. Therefore, *Moringa oliefera*, *Melia azedarach* and *Sesbania sesban* had showed potential to be used as fuel wood, soil conservation, farm implements and others like shade and shelter and medicinal plantation species in Hawi Gudina and in other areas with similar agro-ecology.

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Evaluation of Dry Nursery Management for Coffee Seedlings in Semi-arid and Arid Areas of Daro Labu and Habro Districts of West Hararghe Zone, East Oromia, Ethiopia

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Abstract

The success of plantation program depends to a great extent on success of nursery. Nursery depends on condition and bed type. Beds can be made of three types (raised bed, sunken bed and level bed). The experiment on evaluation of dry nursery management for raising of coffee seedlings was undertaken in arid and semi arid areas of Daro Labu and Habro districts in randomized complete block design with six replications (peasant associations (PAs as replication) in 2013/14 and 2014/15 cropping seasons. Coffee (improved variety Mehara-1) was sown in sunken bed with different treatments (bare root without plastic sheet, bare root with plastic sheet, polyethylene tube without plastic sheet and polyethylene tube with plastic sheet) and normal bed (level bed) as control. Two years data of survival rate, root-shoot ratio, and seedling height and germination percentage were collected and analyzed. The result revealed that there was significant difference ($p<0.05$) in survival rate during first and second years in which bare root without plastic sheet, polyethylene tube without plastic sheet and control showed higher performance than bare root with plastic sheet and polyethylene tube with plastic sheet. Bare root without plastic sheet and polyethylene tube without plastic sheet offered much promise for nursery management for future use in arid and semi-arid areas of the study areas and similar agro-ecologies.

Key words: Dry Nursery**,** Sunken Bed**,** Percentage, Survival Rate, Root-shoot ratio

Introduction

Arid and semi-arid environments are generally very fragile. These environments are associated with low and unreliable rainfall and relatively high temperature. The best example is districts found in West Hararghe Zone where about 70% of land lies in these environments (Farming system of Daro Labu and Boke districts, Mechara Agricultural Research Center unpublished); thus resulting in limited water resources and difficulty for establishment of seedlings and other farming system.

Though rich in natural resources, the increased human pressure on forests and woodlands has created conditions conducive to degradation, deforestation and desertification. There is therefore, great demand for reforestation/afforestation technologies that can promote restoration and management of forests.

The success of plantation program depends to a great extent on success of nursery. If we can produce good and healthy stock in nursery, we can successfully cope up with the plantation target. Nursery practices must be consistent and the various techniques closely integrated. If one element in the chain is lacking there will be a negative impact on seedling quality. Good quality seedlings cannot be produced and sustain without care. Nursery plants need to be protected from extremes of environmental conditions until they are strong enough to withstand.

The nursery industry continues to develop new production methods that encourage the growth of more fibrous roots, preserve more roots at transplanting time, improving root circling in production beds, and prevent root mortality due to thermal heat loading (Appleton, 1993, 1994 and1995). Nursery usually depends on weather condition and bed type. Beds can be made of three types (raised bed, sunken bed and level bed). Based on irrigation facility and in the nursery, raised beds are used in areas with high water tables, sunken ones are used in semi-arid and arid areas while flat beds are used in intermediate areas (Anonymous, 1996).

Dry nursery is nursery maintained without any irrigation or artificial watering like in underground seed bed (sunken bed). Such beds can easily resist the drought with its underground moisture conservation, during dry season. It is also in dry regions, especially on sandy soils with low water-holding capacity, vegetables can be planted in sunken beds. Sunken beds were laid out 30 to 50cm deep from the ground level in order to collect run-off water from adjoining areas and reduce evaporation loss from the sides and conserve water much more effectively than raised beds for two reasons. First, it doesn't have the exposed sides as raised beds from where considerable moisture can be lost by evaporation, and second none of the applied water is lost by runoff (Luna, 2006).

According to Anonymous (1996), the nature of the bed affects the conditions for survival rate and other growth parameters. Preparation of sunken bed could be with plastic sheet under the floor base of beds; this system could be used for controlling root growth penetrating into the ground and save water for seedlings, when moisture availability was good at the first sowing time. This mechanism assumes that water intake of plant/day was saved as compared to normal earthen bed and water requirement of seedlings could be reduced. The objective of conducting this trial was, therefore, to select the best seed bed type that could sustain seedlings in dry period during summer, especially for arid and semi-arid areas of these districts in West Hararghe Zone.

Materials and Method

Description of the study area

The study was undertaken in Habro and Daro Labu districts of West Hararghe Zone that are located to south of Chiro town, the capital of the zone, at distance of 70 and 110km respectively. The altitude range for Daro Labu District is 1350 to 2450masl with area coverage of 434,280 ha whereas that of Habro District varied from 1464 to 2450masl with total area of 730.32 square kilometers (CSA, 2005). Their latitudinal and longitudinal positions are $40^{0}19.114$ East and $08^{0}35.589$ N for Daro Labu District; and $8^{o}36.06$'North latitude and $40^{o}20$'.76''East longitude for Habro District. Both districts have bimodal type of rainfall distribution with average annual rainfall of 1094mm and mean annual temperature $20^{o}C$ (Mechara metrological station 2009-2014) for Daro Labu District and Habro District is 1, 010mm annual rainfall with mean annual temperature of $18.5^{o}C$.

The nature of rainfall in the area is very erratic and often unpredictable causing tremendous erosion. The predominant production systems in the districts are mixed crop-livestock production. The crops grown in the area includes food crops like teff, maize, sorghum, pulses as well as cash crops such as coffee and chat, mango, avocado and citruses are also grown to some extent. The major soil type of the area is Nitisol and its texture is sandy loam clay which is reddish in color particularly in Daro Labu District (Report on farming system of Daro Labu and Boke districts, Mechara Agricultural Research Center unpublished). Nitisol in its lowland part and Vertisol in mid-land are the major soil types found in Habro District. Three PAs that were more or less found at the same level of altitude from each district were selected to conduct the trial (Table 1).

Table 1. PAs where nursery was established in Daro Labu and Habro districts in 2013 & 2014

SN	District	PA	Distance from Chiro town	Altitude
1	Daro Labu	Satewa/Burakisa	14 km from Mechara town	1633m.a.s.l
		Haroresa-qile	23 km ,,	1635 ,,
		Sakina	25 km ,,	1668 ,,
2	Habro	Gerbigoba	3 km from Gelemso town	1703 ,,
		Lagabera	5 km ,,	1707 ,,
		Ibsa	15 km ,,	1701 ,,

The monthly rainfall pattern in 2013/14 and 2014/15 cropping season taken at Mechara (Daro Labu) and Gelemso (Habro) stations is depicted in Figures 1 & 2. The rainfall amount in the second year (2014/15) was recorded low as compared to the first year which has impacted on seedling survival and other growth indicators.

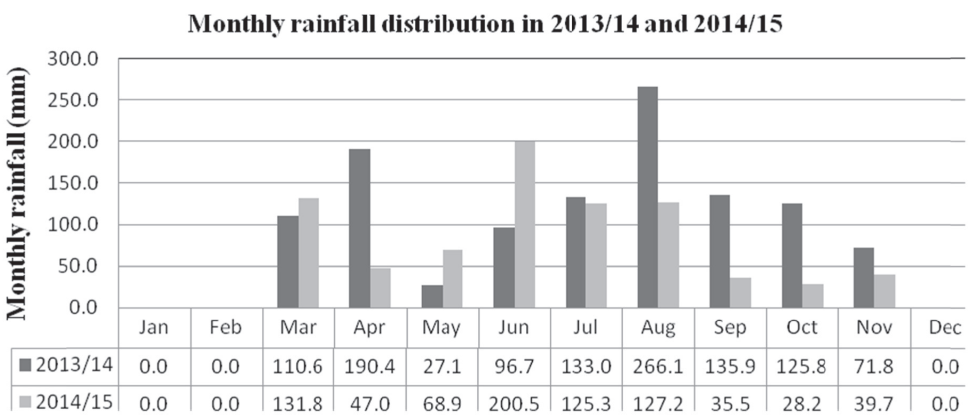

Figure 1. Monthly rainfall distribution in 2013/14 and 2014/15 at Mechara station

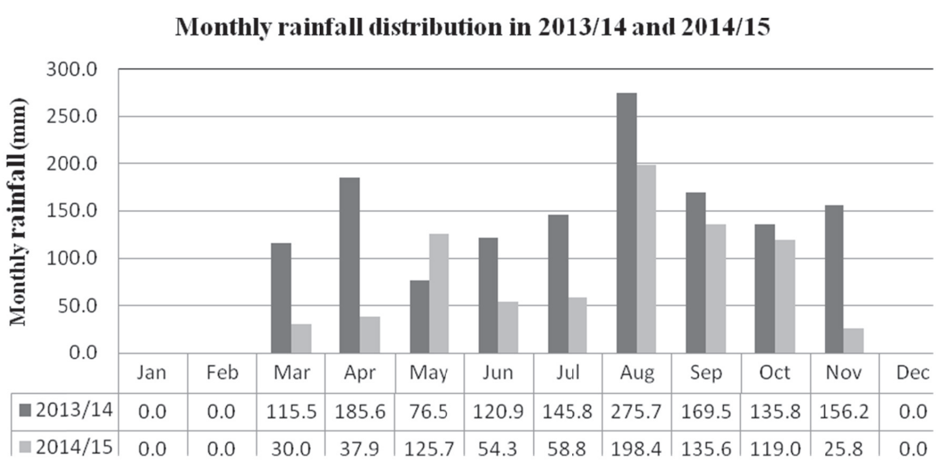

Figure 2. Monthly rainfall distribution in 2013/14 and 2014/15 at Gelemso station

Experimental design and layout

The experiment was laid out in randomized complete block design with six replications (peasant associations were used as replication). Sunken bed was prepared below the general level of the path, because the level path would facilitate underground moisture and it is beneficial in dry soil and well drained localities (Luna, 2006). The sizes of sunken beds were 6m length x1m width x 30 cm depth. The underground plastic sheet had the size of 80cm width and 2.6m length. For bare root, in both sunken beds with plastic sheet and without plastic sheet the soil was refilled to the length of polyethylene tube (22cm). As control, level bed of the same size as of sunken beds was laid in east west directions above the ground. The seeds of coffee (variety Mechara-1) were direct sown on prepared seed bed in all treatments before on-set of rainy season.

Treatments (sunken bed had four treatments + level bed as control):

1. Sunken bed with underground plastic sheet + polythelene tube
2. Sunken bed with underground plastic sheet + bare root
3. Sunken bed without underground plastic sheet + polythelene tube
4. Sunken bed without underground plastic sheet +bare root
5. Level bed (control)

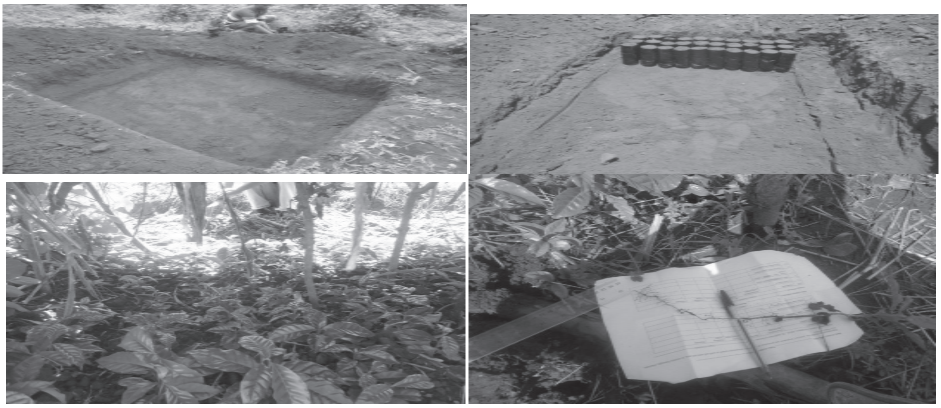

Figure 3. Sunken bed preparation up to final data taking of dry nursery management trial

Data collection and analysis

Data for germination percentage, survival rate, root-shoot ratio and seedling length were collected. Germination percentage was analysed as the proportion of germinated seeds to total number of sown seeds, whearas survival rate was analysed as the proportion of surviving seedling to germinated seeds. Root-shoot ratio was analysed as the ratio of root to shoot and seedling length was the total length of surviving seedlings.

Plot means for four variables were calculated to two decimal places and analysis of variance was performed by stastical analysis (SAS in GLM). Treatment comparisons of means were made at $p < 0.05$ siginificance level using least siginificunt difference.

Results and Discussion

The statistical analysis revealed that there were no significant differences in germination percentage, root-shoot ratio and seedling length during 1st and 2nd years, while there were significant difference in survival rate in 1st and 2nd years in which bare root without plastic sheet, polyethylene tube without plastic sheet in sunken bed and level bed (control) showed higher performance over other treatments.

The study revealed that during the first year all treatments gave <1 root-shoot ratio which means shoot growth exceeded root growth and in the second year, root-shoot ratio >1 for bare root without plastic sheet, polyethylene tube without plastic sheet and control signifying root growth exceeded shoot growth due to shortage of moisture occurred in that year. The result is in agreement with the study of Niklas (1994) and Hunt and Nicholls (1986) that reported root-shoot ratio increased in dry period (roots grow more as compared to shoot in search of moisture to enhance survival of the seedlings). Besides, seedling length measured for level bed (15.67cm), bare root without plastic sheet (17.50cm) and polyethylene tube without plastic sheet (16.83cm) in sunken bed were in agreement with standard seedling length of 15-40cm for out-planting particularly in first planting year. But in the second year it didn't reach standard size due to drought (Table 2).

Table 2. Mean germination percentage, survival rate, root-shoot ratio and seedling length at Habro and Daro Labu districts in 2013/14 and 2014/15 cropping seasons

	Parameters means in 2013/14 and 2014/15							
	Germination (%)		Survival rate (%)		Root to shoot ratio (cm/cm)		Seedling length (cm)	
Treatment	2014	2015	2014	2015	2014	2015	2014	2015
Control	77.67[b]	49	71.91[ab]	44.79[a]	0.83	1.50	15.67	10.84
Bare root without plastic sheet in sunken bed	85.67[ab]	69	86.98[a]	77.25[a]	0.78	1.53	17.50	12.75
Poly tube without plastic sheet in sunken bed	84.33[ab]	57.5	84.09[a]	66.27[a]	0.85	1.73	16.83	11.54
Bare root with plastic sheet in sunken bed	90.00[a]	54.5	50.64[b]	0[b]	0.54	-	13.00	-
Poly tube with plastic sheet in sunken bed	88.00[ab]	53	49.75[b]	0[b]	0.56	-	12.50	-
LSD (5%)	11.07	28.59	30.29	40.616	0.43		6.41	
CV (%)	10.79	32.79	36.62	69.99	50.67	34.47	35.24	11.20

Conclusion and Recommendation

Survival and growth characteristics of seedlings at their early growth are highly affected by environmental conditions. The prevailing conditions in arid and semi-arid areas like in most districts of West Hararghe Zone are low and erratic rainfall pattern and have limited/no irrigation water sources. In these areas use of appropriate nursery management is necessary. Dry nursery management is among available options in the area. The result from the study confirmed that use of sunken bed without lining with plastic sheet and sowing seed bare root or with polyethylene tube increased survival and other growth characteristics of coffee seedlings. Thus, bare root without plastic sheet and polyethylene tube without plastic sheet could be used to survive seedlings in dry areas.

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Non-timber Forest Product Research

Adaptation and Growth Performance of Different Lowland Bamboo Species at Bako on-station, East Wollega Zone, West Oromia, Ethiopia

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Abstract

Bamboo is faster growing non-timber tree species than other trees and starts to yield within three or four years of planting. Even though Ethiopia is one of the most endowed countries in having huge coverage of bamboo resource in Africa, the country has narrow genetic diversity only has two species, Yushania alpine (highland bamboo) and Oxytenanthera abyssinica (lowland bamboo). The adaptation of lowland bamboo at Bako Agriculture Research Center was conducted from 2010 to 2013 to evaluate the adaptability potential of different provenance of the species and to provide the best performing species around Bako areas. Based on the objectives, four different lowland bamboo species were collected from Debrezit Agriculture Research Center and Forestry Research Center. The species were Oxythenantera abyssinica, Guadua amplexofolia, Dendrocalamus hamlitonii and Dendrocalamus memebranceous. Among these species only Oxytenanthera abyssinica was indigenous and the rest were exotic. The experiment was laid out in randomized complete block design with three replications. The selected bamboo species had no problem on survival and adaptability at Bako area except some growth variations. Dendrocalamus hamlitonii showed high difference in new emerging shoots, internodes length, culm height and culm diameter, whereas Guadua amplexofolia revealed low in all growth parameters. Based on these results, Dendrocalamus hamlitonii, Dendrocalamus memebranceous and Oxythenantera abyssinica were recommended for different productions since they had good internodes length, ability to emerge new shoots, culm height and diameter while the growth of Guadua amplexofolia was quite different when compared with others. Therefore, the adaptation of lowland bamboo under Bako and similar agro-ecologies is reliable and it is recommended for further economic and livelihood benefits for different stakeholders through expanding the plantation.

Key words: Bamboo, exotic, indigenous, lowland, plantation

Introduction

Bamboo is perennial plant, which belongs to the Poaceae (sometimes called Gramineae) family (Wang, 2006). In terms of taxonomy, it is considered as a giant grass. Ecologically, bamboo plants have tree-like functions (Dwivedi, 1993; John & Nadgauda, 2002). There are over 1,500 species of bamboo (Sharma, 1998) and Africa alone has 43 species (Kigomo, 1988). Ethiopia is one of the most endowed countries in area coverage of natural bamboo forest of the country that estimated to have about 1 million ha, which is about 7% of the world total and 67% of the African bamboo forest areas (Embaye ,2000).

Even though Ethiopia is one of the most endowed countries in having huge coverage of bamboo resource in Africa, the country has narrow genetic diversity only two species: *Yushania alpine (*highland*)* and *Oxytenanthera abyssinica (*lowland*)*. With only two species, it is very difficult to secure constant supply of bamboo raw materials for bamboo industries and local handcrafts.

Currently, there is indiscriminate forest loss and depletion hence the unique bamboo resource will be appearing before its economical and environmental advantage is appreciated, unless important reversing mechanisms could not take place (Yuming *et al.,* 2004). The current economic policy of the nation strongly urges development practitioners to contribute to the economic development of the country. By the year 2020, Ethiopia is envisioning to reach middle income countries of the world. In this regard bamboo can contribute more in generating income since it can be processed into products for domestic use and export market. It can also create employment opportunity to a considerable portion of the society and harness environmental degradation problems. However, research and development activity on bamboo resource of the country is scanty. Bamboo is not included in tree planting programs in which millions of tree seedlings have been established every year. Up to now only very limited research works have been undertaken, vegetative propagation of highland bamboo (Tesfaye and Yohannes, 2005), propagation of lowland bamboo by seed (Kassahun *et al*, 2003), utilization-suitability of *Yushania alpina* for oriented particle board (Seyum, 2005), the use of lowland bamboo as re-enforcement in construction (Zhaohua, 2004).

Lowland bamboo protects steep slopes, soils and water ways, prevents soil erosion, provides carbon sequestration and brings many other ecosystem services. Its extensive root network may help to prevent erosion. In the future bamboo may increase the bio-capacity by simultaneously increasing the area of fertile global hectares. It has immense potential in reducing CO_2 that is blamed for environmental pollution and the most valuable species for environmental protection. And also bamboo is fast growing and high yielding perennial plant with considerable potential to the socioeconomic development and environmental protection (Baghel *et al.*, 1998; Kumar *et al.,* 1998; Perez *et al.*, 1998). Therefore it is important to introduce and adapt exotic bamboos species of high economic value to improve the income of smallholder farmers to divers the genetic resources of bamboos species and for environmental protection in Ethiopia. Bamboo is versatile with very short growth cycle; it is high yield renewable natural resource for agro-forestry and engineering based products (Robert Henrikson, 2009). Based on all indispensable values of the species, the study of bamboo adaptation was started under Bako condition since 2010 with the objectives to evaluate adaptability potential of different provenances of lowland bamboo species and to provide the best performing lowland bamboo species for the area and similar agro-ecology.

Materials and Methods

Description of the study area

The study was conducted at Bako Agricultural research Center, on-station, which is located at 9^o 07' N latitude and 37^o 05' E longitude. The altitude is 1650masl. The long term weather information revealed that the area has unimodal rainfall pattern extending from March to October, but the effective rain is from May to September (Legesse *et al.*, 1987). The mean annual rainfall is about 1237mm, with peak in July. It has warm humid climate with mean annual minimum and maximum temperature of 13^{o}C and 27^{o}C, respectively and the mean annual temperature is 20^{o}C. Soils at the study site are dominantly reddish brown Nitisols. They are generally clay dominated with pH of 5-6 in surface soils (Legesse *et al.*, 1987).

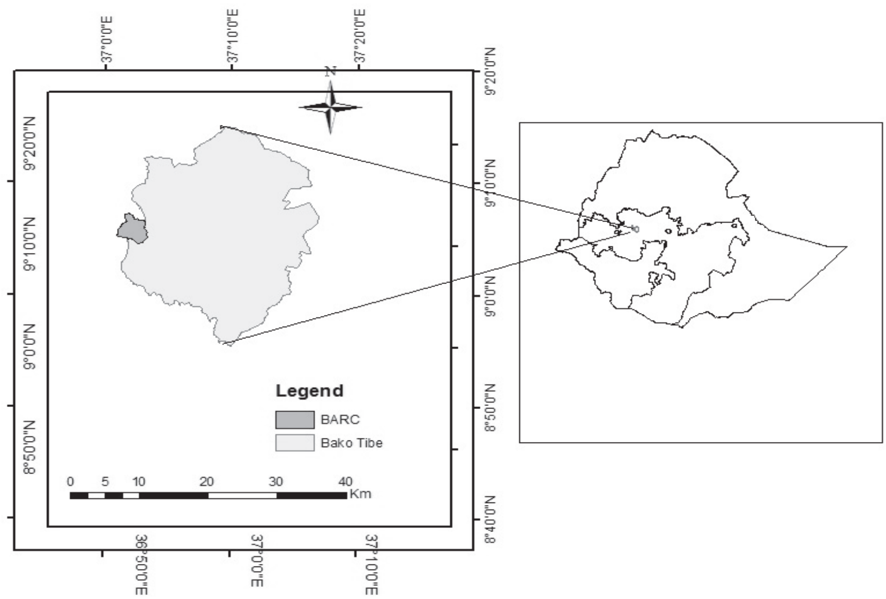

Figure 8. Location map of the study area

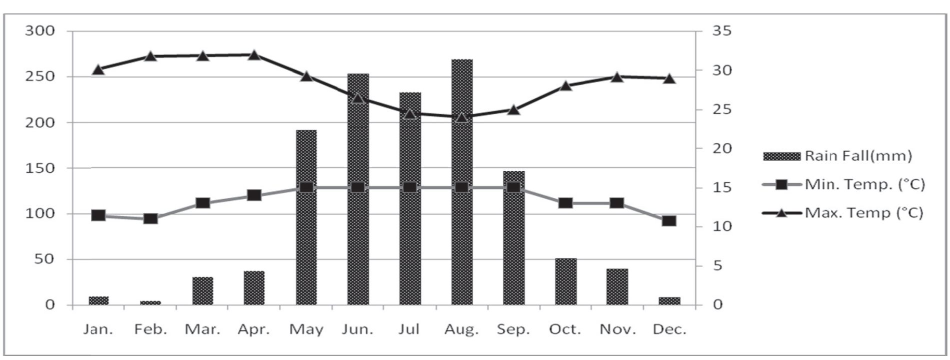

Figure 9. Mean monthly rainfall (RF), maximum and minimum temperature (Temp.) of the study area during the four years trial period (2010-2013)

Methodology

Treatments and experimental design

The adaptation of lowland bamboo at Bako Agriculture Research Center conducted from 2010 to 2013 production years. The experiment was laid out in randomized complete block design with three replications. The block was folded to accommodate the four treatments within fairly uniform field condition. The distances between blocks and plots were 3m and 2m, respectively. And also the space between each plant was 3m and the plot size was 1470 m^2 with the total of 108 plants per plot. As treatments four lowland bamboo species were used, *Oxythenantera abyssinica*, *Guadua amplexofolia, Dendrocalamus hamlitonii* and *Dendrocalamus memebranceous*. Among these species *Oxytenanthera abyssinica* is the indigenous bamboo. The seeds and seedlings were collected from Forestry Research Center and East Africa Bamboo Project. The exotic bamboo species were originally come from China in warm temperate subzone to tropical zone bamboo is growing wildly. The subtropical with annual average temperature of 14-26^{o}C and annual accumulation temperature 4000-8500^{o}C is the most important area for bamboo production in China (Maoyi, 2005). The agro-ecology of bamboo growing area in China is almost similar to Bako conditions.

Data collection

Concerning growth performance of the species, survival rate, culm height, culm diameter, internode length, number of nodes, new shoot emerging, and other growth parameters were considered during data collection. The data were collected at two month interval to observe the changes among the species.

Data analysis

The collected raw data were analyzed with analysis of variance following the General Linear Model (GLM) procedure using SAS statistical software version 9.0. For significant differences, mean separation using least sighnificant difference $p<0.05$. Therefore, for these analyses the following parameters were considered number of new emerging shoots, survival rate, root collar diameter, internodes length, number of nodes, culm height and dimater.

Results and Discussion

New emerging shoots

The capacity of lateral buds forming new rhizome and shoots is closely related to rhizome age, vigor, and nutrient storage. Based on the analysis results of the four year data, *Dendrocalamus hamlitonii* revealed significant difference in number of new emerging shoots throughout the trail periods. This was due to well performance, adaptability and ability of producing new emerging shoots when compared to the other lowland bamboo species tested. The result is similar with the report from Pawe Agriculture Research Center by Yared (2013 unpublished) which showed higher shoot emerging for *Dendrocalamus hamlitonii*. *Dendrocalamus memebranceous* and *Oxythenantera abyssinica* showed good performance in emerging new shoots next to *Dendrocalamus hamlitonii*. Whereas, *Guadua amplexofolia* revealed low performance in emerging new shoots during the trail periods (Table 1).

Table 1. Means comparisons between treatments at p<0.05 significant levels

Treatment	Av. NES	Av. CH (m)	Av. IL (cm)	Av. CD (cm)
Dendrocalamus hamlitonii	3.67±0.17[a]	2.88±0.07[a]	13.54±0.19[a]	2.53±0.08[a]
Dendrocalamus memebranceous	2.92±0.42[a]	2.77±0.11[ba]	11.75±0.72[ba]	2.01±0.08[b]
Guadua amplexofolia	1.75±0.29[b]	1.54±0.05[c]	7.06±0.40[c]	1.59±0.05[c]
Oxythenantera abyssinica	3.58±0.33[a]	2.62±0.03[b]	11.01±0.94[b]	2.32±0.05[a]

** Means with the same letter in a column are not significantly different*

** Av.NES – Average of new emerging shoots*

** Av. CH (m) – Average of culm height in meter*

** Av. IL (cm) – Average of internodes length in centimeter*

** Av. CD (cm) – Average of culm diameter in centimeter.*

According to the comparison made among the treatments *Guadua amplexofolia* was significantly different in new emerging shoots when compared with others but the rest three species were not significantly different (Table 1). The result coincided with the report from Pawe for *Guadua amplexofolia* at both sites it revealed lower shoot emerging ability this might be due the low growth performance of the specie.

Survival rate

During the four year trail period the selected lowland bamboo species adapted and well performed under Bako condition. From the collected data the survival rate for all species was 100%. These indicated that as the agro-ecology of Bako was suit to the species. Beside this during the trial periods the selected lowland bamboo species were not attacked by any disease and pest. These were also another indicator as the species were well performed under Bako condition. But some growth and morphological variations were observed among the species this might be due to growth and adaptability characteristics of the species.

Internodes length

Bamboo culms structure is cylindrical and is divided into sections by diaphragms or nodes. The section between two nodes is internodes. Internodes are hollow in most bamboos, but solid in some species. Directly or indirectly bamboo internodes length can indicate the quality of bamboo product which can be used for different purposes. As the present study revealed that the results of internodes length among the selected species were significantly different. As indicated in Table 1 *Dendrocalamus hamlitonii* showed higher internodes length as compare to others which was similar with the report of Yared (2013 unpublished) which showed higher internodes length for *Dendrocalamus hamlitonii,* whereas, *Guadua amplexofolia* showed lower internodes length.

Culm height and Diameter

Culms are solid in the lower internodes, and are hollow from the upper half up to the top of the culm. The culms of *Oxythenantera abyssinica* are semi-solid when young but solid in older culms. Whereas, *Dendrocalamus hamlitonii* and *Dendrocalamus memebranceous* are relatively semi-solid and hollow at the upper part of the culms when compare to *Oxythenantera abyssinica*.

The full length of the culm may vary among the species. According to the current analysis *Dendrocalamus hamlitonii* was statistical significant (Table 1), while *Guadua amplexofolia* showed the least in culm height compared to the rest. The result agreed with the report from Pawe by Yared (2013, unpublished) which showed higher culm height for *Dendrocalamus hamlitonii* and lower culm height recorded for *Guadua amplexofolia.* This might depend upon the growth performance and adaptability of the species.

Culm diameter is indicated by the thickness or size of the culm which is directly or indirectly related with the quality of bamboo production. As the result, the current analysis showed slight variations among the species on culm diameter. *Dendrocalamus hamlitonii* and *Oxythenantera abyssinica* were significatly higher than both *Dendrocalamus memebranceous* and *Guadua amplexofolia* in culm diameter (Table 1).

Conclusion and Recommendation

Bamboo grows more rapidly than any trees and starts to yield within three or four years of planting. It is one of the fast growing and well responding against drought which can make the species more acceptable in making ever green environment in addition to soil and water conservation, and rehabilitation of degraded lands. Accordingly, for indispensable values of bamboo products, the selected bamboo species were well adapted to Bako condition.

Therefore, the adaptation of lowland bamboo under Bako agro-ecologies is reliable. And it was recommended for further economic and livelihood benefits for different stakeholders through expanding the plantation. *Dendrocalamus hamlitonii* showed high difference in new emerging, internodes length, culm height and culm diameter, whereas *Guadua amplexofolia* revealed low in all growth parameters. Based on these results *Dendrocalamus hamlitonii*, *Dendrocalamus memebranceous* and *Oxythenantera abyssinica* were recommended for different production since they have good quality of internodes length, ability to emerge new shoots, culm height and diameter while the growth of *Guadua amplexofolia* was quite different when compared with others. Due to *Guadua amplexofolia* thorny character on its culm which is not easily damaged by animals, it is better to use for soil and water conservation purpose on degraded area rehabilitation. Since bamboo gives seed once in 40 years which is a big challenge in expansion of the resource, further study is needed on bamboo propagation methods.

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Collection and Characterization of Highland Bamboo (*Arudinaria alpine*) Species in Selected High Land Districts of Guji Zone, South Oromia, Ethiopia

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Abstract

Highland bamboo plays manifold roles in day-to-day life of rural community. To fulfill needs of rural people, collection and characterization of bamboo germplasm is significant for effective conservation and sustainable utilization of the resources. This study was conducted at Bore Agricultural Research Center, on-station, in Bore District of Guji Zone, South Oromia. The overall objective was to collect, characterize and select superior local provenance of Arudinaria alpina. The three local provenances (Okotu, Shanto and Uratiti) were collected from three potential highland districts of the zone. All collected local provenances were planted in randomized complete block design with three replications at spacing of three meters between seedlings, three meters between blocks and two meters between plots. The necessary parameters significant for this study were collected for three consecutive years, 2011-2013. As the results showed survival rate and number of shoots for all local provenances were not significantly different at $p < 0.05$. Okotu provenance was significantly higher ($p<0.05$) than Uratiti by culm diamete, culm height, internode length and number of node. However, there was not significant difference between Shanto and Uratiti in number of nodes, internode length, culm height and diameter. Based on the findings of this study, Okotu was the superior local provenance compared to the remaining local provenances. Therefore, for this superior local provenance and others sustainable conservation should be vital for long term utilization of the resources.

Key words: *Arudinaria alpina*, high land bamboo species, local provenance

Introduction

Bamboo is the fastest growing perennial grass species that belongs taxonomically to the subfamily of Bambusoideae under the family of Pocaceae (Nath *et al.,* 2009). More than 1,500 species and 90 genera of bamboo are found in the world, covering 36 million hectares of land which is distributed in the tropical and sub-tropical belt between 460 North and 470 South latitude at elevations as high as 4000 masl. Bamboo plants are commonly found in Africa, Asia and Central and South America (FAO, 2007).

The Ethiopian natural bamboo forest is more than 1 million hectares, which is about 7% of the world total and 67% of the African bamboo forest area (Luso, 1997). Two species of bamboo comprise the bamboo forest in Ethiopia, the high land bamboo (*Arudinaria alpina*) and the low land bamboo (*Oxytenantera abyssinica*). Out of which the highland bamboo comprises about 300,000 ha and low land bamboo covers 800,000 ha (Luso, 1997; Kassahun, 2003).

Bamboo is plant of enormous importance in several regions of the world and it has age old connection with human needs. It is preferred material for various uses due to its straightness, high strength, light weight, easiness to work with, suitable fiber for pulp production and absence of bark (Sahara and Seen, 1990). Bamboo has become suitable for variety of uses and services. It provides food, shelter and other consumer goods. It has high physical property for construction, industrial utilization and considerable value in agriculture and stabilization of ecological balance (Kasahun, 2003).

Bamboo plays manifold roles in day-to-day life of rural community and it has imperative role in cultural, artistic, industrial, agricultural, construction and household needs of human beings (McNeely, 1995). In order to fulfill material needs of rural people, collection and characterization of bamboo germplasm is paramount for effective conservation and sustainable utilization of bamboo resources (Nayak *et al.,* 2003).

In Ethiopia, highland bamboo species (*Arudinaria alpina*) are widely growing naturally in the south, south-west, central and north-west highlands at altitudes ranging from 2200 to 4000masl (Luso, 1997). Guji Zone, South Oromia, has five potential highland bamboo growing districts and over 7,460 hectares of land is covered by bamboo plantation. However, collection and characterization of different local *Arudinaria alpina* provenances existed in the highland districts of Guji Zone is not yet identified.

In general, the potentials of these fast growing and high yielding perennial plants regarding to the economic development and improvement of the income of smallscale farmers of Guji Zone is very little. Therefore, this research could help overcome these problems through collecting, characterizing, identifying and diversifying the superior local provenances of high land bamboo species of Guji Zone. The objiectives of the study were to evaluate the growth performance of different local *Arudinaria alpina* provenances, and to select the superior native *Arudinaria alpina* provenance of high land bamboo species of the study area.

Materials and Methods

Description of the study area

The trial was conducted at Bore Agricultural Research Center, on-station. It is situated in the Northern part of Guji Zone in Oromia. The center is located at 385km south of Finfinne/Addis Ababa and astronomically located between 5^{o}57'23"– 6^{o}26'52" N latitudes and 38^{o}25'51"– 38^{o}56'21" E longitudes. It has elevation of around 2700masl. The annual rainfall of the district is about 1227mm and the mean annual temperature range from 10 to 20^{o} C. The major soil of the study area is Nitisols (red basaltic soils).

Methods

From the identified five potential high land bamboo growing districts of Guji Zone, local provenances of high land bamboo species were collected from three selected districts. The three native provenance of *Arudinaria Alpina* such as Shanto, Uratiti and Okotu were collected from Bore, Anna Sora and Dama districts. All collected native provenances of high land bamboo species were planted in randomized complete block design with three replications. The collected local provenances were planted at spacing of three meters between seedlings, three meters between blocks and two meters between plots.

Statistical analysis

The collected data were summarized and analyzed using statically package of SAS version 9.1. A one-way analysis of variance was used to compare the means using the least significant difference $p<0.05$. Mean separations were done for parameters which showed statically significant difference using least significance difference.

Results and Discussion

The results indicated that survival rate and number of shoot of all collected local provenances showed relative variations, but statistically not significantly different (P<0.05) (Table 1). In support of this study, Bennet and Gaur (1990) on their study results suggested that the study of young vegetative shoots which sprout annually during rainy season is very significant for identification and characterization of different bamboo species.

Table 18. Summary of parameters results of collection and characterization study of highland bamboo species at Bore Agricultural Research Center

Treatment	Parameters*					
	S rate (%)	Nno	Nsh	Inl (m)	Cht (m)	cdi
Okotu	92.67	24.8 [a]	66.75	24.625 [a]	5.2275[a]	3.4083[a]
Shanto	88.33	21.915 [b]	57.783	22.2[ab]	4.9433[ab]	2.8083[b]
Uratiti	92.267	21.292 [b]	53.702	20.067[b]	4.275[b]	2.772[b]
Mean	92.56	22.67	59.253	20.067	4.8153	2.996
LSD (5%)	NS	2.552	NS	20.067	0.8204	0.3776
CV (%)	11	4.97	13.835	20.067	7.52	5.5587

*Means with the same letter in a column are not significantly different; NS = non-significant; CV = coeffient of variance; Srate = survival rate; Nno = number of node, Nsh = number of shoot, Inl = internodes length; Cht = Culm height; Cdi = Culm diameter

The results of this study revealed that number of node, internode length, culm diameter and culm height of all collected local provenances of high land bamboo species were significantly different at p<0.05. The finding of this study is supported with the previous study of Chatterjee and Raizada (1963) who reported that culm height, culm diameter and other vegetative parameters are a key for identification and good characters for distinguishing the different bamboo species.

From all collected local provenances of highland bamboo species, Okotu provenance was significantly higher (P<0.05) than the remaining ones in internode length, culm diameter, culm height and number of nodes. Accordingly, mean values of number of nodes, internode length, culm diameter and height of Okotu were higher by 2.85, 4.56, 0.412, and 0.412m respectively as compared to the remaining local provenances of highland bamboo species.

However, as compared to Okotu and Shanto local provenances, mean values of Uratiti was the lowest in internode length (0.2m), Culm diameter (0.3m), Culm height (4.28m) and number of nodes (24.29). Shanto provenance was not statistically different from Okotu provenance by internode length and culm height. The finding of this study showed that Okotu was significantly higher (p< 0.05) than Shanto in culm diameter and number of nodes.

Conclusion and Recommendation

Collection and characterization study of locally available different provenances of highland bamboo species is vital for their conservation and effectively use of the resources without over exploitation. In order to identify superior local provenances of *Arudinaria alpina* species for further domestication and conservation, six parameters such as survival rate, Culm height, Culm diameter, number of node, number of shoot and internodal length were collected. As the results of collected parameters showed that in survival rate and number of shoots, all collected three local provenances of *Arudinaria alpina* were similar.

Based on the findings of this study, there was significantly difference among all collected local provenances of *Arudinaria alpina* species (Okotu, Uratit, and Shanto) in terms of the remaining four parameters. From the three local provenances, Okotu was higher than other provenances by its internode length, Culm diameter and Culm height which made it more superior than the others. Whereas, Uratiti was the lowest in internode length, Culm diameter, Culm height and number of nodes as compared to others.

Generally, from the results of collection and characterization study of locally available three native provenances of high land bamboo species, Okotu was the most superior provenance. Therefore, for sustainable utilization of this superior local provenance effective conservation is crucial to diversify benefits of local communities ranging from domestic household products to industrial applications.

The identified native superior local provenance and others of highland bamboo species of the study area should be conserved effectively for sustainable utilization. To ensure sustainable development of local communities, bamboo growers' of the area should be benefited from their owned bamboo plantation and it should be used as input for smallscale bamboo producing industry. Further collection, identification, and characterization study of highland bamboo species existing within Oromia and all over the county should be done.For native highland bamboo species existing in highland districts of Guji Zone, propagation study should be done. Moreover, since it is very difficult to know flowering and fruiting time of bamboo plants, phenological study of highland bamboo species of the area should be assessed.

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Ethno-botanical Study of Wild Edible Fruits in Pastoral and Agro-pastoral Districts of Bale Zone, Southeast Oromia, Ethiopia

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Abstract

The study was carried out in two pastoral districts (Dello-Menna and Medda Welabu) of Bale Zone, Southeast Oromia with the objective of assessing diversity, values and threats associated with Wild Edible Fruits (WEFs). Data were collected using participatory discussion, semi-structured interviews and structured questionnaires. Preference Matrix Ranking (PMR) was used to identify priority WEF species. 48 species belonging to 27 plant families were found to be used as WEFs. Trees and shrubs constituted the highest proportion of WEF species with 52.1 and 43.8%, respectively. Majority (58.8%) of the WEFs recorded were consumed only during famine while 32.8% were used very occasionally. Tamarindus indica and Ximenia americana were the most preferred WEF species by all age groups in the community. 95.8% of the respondents reported that integration of WEFs into the agricultural landscape is constrained by drought, shortage of planting materials, soil fertility, and shortage of land and lack of awareness on nutritional values of WEFs. Deforestation for agricultural land expansion, livestock overgrazing and drought were found to be the dominant factors threatening populations of WEFs. Given the diverse species of WEFs and the underlining threats, domestication of the priority species and enhancement of local uses of the WEFs is vital to insure their conservation and sustainable use through integration into the agricultural landscape.

Key words: Diversity, Family, Priority species, Wild edible fruits

Introduction

Ethiopia is one of the richest countries which are diverse in wild edible plants species. From these species, wild edible plants are one of the major species that could be used as insurance to food shortage, alleviating malnutrition and increase cash income for the community. According to Food and Agriculture Organization of the United Nations, wild edible plant (WEP) is defined as “a plant that grows spontaneously in self-maintaining populations in natural or semi-natural ecosystems and can exist independently of direct human action” (Heywood 1999). Wild edible fruits (WEFs) are notable examples of wild edible plants serving as sources of important nutrients to supplement other food sources. Kalaba *et al.* (2009) noted that wild fruits are important sources of food, income and medicines, which are vital in sustaining rural communities. In southern Africa, it has been reported that indigenous wild fruits contribute on average about 42% of the natural food basket that the rural households rely on (Akinnifesi *et al.,* 2004). They are sources of carbohydrates, protein, energy, minerals and fats with superior nutritional quality over some cultivated fruits and cereal crops (Kebu and Fassil 2006; Jama *et al.,* 2007; Fentahun and Hager, 2009; Debela *et al*., 2011). Research reports (Fentahun and Hager, 2009; Debela *et* *al.,* 2011) indicate that they are used by households as supplementary food during famine, at normal times and during food shortage. Since recently, the diversity of these plants is narrowing down to relatively fewer species (Getachew *et al.,* 2009).

Results of study conducted in East Shewa Zone of Oromia indicated that fruit trees can contribute substantial amounts of dietary carbohydrates, proteins, lipids, fiber, minerals and moisture for rural livelihood (Debela *et al.,* 2011). They are valuable plants particularly during dry seasons for adaptation to climate change and ecosystem services.

In spite of this potential, the nutritional contribution of wild fruits to people's diets remains underutilized (Fentahun and Hager, 2009; Debela *et al*., 2011) and suffering notable disregard from research and development endeavors as they remain inadequately documented (Fentahun and Hager, 2008). There is considerable wealth of knowledge among farmers and rural communities on the value and uses of WEFs (Demel and Abeje, 2004). This knowledge has been used, to some extent, to prioritize species domestication and identify research and development needs.

Woodland vegetation in Bale Zone is home for various tree and shrub species of multiple values to the surrounding community. Indigenous wild edible fruits are among the products that can potentially be extracted by the community. Nevertheless, no efforts have been made so far to bring those species into the farming system. Integration of fruits into the agricultural landscape through fruit-based agro-forestry systems could be one possible option to increase nutritional security and cash income while promoting biodiversity conservation. Apart from the existence of indigenous wild fruits in the surrounding vegetation, the extent of use and preference of the local community for different fruits is not yet determined in order to domesticate for sustainable use and conservation. This study is initiated to counteract the above problems and to fill the information gap on the actual intervention needed towards integrating indigenous wild fruits into the farming system as part of the strategy in improving livelihoods and biodiversity conservation. Therefore the objective is to identify and prioritize WEFs of importance to the local community, to assess preferences, perceptions and values of WEFs, to identify factors hindering integration of WEFs into the agricultural landscape and to suggest further intervention on domestication and improvement of prioritized WEFs.

Materials and Methods

Description of the study area

The study was conducted in Dello-Menna and Medda Welabu districts, Bale Zone of Oromia. Both districts are characterized by low precipitation and high temperatures. In Dello Menna, the mean annual rainfall is 914.9mm with mean annual temperatures of 22.5^{0}C. Its altitude ranges from 800 to 2000masl. The land form is dominated by plain topography followed by rugged and mountainous escarpments. Medda Welabu district exhibits mean annual temperature of 27^{0}C with the mean annual rainfall ranging from 550 to 720mm. The altitudinal range of the area is from 800 to 2000masl. The dominant topography of the area is plain. Nitisol is the dominant soil type in both districts.

The local community depends on livestock production and some practices of farming as their livelihood strategies. Livestock product followed by sorghum and maize are the main sources of food for the local community. Coffee, banana and papaya are the dominant perennial cash crops cultivated by the farmers. The districts have substantial vegetation resources dominated by *Combretum-Terminalia* and *Acacia-Commiphora* dry woodland vegetation. A small part of Harenna forest, moist afromontane forest, also falls in Dello Menna District.

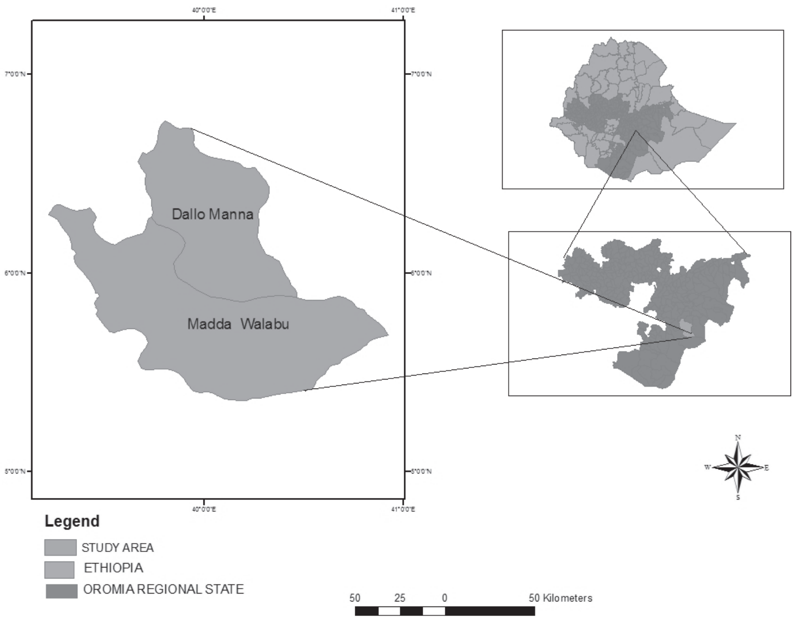

Figure 10. Map of the study area

Data collection

Data were collected by using structured questionnaire among farmers of the two districts with six peasant associations (Chiri, Gomgoma and Melka-amana from Dello-menna, and Barisa, Ele-bidre and Danisa from Meda-welabu). During the interview, the type WEF species in the area and rank based on their preferences were identified. Preference matrix ranking was used to generate species priority list of WEFs preferred by the local community. The highest priority species out of five was assigned 5 points, 4 points to the second highest and the lowest ranked species was assigned 1 point. The points for each species were summed across all respondents. The species were prioritized based on the total points scored. Finally data were analyzed using SPSS software. Also descriptive statistics was used to identify the number and percentage of species, genera and families of WEFs, and frequency of their use. Identification of species was done both in the field and in office by using taxonomic keys and flora of Ethiopia and Eritrea as a reference. Also for few WEF species identification were done at the national herbarium, Addis Ababa University.

Results and Discussion

Wild edible fruits gathered and consumed by the local community

A wide range of wild edible trees and shrubs were identified as sources of food in the study area. In total, 48 species belonging to 34 genera and 27 families were reported. Among these, the family *Tiliaceae* had the highest proportion of WEFs with 10 species (Figure 2). *Anacardiaceae, Fabaceae, Moraceae* and *Myrtacea* were the second dominant families with 3 species of WEFs each. The third WEF species rich families were *Rhamnaceae, Celastraceae, Ebenaceae* and *Sapindaceae* with 2 species each. The remaining families had one species of WEFs each. This implies that about 33% of the families were found to be represented by more than two edible species, whereas the remainings were represented by a single species.

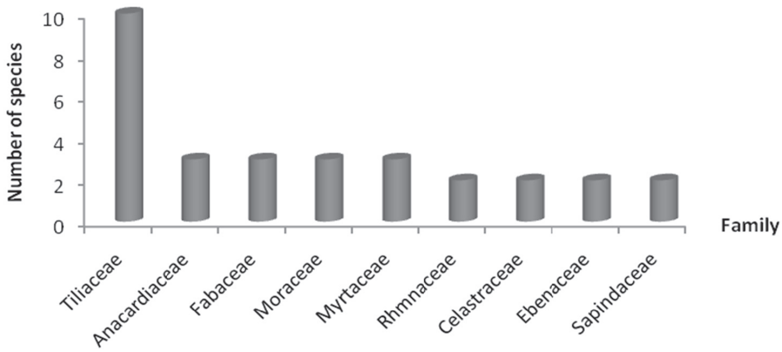

Figure 11. Families represented by more than two edible species of the study area

Results showed that the area was rich in plant species of WEFs. Hence, sustainable management of the area and its plant species is required. Particularly, those species requiring specific habitats and exceptionally difficult to produce in nurseries deserve much attention. The growth forms of the WEF species constitute trees, shrubs, and herbs. Trees (52.1%) and shrubs (43.8%) made up the highest proportion of the recorded species. This implied that 96% of the species were woody perennials. Most of the reported WEF species were reported to be edible elsewhere in Ethiopia. For example, Assegid and Tesfaye (2011) reported that 11 of the WEF species reported in the present study were also recorded in Benna and Tsemay areas of southern Ethiopia. Similar results were reported by Kebu and Fassil (2006). Edibility of these species over wider areas among different communities indicates the existence of common knowledge across a range of subsistence groups of different culture and geographic areas. Some of the wild edible plants recorded in this study were edible very occasionally (32.8%) when it was mature. However, most of them (58.8%) were consumed only during famine or in times of food shortages (Table 1). Famine foods are used only when preferred alternatives are not available and in situations where chronic food shortages prevail.

Table 19. Frequency of wild edible fruits consumption in the household (N=119)

Frequency	Respondents %
Most often	8.4
During food shortage	58.8
Occasionally	32.8

Perception, preferences and values of wild edible fruits

The local communities in the study area preferred some species over the other in their utilization (Table 2). For example, *Tamarindus indica* and *Ximenia americana* were highly preferred by individuals in all age groups. According to the informants' opinion, the major reasons for preferring one species over the other were market values, nutritional values and taste during consumption. Based on market values, *Tamarindus indica* fetched the highest price in local markets. Apart from this, they asserted that *Tamarindus indica* is important medicinal plant species in the area. It is the most economical plant species used in the lowland areas of Bale Zone. Several WEFs were identified from both districts of the study area. Majority (86.4%) of the community interviewed claimed that planting fruit bearing trees and shrubs on farm land is very important (Table 2). However, they did not plant WEFs on their farm lands except *Tamarindus indica*. This low proportion of WEFs on farm land implies that intervention is needed to integrate WEF trees and shrubs into the farming systems. This calls for strategies on increasing the proportion of WEF trees and shrubs on farm land in the districts.

Table 20. List of farmers' priority WEF species in the study area (in order of preference)

Scientific Name	**Local Name**	**Weight**	**Rank**
Tamarindus indica	Roqaa	407	1
Ximenia americana	Hudhaa	316	2
Opuntia- ficus indica	Hadamii	254	3
Psidium guajava	Zeyitunaa	236	4
Diospyros mespiliformis	Qolatii	186	5
Syzygium guineense	Gotuu	165	6
Harrisonia abyssinica	Goraa	160	7
Carisa spinarum	Agamsa	154	8
Embelia schimperi	Hanquu	152	9
Flacoutia indica	Akukuu	140	10
Grewia ferruginea	Bururii	128	11
Grewia villosa	Ogomdii	123	12
Grewia bicolor	Haroresa	108	13
Syzygium guineense	Badesaa	107	14
Berchemia discolor	Jajaba	100	15
Commiphora samharensis	Qanquraa	90	16
Pappea capensis	Biqaa	72	17
Canthium setiflorum	Ladhana	60	18
Grewia kakothamnos	Dhekaa	58	19
Acokanthera schimperi	Qararuu	55	20

The study also revealed that the collection of WEFs was mostly (85.7%) carried out by children and women. This might be due to the fact that collection of WEFs was age and gender specific.

Factors hindering integration of WEFs into the agricultural landscape

The population of WEFs in the agricultural landscape is very low due to several factors. 95.8% of the respondents did not integrate WEF trees/shrubs into their agricultural farms due to drought, shortage of planting materials, infertile soils, shortage of land, lack of awareness on nutritional values WEFs and market problems (Table 3). Such limits pose a great challenge to the cultivation and domestication of the species leading loss of the wild populations as a result of dependency on wild sources.

Table 3. Problems hindering integration of WEFs into the agricultural landscape by farmers (N=119)

Problem	**Response (%)**
Drought	34.50
Lack of planting materials	19.30
Soil fertility	18.50
Awareness on nutritional values of WEFs	10.90
Shortage of land	7.60
Uncertain markets and low price	5.90
Availability of other domesticated fruits	2.50
Not important	0.80

Deforestation for agriculture is the major threat to the conservation and sustainable use of WEFs in the study area. The problem seems to be universal as it was reported by many scholars that farmers do not attach much value to indigenous plant resources and therefore prefer to clear them to open land for crop production. Human population growth is the underlying cause for several factors that cause loss of trees, shrubs and herbs used as edible fruits. Over grazing, settlement, fire hazards and fuel wood collection are some of the major factors reported to cause loss of WEFs in the wild.

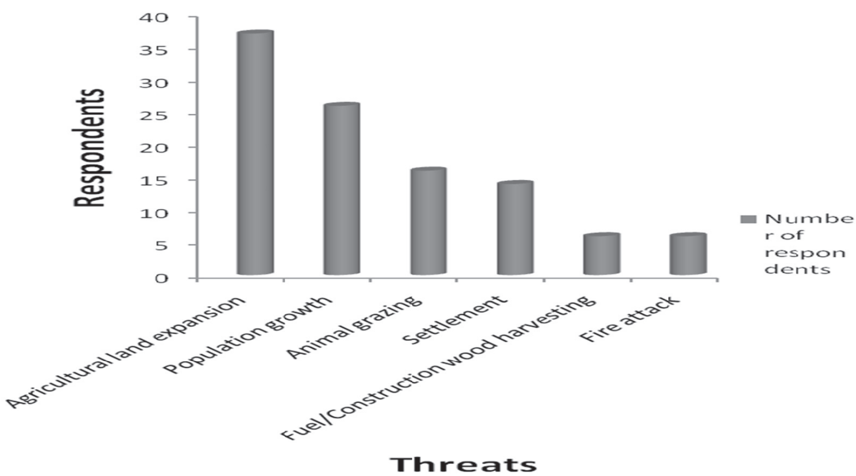

Figure 3. Threats to conservation of indigenous wild edible fruit trees, shrubs and herbs

Cnclusion and Recommendation

Various species of WEFs belonging to diverse plant families were identified from the study area. The number of species of WEFs varied among families from 1 to 10. *Tiliaceae* was found to be the highest species rich family for WEFs. Majority of the plant families were represented by a single species with only 33% more than one species. Based on farmers' preferences and relative importance, *Tamarindus indica*, *Ximenia americana*, *Opuntia ficus-indica*, *Psidium guajava*, *Syzygium guineense* sub spp. *afromontanum* and *Diospyros mespiliformis* were the top priority WEF species in the area. WEFs are consumed most whenever there is food shortage and occasionally as food supplements in the area. The proportion of wild edible fruit trees on the farming landscape is very low. Farmers attribute this to several factors drought and the resulting shortage of moisture being the most important one. The population of WEFs is declining in the wild because of factors such as agricultural land expansion and over grazing. The fact that WEFs are occasionally consumed and the local communities do not attach much value to them is a disincentive for their cultivation with negative implication for future conservation.

Agricultural and natural resource development strategies in the area need to consider enhancing cultivation and conservation of WEF species. The priority WEF species showed above can be considered for further analysis to determine their nutritional properties and their potential as food sources in combating food insecurity and biodiversity conservation for climate change adaptation/miteigation.

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