Soil Fertility and Plant Nutrient Management

Edited by
Getachew Agegnehu
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Tolera Abera
Daniel Muleta

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Ethiopian Institute of Agricultural Research

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Contents

Phosphorous Calibration for Faba bean Production on Nitisols

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Introduction

Faba bean is one of the most important grain legumes in Ethiopia in terms of area, production, source of protein and as a rotation crop ameliorating soil fertility. Despite the importance of the crop in the traditional farming systems, the yield is generally low due to several factors, including poor soil fertility and inadequate plant nutrition, poor seedbed preparation, untimely sowing, sub-optimal weed control, and the lack of improved varieties (Alem et al., 1990; Amare and Adamu, 1994; Getachew and Rezene, 2007; Getachew, 2011). The application of NP significantly increased seed yields of faba bean (Angaw and Asnake, 1994; Amare et al., 1999). Phosphorus is, in fact, the most important growth limiting nutrient factor for pulses including faba bean. Although blanket application of 18/20 kg NP ha^{-1} in the form of diammonium phosphate (DAP) has been recommended for faba bean production in the country, this was not substantiated by research results (Amare *et al*., 1999)

Calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current P recommendations (Evans, 1987, McKenzeie and Kryzanowski, 1997). They enable to revise fertilizer recommendations for an area based on soil and crop type, pH and soil moisture content at time of planting. 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 a particular crop (Muir and Hedge, 2002, Watson and Mullen, 2007). Soil tests are designed to help farmers predict the available nutrient status of their soils. Once the existing nutrient levels are established, producers can use the data to best manage what nutrients are applied, decide the application rate and make decisions concerning the profitability of their operations (Getachew and Berhane, 2013; Getachew et al., 2015). However, local assessments for the soil P critical levels and soil P requirement factors even for the major crops of the country are negligible. Currently, soil fertility research improvement is agreed with respect to site specific fertilizer recommendation in the country.

Soil test-based and site-specific nutrient management has been a major tool for increasing productivity of agricultural soils. The aim of the soil test calibration is to obtain correlation between the contents of the available nutrients in the soil and the crop responses to applications of nutrients in selected areas. Therefore, the objectives of this study were to correlate the Bray-2 soil test P with the relative yield response of faba bean across selected Nitisol areas of West Shewa, to established preliminary agronomic interpretations, and to determine the critical P concentration and P requirement factor.

Materials and Methods

Experimental site

For the selection of representative trial sites across the area, over 320 soil samples (0-20 cm depth) were collected in three years from farmers' fields before the onset of the trial. Soil samples were analyzed for pH using a ratio of 2.5ml water to 1 g soil available P using Bray-II method, Organic carbon was determined by the method of Nelson and Sommers (1982) and total N using Kjeldahl method (Jackson, 1958), exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method at the soil and plant analysis laboratory of Holetta Agricultural Research Center. The available soil P (using Bray-2 method) ranges prior to planting considered for classification were < 10 mg P kg^{-1} for low, 10-25 mg P kg^{-1} for medium, and > 25 mg P kg^{-1} for high (Table 1). Based on this categorization, 4 farmers with low and medium fields available P were selected for the first year, 5 farmers for the second year and 3 farmers with the same categories for the last two years, respectively.

Experimental procedures

The experiment was arranged in randomized complete block design with six levels of phosphorus (0, 5, 10, 15, 20 and 25 kg P ha^{-1}) and replicated three times. The gross plot size was 4m x 5m (20 m^2), and accommodating a minimum of 12 harvestable plants with different rows and space lengths. The net plot size was determined with area and plant density leaving the one outermost row and sides of each row the spacing between Plants, rows, plots and blocks were 0.10m, 0.40m, 0.5m and 1m, respectively. The harvested plot area measured 16 m^2. The source of P was triple super-phosphate (TSP). All agronomic practices were applied based on local research recommendations.

Land preparation was done at the end of May in accordance with a standard practice locally used.An oxen-drawn implement to the depth of 15-20 cm cultivated the experimental plot. An improved faba bean cultivar (Moti)was planted to the specified treatments. Sowing was made from mid of June to the last week of June depending on the onset of rainfall. Cultivation, weeding, chemical spray,and harvesting were done at the appropriate time according to the research recommendations.Application of phosphoruswas done by banding the granules of TSP (Triple super-phosphate) at the depth of 10 cm below and around the seed at planting. Harvesting was done at physiological maturity when the leaves of the faba bean plants senesced.

Table1.Nutrient contents of the trial sites before planting faba bean in 2013-2015

Site/farmers' name	pH (1:2.5 H_2O)	Total N (%)	P* (mg kg^{-1})	cmol(+)/kg		
				Exch. K	Exch. Na	CEC
Bizuayehu	4.2	0.18	7.6	0.64	0.14	18.4
Beyene	4.6	0.16	6.8	0.68	0.16	21.6
Aselefechi	4.4	0.18	6.2	0.72	0.18	16.1
Gemechu	4.2	0.15	7.8	0.54	0.14	15.4
Legesse	5.2	0.21	7.8	0.58	0.17	16.8
Bekele	4.6	0.17	7.2	0.62	0.18	20.4
Ayenelem	4.2	0.18	8.2	0.68	0.15	20.2
Teshome	4.4	0.18	6.6	0.64	0.16	22.8
Nuru	4.6	0.16	7.6	0.62	0.14	18.6
Irko	4.4	0.17	7.4	0.76	0.15	21.2
Gudisa	4.6	0.18	6.8	0.78	0.16	18.4
Hunde	4.8	0.14	6.6	0.72	0.15	22.2

**Bray-2 method*

Agronomic parameters collected were stand count at complete emergence, plant height (cm), number of pods per plant and seeds per pod (average of five plants), total above ground biomass and seed yields and thousand seed weight. The harvested materials were sun-dried and manually threshed. After threshing, seeds were cleaned, weighed and adjusted at 10% moisture level. The total biomass and seed yields recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

Determination of critical P concentration (Pc):to correlate relative yield vs soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray-2 method.The Cate-Nelson graphical method (Dahnke and Olsen, 1990) was used to determine the critical P value using relative yields and soil test P values obtained from 12 P trials conducted at different sites.To assess the relationship between faba bean yield response to nutrient rates and soil test P values, relative grain yields in percent were calculated as follows:

$$Relative yield\,(\%):\quad \frac{yield}{maximum yield} x100 \qquad (1)$$

The scatter diagram of relative of relative yield (y-axis) versus soil test values (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P requirement, while the observations in the lower right quadrant underestimate the P requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level (Dahnke and Olsen, 1990).

Determination of P requirement factor (P_f): phosphorus requirement factor (p_f) is the amount of P in kg needed to raise the soil P by 1mg kg^{-1}. It enables to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1}, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977, 19-39). It was calculated using available P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:

$$Pf = \frac{kgPapplied}{\Delta SoilP} \qquad (2)$$

Therefore, the rate of P to be applied (Pa) was expressed in terms of critical P concentration (P_c), initial soil P value (P_i) and P requirement factor(P_f).

$$Pa = (Pc - Pi)\, xPf \qquad (3)$$

Statistical analysis

The data were subjected to analysis of variance using the procedure of the SAS statistical package version 9.0 (SAS Institute, 2001). Means for the main effects were compared using the means statement with the least significant difference (LSD) test at the 5% level.

Results

Yield and yield components

The responses of plant height, thousand seed weight, grain and biomass yield of faba bean to phosphorus fertilization, year and interaction of year by phosphorus of the combined data of over three years are demonstrated in (Table 2). Analysis of variance over three-year cropping seasons showed that the year effect was significant ($p \leq 0.05$ and 0. 01) for yield and yield components of faba bean (Table 2). The highest mean of grain yield (2180.5 kg ha^{-1}) was obtained in the year 2015 relatively compared to the yield (1966.2 kg ha^{-1} and 2133.9 kg ha^{-1}) achieved in 2013 and 2014 respectively (Table 3).

Table 2.Year, P rate, and their interactions on yield components of fababean across sites in 2013, 2014 and 2015

Parameters	Year(Y)	Phosphorous(P)	Y * P
Plant height	*	*	Ns
Grain yield	*	**	Ns
Biomass yield	*	**	Ns
Thousand seed weight	*	*	Ns

**, ** Significant at 0.05 and 0.01 probability levels, respectively; ns, not significant*

The effects of year by P rate (Y x P) were not significant ($P \leq 0.05$) for grain yield and yield components (Table 3). Significantly higher grain yields were obtained from the application of 20 kg P ha-^{1}.The application of P at rates of 5, 10,15, 25 and 20 kg ha^{-1} increased grain yield of faba beanby 25, 28, 42 and 58%, respectively, compared to the control (without P). Grain yield consistently increased as P rate increased, but showed slight decrease beyond 20 kg^{-1}.

Table 3.Means for main effects of P, year and fertilizer rate on fababean

Factor	Plant height(cm)	Grain yield (kg)	Total biomass yield (tha^{-1})	Thousand seed weight(g)
Year				
2013	131.6^{c}	2133.9^{a}	45.24^{a}	754.02^{a}
2014	133.7^{b}	1966.2^{b}	41.47^{b}	755.18^{b}
2015	136.3^{a}	2180.5^{a}	45.6^{a}	765.9^{a}
P				
0	129.4^{b}	1630.1^{d}	37.29^{c}	686.7^{c}
5	132.7^{b}	1958.1^{c}	42.7^{b}	755.2^{ab}
10	128.9^{b}	2042.2^{c}	41.96^{bc}	765.9^{ab}
15	129.7^{b}	2077.8^{c}	45.2^{b}	790.9^{a}
20	136.7^{ab}	2580.2^{a}	52.9^{a}	781.7^{ab}
25	143.9^{a}	2307.7^{b}	45.2^{b}	725.4^{bc}
CV	11.34	17.4	19.3	13.6

Within each column, means with different letters are significantly different at $P <$ 0.05; CV, coefficient of variation

Critical P concentration (Pc) and P requirement factor (Pf)

Soil P values determined three weeks after planting differed significantly ($P \leq 0.01$) among P levels. The main effect of P treatments resulted in mean soil test P values 4.6 to 12.5 mg kg^{-1} (Table 4).Bray-2 soil test P values below 10 mg kg^{-1} are considered low. The increase in soil P content in response to P application was linear up to 20 kg P ha^{-1}. The highest mean soil P concentration (12.2 mg kg^{-1}) was recorded from 20 kg P ha^{-1}(Table 4).

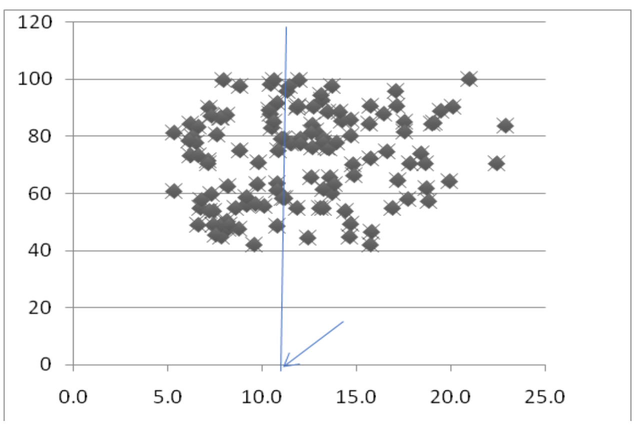

Figure 2: Relationships between relative yield response of faba bean and soil-test P measured using Bray-2 method. The arrow indicates the critical P concentration (*Pc*) for faba bean on Nitisols.

Table 4. Determination of P requirement factor for faba bean on Nitisols in 2013, 2014 and 2015

Phosphorous rate ($kgha^{-1}$)	Soil test P (Bray- II)		P increase over control	P requirement factor (Pf)
	Range	Average		
0	6.2 - 18.2	8.8		
5	6.4 - 21.0	9.9	1.1	4.6
10	7.2 – 23.1	10.4	1.6	6.3
15	7.4 - 22.8	11.4	2.6	5.8
20	7.6 - 26.3	12.2	3.4	5.9
25	6.8 - 22.4	10.8	2.0	12.5
Average				7.02

The relationship between relative faba bean yield response and soil P measured with the Bray-2 method is shown in the figure 2. The critical P concentration (*Pc*) was determined from the scatter diagram drawn using relative tuber yields of faba bean and the corresponding soil test P values for all P levels (0 – 25 kg ha^{-1}). The *Pc* defined by the Cate- Nelson method in this study was about 12.5 mg P Kg^{-1}, with mean relative grain yield response of about 80% (Figure 2).

When the soil test value is below the critical level additional information is needed on the quantity of P required elevating the soil P to the required level. This is the P requirement factor (*Pf*), the amount of P required to raise the soil test P by 1mg kg^{-1}, computed from the difference between available soil test P values from plots that received 0–25 kg P ha^{-1} using the second formula mentioned above. Accordingly, the calculated *Pf* were 4.6–12.5 and the overall average *Pf* of all treatments for the study area were 7.02 (Table 4). Thus, the rate of P required ha^{-1} can be calculated using the soil critical P concentration, initial soil P determined for each site before planting (Table 1) and the P requirement factor as indicated above in the third formula.

Discussion

Our results showed that significant variations in yield and other agronomic parameters were observed due to cropping season. Analysis of variance show that phosphorous had a highly significant effect on yield and yield component of faba bean. Grain yield consistently increased as the rate of P increased up to 20kg P ha^{-1} then a slight decrease in yield was observed at the highest P rate (25 kg P ha^{-1}) (Table3).

According to the Cate- Nelson method, the critical levels of Bray-2 P in the top 15 cm of soil is about 12.5 mg kg^{-1}; at values of greater than or equal to 12.5 mg kg^{-1}, the crop achieved about 80% of its maximal yield in the absence of P application (Figure 3). This implies that P application could be recommended for a build-up of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P to produce extra yield would likely be greater than the value of additional yield. Thus, in soils with available P status below 12.5 mg kg^{-1}, yield of faba bean could show a significant response to applications of P whereas in areas with available P status greater than 12.5 mg kg^{-1}, the P concentration in the soil exceeds crop needs so that addition of P may not result in a profitable yield increase.

According to the result of our study, some yield responsive sites to P applications had soil test levels above the critical level. Hence, to protect a potential loss of faba bean yield, at least a maintenance application of 12.5 kg P ha^{-1} may be required depending on the grain yield goal and profitability. Following the pre- planting soil analysis results all of the trial sites had lower soil P values than the critical P concentration. This had a direct relationship with the crop growth and grain yields. In most cases, soil pH less than 5.5 is deficient in available P and exchangeable cations (Brady and Weil, 2010). In such soils, the proportion of P that could be available to a crop becomes inadequate (Brady and Weil, 2010), unless amended through organic matter maintenance or liming.

Conclusions

The results seem promising and could be used as a basis for soil-test P recommendation for the production of faba bean on Nitisol areas of central Ethiopian highlands and to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, more research assisted by appropriate soil P extraction methods is required to generate sufficient information for the most important crop-soil systems.

The results may be used as a basis for P recommendations for the production of faba bean on Nitisol areas of Ethiopian highlands. They can also be used for future intensification in other areas for developing a system for soil-test P recommendations. Further field trials involving different N levels, climatic conditions, soil P test methods, and perhaps limiting treatments, would further our understanding of limiting factors and facilitate better fertilizer recommendations.

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Phosphorous Calibration for Potato on Nitisols of Central Highlands of Ethiopia

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Introduction

The low acreage yield of potato in Ethiopia is attributed to many factors. The major ones are the lack of well-adapted and high-yielding cultivars, unavailability and high cost of fertilizers, inappropriate agronomic practices, and lack of marketing and suitable post-harvest management facilities, pests and disease (Gildemacher et al., 2009).

Phosphorous is the most yield limiting of soil-supplied elements, and soil P tends to decline when soils are used for agriculture (David and David, 2012). Studies have demonstrated that Nitisol areas in the central highlands of Ethiopia are marginally to severely deficient in P (Taye et al., 1996; Hailu and Getachew, 2011).

The blanket recommendations that are presently in use all over the country were issued several years ago, which may not be suitable for the current production systems (Taye et al., 2002, Gete et al., 2010). Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying the same P rate to their fields regardless of soil fertility differences.

Soil test-based and site-specific nutrient management has been a major tool for increasing productivity of agricultural soils. The aim of the soil test calibration is to obtain correlation between the contents of the available nutrients in the soil and the crop responses to applications of nutrients in selected areas. Therefore, the objectives of this study were to correlate the Bray-2 soil test P with the relative tuber yield response of potato across selected Nitisol areas of West Shewa, which is located in the central highlands of Ethiopia, to established preliminary agronomic interpretations, and to determine the critical P concentration and P requirement factor.

Materials and Methods

Description of the experimental sites

For the selection of representative trial sites across the area, over 360 soil samples (0-20 cm depth) were collected in three years from farmers' fields before the onset of the trial. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil; available P using Bray-II method; organic C content using Walkley and Black method;

total N content using Kjeldahl method; and exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method at the soil and plant analysis laboratory of Holetta Agricultural Research Center. The available soil P (using Bray-2 method) ranges prior to planting considered for classification were < 10mg P kg^{-1} for low, 10-25 mg P kg^{-1} for medium, and > 25 mg P kg^{-1} for high (Table 1). Based on this categorization, 9 farmers with low and medium fields available P were selected for the first year, 4 farmers for the second year and 3 farmers with the same categories for the last two years, respectively.

Experimental procedures

The experiment was arranged in randomized complete block design with six levels of phosphorus (0, 15, 30, 45, 60 and 75 kg P ha^{-1}), replicated three times. The gross plot size was 4m x 4.5m (18 m^2), and accommodating a minimum of 40 harvestable plants with different rows and space lengths. The net plot size was determined with area and plant density leaving one outermost row and sides of each row. The spacing between plants, rows, plots and blocks were 0.75 m, 0.30 m, 0.5 m and 1 m, respectively. The harvested plot area measured 12 m^2. The sources of N and P were urea and triple super-phosphate (TSP), respectively. All agronomic practices were applied based on local research recommendations.

Land preparation was done at the end of May in accordance with a standard practice, which is locally used.The experimental plot was cultivated by an ox-drawn implement. The land was levelled and ridges were made manually.Sprouted medium sized seed tubers (with a sprout length of 1.5 to 2.5 cm) were planted to the specified treatments.Cultivation, weeding, chemical sprayand harvesting were done at the appropriate time according to the research recommendations.

Application of phosphorus was done by banding the granules of TSP (Triple super-phosphate) at a depth of 10 cm below and around the seed tuber at planting. Nitrogen was applied at the rate of 75 kg N ha^{-1} in the form of urea in three splits [(1/3rd at planting, 1/3rd at mid-stage of (at about 45 days after planting), and 1/3rd at the initiation of tubers (start of flowering)]. Harvesting was done at physiological maturity when the leaves of the potato plants senesced. Ten days before harvesting, the haulms of the potato plants were mowed using a sickle to toughen the periderm and pre-empt predisposal of tubers to skinning and bruising during harvesting.

Data collection

Agronomic parameters collected were stand count, days to flowering (50%), plant height (cm), days to maturity (95%), and tuber yield. Marketable tuber yield (t ha^{-1}) included marketable and healthy tubers with size categories greater than 25 g. Unmarketable tuber yield (t ha^{-1}) included unhealthy tubers as well as healthy tubers, weighing less than 25 g and total tuber yield (t ha^{-1}) was recorded as the sum of all marketable and unmarketable tubers. Marketable tuber yield, unmarketable tuber yield and total tuber yields recorded on plot basis were converted to t ha^{-1} for statistical analysis.

Table1. Soil nutrient contents of the trial sites before planting potato in 2013, 2014 and 2015

Site/farmer's name	pH (1:2.5 H_2O)	Total N (%)	P* (mg kg^{-1})	Exch. K ($cmol_c$ kg^{-1})	Exch. Na ($cmol_c$ kg^{-1})	CEC $cmol_c$ kg^{-1})
Bizuayehu	4.6	0.16	8.2	0.62	0.12	21.4
Dereje	4.4	0.18	5.8	0.72	0.14	20.6
Aselefechi	4.8	0.16	6.4	0.62	0.15	17.1
Boja	5.0	0.14	7.6	0.58	0.16	19.4
Sufa	5.2	0.18	8.4	0.68	0.15	19.8
Bekele	4.4	0.15	7.8	0.56	0.12	20.4
Ayenelem	4.6	0.17	6.2	0.68	0.16	18.2
Teshome	4.8	0.15	6.6	0.60	0.14	16.8
Nuru	4.2	0.18	7.2	0.66	0.13	18.6
Diriba	4.43	0.17	8.6	0.74	0.13	24.6
Gudisa	4.8	0.18	7.8	0.78	0.16	18.3
Biru	4.6	0.14	6.6	0.76	0.15	22.2

**Bray-2 method*

Determination of critical P concentration (Pc): to correlate relative yield vs soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray-2 method.

The Cate-Nelson graphical method (Dahnke and Olsen, 1990) was used to determine the critical P value using relative yields and soil test P values obtained from 12 P trials conducted at different sites. To assess the relationship between tuber yield response to nutrient rates and soil test P values, relative tuber yields in percent were calculated as follows:

$$Relative yield\,(\%) = \frac{Yield}{Maximum yield} X100 \quad (1)$$

The scatter diagram of relative yield (y-axis) versus soil test values (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level (Dahnke and Olsen, 1990).

Determination of P requirement factor (P_f): phosphorus requirement factor (p_f) is the amount of P in kg needed to raise the soil P by 1mg kg^{-1}. It enables to determine the quantity of P required ha^{-1} to raise the soil test by 1 mg kg^{-1}, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977). It was calculated using available

P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:

$$Pf = \frac{kgPapplied}{\Delta \text{ soil P}} \qquad (2)$$

Therefore, the rate of P to be applied (*Pa*) was expressed in terms of critical P concentration (P_c), initial soil P value (P_i) and P requirement factor(P_f).

$$Pa = (Pc - Pi)xPf \qquad (3)$$

Statistical analysis

The data were subjected to analysis of variance using the procedure of the SAS statistical package version 9.0 (SAS Institute, 2001). Means for the main effects were compared using the means statement with the least significant difference (LSD) test at the 5% level.

Results

Yield and yield components

Analysis of variance over three cropping seasons showed that the year effect was highly significant ($p \leq 0.01$ and $p < 0.001$) for yield and yield components of potato (Table 2). The highest mean total tuber yield (23.89 t ha^{-1}) was obtained in the year 2015 compared to the yield (20.14 t ha^{-1} and 22.7 t ha^{-1}) achieved in 2013 and 2014, respectively (Table 2).

The maximum plant height, days to flowering, days to maturate and unmarketable tuber yield were also recorded in 2013 cropping season (Table 2). Similarly, marketable tuber yield was recorded in 2015 cropping season. Total tuber yield, market tuber yield, plant height, days to flowering and days to maturate of potato significantly responded ($p < 0.05$ and 0.01) to P application rate. Unmarketable tuber yield was significantly affected at (p< 0.05) by year only but not by P application.

The effects of year by P rate interaction (Y x P) were not significant ($P \leq 0.05$) for tuber yield and yield components. Significantly, higher tuber yields were obtained from the application of 75 kg P ha-$^{1.}$ The application of P at rates of 15, 30, 45, 60 and 75 kg ha^{-1} increased total tuber yield of potato by 14, 18, 21, 29 and 45%, respectively, compared to the control (without P). Total tuber yields consistently increased as P rate increased (Table 2).

Table 2. Means for main effects of P application year and fertilizer rate on potato tuber parameters

Factor	Plant height (cm)	Days to flowering (when > 50% plants produced flower)	Days to Maturate (when > 90% plants read to harvest)	Marketable tube yield (tha^{-1})	Total tuber yield (tha^{-1})
Year					
2013	58.5^{a}	64.6^{a}	117.5^{a}	9.97^{c}	20.14^{c}
2014	56.3^{b}	61.7^{b}	114.3^{b}	13.75^{b}	22.7^{b}
2015	52.0^{c}	62.8^{c}	111.4^{c}	16.6^{a}	23.89^{a}
P					
0	53.7^{b}	73.87^{a}	123.5^{a}	9.13^{e}	18.1^{d}
15	54.73^{ab}	65.0^{b}	118.5^{b}	10.75^{d}	20.56^{c}
30	57.1^{a}	64.3^{b}	115.67^{c}	11.25^{cd}	21.27^{bc}
45	57.9^{a}	61.87^{c}	113.87^{d}	12.49^{c}	21.92^{bc}
60	56.8^{ab}	58.27^{d}	111.5^{e}	15.06^{b}	23.37^{b}
75	57.6^{a}	55.07^{e}	106.9^{f}	18.11^{a}	26.31^{a}
CV	8.16	1.86	1.3	17.1	15.02

Within each column, means with different letters are significantly different at $P < 0.05$; CV, coefficient of variation

Critical phosphorus concentration (Pc) and phosphorus requirement factor (Pf)

Soil P values determined three weeks after planting differed significantly ($P \leq 0.01$) among P levels. The main effect of P treatments resulted in mean soil test P values 9.2 to 14.5 mg kg^{-1} (Table 3). Bray-2 soil test P values below 10 mg kg^{-1} are considered low. The increase in soil P content in response to P application was linear up to 75kg P ha^{-1}. The highest mean soil P concentration (14.5 mg kg^{-1}) was recorded from 75 kg P ha^{-1}(Table 3).

The relationship between relative potato tuber yield response and soil P measured with the Bray-2 method is shown in the figure1. The critical P concentration (*Pc*) was determined from the scatter diagram drawn using relative tuber yields of potato and the corresponding soil test P values for all P levels (0–75 kg ha^{-1}). The *Pc* defined by the Cate- Nelson method in this study was about 16 mg P kg^{-1}, with mean relative grain yield response of about 80% (Figure 2).

When the soil test value is below the critical level additional information is needed on the quantity of P required to elevate the soil P to the required level. This is the P requirement factor (*Pf*), the amount of P required to raise the soil test P by 1 mg kg^{-1}, computed from the difference between available soil test P values from plots that received 0–75 kg P ha^{-1} using the second formula mentioned above. Accordingly, the calculated *Pf* were 10.7–18.8, and the overall average *Pf* of all treatments for the study area was 15.3 (Table 5). Thus, the rate of P required per ha can be calculated using the soil critical P concentration, initial soil P determined for each site before planting (Table 1) and the P requirement factor as indicated above in the third formula.

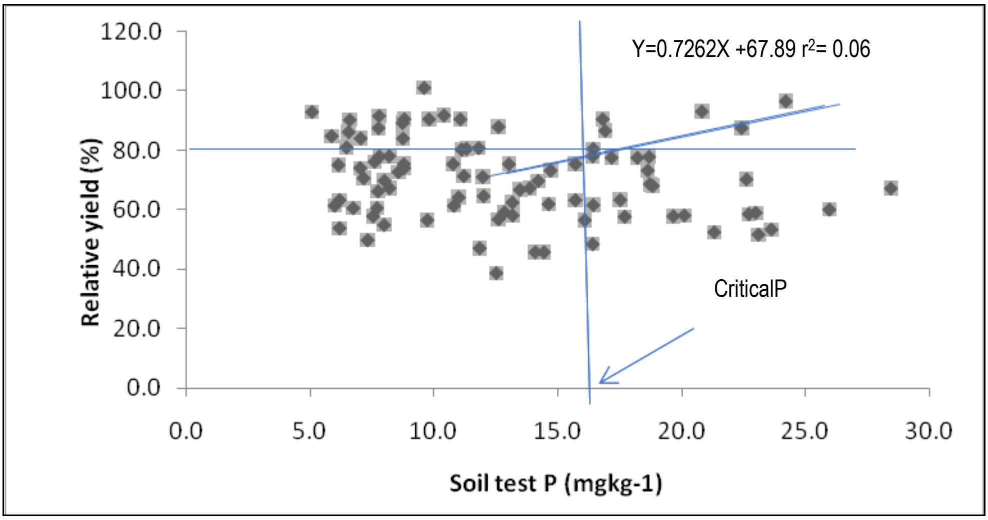

Figure 2: Relationships between relative yield response of potato and soil-test P measured using Bray-2 method. The arrow indicates the critical P concentration (*Pc*) for potato on Nitisols.

Table 3. Determination of P requirement factor for potato on Nitisols in 2013, 2014, and 2015

P (kg ha^{-1})	Soil test P (Bray- II)		P increase over control	P requirement factor (Pf)
	Range	Average		
0	5.6 - 20.9	9.2		
15	6.19 - 23.08	10.6	1.4	10.7
30	6.14 - 22.69	11.2	2.0	15
45	6.4 -23.97	11.7	2.5	18
60	6.8 - 25.94	12.4	3.2	18.8
75	7.04 - 28.42	14.5	5.3	14.2
Average				15.3

Discussion

Our results showed that significant variations in yield and other agronomic parameters were observed due to cropping season. Availability of nutrients to crops is a function of the soil, crop, environment, and management; their interactions affects fertilizer use efficiency and the crop growth condition (Getachew and Berhane, 2013; Getachew et al., 2015). These factors need to be considered when using methods to calibrate soil-test nutrient values with relative grain yields. Something that should be considered in this region in the future is the interaction of P response with N supply, soil pH, and weather condition. In 2012, lower tuber yield was recorded due to disease during the maturation period in late September. According to Jones (2011), low nutrient uptake early in a plant's growth stage lowers nutrient quantity for the seed affecting yield. Analysis of variance showed that phosphorous had a highly significant effect on tuber yield and yield component of potato, and tuber yield consistently increased as the rate of P increased.

According to the Cate- Nelson method, the critical levels of Bray-2 P in the top 15 cm of soil is about 16 mg kg^{-1}; at values of greater than or equal to 16 mg kg^{-1}, the crop achieved about 80% of its maximal yield in the absence of P application (Figure 3). This implies that P application could be recommended for a build-up of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P to produce extra yield would likely be greater than the value of additional yield. Thus, in soils with available P status below 16 mg kg^{-1}, yield of potato could show a significant response to applications of Ps. whereas in areas with available P status greater than 16 mg kg^{-1}, the P concentration in the soil exceeds crop needs so that further addition of P may not result in a profitable yield increase. Mallarino (2003) reported a critical concentration of 13 mg P kg^{-1} for corn response within this category (13-20 mg P kg^{-1}) may be considered small, and maintenance fertilization can be recommended based on expected nutrient removal with harvest.

Phosphorous fertilizer application at optimum level is necessary to improve tuber yield of potato. Soil fertility is sub-optimal for the production of potato in Ethiopian highlands, particularly on Nitisols where soil pH and the associated P availability is low. Following the pre-planting soil analysis results all of the trial sites had lower soil P values than the critical P concentration. This had a direct relationship with the crop growth and tuber yields. In most cases, soil pH less than 5.5 is deficient in available P and exchangeable cations (Brady and Weil, 2010). In such soils, the proportion of P that could be available to a crop becomes inadequate (Brady and Weil, 2010), unless amended through organic matter or liming.

The results seem promising and could be used as a basis for soil-test P recommendation for the production of potato on Nitisol areas of central Ethiopian highlands. They can also be used for future intensification in other areas for developing a system for soil test based fertilizer recommendation (Getachew and Berhane, 2013; Getachew et al., 2015). Nevertheless, to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, more research assisted by appropriate soil P extraction methods is required to generate sufficient information for the most important crop-soil systems.

Conclusions

There were clear positive effects of P on yield and yield components of potato on Nitisols of central highlands of Ethiopia. Across all 12 sites, the critical soil P concentration was 16 mg ka^{-1} (Bray 2 method). The results may be used as a basis for P recommendations for the production of potato on Nitisol areas of Ethiopian highlands. They can also be used for future intensification in other areas for developing a system for soil- test P recommendations. Further field trials involving different N levels, climatic conditions, soil P test methods, and perhaps limiting treatments, would further our understanding of limiting factors and facilitate better fertilizer recommendations.

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Response of Yield and Yield Components of Linseed to Phosphorous on Nitisols in Central Highlands of Ethiopia

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Introduction

Soil fertility management is continuously modified and adapted as conditions change in time. The intensification of soil fertility depletion increases, when population pressure increases and suitable land becomes scarce (Boesen and Hansen, 2001). In Ethiopia, low-input agricultural production systems and poor agronomic management practices, limited awareness of communities and absence of proper land-use policies have aggravated soil fertility degradation (Getachew and Tilahun, 2017). This has also encouraged the expansion of farming to marginal, non-cultivable lands, including steep landscapes and range lands (Getachew and Taye, 2005).

Linseed is one of the major oil crops grown in Ethiopia since antiquity primarily for food and to generate cash revenues for farmers (Niguissie et al., 1992). The crop is a multipurpose crop which can be used as edible oil, industrial use, functional food, and fiber. Despite its many use, linseed national productivity is not more than 1 t ha^{-1} (CSA, 2015). One of the main challenges of low productivity is growing of the crop under sub-optimal condition. Most linseed farmers in the highlands of Ethiopia apply little or no fertilizer for linseed production (Temesgen et al., 2011).

In Ethiopia, some studies conducted on the response of fertilizer on yield and yield component of linseed (Hiruy and Nigussie, 1988), however, inconsistent despite many studies in other countries showed proper application of crop management along with fertilizer application showed positive response for N and P (Temesgen et al., 2011). Shiferaw et al (2011) reported that applications of different levels of P s had significant effect on seed yield of linseed.

Phosphorous is the most yield limiting of soil-supplied elements, and soil P tends to decline when soils are used for agriculture (David and David, 2012). Studies on Nitisol areas, in the central highlands of Ethiopia are marginally to severely deficient in P (Hailu et al., 2011). The blanket recommendations that are presently in use all over the country were issued several years ago, which may not be suitable for the current production systems (Taye et al., 2002; Gete et al., 2010). Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying the same P rate to their fields regardless of soil fertility differences.

Phosphorus calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrient to the soil as fertilizer. It provides information how much nutrient should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the validity of current P recommendations (Evans, 1987, McKenzeie and Kryzanowski, 1997; Getachew and Berhane, 2013, Getachew et al., 2015). They enable to revise fertilizer recommendations for an area based on soil and crop type, pH and soil moisture content at time of planting. 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 a particular crop (Muir and Hedge, 2002; Watson and Mullen, 2007). Soil tests are designed to help farmers predict the available nutrient status of their soils. Once the existing nutrient levels are established, producers can use the data to best manage what nutrients are applied, decide the application rate and make decisions concerning the profitability of their operations (Girma, 2016). However, local assessments for the soil P critical levels and soil P requirement factors even for the major crops of the country are negligible (Getachew et al., 2015). Currently, soil fertility research improvement is agreed with respect to site-specific fertilizer recommendation in the country.

Soil test-based and site-specific nutrient management has been a major tool for increasing productivity of agricultural soils. The aim of the soil test calibration is to obtain correlation between the contents of the available nutrients in the soil and the crop responses to applications of nutrients in selected areas. Therefore, the objectives of this study were to correlate the Bray-2 soil test P with the relative seed yield response of linseed across selected Nitisol areas of west Showa, to established preliminary agronomic interpretations, and to determine the critical P concentration and P requirement factor.

Materials and Methods

Description of experimental sites

The response of linseed to phosphorus was studied on farmers' fields in 2013, 2014 and 2015 cropping seasons in West Showa, in the central highlands of Ethiopia. The average annual rainfall is about 1100 mm, and the average minimum and maximum air temperatures are 6.2 and 22.1 ^{0}c, respectively. The major soil type of the trial sites is Eutric Nitisol (FAO Soil Classification, 1998).

Over 320 soil samples (0-20 cm depth) were collected in three years from farmers' fields to select representative trial sites before the onset of the experiment. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1g soil; available P using Bray-II method; organic carbon was determined by the method of Nelson and Sommers (1982), and total nitrogen using Kjeldahl method (Jackson, 1958), exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method at the soil and plant analysis laboratory of Holetta Agricultural Research Center. The available soil P (using Bray-2 method) ranges prior to planting considered for classification were < 10 mg P kg^{-1} for low, 10-25 mg P kg^{-1} for medium, and > 25 mg P kg^{-1} for high (Table 1). Based on this categorization for available P, five farmers with low and medium fields were selected for the first year, five farmers for the second year and three farmers with the same categories for the last two years, respectively.

Experimental procedures

The treatments comprised six levels of phosphorous fertilizer (0, 5, 10, 15, 20 and 25 kg P ha^{-1}). The experiment was laid out in a randomized complete block design with three replications. The gross plot size was 4m x 5m = (20 m^2), and accommodating a minimum of 12 harvestable plants with different rows and space lengths. The net plot size was determined with area and plant density leaving the one outermost row and sides of each row. The spacing between rows, plots, and blocks were 0.20 m, 0.5 m and 1 m, respectively. The harvested plot area was 16 m^2. The source of P was triple super-phosphate (TSP). All agronomic practices were applied based on local research recommendations.

Land preparation was done with local maresha using oxen plough. An improved linseed cultivar (*Belay 96*) was planted to the specified treatments. Sowing was made from end of May to the last week of June depending on the onset of rainfall. Weeding, chemical spray and harvesting were done at the appropriate time according to the research recommendations. Application of phosphorus was done by banding the granules of TSP at a depth of 10 cm below and around the seed at planting. Harvesting was done at physiological maturity when the leaves of the linseed plants senesced.

Agronomic parameters collected were plant height (average of ten randomly reselected plants per plot), days to maturity (when 95% percent of the plants of different treatments were ready for harvest), number of pods per plant and seeds per pod (average of ten plants), total above ground biomass, seed yields and thousand seed weight. The harvested materials were sun-dried and manually threshed. After threshing, seeds were cleaned, weighed and adjusted at 10% moisture level. The total biomass and seed yields recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

Table1: Soil nutrient contents of the trial sites before planting linseed in 2013-2015

Site/farmer's name	pH (1:2.5 H_2O)	Total N (%)	Av. P* (mg kg^{-1})	Exch. K ($cmol_c$ kg^{-1})	Exch. Na ($cmol_c$ kg^{-1})	CEC ($cmol_c$ kg^{-1})
Alemu	4.8	0.2	10.8	0.62	0.16	19.4
Beyene	4.2	0.16	8.4	0.66	0.18	22.2
Tefesa	5.4	0.22	10.2	0.62	0.14	18.1
Kebebe	4.4	0.15	12.2	0.54	0.14	15.4
Legesse	5.2	0.21	7.8	0.58	0.17	16.8
Bekele	5.0	0.17	7.2	0.62	0.18	20.4
Beyi	4.2	0.18	6.2	0.60	0.16	21.2
Taresa	4.8	0.18	11.6	0.66	0.15	22.4
Gadisa	4.6	0.16	7.6	0.62	0.14	18.6
Irko	4.4	0.14	6.4	0.56	0.15	21.2
Gudisa	4.6	0.15	6.8	0.68	0.16	19.6
Hunde	4.2	0.14	7.2	0.72	0.15	20.2
Makonin	4.5	0.16	7.6	0.66	0.17	19.4

**Bray-2 method*

Determination of critical P concentration (Pc): to correlate relative yield vs. soil test P values and determine critical P concentration, the available P was extracted from the soil samples taken three weeks after planting from each plot of all experimental fields using Bray-2 method.

The Cate-Nelson graphical method (Dahnke and Olsen, 1990) was used to determine the critical P value using relative yields and soil test P values obtained from 13 P trials conducted at different sites. To assess the relationship between seed yield response to nutrient rates and soil test P values, relative seed yields in percent were calculated as follows:

$$Relativeyield(\%): \quad \frac{yield}{maximumyield} x100 \qquad (1)$$

The scatter diagram of relative yield (y-axis) versus soil test values (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level (Dahnke and Olsen, 1990).

Determination of P requirement factor (P_f): phosphorus requirement factor (P_f) is the amount of P in kg needed to raise the soil P by 1mg kg^{-1}. It enables to determine the quantity of P required per hectare to raise the soil test by 1mg kg^{-1}, and to determine the amount of P required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977, 19-39). It was calculated using available P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:

$$Pf = \frac{kgPapplied}{\Delta SoilP} \qquad (2)$$

Therefore, the rate of P to be applied (*Pa*) was expressed in terms of critical P concentration (P_c), initial soil P value (P_i) and P requirement factor(P_f).

$$Pa = (Pc - Pi)\ xPf \qquad (3)$$

Statistical analysis

Data were subjected to analysis of variance using the procedure of SAS statistical package, version 9.0 (SAS Institute, 2001). Means for the main effects were compared using the means statement with the least significant difference (LSD) test at 5% level.

Results

Yield and yield components

The responses of plant height, pod numbers per plant, seed yield and total biomass of linseed to phosphorus fertilization, year and interaction of year by phosphorus of the combined data of over three years are presented in Table 2. The year effect was significant ($p \leq 0.05$ and 0. 01) for seed yield and total biomass of linseed (Table 2). The highest mean seed yield of 542 kg ha^{-1} was obtained in the year 2014 relatively compared to the yields of 486 kg ha^{-1} and 406 kg ha^{-1} achieved in 2013 and 2015, respectively (Table 3).

Table 2: Effects of year, P rate and their interaction on yield components of linseed across sites in 2013, 2014 and 2015

Parameter	Year (Y)	Phosphorous (P)	Y * P
Plant height	Ns	Ns	Ns
Seed yield	*	*	Ns
Total biomass	*	*	Ns
Number of pods/plan	Ns	Ns	Ns

*, ** *Significant at 5 and 1% probability levels; Ns = Not significant*

The maximum seed yield and total biomass of linseed were recorded in 2014 cropping season (Table 3). The effects of year by P rate interaction (Y x P) were not significant ($P \leq 0.05$) for seed yield and yield components (Table 3). Application of P significantly ($P < 0.05$) affected seed yield and total biomass, but not plant height and number of pods per plant. The highest seed yield was obtained from the application of 20 kg P ha-^{1}. The application of P at the rates of 5, 10,15, 25 and 20 kg ha^{-1} increased seed yield of linseed by 20, 16, 35, 34 and 43%, respectively, compared to the control (without P).

Critical P concentration (Pc) and P requirement factor (Pf)

Soil P values determined three weeks after planting differed significantly ($P \leq 0.01$) among P levels. The main effect of P treatments resulted in mean soil test P values 4.3 to 10 mg kg^{-1} (Table 4). Bray-2 soil test P values below 10 mg kg^{-1} are considered low. The increase in soil P content in response to P application was linear up to 20 kg P ha^{-1}. The highest mean soil P concentration (9 mg kg^{-1}) was recorded from 20 kg P ha^{-1} (Table 4).

Table 3. Means for main effects of P application year and fertilizer rate on linseed parameters

Factor	Plant height (cm)	Numbers of pod/plant	Seed yield (kg ha^{-1})	Total biomass (t ha^{-1})
Year				
2013	64	16	485.6^{b}	20.6^{b}
2014	66	18	541.6^{a}	21.2^{a}
2015	62	14	406.2^{c}	18.6^{c}
P				
0	62	12	350.9^{c}	19.52
5	64	16	421.1^{ab}	21.75
10	65	14	408.3^{ab}	19.59
15	64	16	473.4^{ab}	17.39
20	68	18	501.3^{a}	21.73
25	66	15	469.1^{ab}	20.15
CV	11.3	7.4	21	17.6

Within each column, means with different letters are significantly different at P< 0.05; CV, coefficient of variation

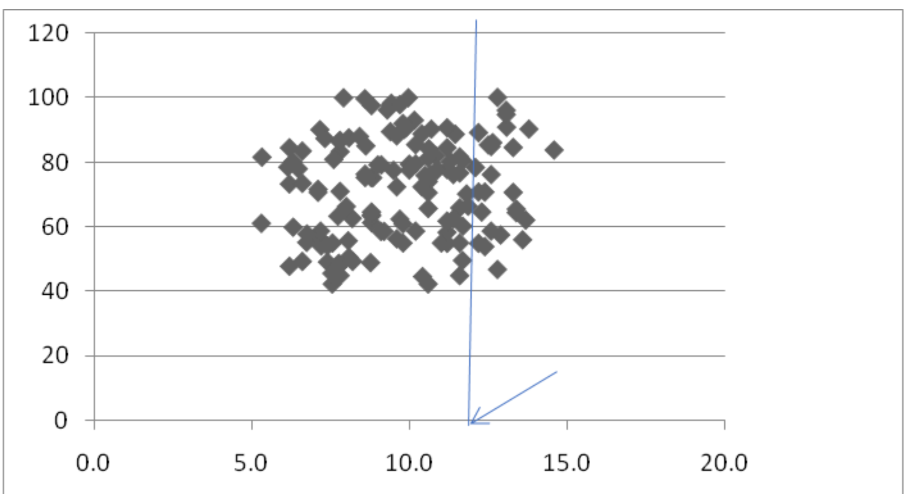

Figure 1: Relationships between relative yield response of linseed and soil-test P measured using Bray-2 method. The arrow indicates the critical P concentration (*Pc*) for linseed on Nitisols.

Table 4. Determination of P requirement factor for linseed on Nitisols in 2013, 2014 and 2015

Phosphorous rate ($kgha^{-1}$)	Soil test P (Bray- II)		P increase over control	P requirement factor (Pf)
	Range	Average		
0	5.8 - 16.6	8.2		
5	6.2–19.8	9.4	1.2	4.2
10	6.8 – 20.4	9.8	1.6	6.3
15	7.2 - 21.8	11.6	3.4	4.4
20	7.6 - 20.3	10.2	2.0	10
25	6.8 - 24.6	12.6	4.4	5.7
Average				6.12

The relationship between relative linseed yield response and soil P measured with the Bray-2 method is shown in the Figure 1. The critical P concentration (*Pc*) was determined from the scatter diagram drawn using relative seed yields of linseed and the corresponding soil test P values for all P levels (0-25 kg ha^{-1}). The *Pc* defined by the Cate- Nelson method in this study was about 11 mg P Kg^{-1}, with mean relative seed yield response of about 80% (Figure 1).

When the soil test value is below the critical level, additional information is needed on the quantity of P required to elevate the soil P to the required level. This is the P requirement factor (*Pf*), the amount of P required to raise the soil test P by 1mg kg^{-1}, computed from the difference between available soil test P values from plots that received 0–25 kg P ha^{-1} using the second formula mentioned above. Accordingly, the calculated *Pf* were 4.2–10 and the overall average *Pf* of all treatments for the study area was 6.12 (Table 4). Thus, the rate of P required per ha can be calculated using the soil critical P concentration, initial soil P determined for each site before planting (Table 1) and the P requirement factor as indicated above in the third formula.

Discussion

Significant variations in yield and other agronomic parameters were observed due to cropping season. The maximum yield attainable at any given location depends not only on the soil available nutrients and the amounts of fertilizer applied, but also on the amount and distribution of rainfall during the crop season. Availability of nutrients to crops is a function of the soil, crop, environment, and management; their interactions affects fertilizer use efficiency and the crop growth condition (Smilde, 1987; Fageria, 2009). These factors need to be considered when using methods to calibrate soil- test nutrient values with relative seed yields.

According to the Cate-Nelson method, the critical levels of Bray-2 P in the top 15 cm of soil is about 9.8 mg kg^{-1}; at values of greater than or equal to 9.8 mg kg^{-1}, the crop achieved about 80% of its maximal yield in the absence of P application (Figure 1). This implies that P application could be recommended for a build-up of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P to produce extra yield would likely be greater than the value of additional yield. Thus, in soils with available P status below 9.8 mg kg^{-1}, yield of linseed could show a significant response to applications of Ps. Whereas in areas with available P status greater than 9.8 mg kg^{-1}, the P concentration in the soil exceeds crop needs so that further addition of P may not result in a profitable yield increase. Mallarino (2003) reported a critical concentration of 13 mg P kg^{-1} for corn response within this category (13-20 mg P kg^{-1}) may be considered small, and maintenance fertilization can be recommended based on expected nutrient removal with harvest.

Phosphorous fertilizer application at optimum level is necessary to improve seed yield of linseed. Soil fertility is sub-optimal for the production of linseed in Ethiopian highlands, particularly on Nitisols where soil pH and the associated P availability is low. Following the pre-planting soil analysis results, all of the trial sites had lower soil P values than the critical P concentration. This had a direct relationship with the crop growth and seed yields. In most cases, soil pH less than 5.5 is deficient in available P and exchangeable cations (Brady and Weil, 2010). In such soils, the proportion of P that could be available to a crop becomes inadequate (Brady and Weil, 2010), unless amended through organic matter or liming.

The results seem promising and could be used as a basis for soil-test P recommendation for the production of linseed on Nitisol areas of central Ethiopian highlands. Nevertheless, to develop an effective guideline for wider applicability of soil test based fertilizer recommendations, more research assisted by appropriate soil P extraction methods is required to generate sufficient information for the most important crop-soil systems.

Conclusions

There were clear and positive effects of P on yield and some yield components of linseed on Nitisols of central highlands of Ethiopia. Across all 13 sites, the critical soil P concentration was 9.8 mg ka^{-1} (Bray 2 method). The results may be used as a basis for P recommendations for the production of linseed on Nitisol areas of Ethiopian highlands. They can also be used for future intensification in other areas for developing a system for soil-test P recommendations. Further field trials involving different N levels, climatic conditions, soil P test methods, and perhaps limiting treatments, would further our understanding of limiting factors and facilitate better fertilizer recommendations.

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Phosphorus Calibration for Tef on Andosols in the Central Rift Valley of Ethiopia

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Introduction

Fertilizer use in Ethiopia has focused mainly on the use and application of nitrogen and phosphorous fertilizers in the form of di-ammonium phosphate (DAP) and urea for almost all cultivated crops for both market and food security purposes for the last several years. Such unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements in soils, such as K, Mg, Ca, S and micro-nutrients. However, N, P, and K are the three major nutrient elements required in large quantities for normal growth and development of crops. Some nutrient elements such as potassium (K) are not being used as a commercial fertilizer for agricultural crop production under Ethiopian conditions. This is merely because of the generalization that Ethiopian soils are believed to contain sufficient quantity of the K nutrient. Nevertheless, some reports indicated that elements like K, S, Ca, Mg and micro-nutrients particularly Cu, Mn, B, Mo and Zn are becoming depleted and deficiency symptoms are observed on major crops in different areas of the country (Abiye et al., 2001; Asgelil et al., 2007).

Soil test calibration is the process of relating the soil test measurement in terms of crop response (Bray, 1945; Truog, 1930; Olson et al., 1958; Corey, 1987; Getachew and Berhane, 2013; Getachew et al., 2015). Soil test calibration should describe soil test results in easily understood terminology and simplify the process of making fertilizer recommendations by placing soils in response categories (Dahnke and Olson, 1990). These response categories cannot be used to predict yield, but can offer the probability that a response to fertilization will occur.

The use of soil testing for regulatory or environmental purposes requires a concerned and coordinated regional institutions and stakeholder efforts. Therefore, this report addresses the need for reliable soil nutrient calibration/correlation data, with the aim of extending the information to the major agro-ecologies of the country.This experiment was initiated with the objectives of improving the livelihood of the farming community by providing appropriate soil fertility technologies through soil test calibration that help enhancing production as well as contributing to local and export markets with highly competitive quality products. It may contribute towards yield increments (quantity and quality) of tef crop on Andosol soil types of Alem Tena, and increase the sustainability of the natural resources.

Materials and Methods

Description of the study area

The study was conducted from 2012-2014 for three consecutive years under rain fed conditions on selected 20 farmers' fields at Alem Tena District, South East Shewa Zone of Oromia Regional State. Alem Tena is located at about 112 kilometers (km) south East of Addis Ababa on the main road to Hawassa.

Experimental materials, treatments and design

The experiment comprised of seven treatments, i.e. six levels of phosphorus (0, 10, 20, 30, 40, 50 kg P ha^{-1}) and one KCl as a satellite treatment. The field experiments were laid out in a randomized complete block design with three replications. Urea (46% N) was used as the source of N whereas triple super phosphate (TSP, 46% P_2O_5) was used as the source of P. Full dose of P was applied at time of planting and the recommended amount of nitrogen (90 kg/ha) was applied in split doses to all experimental plots including the control. Improved tef variety known as *Boset* was used as a test crop.

Experimental procedures, field management, and data collection

The experimental plot was prepared using local plow (Maresha) according to the local farmers' conventional practice. Accordingly, the field was plowed three times before sowing. The plot size was 5m x 5m (25 m^2). The plots within a block as well as between block were separated by 1m wide open space area. The necessary cultural and recommended agronomic management practices were all carried out. Weeding was done manually three times during the crop growth period. The crop data collected include plant height, grain yield, straw yield, and total aboveground biomass.

Soil sampling and analysis

Before planting, soil samples were collected from farmers' fields for the determination of available phosphorous. Depending on laboratory results 20 farmers' fields which had low available P were selected using Olson methods. Intensive composite soil samples were also collected at 30 cm depth three weeks after planting from each plot by replication for the determination of available phosphorous for the correlation study. The available phosphorous was determined using Olson methods at Debre Zeit laboratory.

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. The Cate-Nelson graphical method is based on dividing the Y-X scatter diagram into four quadrants and minimizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson and Anderson, 1977). Steps in the Cate-Nelson graphical methods are as follows:

Percentage yield values are obtained for a wide range of locations where results of fertilizer rate studies are available.

Percentage yield =

$$\frac{Yield\ at\ 0-level\ of\ nutrient\ being\ studied;\ other\ factors\ at\ adeqauet\ but\ not\ excessive\ levels}{Yield\ where\ all\ factors\ are\ at\ adequate\ but\ not\ excessive\ level}$$

Statistical analysis

The data were subjected to analysis of variance (ANOVA) appropriate to randomized complete block design using SAS software program (SAS Institute, 2000). The analysis results of the soil samples were interpreted using descriptive statistics. When significant differences were observed, comparisons of means were performed using the least significant difference (LSD).

Results and Discussion

Selected soil chemical properties prior to planting

The pH of a soil is one of the most important properties influencing plant growth and production as it affects ion exchange capacity and nutrient availability. The mean pH values of the composite surface (0-30 cm) soil samples were moderately alkaline. As the result in Table 1 shows the organic matter content of the soils of the study were classified as low to very low organic matter content (London, 1991). The reasons for the very low content of OM could be intensive cultivation of the land and the total removal of crop residues for animal feed. Moreover, there is no practice of addition of organic fertilizers, such as farmyard manure and green manure that would have contributed to the soil OM pool. In line with the current results, Tesfaye and Sahlemedhin (2002) also indicated that the organic matter contents and nutrient supplying power of most cultivated soils in Ethiopia are low.

The total N contents of the composite surface soil samples rated from low up to high (Table 1) based on the classification of Landon (1991). The low total N contents indicate that the soils of the study area are deficient in N to support proper growth and development of crops, which confirms that the site must be fertilized with external N inputs.

Tisdale et al.(2002) have indicated that for Olson extractable P below 3 mg kg^{-1} is considered as very low; between 4 and 7 mg kg^{-1} as low; between 8 and 11 mg kg^{-1}medium, and greater than 12 mg kg^{-1} as high. Thus, the available P content of the composite surface soil sample of the experimental sites could be rated as low. Generally, existence of low contents of available P is a common characteristic of most soils in Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002; Wakene and Heluf, 2003).

Table1. Organic matter, total nitrogen, and available P contents

Site	%OM	%N	P (ppm)
1	3.02	0.12	5.3
2	1.52	0.61	4.6
3	3.50	0.16	5.19
4	2.36	0.13	4.6
5	3.64	0.15	5.15
6	4.90	0.11	7.1
7	0.97	0.25	5.4
8	3.57	0.14	5.2
9	2.10	0.22	5.5

Response of tef to the applied phosphorus

Plant height

The effect of applied fertilizers on plant height was found highly significant ($P \leq 0.01$). However, there was no statistically significant difference between the rates of P treatment means except the application of no phosphorus. As indicated in Table 1 the minimum (91.0 cm) plant height was obtained from the application of no phosphorus (Table 2).

Table 2.Response of tef different rates of P

Levels of P (kg ha^{-1})	Plant Height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biomass yield (kg/ha)
0	91.0b	833.11d	3723.8b	4614.9d
10	95.1a	961.04c	3976.1ab	4884.7cd
20	94.8a	1120.32b	4017.3a	5114.4cd
30	95.5a	1151.78b	4191.1a	5356.6ab
40	94.0a	1259.93a	4192.9a	5485.9a
50	93.7a	1175.28b	4063.6a	5210.9ab
90/34/40 $N/P_2O_5/K_2O$	95.3a	1158.57b	4172.0a	5320.4ab
LSD (0.05)	2.1	75.6	269.93	287.02
CV (%)	6.18	18.75	18.1	15.15

**Means within a column and the same site sharing common letter(s) are not significantly different at P > 0.05; LSD = Least significant difference; CV = Coefficient of variation;*

Grain yield, straw yield, and total biomass

Application of different rates of P was significant ($P \leq 0.01$) for grain yield. As shown in Table 1 the highest (1260 kg ha^{-1}) and lowest (833 kg ha^{-1}) mean grain yield were obtained from the application of 40kgP/ha and the control plots, respectively. As P rate, increased grain yield also correspondingly increased up to 40kgP/ha levels. The critical P concentration for tef was 11.9 mg/kg (Fig. 1), and the P requirement factor (Pf) was 7.6 (Table 3).

As indicated in table 2. The highest and the lowest straw and total biomass yield were obtained from the application of 40 kg P ha^{-1} and 0 kg P ha^{-1}, respectively. It did not also show a consistent trend with increasing levels of P.

Validation of calibrated phosphorus

After getting the critical P concentrations for tef and the soil type the validation of calibrated phosphorus was also conducted and the results revealed that the highest grain yield of tef was obtained at the application rate of 50 kg P ha^{-1} with the yield advantage of 27% from precisely used recommendation

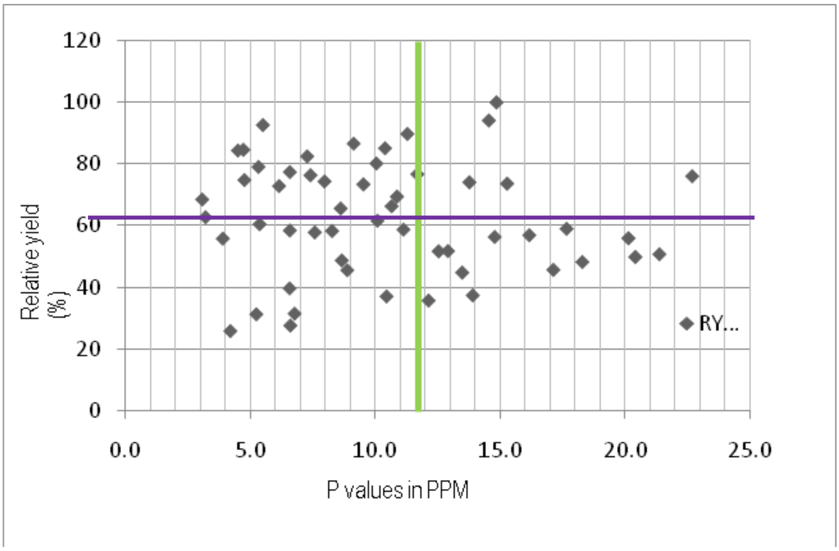

Fig. 1. Critical P concentration for tef on Andosol

Table 3.Determination of P requirement factor (P_f) for tef on Andosol of AlemTena

P rate (kg/ha)	Soil test P		P increase overcontrol	P requirement factor (P_f)
	Range	Average		
0	3.1-11.1	7.1		
10	3.2-12.9	8.05	0.95	10.53
20	5.4-17.1	11.25	4.15	4.82
30	4.5-18.3	11.4	4.3	6.98
40	4.8-17.7	11.25	4.15	9.64
50	8.0-22.7	15.35	8.25	6.06
	Average			7.60

Table 4. Validation of calibrated phosphorus

Treatment ($kgha^{-1}$)	Plant height (cm)	Grain yield (kg ha^{-1})	Straw yield ($kgha^{-1}$)
Recommended NP (15 kg P/ha + 90 kg N/ha)	95.63	1157.50	3157.5
Calibrated P + recommended N (50 kg P/ha + 90 kg N/ha)	95.60	1473.25	3616.3

Conclusion

The highest and the lowest straw and total biomass yields were obtained from the application of 40 kg P ha^{-1} and 0 kg P ha^{-1}, respectively. The critical P concentration for tef was 11.9 mg kg^{-1}, and the P requirement factor (Pf) was 7.6. Based on the results of the study validation of the current findings with previous results on larger plots was also conducted for one year, and the highest grain yield of tef was obtained at the application rate of 50 kg P ha^{-1} with the yield advantage of 27% . Hence, application of 50 kg P ha^{-1} for tef and for similar soil type of the study area can be recommended.

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Potassium Calibration for Tef and Wheat Production under Vertisols of the Central Highlands of Ethiopia

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Introduction

Potassium (K) fertilizer application is not common in Ethiopian agriculture mainly due to the view that potassium is not a limiting nutrient in Ethiopian soils; a conception which was based on the report by Murphy (1959) and Hofner and Schmitz (1984). However, Ethiopian agriculture is a highly exploitative type in which plant nutrients including potassium is extracted or mined from the soil whereby very little or no crop residues are returned back to the soil.

Potassium deficiency can be caused by insufficient K supply and leaching mainly on acid sandy soils. Uptake of K, on the other hand, can be limited due to very high concentrations of Ca and Mg in calcareous soils or heavy application of N. It has been known that K deficiency can cause sharp drop of photosynthesis rates in plants. Considering the above facts, there is no reason that K in some soil types of Ethiopia may be less than the plant requirement. In most soils, higher percent of the total potassium present in soils is found in insoluble primary minerals such as feldspars and micas. These minerals consist of potassium-aluminum silicates which are resistant to chemical breakdown. They release potassium slowly, but in small quantities compared to total needs of growing crops. According to Lahav (1995), banana crop yielding 50 t/ha of fresh fruit was reported to extract about 390 kg N/ha, 50 kg P/ha and 1440 K kg/ha from the soil.

In most of the intensive cropping systems in India, K balance is negative since the additions of K seldom match the K removals resulting in larger dependence on soil K supply. Under such conditions, there is greater pressure on non-exchangeable K for meeting the K requirement of crops. Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields (Swarup, 1998). Higher crop K requirement comes with higher crop yields. The importance of K in plant growth and development has been known for over 150 years. Most crops take up as much or more K than N, 70 to 75% of the K absorbed is retained by leaves, straw, and stover. The remainder is found in harvested portions such as grains, fruits, nuts, etc. Whenever the soil cannot adequately supply the K required to produce high yields, farmers must supplement soil reserves with fertilizer K (Cavalot et al., 1990). It is necessary to continually emphasize the role and importance of K in crop production as balanced fertilizer use has a direct bearing on the country's capability to produce its ever-increasing requirement of food, fibre, and other farm-based commodities. Improvements in both quantity and quality will add to export earnings. It is thus clear that for the long-term and sustainable use of agricultural lands, the removal of K needs to be balanced by adequate K inputs if a decline in soil fertility is to be avoided. The most important potassium fertilizers are potassium chloride (muriate of potash), sulphate of potash, sulphate of potash magnesia, Kainit, potassium nitrate, potassium metaphosphate (15). Two major groups may be distinguished, the chlorides and the sulphates. The latter are more expensive than the chlorides. For this reason, the chlorides are preferred, provided that the crop is not chlorophobic. Most field crops are not sensitive to chloride and should therefore be fertilized with potassium chloride.

As indicated by Abayneh et al. (2001), the soils of some of the regional and federal agricultural research centers such as Areka and Pawe were found to be deficient in K status. Results from some trials involving potassium fertilizer in Ethiopian soils depicted positive crop responses to potassium application (Paulos, 1986). For instance, coffee yield improvement was reported when the level of potassium was increased from zero to 62 kg/ha at Melko (Abay et al., 2010 unpublished). A field experiment conducted on acidic soils of Chencha for two years (2007-2008) also showed significant increase on tuber yield of Irish potato over the control due to K application (Wassie et al., 2010 unpublished). The report also showed that increasing K application rate has successively increased the tuber yield up to K level of 150 kg/ha. Application of K at the rate of 150 kg/ha increased the tuber yield from 15 tons in the control to 57.2 tons/ha in 2007. The corresponding increases in 2008 ranged from 21.3 tons to 50.4 tons/ha, i.e. yield increments of 21 to 137%.

The above information on crop responses to potassium application is indicative enough to initiate experiments for major crops where its deficiency is expected. Thus, this experiment was initiated to assess and evaluate the K fertilizer requirement of wheat and tef based on soil test crop response on Vertisol, and give quantitative guidelines and recommendations of K fertilizer for tef and wheat on Vertisols of Akakii and Chefe Donsa districts.

Material and Methods

Experimental procedures

The study was conducted in 2013 and 2014 for 2 cropping seasons under rain fed conditions on selected farmers' fields at Akakii and Chefe Donsa district, East Shewa Zone of Oromia Regional State.

The treatments comprised six levels of K fertilizer (0, 20, 40, 60, 80 and 100 kg K/ha). The field trials were laid out in a randomized complete block design with four replications. Urea (46% N) was used as the source of N, triple super phosphate (TSP, 46% P_2O_5) as the source of P, and KCl as the source K. Full doses of K and P were applied at the time of planting and the recommended amount of nitrogen (60 kg/ha) was applied in split doses for all experimental plots. Improved tef and wheat varieties known as *Kuncho* and *Yerer* were used as test crops, respectively.

The experimental plot was prepared using local ox-drawn implement (Maresha) according to the local farmers' conventional practice. The field was plowed three times before sowing. The plot size was 5 m x 5m (25 m^2). The plots within a block as well as between blocks were separated by 1 m wide open space area. The recommended agronomic management practice was all carried out. Weeding was done manually three times during the crop growth period. The crop data collected were plant height, grain yield, straw yield, and total aboveground biomass. Before sowing, composite surface soil samples were collected, from selected farmers' fields to determine soil pH, OM, total N, available P and exchangeable K for soil fertility evaluation.

Statistical analysis

The yield and crop agronomic data were subjected to analysis of variance (ANOVA) appropriate to randomized complete block design using SAS software program (SAS Institute, 2000). The analysis results of the soil samples were interpreted using descriptive statistics. When significant differences were observed, comparisons of means were performed using the least significant difference (LSD).

Results and Discussion

Selected soil chemical properties before planting

The data in Table 4 shows that the pH values of the study area ranged from slightly acidic to moderately alkaline as per the classification of Foth and Ellis (1997). In agreement with the current results, Eylachew (2000) also showed that Vertisols characterized in different parts of the country have shown pH ranges of 6.3 to 7.6 on the surface layer. As per the classification set by London (1991), the organic matter contents of all the study sites rated under very low organic matter content. The reasons for the very low content of OM could be intensive cultivation of the land and the total removal of crop residues for animal feed and source of energy. Moreover, there is no practice of addition of organic fertilizers, such as farmyard manure and green manure that would have contributed to the soil OM pool in the study area.

Table1. Soil pH, organic matter, total nitrogen exchangeable K and available P before planting

Site	pH (H_2O)	OM (%)	Total N (%)	Exch. K (cmol/kg)	Av. P (ppm)
Chefe Donsa					
1	7.66	1.89	0.05	0.99	24.36
2	7.54	1.87	0.048	0.80	13.59
3	6.83	1.86	0.045	1.04	33.38
Akakii					
1	7.88	1.77	0.05	1.18	13.73
2	7.04	1.55	0.053	1.19	21.80
3	7.01	1.99	0.067	1.01	12.11
4	7.14	1.86	0.046	1.27	15.34

OM = Organic matter; AP = Available phosphorus; Exch. K = exchangeable potassium

The total nitrogen contents of all the study sites fall under very low nitrogen (Table 4). Thus, the low total N contents indicate that the soils of the study area are deficient in N to support proper growth and development of crops, which confirms that the site must be fertilized with external N inputs. Furthermore, other research works carried out in Ethiopia on Vertisols also indicated that N is the most deficient nutrient element of other essential elements in these soils and has called for the application of inorganic fertilizers and need for a sound management of soil OM through addition of organic fertilizer sources (Tekalignet al., 1988; Mesfin, 1998; Eylachew, 1999, Engdawork, 2002; Mohammed, 2003).

According to the classification of exchangeable bases set by FAO (2006), the exchangeable K contents of the surface soil could be rated as high to very high (Table 4). Generally, the soil of the study area has the potential to supply K for crop growth and hence, calls for protection and maintenance of the surface soil to secure sustainable crop production without any external addition of K fertilizers. The result obtained for exchangeable K agrees with the common idea that Ethiopian soils are rich in potassium.

The available phosphorus contents of surface composite soils of the study area ranged from 12.11 to 33.38 mg kg^{-1} (Table 4). Tisdale et al. (2002) indicated that for Olson extractable P below 3 mg kg^{-1} is considered as very low; between 4 and 7 mg kg^{-1} as low; between 8 and 11mg kg^{-1} as medium, and greater than 12 mg kg^{-1} as high. Thus, the available P content of the mean composite surface soil samples of the experimental sites could be rated as high soil available P. Mitiku (1987) also reported that the available P in Ethiopian Vertisols of the central highlands as determined by the Olsen method showed a wide range of values (8-28 gm kg^{-1}), which is low to moderately high in relation to the fertility status of the soil.

Application of different rates of potassium fertilizer did not show significant ($P > 0.05$) effect on plant height of tef at both experimental sites. However, at Akakii site the highest (121.6 cm) and lowest (114 cm) plant heights were obtained from plots which received the highest potassium fertilizer and the control plots, respectively (Table 2).

Table 2. Plant height, grain and straw yields, and total biomass of tef as influenced by different rates of K fertilizer.

K_2O (kg/ha)	PH (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biomass yield (kg/ha)
Akakii				
0	114.0b	1095.1	3842.4	4937.5
20	119.5a	1073.1	3333.2	4406.3
40	121.0a	1088.4	3568.1	4656.3
60	116.7ab	1028.6	3409.3	4437.5
80	120.0a	1176.6	4198.5	5375.0
100	121.6a	1023.9	3070.2	4093.8
LSD (0.05)	5.14	ns	Ns	ns
CV (%)	4.3	18.35	23.8	20.03
ChefeDonsa				
0	85.8	1848.1	4691.3	6539.4ab
20	87.1	1939.3	4689.3	6628.5a
40	84.8	1742.4	4186.6	5929.1b
60	85.5	1913.5	4725.5	6639.0a
80	85.8	1871.4	4501.3	6372.6ab
100	85.4	1780.3	4618.9	6399.2ab
LSD (0.05)	ns	ns	Ns	636.34
CV (%)	8.5	17.5	17.4	14.1:

PH = plant height; LSD = Least significant difference; CV = Coefficient of variation;

In line with the plant height, grain yield, straw yield and total biomass did not also show significant ($P \leq 0.05$) difference for K fertilizer application at both experimental sites (Table 2). However, at Chefe Donsa site, relatively higher mean tef grain yield, straw yield and total biomass were obtained due to K fertilizer application, which could be due to soil K content of the study site.

Grain yield of tef did not also show consistent relationship with increasing K fertilizer rate at both experimental sites.

Table 3.Response of plant height, grain and straw yields and total biomass of wheat to different K fertilizer rate.

K_2O (kg/ha)	PH (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Total biomass (kg/ha)
		Chefe Donsa		
0	65.7b	2331.0	4535.8	6866.9
20	66.9a	2317.9	4955.4	7273.4
40	66.4ab	2447.3	4644.8	7092.3
60	65.8ab	2186.9	4586.2	6773.3
80	67.6ab	2615.9	5117.8	7733.8
100	68.2a	2573.1	4824.1	7397.2
LSD (0.05)	2.4	ns	ns	ns
CV (%)	5.1	25.8	30.07	23.19
		Akakii		
0	76.75	1917.9	3176.4	5093.8
20	80.62	1898.9	3351.6	5250.0
40	78.25	1806.9	3443.4	5250.0
60	80.37	1978.8	3115.5	5093.8
80	78.25	1906.8	3312.3	5218.8
100	82.75	2055.0	3132.9	5187.5
LSD (0.05)	ns	ns	ns	ns
CV (%)	5.49	20.89	12.56	15.86

PH = plant height; LSD = Least significant difference; CV = Coefficient of variation;

Similar to that of tef, application of K fertilizer at different rate did not show significant ($P \leq 0.05$) effect on wheat grain and straw yields, and total biomass at both locations (Table 3). However, the highest mean grain yields of wheat (2615.9 kg/ha) and (2055 kg/ha) at Chefe Donsa and Akakii were obtained from the applications of 80 kg K_2O/ha and 100 kg K_2O/ha, respectively.

Conclusions and Recommendations

Based on the results achieved from two years agronomic as well as soil data it can be concluded that K may not be a yield-limiting nutrient for the study sites. Thus, application of K containing fertilizer may not be necessary at least for the time being in the soils of the study area. However, based on the results of wheat yield at Chefe Donsa soil K monitoring could be important as necessary to evaluate its status, and recommend at least a maintenance level of K.

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Effects of Nitrogen Application on Durum Wheat under Vertisol Conditions of Chefedonsa and Akakii Area

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Introduction

Like all organisms, higher green plants need nutrients for their growth and development. Nutrients are indispensable as plant constituents, for biochemical reactions, and for the production of organic materials referred to as photosynthesis (carbohydrates), optimal crop nutrition is an important prerequisite for obtaining high yields and good quality produce. The nutrients required by plants are obtained both from soil reserves and external nutrient sources (fertilizers, organic manures, the atmosphere, etc).

Globally, nitrogen (N) is considered as the second most limiting factor in the crop production and limits yield in non-fertilized agriculture. It is applied to increase yield and improve crop quality. Nitrogen is also the most abundant mineral nutrient in plants. It constitutes 2–4 percent of plant dry matter. It is responsible for the dark green color of stems and leaves, vigorous growth, branching/tillering, leaf production, size enlargement, and yield formation.

Nitrogen is one of the essential nutrient elements that is taken up by plants in greatest quantity after carbon, oxygen and hydrogen, but is one of the most deficient macronutrients in crop production (Mesfin, 1998). Nitrogen also promotes P uptake of plants by increasing shoot and root growth, altering plant metabolism and increasing the solubility and availability of P (Tisdale et al.,1995).

Cereal grains are major contributors to human nutrition throughout much of the world (Hoveland, 1980). Wheat is one of the most important cereal crops grown in the Ethiopian highlands both in terms of area coverage and production (Hailu, 1991). It accounts for more than 15% of the total cereal output. It is an important crop commodity, which could contribute a major part in achieving the country's agricultural policy objective of food grain self-sufficiency. It is grown as a staple food in the highlands at altitudes ranging from 1500 to 3000 m.a.s.l. Despite the significant area of wheat production and its importance in Ethiopia, the mean national wheat yield of 1.68 t ha^{-1} is 32 % and 39 % below Kenyan and South African averages, respectively (Demeke and Marcantonio, 2013).

Even though different factors are contributing to low productivity, soil fertility is a major concern of crop production in mid and highlands of the country. Nitrogen and phosphorus are highly limiting nutrients to support good crop growth and development (Tenaw et al., 2006). However, there is little information on the impact of higher applications of nitrogen on wheat grain yield, under Vertisols in particular. Thus, information on production practices to optimize the grain yield and quality of durum wheat by applying the appropriate rate of N will be important to the wheat sector in Ethiopia. Therefore, this study was initiated with the objective to determine the optimum N rate for durum wheat production under Vertisol condition.

Materials and Methods

Description of the study Area

The field experiment was conducted at Akakii and Chefe Donsa districts during 2013-2014 on selected farmers' fields under rain fed conditions of East Shewa Zone, Oromia. Soil samples were collected before sowing from different spots for each farmer's field to form one composite soil sample per farmer and analyzed by following the standard analysis procedure.

Experimental design and trial management

The treatments comprised five levels of N (0, 30, 60, 90 and 120 N kg/ha). The experiment was laid out in a randomized complete block design with three replications. Urea (46% N) was used as the source of nitrogen whereas triple super phosphate (TSP; 46% P_2O_5) was used as the source of phosphorus. An improved durum wheat crop variety known as *Yerer* was used as a test crop. The plot size was 5 m x 5 m (25 m^2) and the plots within a block as well as blocks were separated by 1 m wide open space area. The full dose of P and half dose of N of the respective treatments were applied at planting and the remaining half N was top dressed at the mid tillering stage, i.e. 35 days after planting.

The data collected were subjected to analysis of variance (ANOVA) appropriate to randomized complete block design using SAS software program (SAS Institute, 2000). The analysis results of the soil were interpreted using descriptive statistics.

Results and Discussions

Soil physicochemical properties before planting

The pH of a soil is one of the most important properties influencing plant growth and production as it affects ion exchange capacity and nutrient availability. The mean pH values of the composite surface (0-15 cm) soil samples ranged from neutral (pH = 7.06) to moderately alkaline (7.6), low organic matter, very low total nitrogen contents and medium to high available phosphorus (Tekalign, 1991; Berhanu, 1980).

Table 1.Selected soil chemical properties of composite soil samples (0-15 cm) collected from Akakii and Chefe Donsa sites

Sites	pH 1:2.5 H2O	OM (%)	TN (%)	Available P (ppm)	Texture
1	7.5	1.63	0.04	13.19	Clay
2	7.06	1.65	0.05	27.99	Heavy clay
3	7.74	1.89	0.05	14.94	ND
4	7.4	1.73	0.04	10.77	ND
5	7.6	1.86	0.05	10.23	ND

OM = Organic matter; TN = Total Nitrogen AP = Available phosphorus; ND = not determined

Effects of N on yield and yield components of wheat

As the data indicated in Table 2, plant height, grain yield, straw yield as well as total biomass of wheat exhibited significant response to nitrogen rates, at both experimental sites. The highest mean plant height was recorded from 120 kg N/ha, but it was statistically at parity with N applied at 60 and 90 kg/ha at both locations. Mean values for nitrogen rates also showed that plant height increased with each increment of nitrogen rates from the control to the highest rate. In line with the current result, Amsal et al. (2000) reported a positive and linear response to applied fertilizer to this trait in the central highlands of Ethiopia. Several other studies in Ethiopia also exhibited dramatic plant height enhancement in response to each incremental dose of fertilizer N (Zewdu et al., 1992; Tilahun et al., 1996a).

Similarly, grain yield of wheat was significantly ($P \leq 0.05$) increased due to the different rates of nitrogen at both experimental sites. The highest mean grain yields of 2457.9 kg/ha and 2136.67 kg/ha were obtained from N applied at 90 kg N/ha at Chefe Donsa and Akakii sites, respectively, but there was no statistically significant difference between 90 and 120 kg N/ha at Chefe Donsa site (Table 2). Nitrogen applied at 90 kg/ha significantly increased the yield of wheat by 194% and 98% at Chefe Donsa and Akakii sites, respectively, compared to the control even though the overall yield is very low. The lowest grain yield was recorded from the control at both sites, which differs significantly from all other treatments. The low yield was mainly attributed to the very low OM and total N contents of the soils of the study area which require external N input to support proper growth and development of the crop.

All N levels have significantly increased wheat grain yield and total biomass compared with the control at both locations ((Table 2). However, the highest grain yield and total biomass were obtained from N applied at 120 kg/ ha. These treatments increased the straw yields by 93 and 78% at Chefe Donsa and Akakii over that obtained with the control, respectively. The corresponding biomass yield increase was also 82 and 99 % at Chefe Donsa and Akakii site over the control, respectively. However, statistically there was no significant difference between the three N rates (60, 90 and 120 kg/ha) in their effect on wheat straw yield and total biomass at both locations. In agreement with the current results, Amsal et al.(2000) reported that N rate significantly enhanced the straw yield of wheat since N usually promotes the vegetative growth of a plant. Generally, a linear increment in biomass production was also observed with an increase in N rates from 0 to 120 kg ha^{-1}. This is in agreement with the findings of Amanuel et al. (1991) who reported a significant increase of wheat total biomass as a result of N rate increase.

Table 2. Plant height, grain and straw yields and total and biomass of durum wheat

Treatment N (kg/ha)	Plant height (cm)	Grain yield (kg/ha)	Straw yield (kg/ha)	Total biomass (kg/ha)
Chefe Donsa				
0	59.08c	836.7d	2401.8c	3238.3c
30	65.25b	1443.3c	3531.0b	4974.2b
60	72.25a	2114.4b	4052.3ab	6166.7a
90	73.58a	2457.9a	4021.3ab	6479.2a
120	73.75a	2394.9ab	4251.2a	6645.8a
LSD (0.05)	4.63	297.48	665.21	817.92
CV (%)	8.22	19.62	22.22	18.14
Akakii				
0 kg/ha	63.66b	1083.33d	1750.0c	2833.3c
30 kg/ha	74.66a	1312.67c	2604.0b	3916.7b
60 kg/ha	77.33a	1444.00c	3056.0ab	4500.0ab
90 kg/ha	76.00a	2136.67a	2696.7ab	4833.3a
120 kg/ha	77.66a	1785.33b	3381.3a	5166.7a
LSD (0.05)	5.60	214.48	686.97	749.2
CV (%)	5.60	7.33	13.52	9.36

PH = plant height; LSD = Least significant difference; CV = Coefficient of variation;

Conclusion and Recommendation

Nitrogen is the most abundant mineral nutrient in plants. It constitutes 2–4 percent of plant dry matter.The results of this experiment indicated that mineral nitrogen fertilization significantly increased grain and straw yields of wheat. The highest mean grain yields of 2457.9 kg/ha and 2136.7 kg/ha were obtained from the application of 90 kg N/ha at Chefe Donsa and Akakii sites, respectivelyand the lowest was obtained from the control plot at both experimental sites. According to the results obtained from two years agronomic and soil data, nitrogen is one of the most yield limiting nutrients for wheat production in the study sites.Based on the result of this study we have to validate the current findings with previous results on larger plots so that fertilizer recommendation can be suggested to the extension and end users for the study area, and other similar areas.

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Response of tef to Nitrogen and Phosphorus Fertilizer Application at Bambasi and Assosa Areas

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Introduction

Tef (*Eragrostis tef* **)** is among the major cereal crops in Ethiopia both in terms of area coverage and nutritional importance(CSA, 2016). It is one of the leading traditional food crops of Ethiopia. It ranks second in the country following maize in total production (CSA, 2016). The crop is utilized in different forms where the grain is used for human consumption and homemade beverage, while the straw is commonly used as feed to animals (Seyfu, 1997). Similarly, Tef is the food crop in the Benishangul-Gumuz region in general and in Assosa zone in particular. Tef production in the zone is found both in shifting and permanent farming systems, which are practiced among natives and settlers farming communities, respectively.

The productivity of tef has been by far lower than the potential yields obtained on research stations and on farm verification trials, which could be attributed to several abiotic factors though the genetic potential of the crop also takes vital share. Further its productivity varies from region to region in the country depending on agroecological suitability, availability of improved cultivars and farmers' management practices. The growth, development, and yield of cereal crops can be adversely affected when there is deficiency or excessive supply of any of the essential elements and other toxic substances (Hay and Walker, 1992).

In Benishangul Gumuz region, especially in Assosa zone, its productivity (1.2 t ha^{-1}) lagged behind the national average i.e. 1.57 t ha^{-1} (CSA, 2016). Poor soil fertility, erratic rainfall and suboptimal management practices could be among the main factors to be responsible. Soil nutrient status is widely constrained by the limited use of inorganic and organic fertilizers and by loss of nutrients mainly due to erosion and leaching (Balesh et al., 2007; Gete et al., 2010; Getachew et al., 2014). Many smallholder farmers do not have access to synthetic fertilizer because of its high price, lack of credit facilities, poor distribution, and other socio-economic factors. Consequently, crop yields are low, and the sustainability of the current farming system is at risk.

Tef research has been conducted in the region since the past few years and some promising varieties have been adapted and under production in the area. Among the released varieties, Quncho had better yield advantage over others under research and farmers' field. Yet, improvement of its production has not been possible due to a number of soil-plant-management related factors. Apparently, low soil fertility and inadequate nutrient management are among the major factors determining its yield level. Continuous cropping, high proportions of cereals in the cropping system, and the application of suboptimal levels of mineral fertilizers by farmers aggravates the situation in the area. The continuous removal of biomass (grain and crop residues) from crop land without adequate nutrient replenishment can rapidly deplete the soil nutrient reserves and jeopardize the sustainability of agricultural production (Gete et al., 2010; Getachew et al., 2015; Legesse, 2004). To maintain high crop production level, the nutrient status of the soil has to be maintained through crop rotation, addition of organic and inorganic fertilizers. Inorganic fertilizers are important inputs in any agricultural production system because they supply the required nutrients in a readily available form for immediate plant use. Generally, the recommended rate of fertilizer for tef is 25 - 40 kg N and 10- 20 kg P ha^{-1} on light soils such as Nitosols, Luvisols and Cambisols, and 50-60 kg N and 30-35 kg P per hectare for heavy soils such as Vertisols (Deckers *et al.,* 2001).

So far efforts regarding the determination of optimum fertilizer rates and other agronomic requirement of tef in the area are inadequate. s, Nitrogen and P are the most important nutrients among major yield limiting plant nutrients as they are required in large quantity by the crop. However, there is no adequate research information for nitrogen and phosphorus application rates in the area. This implies that effort has to be made to improve the production and productivity of tef through application of appropriate level of N and Ps. In view of this, the activity was initiated with the following objectives: 1) to investigate the main and interaction effects of different levels of N and Ps on yield and yield components of tef; and 2) to determine the economic optimum N and P rates for tef production.

Materials and methods

Description of the study area

The experiment was conducted in Assosa Zone, in two districts, namely Bambasi and Assosa districts, western Ethiopia, in the main rainy seasons of 2012 and 2013. The research sites are located between 1300 and1470 m.a.s.l. with the minimum and maximum temperatures of 14.5 and 28.8^{o}C, respectively. The average annual rainfall is 1358mm of which 1128.5mm were received between May and October during the cropping season.

Treatments and experimental design

The fertilizer treatments consisted of factorial combinations of five levels of N (0, 23, 46, 69 and 92 kg N ha^{-1}) and four levels of P (0, 10, 20, and 30 kg P ha^{-1}). The experiment was conducted was laid out in a randomized complete block design (RCBD) with three replications on a plot size of 5 m x 4m. Urea and triple super phosphate (TSP) were used as the sources of N and P, respectively. Application of urea was in two splits, while the full rate of phosphorus was applied at sowing in band.

The experimental land was well prepared. Each plot and block was separated by 0.50 m and 1.5m, respectively. Tef (*Kuncho variety*, Dz-Cr-387) was used for the experiment with broadcast method. Important agronomic practices were uniformly applied to all experimental plots as often as required.

Soil sampling and analysis

Composite soil samples were collected from the experimental plots in a diagonal pattern from the depth of 0-20 cm before planting. Uniform slices and volumes of soil were obtained in each sub-sample by the vertical insertion of an auger and made a composite soil sample. The soil samples were dried, ground using a pestle and a mortar and allowed to pass through a 2-mm sieve and analyzed for the selected physico-chemical properties mainly organic carbon, total nitrogen, soil pH, available phosphorus, cation exchange capacity (CEC) and textural analysis using standard laboratory procedures.

Organic carbon(OC) content was determined by the volumetric method (Walkley and Black, 1934) as described in the Food and Agriculture Organization (FAO) guide to laboratory establishment for plant nutrient analysis (FAO, 2008) using 1.0 g of the prepared soil sample. Total nitrogen was analyzed by Micro-Kjeldhal digestion method with sulphuric acid (Jackson, 1962). The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight/volume) soil sample to water solution ratio using a glass electrode attached to digital pH meter. The cation exchange capacity (CEC) was measured after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc (Chapman, 1965). Available phosphorus was determined by the Bray II method.

Data collection and analysis

Sampling and data collection were done from the center of each plot. Growth indicating parameters such as plant height, panicle length and grain yield was collected. Plant height (cm) was measured from the base of the plant to the top most leaves of the plant. The average value was computed from five randomly selected plants. The grain yield was sampled and measured from the center of each plot, and converted to kg ha^{-1} for statistical analysis. Analysis of variance was performed following statistical procedures appropriate for the experimental design using SAS computer software. Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) test at 5 % level of significance.

The partial budget analysis was done following the method described in CIMMYT (1988).

Results and discussion

Soil physico-chemical properties before sowing

Soil physical and chemical properties were analyzed for the surface composite soil sample taken from the experimental field. The texture of the soil was with particle size distribution of 53.8% clay, 30.2% sand and 16% silt. The soil texture is clayey. According to the rating of Landon (1991), the soil used for this study ranged from very strongly acidic (pH 4.29) to moderately acidic (pH 5.52) classes, indicating the possibility of Al toxicity and deficiency of certain plant nutrients. The exchangeable K of the soil before the application of the treatments ranged from 0.192 to 0.42 Cmol(+)kg^{-1}. All experimental soils had deficient to adequate K content. According to Landon (1991), available (Bray II extractable) soil P level of less than 10 mg kg^{-1} is rated as low, 11-31 mg kg^{-1} as medium and greater than 18 mg kg^{-1} is rated as high. Thus, most trial location had very low to medium available (Bray II extractable) P (Table 1). Following the rating of total N by Landon (1991), > 1% is rated as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and < 0.1% as very low N status. The experimental soils qualify for very low total N. Similarly, the organic carbon (OC) content of the soil was also very low to low in accordance with Landon (1991), who categorized OC content as very low (< 2%), low (2- 4%), medium (4-10%), high (10-20%). The very low OC and low N content in the study area indicate low fertility status of the soil. This could be due to continuous cultivation and lack of incorporation of organic materials (Table1).

Table 1.Chemical properties of some experimental soil samples prior to planting

Soil parameters	Nebar keshmando	Amba 14	Megel 33
pH_{H2O} (1:2.5)	5.2	4.8	4.3
CEC ($cmol_{(+)}$ kg^{-1})	29.0	17.2	25.9
OC (%)	2.5	1.7	2.1
Total N (%)	0.2	0.2	0.2
Available P (Bray II) (ppm)	3.4	3.4	3.2
K ($cmol_{(+)}$ kg^{-1})	0.4	0.2	0.3

Plant height

The analysis of variance showed that plant height was significantly affected ($P \leq 0.05$) by the interaction of N and P application. Plant height generally increased with the increase in the rate of NP application (Table 3). In line with this, Rashid et al. (2007) indicated that plant height was linearly increased with increasing levels of NP fertilization. The maximum plant height (104.1 cm) was obtained from application of 23kg N ha^{-1} and 10 kg P ha^{-1}, while the lowest (77.3 cm) from the control treatment (Table 3). The increase in plant height was not consistent with the increase in NP rates.The plant heights obtained from all NP fertilized plots were significantly higher than unfertilized plots. This is because the applications of NPs have great roles in plant growth. Many studies revealed significant influence of N on plant height as it plays a vital role in vegetative growth of plants. A similar result was reported by Haftom et al.(2009) showing that a tef plant with higher plant height was found by applying a high amount of N. This may be attributed to the fact that N usually favours vegetative growth of tef, resulting in higher stature of the plants with greater panicle length. Legesse (2004) also reported that high N application resulted in tef plants with significantly taller plants due to direct effect of N on vegetative growth of plants. This result is in line with the report of Wakene et al. (2014) who stated that plant height of barely increased with increasing rates of NP from 0/0 to 69/30 kg ha^{-1}.

Table 2. Plant height (cm) of tef as affected by N*P interaction at Assosa Zone, 2012 – 2013

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	77.3^{h}	89.4^{cdef}	88.9^{defg}	86.3^{fgh}	85.5
23	79.3^{h}	104.1^{a}	95^{bcde}	97.6^{abcd}	94.0
46	80.1^{gh}	95.5^{abcd}	99.2^{ab}	100.3^{ab}	93.8
69	79.5^{h}	94.4^{bcde}	99.0^{ab}	98.1^{abc}	92.8
92	82.4^{fgh}	97.6^{abcd}	96.9^{abcd}	101.1^{ab}	94.5
Mean	79.7	96.2	95.8	96.7	
LSD (5%) N*P = 4.52			CV (%) =10.43		

Straw yield

Straw yield was significantly (P≤0.05) affected by the main effect of N and P application as well as their interaction. Generally, the combined application of N and P resulted in increased straw yields (Table 4). Thus, the application of 46 kg N ha^{-1} and 10 kg P ha^{-1} resulted in the highest (3135.4 kg ha^{-1}) straw yield, with the yield increment of 129% compared to the control. I contrast the lowest (1396.4 kg ha^{-1}) straw yield was recorded from the control treatment (unfertilized plot). Consistent with this finding, Melesse (2007) reported that wheat cultivars produced higher straw yields in response to the combined application of higher rates of N and P. The increased straw yield might be due to the effect of high N application on the production of effective large numbers of tillers, increased plant height, and panicle length. Similar results were reported by Temesgen (2012), Haftamu et al. (2009) and Mitiku (2008) who indicated that the highest straw yield was obtained in response to the application of higher rates of N application, which enhanced the production of significantly longer panicle sizes and taller plants, and as a result greater biomass yield.

Table 3. Straw yield (kg ha^{-1}) of tef as affected by N*P interaction at Assosa Zone, 2012 - 2013

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	1396.4^{i}	2106.4^{ef}	2266.2^{de}	2294.6^{de}	2015.8
23	1863.7^{fgh}	2869.1^{ab}	2604.3^{bcd}	2748.5^{abc}	2521.4
46	1716.8^{fghi}	3135.4^{a}	2505.4^{bcd}	2468.1^{cde}	2456.4
69	1597.9^{hi}	2286.4^{de}	2436.5^{cde}	2468.7^{cde}	2197.4
92	1708.6^{ghi}	2600.4^{bcd}	2367.2^{cde}	2089.0^{efg}	2191.3
Mean	1656.7	2599.54	2435.9	2413.8	
N *P , LSD(5%)=201.1			CV (%) =18.75		

Grain yield

Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crops (Khan et al., 2008). The analysis of variance showed that grain yield of tef was significantly ($P \leq 0.05$) influenced by the main effect of N and P rate as well as by the interaction of N and P rates (Table 5).

The maximum grain yield (1681.1 kg ha^{-1}) was obtained from application of 46 kg N ha^{-1} and 10 kg P ha^{-1} while the minimum grain yield of tef was recorded from the unfertilized plots. Grain yield significantly increased ($P \leq 0.05$) from 708.6 to 1681.1 kg ha^{-1} with the increase in the levels of N/P from the control (0/0 N/P) to 46 kg N ha^{-1} along with 10 kg P ha^{-1}, butdecreased with further increase in applied N and P. The magnitude of increase in grain yield due to application of 46 kg N ha^{-1} and 10 kg Pha^{-1} was higher by 137 % than the control. This might be due to the uptake of balanced amounts of nitrogen by plants throughout the major growth stages; enhanced synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone in sufficient amounts. Temesgen (2001) reported that application of different levels of N significantly affected grain yield of tef on farmer's field. In this experiment, the reduction in grain yield with higher N and P levels beyond 46 kg N and 10 kg P ha^{-1} might be mainly related to the reductions observed in the yield components and thereby decreased grain yield. Consistent with this suggestion, Reinke *et al.* (1994) indicated that where the grain yield response is negative, yield reduction is primarily caused by a reduction in the proportion of the number of filled spikelets per panicle. Singh et al.(1995) also reported a decrease in grain yield of rice with application of high doses of N.

Table 4. Grain Yield (kg ha^{-1}) of tef as affected by N*P interaction at Assosa Zone, 2012- 2013.

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})				
	0	10	20	30	Mean
0	708.6^{h}	1005.8^{de}	1257.2^{bc}	1179.4^{cd}	1037.8
23	812.6^{gh}	1220.2^{bcd}	1316.0^{b}	1212.0^{bcd}	1140.2
46	832.6^{fgh}	1681.1^{a}	1142.0^{cd}	1312.0^{b}	1241.9
69	966.1^{efg}	1039.0^{de}	1015.8^{ef}	1105.3^{cde}	1031.6
92	921.3^{efg}	1079.6^{de}	1042.4^{de}	947.5^{efg}	997.8
Mean	848.2	1205.1	1154.7	1151.2	
N *P , LSD(5%)= 99.8			CV (%) =18.53		

Effects of np on economic feasibility of tef production

The higher net return EB 19043.8 Birr ha^{-1} with marginal rateof return of 1221% was obtained with application of 46/23 kg N P_2O_5 ha^{-1}. Thus, planting tef with application of 46 kg N ha^{-1} combined with 23 kg P_2O_5 ha^{-1} resulted in 79.9 % surplus income from grain sale compared to adopting national blanket fertilizer recommendation (46 kg N ha^{-1} combined with 46 kg P_2O_5 ha^{-1}) recommended by Ministry of Agriculture (Tables7). Thus, 46 kg N ha^{-1} combined with 23 kg P_2O_5 ha^{-1} fertilizer rate application are the most economical feasible to tef growers compared to the other levels .

Table 5. Effects of NP rates application on economic feasibility of tef production of at Assosa

(kg ha^{-1})							
N	P_2O_5	AGYT	TVC (BIRR)	Revenue (BIRR)	Net Benefit (BIRR)	Value to Cost ratio	Marginal rate of return (%)
0	0	637.7	9885	2085	7800	3.7	
23	0	731.3	11336	2777.5	8558.3	3.1	110
0	23	905.2	14031	3022.5	11008.4	3.6	1000
46	0	749.3	11615	3470	8144.8^{D}	2.3	
23	23	1098.2	17022	3715	13306.8	3.6	332
0	46	1131.5	17538	3960	13577.9	3.4	111
69	0	869.5	13477	4162.5	9314.6^{D}	2.2	
46	23	1513	23451	4407.5	19043.8	4.3	1221
23	46	1184.4	18358	4652.5	13705.7^{D}	2.9	
92	0	829.2	12852	4855	7997.1^{D}	1.6	
0	69	1061.5	16453	4897.5	11555.1^{D}	2.4	
69	23	935.1	14494	5100	9394.1^{D}	1.8	
46	46	1027.8	15931	5345	10585.9^{D}	2	
23	69	1090.8	16907	5590	11317.4^{D}	2	
92	23	971.6	15060	5792.5	9967.9^{D}	2	
69	46	914.2	14170	6037.5	8132.9^{D}	1.3	
46	69	1180.8	18302	6282.5	12019.9^{D}	1.9	
92	46	937.8	14536	6730	8505.9^{D}	1.4	
69	69	994.8	15419	6975	8443.9^{D}	1.2	
92	69	852.8	13218	7667.5	6250.1^{D}	0.9	

* Price of Urea =13.85 BIRR/kg, TSP=18.75BIRR/kg, DAP=14.35BIRR/kg, Price of tef=15.50 BIRR/kg and price of tef for seed=20 BIRR/kg, AGYT= Adjusted grain yield of tef and D=Dominated

Conclusion

In this study, it was found that application of N and P had significant effect on crop phenology, growth, yield and yield components of tef. Application of 46 kg N along with 10 kg P ha $^{-1}$ resulted in both the maximum straw and grain yields of tef. The partial budget analysis also indicates that applications of 46 kg N ha^{-1} and 10 kg P ha^{-1} are the most economical fertilizer rates to tef growers at the study area. Thus, in the light of the significant response of tef to both N and Ps, further studies aimed at promoting integrated soil fertility management and formulation of fertilizer recommendation on soil test basis over locations are desirable.

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Influence of Phosphorous and Nitrogen Rate on Grain Yield of Rice at Kamashi Zone of Benshangul Gumuz Region, Ethiopia

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Introduction

The demand for rice far exceeds the production which in the last 30 years in sub-Saharan Africa (SSA) has increased by 70% due mainly to land expansion and only 30% due to increase in productivity (Fagade, 2000). This increase in production, not withstanding, rice production has not kept pace with the demand as a result of rapid population growth. The low productivity arises from the use of low yielding varieties, pest and disease problems, inherently low soil fertility, and poor nutrient supply.

The cultivation of rice in Ethiopia is of more recent history than its utilization as a food crop. Some evidences indicate that cultivation of rice in Ethiopia was first started at the Fogera and Gambella plains in the early 1970s. Currently, the Fogera, Gambella, Metema, and Pawe plains located in the northern, northwestern, and western regions are developing in to major rice-producing areas in Ethiopia (Mulugeta, 2000). At the Fogera plain, rice plays an important role in relaxing the problem of food-insecurity of the farming community.

Benishangul-Gumuz Regional State (BGRS) is one of the potential regions in Ethiopia with ample rainfall, i.e. for six months and conducive environment which are suitable for rice production. About 4.9 million ha of land is estimated to be potential for rain fed rice production (MoA, 2010). About two million ha is highly suitable and the rests are suitable and moderately suitableboth for upland and low land rice ecosystems. Rice production in Kemashi zone was first realized by settler community through informal rice seed exchange from other regions. Following this, on station and on farm research activities were started a few years back under rain fed condition in other similar weredas of Assosa zone. Except the breeding, other research components like agronomic aspects of rice are found at infant stage. Across location, varietal selection research activities reveal that rice is a well adaptable commodity for the region because of long rainfall duration (MoA, 2010). The agro-ecology allows for the production of several crops and rice can be the main demand driven item for the area.

Rice research activity has been conducted in the region for the past few years and some promising varieties have been adopted. Among the released NERICA varieties, NERICA-4 had better yield advantage over others under on-station and on-farm conditions (Assosa ARC, Completed activity Report). Yet, improvement of its production has not been possible due to low soil fertility and inadequate nutrient management among other factors (Heluf and Mulugeta, 2006). Continuous cropping, high proportions of cereals in the cropping system, and the application of suboptimal levels of mineral fertilizers by farmers aggravates the situation in the area (MoA, 2010). These further imply the need for participatory evaluation and determination of optimum rate of fertilizers for upland rice production and for the improvement of farmers' knowledge and skills on optimum utilization of inputs (fertilizers). Therefore, the objective of the study was to determine the optimum rate of N and Pfor upland rice (NERICA-4) in the area in terms of yield increase and economic return under Nitosols condition.

Materials and Methods

Description of the study site

A field experiment was conducted under rain fed conditions during the main rainy season (June to October) of 2014 and 2015. The aim of the study was to investigate the effects of N and Ps on grain yield and yield components of upland rice under research fields on Nitisols of the Kamashi zone. Kamashi Wereda is one of the five districts found in Kamashi Zone whose is capital also known as Kamashi town located at 560 km west of Addis Ababa and 246 km south east of Assosa. Its altitude ranges from 1000 to 1350 m a. s. l. with annual rainfall of 900 to 1400 mm. The temperature ranges from 20^{o}C to 30^{o}C. Agriculture is the main occupation and livelihood source of the area. Crop production is characterized by hoe based shifting cultivation with little oxen plow. The major crops grown are sorghum and maize mainly for home consumption while sesame and groundnut are grown for cash.

Experimental procedure

The experiment was conducted using a factorial experiment involving 4 x 4 combinations of inorganic N and Ps in a randomized complete block design with three replications. The fertilizer treatments considered in the study included four levels of N (0, 46, 92, and 138 kg ha^{-1}) and four levels of P (0, 10, 20 and 30 kg ha^{-1}) consisting of a total of 16 treatments. The plot size was 3 × 4 (12 m^{2}) with spacing of 1.5 m between blocks and 0.75 m between plots within blocks. A composite soil sample (0-30cm) was collected from the site for laboratory analysis before land preparation. Soil bunds were constructed around each plot and around the entire experimental field to minimize nutrient and water movement from plot to plot. Seeds were planted by hand drilling at a rate of 65 kg ha^{-1} in rows spaced 30 cm apart. Nitrogen was applied in two equal splits as urea (46% N), i.e. 50% of the N rate was applied basal at planting, and the remaining half was top dressed at the maximum tillering stage, which occurred 35-45 days after germination. Unlike N, the total dose of P was applied basal as triple super phosphate (20% P) during sowing.Due to the frequent prevalence of vigorous growth and high infestation of weeds, the field was hand weeded five times at 20, 35, 50, 65 and 90 days after sowing.

Data collection and statistical analysis

The agronomic date collected were date of emergence, date of heading, date of maturity, number of tiller per plant, plant height, panicle length, number of panicle per plant, number of effective tiller per plant, and yield per plot and kg ha^{-1}. Number of tillers per plant was counted after maximum tiller formation stage and mean number of tillers determined, while plant height was measured at harvest. At maturity, an area of $1m^2$ excluding border rows was measured in each plot, number of panicles was counted and harvested. Grain and Stover yield were measured and yield per ha estimated. Panicles were also collected from non-border rows and mean individual weight per panicle was determined. Grain and straw yields were determined by harvesting the entire net plot and converted into kg ha^{-1} for statistical analysis. The data recorded in this study were subjected to statistical analysis by using STATISTIX 8.

Economic analysis

Economics analysis was conducted to investigate the economic feasibility of the treatments; partial budget, dominance and marginal rate of return were performed (CIMMYT, 1988). The average yield was adjusted downwards to reflect the difference between the experimental plot yields. The average open market price (Birr kg^{-1}) for rice and the official prices of N and Ps were used for the economic analysis.

Results and Discussion

Soil physicochemical properties before sowing

Nitosols is the major soil types found in all Weredas of Kamashi zone. This soil type occurs in high rainfall areas on flat to slopping terrains. It is dark reddish brown to dark red in color, with deeply developed clay alleviation horizon of high structural stability. Nitisols are well drained, porous with high water holding capacity. The chemical and physical properties of the soils of the experimental fields are indicated in Table 1. The soil pH for this study ranges from very moderate acidic (pH 5.46) to slightly acidic (pH 5.71) class, indicating the possibility of Al toxicity and deficiency of certain plant nutrients. The fields are very low in organic carbon content (< 2 %), low in total nitrogen (0.11-0.17 %), low in bray II extractable available phosphorus (< 11 ppm) and adequate K content in all experimental soils (Landon, 1991). The soil textural classes for both experimental fields are sandy loam. The very low OC and low N content in the study areas indicate low fertility status of the soil. This could be due to continuous cultivation and lack of incorporation of organic materials.

Table 1. Chemical analysis of some parameters of soil prior to cropping

Year	Depth (cm)	P^H	Organic carbon (%)	Total nitrogen (%)	Avail. P (ppm)	Potassium (meq/100g)	CEC (meq/100g)
2014	0-30cm	5.71	1.476	0.11	10.8	0.51	22.6
2015	0-30cm	5.46	1.870	0.17	9.8	0.46	23.2

Influence of N and P on yield and yield components of upland of rice

Year had highly significant (P < 0.01) influence on all grain yield and yield components measured. The main effect of phosphorus was also highly significant ($P < 0.01$) on yield and yield components measured, except number of panicle per m^2, number of tiller per plant and panicle length. Nitrogen had a highly significant ($P < 0.01$) effect on allparameters measured, except panicle length (Table 1). Year had a significant influence on nitrogen as there was a significant year × nitrogen interaction on grain yield ($P< 0.05$), number of tiller per plant($P< 0.05$), number of tiller per m^2 ($p< 0.01$)and straw yield($P< 0.001$) (Tables1and3). Besides, the mean squares due to N×P interactions were significant only for panicle length($P< 0.05$) and straw yield ($P< 0.01$).

Table 2. Analysis of variance for yield and yield components of rice on Nitosols of Kamashi at Benshal-gul Gumuz Regional State

Source of variation	df	Mean squares						
		Grain yield	No. of panicle/m^2	No. of tiller/plant	No. of tiller/m^2	Plant height	Panicle length	Straw yield
N	3	1.479^{***}	12785^{**}	5.0228^{**}	5833^{**}	466.05^{***}	0.914^{NS}	61.088^{***}
P	3	8946895^{***}	1748^{NS}	1.080^{NS}	1579^{NS}	87.86^{**}	3.12^{NS}	28.595^{***}
Year	1	1.224^{**}	475314^{***}	13.60^{***}	405601^{***}	3542.94^{***}	242.88^{***}	660.76^{***}
N*P	9	2129549^{NS}	1084^{NS}	0.550^{NS}	1829^{NS}	10.76^{NS}	2.708*	9.500^{**}
N*Year	3	1453087^{*}	2412^{NS}	1.7828^{*}	4257^{**}	270.31^{***}	0.775^{*}	29.487^{***}
P*Year	3	1453087^{NS}	112^{NS}	0.423^{NS}	607^{NS}	9.45^{NS}	0.628^{NS}	2.648^{NS}
N*P*year	6	782659^{NS}	466^{NS}	1.857^{NS}	1257^{NS}	13.45^{NS}	1.854 NS	6.458^{NS}
Error	62	1449946	1141	1.4029	1612	22.45	1.532	3.832

NS: non-significant; df: degree of freedom; *, ** and *** indicate significant difference at probability levels of 5%, 1% and 0.1% respectively.

Analysis of variance for the study revealed highly significant grain yield difference due to the main effects of N and P application (Table 2). However, the mean squares due to N×P interactions were not significant for the yield of upland rice. Mean grain yield was significantly increased by 34.6% with the application of 30 kg P ha^{-1} over the control, but it was statistically at par with P applied at 20 kg ha^{-1} (Table 3). On the other hand, the lowest grain yield of 4205 kg ha^{-1} was recorded in P rate of zero kg ha^{-1}

that was statistically at par with P applied at 10 kg ha^{-1}. Mengel (1987) reported that phosphorus deficiency in small grains is usually expressed as stunted growth. Similarly, the yield of rice was significantly influenced by the main effect of N rates. High N level at 138 kg ha^{-1} significantly ($P < 0.001$) increased the yield of rice by 47.2%, while 92 and 46 kg N ha^{-1} increased the grain yield by 36.2% and 32.5%, respectively, compared to the control, whilst no significant differences were observed between themselves. The lowest grain yield (3867 kg ha^{-1}) was recorded for the control, which differs significantly from all other treatments.

In line with applied N, application of P increased rice grain yield through its effects on major yield attributes such as number of panicles per m^2 and spikelets per panicle. Zaman et al. (1995) also reported similar response in rice yield and yield components to increasing rates of applied P. Increase in the magnitude of yield attributes is associated with better root growth and increased uptake of nutrients favoring better growth of the crop (Kumar and Rao, 1992). Phosphorus application has also improved number of panicles per m^2, panicle length and plant height thereby indirectly contributing to the increment of grain yield.

Year had a significant influence on nitrogen as there was a significant($P< 0.05$) year × nitrogen interaction on grain yield of rice (Tables1and3). Year by nitrogen rate interaction was significant ($P < 0.05$) for grain yield, in which rice had higher grain yield in 2014(6934.7 $kgha^{-1}$) than in 2015 (4450.9 kg ha^{-1}) (Table 3). However, year by phosphorous interaction was not significant ($P> 0.05$) for grain yield (Table 1).

Mean values for nitrogen rates showed that panicle length m^{-1} increased with each increment of nitrogen rates from the control to the highest rate, but statistically at par between three N levels (Table 2). Similarly, the main effect of P fertilization on rice panicle number m^{-2} was found to be slightly significant, but the interaction of N and P was not statistically significant for panicle number. The plots that received 30 kg ha^{-1} P had increased significantly ($P \leq 0.05$) plant panicle number as compared to the control. In general, number of rice panicle m^{-2} increased almost consistently with increased phosphorus application rates. Heluf and Mulugeta (2006) noted that panicle number is the most important factor that causes variation in the grain yield of rice.

Table 3. Yield and yield components of rice as influenced by year, phosphorus and nitrogen rates during 2014 and 2015.

Source of variation	Grain yield kg ha^{-1}	No. of panicle m^{-2}	No. of tiller plant-	No. of tiller m^{-2}	Plant height	Panicle length	Straw Yield (t ha^{-1})
Year							
2014	6117.0A	282.03A	5.31A	298.92A	92.90A	22.62A	10.21A
2015	3858.1B	141.31B	4.42B	168.92B	80.75B	19.44B	4.97B
LSD	491.33	13. 78	0.48	16.38	1.93	0.50	0.79
Phosphorous (P)							
0	4205.9C	200.17B	4.59	222.14A	84.90B	20.74	6.28C
10	4886.4BC	211.4AB	4.82	235.08A	86.12B	20.83	7.17BC
20	5197.5AB	214.6AB	5.06	239.92A	86.8AB	20.98	8.15 AB
30	5660.6 A	220.46A	5.00	238.53A	89.43A	21.55	8.76A
LSD	694.85***	19.48	0.68	23.17	2.73	0.71	1.12
Nitrogen (N)							
0	3867.0B	192.64B	4.57B	211.68B	81.38C	20.76	5.88C
46	5124.9 A	214.13A	4.78 B	238.79A	85.77B	21.13	6.95BC
92	5265.7A	216.28 A	4.58 B	237.11A	88.27B	21.01	7.89B
138	5692.8 A	223.64 A	5.54 A	248.08A	91.86A	21.20	9.65A
LSD	694.85***	19.48	0.68	23.17	2.73	0.71	1.12
CV%	24.14	15.96	24.32	17.17	5.46	5.88	25.77

Influence of N and P on yield components of upland of rice

The panicle length of rice was not affected significantly ($P > 0.05$) by the main effect of applied N and Ps while their interaction had a significant effect on panicle length even though the result is inconsistent (Tables 2 and 3). With regards to the interaction between N and Ps, the highest panicle length (22.65 cm) was obtained from the combined application of 46 kg N and 30 kg P ha^{-1}that was statistically at par with the combined application of 92 N and 30 P kg ha^{-1}, 138 N and 30 P kg ha^{-1}, and 138 N and 10 P kg ha^{-1}, while the lowest was obtained from the plot received only 30 kg ha^{-1} P (Table 4).

Table 4. Panicle length of rice as affected by N x P interaction during the 2014/2015 main cropping season

Nitrogen (N) level	Phosphorus (P) level			
	0	10	20	30
0	21.16^{BCD}	20.70^{BCD}	20.98^{BCD}	20.20^{D}
46	20.78^{BCD}	20.25^{CD}	20.85^{BCD}	22.65^{A}
92	20.70^{BCD}	20.73^{BCD}	20.98^{BCD}	21.65^{ABC}
138	20.33^{BCD}	21.66^{ABC}	21.13^{BCD}	21.70^{AB}

Means followed by the same letter within a column or row are not significantly different at 5% level of significance; CV (%) = 5.88

Plant height, measured at physiological maturity, showed statistically significant difference due to the main effect of N and P, but the interaction of N and P was not statistically significant for plant height (Tables 2 and 3). Mean values for nitrogen rates showed that plant height increased with each increment of nitrogen rate from the control to the highest rate, which differs significantly from all other treatments. The increased plant height at the highest level of nitrogen was probably due to the availability of more nutrients, which helped in maximum vegetative growth of rice plants. Similarly, a study conducted by Ethal et al (2001) in Nigeria indicated that there were significant increases in plant height with increasing levels of N, compared to the control. A similar trend was observed for different levels of P application. For both nutrients, the maximum and minimum records were obtained at the highest and the lowest rates, respectively. In this case, the maximum plant height of 81.69 and 84.93 cm were recorded from the application of 138 N and 30 kg P ha^{-1}, respectively.

The straw yield of rice was significantly (*P* <0.001 affected by the main effect of applied P and Ns, and also by their interaction (Tables 2 and 3). All N levels have significantly increased grain yields of rice compared with the control. However, the highest grain yield of rice was obtained from the application of 138 kg N ha^{-1}, which increased by 64 % compared to the control. The results of the present study are in agreement with the findings of Heluf and Mulugeta (2006) who observed increased dry matter accumulations due to the increased rates ofapplied mineral N. This is attributed to enhanced plant N uptake (Dalal and Dixit, 1987) thereby promoting vigorous vegetative growth of the rice crop plants. Similar to inorganic N, P application also highly significantly influenced straw yield (Table 5). The application of P at the rate of 30 kg ha^{-1} resulted in the highest straw yield, which was significantly higher than the other treatments. Likewise, Zama et al (1995) also reported that increased rates of P increased dry matter accumulation as a result of increased vegetative growth favored by enhanced nutrient uptake by rice plants.

The effect of the interaction of nitrogen and phosphorus rates on the straw yield of rice showed that mean yield increased with the corresponding increased rates of N and P. With regards to the interaction between N and Ps, the highest straw yield (11.91 t ha^{-1}) was obtained from the combined application of 138 kg N and 20 kg P ha^{-1},followed by 11.68 t ha^{-1} which was obtained from the treatment combinations of 138 N and 30 kg P ha^{-1}, whilst no significant differences were observed between themselves. On the other hand, the lowest straw yield of 5.06 t ha^{-1} was obtained from the application of 10 kg P ha^{-1}.

Economic analysis

Economic analysis revealed that the gross return and net return were maximum with application of 46 N and 10 P kg ha^{-1} followed by the application of 138 N and 30 P kg ha^{-1}. Application of 46 N and 10 kg P ha^{-1} was well above the 100% minimum rate of return (MMR) (CIMMYT, 1988). But investing on additional fertilizer rate gave less MRR. According to CIMMYT (1988) experience and empirical evidence, for the majority of situations indicated that the minimum rate of return acceptable to farmers would be between 50-100%. Therefore, the treatments that have highest marginal rate of return (MRR%), i.e. application of 46 N and 10 P kg ha^{-1} is recommended for rice production in Kamashi zone.

Table 5. Partial Budget Analysis of NP application rates on Upland rice at Kamashi Zone.

Treatments	Total cost of Production (BIRR/ha)	Yield (kg ha^{-1})		Gross Return (BIRR/ha)			Net return	Marginal rate of return
		Straw	Grain	Grain yield	Straw yield	Total		
P kg ha^{-1}								
0	3375.0	6080	3785.3	47316.4	608	47924.4	44549.4	
10	4312.5	7060	4397.8	54972.0	706	55678.0	51365.5	727
20	5250.0	8020	4677.8	58471.9	802	59273.9	54023.9	284
30	6187.5	9205	5094.5	63681.8	920.5	64602.3	58414.8	468
N kg ha^{-1}								
0	3375.0	5885	3480.3	43503.8	588.5	44092.3	40717.3	
46	4760.0	6950	4612.4	57655.1	695	58350.1	53590.1	929
92	6145.0	7900	4739.1	59239.1	790	60029.1	53884.1	21
138	7530.0	9645	5123.5	64044.0	964.5	65008.5	57478.5	259

Recommendations and Conclusions

The study was designedto determine the effects of N and P applications on grain yield and yield components of rice on Nitisols of Kamashi Zone. The results obtained from this study showed that grain yield and some yield components of rice were significantly influenced by the application of nitrogen and/or phosphorous fertilizer. In this study, number of panicles per m^2 and number of filled spikelets per panicle as well as panicle length were the most important yield attributes causing significant variation in grain yield of rice. Panicle length contributed to grain yield increment indirectly by increasing the number of spikelets per panicle.

From this result, it can be concluded that farmers of Kamashi area need to apply 46 kg N and 10 kg P ha^{-1} in order to improve the grain yield and yield components of rice on Nitisols under rain fed conditions. Thus, in the light of the significant response of rice to both N and Ps, further studies aimed at promoting integrated soil fertility management and formulation of fertilizer recommendation on soil test basis over locations are desirable.

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Micronutrients Requirement of Tef Grown on Vertisolsof Adaa and Akaki areas in Central Highlands of Ethiopia

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Introduction

Fertilizing soils with only few macronutrient elements are likely to promote imbalance between nutrient elements in the soil. The use of high yielding varieties in the production system with uncontrolled loss of nutrient through crop removal and erosion, or the replacement of nutrient elements to the soil in incomparable amount have been reported for their acceleration of exhaustion of the supply of available micronutrients from the soil bank (Asgelil et al., 2007). It has been reported that with the favorable developments in the use of nitrogen and phosphoruss to increase crop production, two to six times more of the micronutrients are being removed annually through crop harvest from the soil (Katyal and Randhawa, 1983). This can particularly happen in countries like Ethiopia where only DAP and urea have been applied for decades without application of micronutrients in the form of chemical fertilizer, or as organic amendments.

Both high and low pH and calcareous nature of the soils are among major soil problems that could also potentially contribute towards low availability of some micronutrients as well as phosphorus (Charles et al., 2008). Solubility of Fe was reported to decrease a thousand-fold for each unit increase in soil pH in the range 4 to 9 while it decreases 100-fold for Mn, Cu and Zn (Lindsay, 1979). Excessive presence of free lime also reduces the availability of P, Fe, Mn and Zn, which results in deficiencies/disorders associated with these elements (Andhra Pradesh Agricultural University and Department of Horticulture, 1994). Free calcium carbonate ($CaCO_3$) concentrations greater than 3% is reported to have a negative effect on the availability of P, Fe, Mn and Zn (Obreza et al., 1993). Zinc and Cu were found to be deficient in 65% and 89% of soil samples collected across the country, respectively (Desta Beyene, 1983). Similarly, in a separate study, over 75% of Vertisol, Cambisol, and Fluvisol soil samples analyzed were also reported to be Zn-deficient (Asgelil et al., 2007). At the upper Awash agro-industry enterprise (UAAIE), Zn in soil was reported to be in the range of 0.47-2.85 ppm; low to optimum while it was 0.25-0.61 ppm for copper that is completely deficient (Dejene, 2009).

Micronutrients, such as zinc (Zn) and boron (B), and secondary nutrients like sulfur (S) are needed in small quantities by crops, but are as important as nitrogen (N), phosphorus (P) and potassium (K) for plant growth and increasing the quality and quantity of crop yields. Insufficient soil micronutrients are affecting both crop yield and reduce quality, and it is partly responsible for decreasing efficiency of N, P and K fertilizers. In rain fed areas, in spite of subsistence agriculture over a long period, soils are depleted not only major nutrients but also micro-and secondary nutrients (FAO, 2006).

Plants need a proper supply of all macro- and micronutrients in a balanced ratio throughout their growth period. Previously, it was rightly concluded that on many soils, the application of N without simultaneous supplies of phosphate and potash made little sense. Today, in view of multiple nutrient deficiencies and increasing costs of crop production, fertilization with N or NPK without ensuring adequate supplies of all other limiting nutrients such as S, Zn, B, etc. makes little sense and, in fact, becomes counterproductive by reducing the efficiency of the nutrients that are applied.

The availability of both macro- and micronutrients is influenced by soil chemical and physical properties. The soil nutrient content may not be always enough to fulfill crop requirement. Similarly, most of the micronutrients, for example Fe and Mn are readily fixed in soils having alkaline pH as carbonates and/or bicarbonate compounds. Plant roots are unable to absorb these nutrients adequately from dry topsoil (Graham et al., 1992; Foth and Ellis, 1997). Similarly, some nutrient elements, such as Ca, Mg and Mn are not easily translocated to leaves within the plant system (Foth and Ellis, 1997). Therefore, the objectives of this study were to: determine the response of tef to micronutrient applications (Zn, Cu, Mn, Fe and Mo), and determine economically optimum rates of micronutrients for tef on a Vertisol of Akakii and Adaa district of East Shewa Zone, Oromia.

Material and Methods

Experimental procedure

The study was conducted in 2013 and 2014 cropping seasons for two consecutive years under rain fed conditions on selected farmers' fields at Akakii and Adaa District of East Shewa Zone, Oromia Regional State. Before sowing, composite surface soil samples were collected, from selected farmers' fields to determine soil pH, OM, total N, available P and exchangeable K for soil fertility evaluation.

The experiment comprised seven treatments: 1) recommended nitrogen and phosphorus rate; 2) recommended NP + KCl fertilizer applied at 50 kg/ha; 3) 100% NPK + Cu-chelate foliar fertilizer 14% Cu; 4) 100% NPK + Zn-chelate foliar fertilizer 14% Zn; 5) 100% NPK + Mn chelate foliar fertilizer 13% Mn; 6) 100% NPK + Fe-chelate foliar fertilizer 13.2% Fe; and 7) 100% NPK + Chelate of 14% Cu, 14% Zn, 13% Mn, and 13.2% Fe). The field experiments were arranged in a randomized complete block design with four replications. Urea (46% N) was used as the source of N, triple super phosphate (TSP; 46% P_2O_5) as the source of P, and KCl was used as the source of K. Full doses of K and P were applied at the time of planting and the recommended amount of nitrogen (60 kg/ha) was applied in split doses to all experimental plots. All micronutrients were applied in split at tillering and 15 days after the first application. Improved tef variety, *Kuncho* was used as a test crop.

The experimental plot was prepared using local ox-drawn implement (Maresha) according to the local farmers' conventional practice. Accordingly, the field was plowed three times before sowing. The plot size was 5 m x 5m (25 m^2). The plots within a block as well as between block were separated by 1 m wide open space area. The necessary recommended agronomic management practices were all carried out. Weeding was done manually three times during the crop growth period. The agronomic data collected were plant height, grain yield, straw yield and total aboveground biomass.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) appropriate to randomized complete block, using SAS software program (SAS Institute, 2000). The analytical results of the soil samples were interpreted using descriptive statistics. When significant differences were observed, comparisons of means were performed using the least significant difference (LSD).

Results and Discussion

Selected soil chemical properties prior to planting

As indicated in Table 1 the pH values of the study area were neutral based on Foth and Ellis (1997), and the organic matter and total nitrogen contents of all the study sites were very low according to London (1991). Tesfaye and Sahlemedhin (2002) also reported that organic matter content and nutrient supplying power of most cultivated soils in Ethiopia are low. The total nitrogen content of the experimental soil is in agreement with other studies (Tekalign et al.,1988; Mesfin, 1998; Eylachew, 2000; Engdawork, 2002; Mohammed, 2003). They also indicated that N content of Vertisols in Ethiopia is the most deficient nutrient element of any other essential elements in these soils and has called for the application of inorganic fertilizers and need for a sound management of soil OM.

Table 1. Selected soil chemical properties of composite surface soils of the study before planting

Site	pH (H_2O)	OM (%)	Total N (%)	Exch. K (cmol/kg)	Av. P (ppm)
1	6.7	2.2	0.06	1.39	17.23
2	7.04	1.55	0.05	1.19	21.08
3	6.14	2.39	0.07	1.2	34.72
4	6.31	2.08	0.06	1.17	18.03
5	6.17	1.99	0.08	1.59	ND

OM = Organic matter; AP = Available phosphorus; Exch. K = exchangeable potassium; ND = Not determined

According to the classification of exchangeable bases set by FAO (2006), the exchangeable K content of the surface soil could be rated as high to very high (Table 1). Generally, the soil of the study area has the potential to supply K for crop growth and hence, calls for protection and maintenance of the surface soil to secure sustainable crop production without any external addition of K fertilizers.

The available P contents of surface soils of the study area ranged from 17.23 to 34.72 ppm (Table 1). Tisdale et al. (2002) indicated that for Olson extractable P below 3 mg kg^{-1} is considered as very low; between 4 and 7 mg kg^{-1} as low; between 8 and 11mg kg^{-1} medium, and greater than 12 mg kg^{-1} as high. Thus, the available P content of the mean composite surface soil sample of the experimental sites could be rated as high soil available P.

Table 2. Treatment effects on plant height, grain and straw yields, and total biomass of tef

Treatments (kg/ha)	PH (cm)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Biomass Yield (kg/ha)
Adaa				
Recommended NP	116.2	1645.4	3723.4ab	5368.7ab
Recommended NP + K_2SO_4	116.0	1690.4	3485.1b	5175.5a
100%NPK + Cu chelatefoliar	116.0	1528.9	3536.6b	5065.5b
100%NPK +Zn chelatefoliar	114.8	1817.5	4051.4ab	5868.9a
100% NPK +Mnchelatefoliar	116.1	1732.1	3580.5ab	5312.7ab
100% NPK + Fe chelatefoliar	114.6	1684.3	4208.7a	5893.0a
100% NPK + chelate of 14%Cu 14% Zn, 13% Mn and 13.2% Fe	113.8	1572.1	4208.7ab	5198.7ab
LSD (0.05)	ns	ns	ns	ns
CV (%)	7.9	25.9	24.4	19.4
Akakii				
Recommended NP	110.33	1171.7 b	4453	5625
Recommended NP + K_2SO_4	108.33	912.0 b	4818	5730
100%NPK + Cu chelatefoliar	114.33	1338.7 b	3453	4792
100%NPK +Zn chelatefoliar	117.66	2078.3 a	2818	4896
100% NPK +Mn chelate foliar	118.00	1053.0 b	4364	5417
100% NPK + Fe chelatefoliar	112.00	1330.3 b	3774	5104
100% NPK + chelate of 14% Cu, 14% Zn, 13% Mn and 13.2% Fe	108.33	808.7 b	4087	4896
LSD (0.05)	ns	591.91	ns	ns
CV (%)	8.92	26.79	33.07	25.15

PH = plant height; LSD = Least significant difference; CV = Coefficient of variation;

Application of different micronutrient contenting fertilizers didn't show significant ($P > 0.05$) effect on selected agronomic parameters at Adaa. However, the analysis of variance showed that the applied fertilizers had significant ($P \leq 0.01$) influence on grain yield at Akakii site, where the highest mean grain yields of 1817.5 kg/ha and 2078.3 kg/ha were obtained from the application of 100% NPK + Zn chelate at Adaa and Akakii sites, respectively, indicating that in addition to the macronutrient, Zn could be one of yield limiting micronutrient for the study site (Table 2).

Conclusions and Recommendations

Micronutrients, such as zinc (Zn) and boron (B), and the secondary nutrients like sulfur (S) are needed in small quantities by crops but are as important as nitrogen, phosphorus and potassium for plant growth and increasing the quality and quantity of crop yields. Deficiency of soil micronutrients is affecting both crop yield and quality, and it is partly responsible for decreasing efficiency of N, P and K fertilizers. Based on the results of the study, application of different micronutrient containing fertilizers didn't show significant effect ($P > 0.05$) on crop parameters tested for tef at both sites. However, the highest tef grain yields of 1817.5 kg/ha and 2078.3 kg/ha were recorded from the application of 100% NPK + Zn chelate at Adaa and Akakii sites respectively, indicating that in addition to the macronutrients, Zn could be one of the yield limiting micronutrient for the study site, especially at Akaki although soil analysis result is not included for micronutrients for the study sites.

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Response of Tef to Micronutrient Application in Central Rift Valley of Ethipia

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Introduction

Fertilizer use in Ethiopia has focused mainly on the use and application of nitrogen and phosphorous fertilizers in the form of di-ammonium phosphate (DAP) and urea for almost all cultivated crops for both market and food security purposes for the last several years. When micronutrients are not applied in the soil in combination with commoNs, fertilizing soils with macronutrients are likely to encourage disparity between these nutrient groups and individual nutrients. Moreover, increased yield through exhaustive cropping and use of high yielding varieties, losses of micronutrients through leaching and decreased farmyard manure application compared to chemical fertilizers contributed towards hastened exhaustion of the supply of available micronutrients from the soil (Asgelil et al., 2007). It has been reported that, in spite of favorable developments in the use of nitrogen and phosphoruss to increase crop production, two to six times more of the micronutrients are being removed annually through crop harvest from the soil than are applied to it (Katyal and Randhawa, 1983). This is particularly true in countries like Ethiopia where there is no micronutrient application in the form of chemical fertilizer or organic amendments.

Some reports indicated that elements like K, S, Ca, Mg and micronutrients, particularly Fe, Cu, Mn, B, Mo and Zn are becoming depleted and deficiency symptoms are being observed on major crops in different areas of the country (Asgelil et al., 2007). Trace elements deficiencies are now more widely recognized in tropical soils than before. Since the availability of trace elements is influenced by soil reaction, modifying the soil pH sometimes cures trace element deficiencies. More commonly, they are corrected by applying small amounts of the missing elements either to the soil or direct to the plant, as in foliar sprays (Jones et al, 1972).

Responses to application of micronutrients are reported elsewhere. In Turkey, application of Zinc at the rate of 15 kg/ha increased yield of lentil by 26.2% over the control (Ciftci et al., 1998). In Japan, foliar application of Fe-DTPA increased dry herbage yield and oil content of mint (*Meatha arvensis* L.) (Subrahmanyam et al., 1992). In Australia, it was found that Zn-deficient wheat plants were more susceptible to take-all infection than Zn-adequate plants (Brennan, 1992). Moore et al. (1988) reported that Zn-deficient flooded rice resulted in less ATP production thereby reducing vital metabolic activities of the roots. They suggested that foliar application of Mn at a rate of 40 kg Mn ha^{-1} provided desirable medium for peanut production. In China, it was shown that transplanted oil rapeseed (*Brassica napus* L.) appeared to be sensitive to zinc deficiency (Mulyati et al., 1997). An interesting research result in Turkey indicated that grain yield from seeds of bread wheat with high zinc content was significantly higher than seeds of low zinc content, indicating the importance of Zn for grain yield increase (Yilmaz et al.,1997)

However, the study on the effect of micronutrients on crop yield in Ethiopia is scanty. Therefore, this study was initiated to investigate the response of tef to some micronutrients in tef growing Woredas of central Rift Valley of Ethiopia. The objective of the trial was to determine the response of tef to micronutrient foliar applications (Zinc, Copper, Manganese, and Iron) under CRV soil types.

Materials and Methods

The study was conducted on 3 to 5 farmers' fields at Boset, Adama, and Dodota Woreda depending on the availability of land for the experiment, and at MARC station from 2014-2015 in two consecutive cropping seasons. A recommended seed rate of 25 kg ha^{-1} of tef variety *Gemechis* was used.

Each plot size of the trial was 5 m by 5 m, and 3 m by 3 m harvestable area. All agronomic practices, fertilizer recommendation and other crop management practices were used for specific area. The detail treatment plan for the first year of the project period and appropriate treatment application period (crop development stage) are indicated in Table 1. The treatments were arranged in randomized complete block design (RCBD) with three replications. Applications of micronutrients were based on the product formulation and recommendation.

Study site description

The trials were conducted at three Woredas, i.e. Boset, Adama and Dodota. Wolenchiti is situated some 120 km away from Addis at Boset Woreda, one on-farm and one sub-station trials were conducted. The latitude of the trial site is 8^0 30' 15.4"N and 39^0 39' 28.8"E at the elevation of 1443 masl. Annual rainfall is about 745 mm, and the maximum and minimum temperatures of the area are 24.2 ^{0}C and 19.3 ^{0}C, respectively (see the climate data in annex 1). Adulala and Melkassa are situated some 100 and 107 km away from Addis, respectively at Adama Woreda, one on-farm and on-station trials were conducted (see the climate data in annex 1). Dera is situated some 117 km away from Addis at Dodota Woreda, where one on-farm trial was conducted (see the climate data in annex 1).

Soil sample collection and analysis

Composite soil samples were collected 0-15 cm depth before planting from all Woredas and experimental sites using auger. Soil samples taken from each experimental site were mixed in plastic bags to make one composite sample for each Woreda, and a total of four composite samples were collected. The soil samples were air-dried, crushed with mortar and pestle, passed through 2 mm wire sieve for analysis of various soil physicochemical parameters.

Soil texture, bulk density, pH, EC, total nitrogen, available phosphorus and organic carbon were determined at Melkassa Agricultural Research Center soil laboratory. Other chemical parameters, including soil exchangeable cations (K, Na, Ca, Mg), cation exchange capacity (CEC), Zinc (Zn), Copper (Cu), Iron (Fe) and Manganese (Mn) in both soil and plant samples were determined at Debre Zeit Agricultural Research Center soil laboratory. Particle size distribution of the soil samples was determined by hydrometer method (Bouyoucos, 1962). Soil bulk density was determined on the undisturbed core sampling method after drying the soil samples in an oven at $105^{o}C$ to constant weights.

Potentiometric method using a glass calomel combination electrode was used to measure pH of the soils in water suspension in a 1:2.5 (soil: water ratio) (Van Reeuwijk, 1992). Electrical conductivity (EC) was measured using a conductivity meter from the same soil water suspension extract. The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon (OC) content. Total nitrogen content of the soil was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Available P was determined using the standard Olsen et al. (1954) extraction methods. The absorbance of available P extracted was measured using spectrophotometer after color development. Exchangeable cations (Ca, Mg, K and Na) were determined after extracting the soil samples by 1N neutral ammonium acetate (1N NH4OAc) solution adjusted to a pH 7.0. Exchangeable Ca and Mg in the extract were measured by atomic absorption spectrophotometer (AAS), whilstsoil K and Na content were determined using flame photometer from the same extract (Okalebo et al., 2002). Cation exchange capacity of the soils was determined from the ammonium acetate saturated samples through distillation and measurement of ammonium using the modified Kjeldhal procedure as described by Okalebo et al. (2002). Micronutrients (Fe, Mn, Zn, Cu) in both soil and plant samples were extracted by Di-ethyl Tri-amine Penta-acetic acid (DTPA) as described by Tan (1996), and all these micronutrients were measured by AAS.

Thirty to fifty plant samples were collected from both treated and untreated plots a week after the foliar treatment applied, using a paper bug. The samples were well managed and labeled and transported to Melkassa Agricultural Research Center soil laboratory. Air-dried tef samples were ground with mortar and pestle to pass a 2 mm sieve. To avoid contamination, the samples were stored in plastic bags. The samples were again oven dried at $75^{o}C$ for 24 hours until it maintained a constant weight and cooled in desiccators for 2 hours. Five g of each sample was weighed before ashing. The oven dried samples described above were ashed by muffle, raising the temperature slowly up to $450^{o}C$ for about 2.5 h, and maintaining this temperature overnight. The ash samples were moistened with a few drops of water and covered with a watch glass for the determination of Cu, Fe, Mn, and Zn.

Treatment arrangement and preparation of spray solutions

As per the recommendation for tef, a full basal dose of 41 kg N ha^{-1} from urea and DAP, 46 kg P_2O_5 ha^{-1} from DAP, and 51 kg K_2O ha^{-1} from K_2SO_4 were applied as one treatment.Four micronutrients (copper, zinc, iron, manganese, and mixture of all) at a single rate alone in the form of blended type were applied at two tef growing stages: 1) 21 days after crop emergence, and 2) at panicle initiation.

Cu chelate (14% Cu), Zn chelate (14% Zn), Mn chelate (13% Mn), Fe chelate (13.2% Fe) and mixture of all of these (Cu + Zn + Fe + Mn), were used as source of Cu, Zn, Mn, and Fe respectively. The volume of water (1.5 liters per plot) was estimated by calibrating the average volume of water required to wet completely the tef plant of each plot. The spray solution was prepared for each micronutrient in five well-labeled 2 liters polyethylene manual sprayers at the rate of 1.12 kg ha^{-1} in 600 liters of water according to the product recommendations 1 kg of the product mixed with 500 L water. Water without micronutrient was also applied to all the control plots to avoid the wetting effect difference of the tef plots due to spray. The detail treatment combinations are given in Table 1.

Table 1.Treatment setup.

Treatments	**Other Fertilizers kg ha^{-1}**	Zn	Cu	Fe	Mn
		kg per plot based calculation			
		kg ha^{-1} in 600 L of water			
Zn_0, Cu_0, Fe_0, Mn_0, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O	--	--	--	--
Zn_0, Cu_0, Fe_0, Mn_0, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O_5,51K_2O	--	--	--	--
Zn_0, Cu_1, Fe_0, Mn_0, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O_5,51K_2O	1.12	--	--	--
Zn_1, Cu_0, Fe_0, Mn_0, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O_5,51K_2O	--	1.12	--	--
Zn_0, Cu_0, Fe_1, Mn_0, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O_5,51K_2O	--	--	1.12	--
Zn_0, Cu_0, Fe_0, Mn_1, $(Zn+Cu+Fe+Mn)_0$	41N, 46 P_2O_5,51K_2O	--	--	--	1.12
Zn_0, Cu_0, Fe_0, Mn_0, $(Zn+Cu+Fe+Mn)_1$	41N, 46 P_2O_5,51K_2O	0.56	0.56	0.56	0.56

Results and Discussion

The soil test result indicated that the soils of all experimental sites were sand dominated light in its density (Table 2). This showed that they have low moisture retention capacity, good aeration and root respiration. The soil reaction indicated that the soil of experimental sites was from slightly to moderately alkaline. This reveals that the experimental soil has some fixation problem of some nutrients, especially phosphorus and most micronutrients are deficient in these soils, which is supported experimentally by the soil analysis results in Table 2.

The EC of the experimental sites were low, indicating that the soil of the experimental sites is suitable for all crops. There is no salinity problem in the experimental sites. Other soil parameters, such as organic carbon (OC), total N, available P, and exchangeable K in the experimental sites were in adequate level for the growth of plants.

Table 2. Soil analysis results at a depth of 0-15 cm

Parameters		Dodota	Wolenchiti	Adulala	MARC	rate	References
Sand	%	71	63	66	49		
Clay		11	14	8	19		
Silt		18	23	26	32		
T. Class		SL	SL	SL	SCL		
BD	gcm^{-3}	1.18	1.19	1.21	1.12		
pH		8.3	7.6	7.8	7.5		
EC	dSm^{-1}	0.6	0.5	0.2	0.9		
AP	ppm	10.7	14.3	12.6	15.3	low	Clements and McGowen (1994).
TN	%	0.1	0.2	0.1	0.2	low	Bruce and Rayment (1982).
OC		1.6	2.8	1.8	1.1	Low-high	Charman and Roper (2007).
Exch. Na	$cmol(+)kg^{-1}$	1.2	1.5	0.2	0.5	low	FAO (2006)
Exch. K		2.6	2.0	3.8	3.0	high	FAO (2006)
Exch. Ca		24.5	18.8	14.4	14.0	high	FAO (2006)
Exch. Mg		4.9	3.2	2.4	3.4	High-very high	FAO (2006)
CEC		44.1	39.8	21.6	33.0	High-very high	Hazelton and Murphy (2007)
Cu	$mg\ kg^{-1}$	0.5	0.4	0.3	0.7	Low-high	Jones, J. Benton (2003)
Fe		3.3	1.7	2.3	6.1	Low-high	Jones, J. Benton (2003)
Mn		16.3	7.4	6.3	12.4	Very high	Jones, J. Benton (2003)
Zn		2.3	0.1	0.1	0.7	Low-high	Jones, J. Benton (2003)

Table 3. Plant analysis results in mg kg^{-1} and standards (Mills and Jones, 1996)

Location	Treatment	NP	NPK	NPK + Cu	NPK + Zn	NPK + Fe	NPK + Mn	NPK + Cu + Zn	Mills & Jones, 1996
									Mg kg^{-1}
Melkassa	**Cu**	trace	trace	6.1	trace	trace	trace	trace	5-15
	Fe	23.1	76.8	56.1	62.3	145	111.9	52.3	21-200
	Mn	25.1	27.6	28.1	30.2	29.6	65.2	32.2	20-150
	Zn	15.19	16.07	14.02	21.7	14.5	15.32	17.9	20-70
Wolenchiti	**Cu**	trace	trace	5.4	trace	trace	trace	trace	5-15
	Fe	39.3	34.45	40.65	56	165.05	118.1	148.2	21-200
	Mn	40.95	42.05	65.3	65.7	68.25	74.0	66.65	20-150
	Zn	19.9	20.2	20.7	25.0	25.87	25.46	24.25	20-70
Adulala	**Cu**	trace	3.1	6.7	2.8	1.5	1.3	3.4	5-15
	Fe	81.9	64.3	62.1	83.4	185.9	88.0	158.5	21-200
	Mn	50.7	56.5	49.7	43.3	52.3	78.4	69.7	20-150
	Zn	28.5	27.9	29.2	36.8	27.8	29.0	26.3	20-70
Dodota	**Cu**	trace	trace	4.2	trace	trace	trace	trace	5-15
	Fe	74.1	81.6	73.4	77.6	97.5	71.9	87.4	21-200
	Mn	46.5	42.0	56.7	89.4	65	99.9	55.8	20-150
	Zn	26.08	25.52	26.31	25.71	24.2	25.3	23.75	20-70

The results of plant analysis showed that at Melkassa the concentrations of copper, except copper treated plot, were below 0.1 ppm. The concentrations of iron and manganese were in adequate level before and after foliar spry of these nutrients. However, according to the standard given by Mills and Jones (1996), zinc treated plots had higher zinc concentration than other treatments. At Wolenchiti, copper concentrations, except copper treated plots were too small, below 0.1 ppm. Other micronutrients were in adequate level, all plots which received micronutrients foliar spry resulted in improved concentration of these nutrients as compared with the standard given by Mills and Jones (1996).

Tef tissue analysis at Adulala revealed that except copper, other micronutrients were adequate. However, the foliar application of these nutrients improved their concentration on plots treated with these nutrients. The foliar spry of copper improved the copper concentration in the tef tissue as shown in Table 3. At Dodota, the concentration of micronutrients in plant tissue was not significantly influenced by the foliar application of these nutrients (Table 3). Foliar spry of copper increased the concentration of copper though, not in adequate amount as per the standard given by Mills and Jones (1996).

Yield and yield components

The combined analysis of variance over years indicated that tef grain yield was significantly influenced by the foliar application of copper at MARC, compared to the control (Table 4). The grain yield of tef was increased by 15.7% by the application of Cu. Similarly, Kumar et al. (2009) reported the increase in wheat grain yield due to the application of Cu in Pakistan. However, other yield parameters of tef were not significantly affected by these treatments at MARC. At Adulala, plant height, grain yield and total biomass of tef were significantly increased by the application of micronutrients (Table 4). All plots treated with K and micronutrients were superior to the NP control. The application of Cu increased tef yield by 38.58% compared to the NP control. Other agronomic parameters, including plant height and total biomass were significantly influenced by the application of Cu and Cu at Adulala.

Table 4. Plant growth and yield of tef as influenced by micronutrients at MARC and Adulala

	MARC				**Adulala**			
Treat	PH	PL	GY	BM	PH	PL	GY	BM
Rec.NP	106.5	38.83	1166.7^{c}	7750	95.27^{ab}	32.6	1436.7^{b}	4683.3^{ab}
Rec.NPK	108.0	39.48	1200^{bc}	8916.7	92.07^{b}	33.6	1800^{a}	4366.7^{ab}
Rec.NPK+Cu	108.4	42.5	1350^{a}	6833.3	99.17^{ab}	33.733	1991.7^{a}	5433.3^{a}
Rec. NPK+Zn	108.9	41.83	1333.3^{ab}	8833.3	93.63^{ab}	32.767	1826.7^{a}	5066.7^{a}
Rec.NPK+Fe	103.1	43.43	1266.7^{abc}	9250	99.97^{a}	32.267	1753.3^{a}	4766.7^{ab}
Rec.NPK+Mn	109.3	42.63	1300^{abc}	8666.7	92.1^{b}	32.767	1805^{a}	3433.3^{b}
Rec.NPK+Zn+Cu	106.6	43.03	1250^{abc}	8166.7	96.43^{ab}	32.567	1738.3^{a}	4516.7^{ab}
CV%	7.75	11.86	9.98	26.54	6.47	6.62	13.85	26.14
LSD<0.05	ns	ns	148.3	ns	7.25	ns	286.8	1412.4

BM= biomass yield, GY= grain yield, PH= plant height and PL= panicle length

At Wolwnchiti, analysis of variance over two years showed that plant height and panicle length significantly were influenced by the application of zinc, manganese and micronutrients mixture (Table 5). However, grain yield and total biomass of tef were not significantly affected by the application of micronutrients. At Dodota, plant height, panicle length and grain yield of tef were significantly increased by the application of micronutrient. At Dodota, the application of manganese significantly ($P < 0.05$) increased plant height and grain yield of tef. The application of zinc significantly ($P < 0.05$) improved the panicle length, but the total biomass was not significantly influenced by the application of micronutrients.

Table 5. Tef plant height, panicle length (cm), grain yield and biomass ($kgha^{-1}$) as influenced by the foliar application of micronutrients Wolenchiti and Dodota.

	Wolenchti				**Dodota**			
Treat	PH	PL	GY	BM	PH	PL	GY	BM
Rec.NP	99.83^{b}	35.97^{b}	1646.7	9100	74.27^{b}	23.33^{b}	1106.1^{b}	3052.30
Rec.NPK	104.83^{ab}	38.33^{ab}	1640	9200	81.07^{a}	28.67^{a}	1274.8^{b}	3715.30
Rec.NPK+Cu	108.17^{ab}	39.0^{ab}	1936.7	8333	79.53^{ab}	28.00^{ab}	1577.6^{ab}	3912.60
Rec. NPK+Zn	114.5^{a}	39.17^{ab}	1780	8800	79.67^{ab}	29.87^{a}	1511.4^{ab}	3100.90
Rec.NPK+Fe	101.33^{b}	37.27^{ab}	1696.7	10200	77.53^{ab}	27.8^{ab}	1179.6^{b}	3509.80
Rec.NPK+Mn	112.83^{a}	39.83^{a}	1773.3	9133	81.93^{a}	27.0^{ab}	1920.8^{a}	3570.80
Rec.NPK+Zn+Cu	105.03^{ab}	40.33^{a}	1780	9267	80.93^{a}	29.6^{a}	1367.6^{ab}	3808.30
CV%	5.72	5.6	10.16	15.49	4.36	9.63	23.03	21.87
LSD<0.05	10.85	3.84	ns	ns	6.14	4.75	581.5	ns

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Response of Artemisia (*Artemisia annua* L.) to Nitrogen and Phosphoruss Application at Wondo Genet and Koka Areas

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Introduction

Nowadays, the promotion of human health is a priority of crop producers. *Artemisia annua (*Asteraceae*)*, commonly known as “sweet or annual wormwood,” is an annual medicinal and aromatic herb that possesses a wide range of health benefits and has therefore been widely used as herbal medicine (Obolskiy et al., 2011). It has anti-malarial effect due to the presence of artemisinin which is one of the most important advances in malaria control in modern times. Medicinal herbal tea can also be prepared from dried leaf of *Artemisia annua* for the treatment of malaria without negative side effect (Hirt and Lindsey, 2000).

Plant nutrition is one of the most important factors that increase plant production. Plant uptake and tissue concentration of elements are mainly dictated by the combined influences of both genetic and environmental factors, such as soil composition, the use of fertilizers, plant’s maturity at harvest and the storage conditions (Sanchez-Castillo et al., 1998). Thus, one of the most important needs in agricultural planning is to achieve high yield and good quality plant nutrition evaluation of various systems.

Nitrogen (N) is the most recognized element in plants for its presence in the structure of the protein molecule. Accordingly, N plays an important role in the synthesis of plant constituents through the action of different enzymes (Saber and Khalid, 2011). Limitation of N increases volatile oil production in annual herbal plants. N fertilization has been reported to reduce essential oil content in creeping juniper (*Juniperus horizontalis*) (Robert and Francis, 1986), although it has been reported to increase total essential oil yield in thyme (*Thymus vulgaris* L.) (Baranauskienne et al., 2003). Phosphorus also plays an important role in various metabolic processes. It activates coenzymes for amino acid production used in protein synthesis. Phosphorus also aids in root development, flower initiation, seed and fruit development. Hornok (1980) indicated that NP fertilization is not only effective on the quantity of vegetative and generation mass, but also on the oil content of dill (*Anethum graveolens* L.). According to Emongor (1990), high P rates (more than 7.47 kg P ha^{-1}) decreased chamomile essential oil yield. From all these results, it can be inferred that it is essential to apply N and P to medicinal plants supposed to be grown in soils which are deficient in these nutrients.

In this regard, researches show that excessive use of chemical fertilizers decreases crop yield due to soil acidification, loss of biological activity in the soil, changes in soil physical properties and lack of micronutrients in agricultural land (Adediran et al., 2004). To reduce these risks, inputs should be used in an optimum level to the current needs of the plant. This implies that there is a need to test and establish optimum N and P rates for adequate production of Artemisia. Therefore, this research was conducted at Wondo Genet Research Center and Koka area to determine optimum N and P rates for improving yield and yield component of Artemisia.

Materials and Methods

Field trials were carried out under irrigated condition for two consecutive cropping seasons (2013/2014 and 2014/2015) at Wondo Genet Agricultural Research center experimental site and Koka experimental substation. Wondo Genet experimental site was geographically located at 07° 19.1' North latitude and 38° 30’ East longitude at an altitude of 1780m.a.s.l. It received mean annual rainfall of 1128 mm with minimum and maximum temperature of 11 and 26°C, respectively. The texture of the top soil (0-20 cm) was clay with slightly acidic (pH 5.91, 1:2.5 soil water suspensions). Koka was geographically located at 08°26.1' North latitude and 39° 01’ East longitude at an altitude of 1617m.a.s.l. The texture of the top soil (0-20 cm) was loam with slightly alkaline (pH 8.01).

An auger was used to take soil samples at random from different spots to make composite samples per trial field at depth of 0-20 cm before fertilizer application. Composite soil samples were air-dried, ground using mortar and sieved through a 2-mm mesh and subjected to chemical analysis. The soil was analyzed for pH, organic matter content, total nitrogen, available phosphorus, exchangeable K, Na and Ca, following standard laboratory procedures (Sahlemedhin and Taye, 2000). Seedlings of Artemisia were raised in the nursery for three months and transplanted to actual field on well tilth land for planting. Factorial combinations of four nitrogen levels (0, 46, 92, 138 kg ha^{-1}) and four phosphorus levels (0, 10, 20, 30 kg ha^{-1}) were laid out in a randomized complete block design (RCBD) with three replications. Urea and triple super phosphate (TSP) were used as sources of nitrogen and phosphorous fertilizer, respectively. Full dose of phosphorous was applied as basal dressing during planting. Nitrogen was applied in split form (1/3 during planting and remaining 2/3 two months after transplanting). The plot size for each treatment was 4.80 m x 4 m on which Artemisia was planted with intra-and inter-row spacing of 60 cm. All agronomic practices including weeding and harvesting was done as per the recommendation for the crop.

Five plants were selected randomly from each plot by excluding borders to collect yield and yield contributing characters, such as plant height (cm), number of branch/plant, aboveground biomass (g), leaf fresh weight (g), stem fresh weight (g), leaf dry weight (g), essential oil yield (g), and essential oil content (w/w, wet based%) of the plant. Essential oil yield analysis was done using gas chromatography-mass spectrophotometer or modified Clevenger collector apparatus.The collected data were subjected to analysis of variance using SAS computer software version 9.0 (SAS, 2000). Whenever treatment effects were significant, the means were separated using the least significant difference (LSD) at 5% level of significance.

Results and Discussion

Properties of the experimental soil before planting

Selected physicochemical properties of the composite surface soil (0-20 cm) collected before planting showed that the textural class of the soil was clay with slightly acidic (pH 5.91) at Wondo Genet and loam with slightly alkaline (pH 8.01) at Koka (Table 1), whichare favorable for Artemisia production.*Artemisia annua* grows in most soil types having deep topsoil and good drainage properties with the pH of the soil between 4.5 and 8.5 (Ferreira et al, 1995).

The organic carbon content of the experimental soil was 1.4% for Koka and 2.8% for Wondo Genet sites.Landon (1991) classified total nitrogen content < 0.1, 0.1-0.15, 0.15-0.25 and > 0.25 as very low, low, medium, and high respectively. Similarly, Tekalign (1991) also classified total nitrogen content of < 0.05, 0.05-0.12, 0.12-0.25, and > 0.25 as very low, low, medium, and high, respectively. for At Koka, the total N content of 0.08 % was low, and at Wondo Genet the total N content of 0.24% was medium (Table 1), which are in accordance with the ratings of both authors. This indicates that nitrogen was a limiting factor for crop growth at Koka, possibly due to continuous cultivation and lack of incorporation of organic materials, and therefore application of N tended to reduce this limiting factor of growth. However, medium N content was observed at Wondo Genet experimental site, which is why N and P experiments didn't bring significant variation among treatments.

The available P content of 18 mg kg^{-1} at Koka and 44 mg kg^{-1} at Wondo Genet could be considered as high (Tale 1), in accordance with Landon (1991), who classified available P of the soil < 5, 5-15 and > 15 as low, medium and high respectively. This indicated that P is not a limiting nutrient for optimum crop growth and yield at both experimental sites. In general, the properties of the experimental soil and the weather conditions at the two sites were conducive for the growth of Artemisia.

Table1. Selected soil physical and chemical properties of the experimental sites before planting.

Location	**Particle Size Analysis (%)**				**pH 1:2.5**	**OC %**	**Total N (%)**	**Avail P (mg kg^{-1})**
	Sand	Silt	Clay	Class				
Koka	42	32	26	Loam	8.01	1.45	0.08	18
W/Genet	10	40	50	Clay	5.95	2.78	0.24	44

Effects of N and P on plant growth

For both testing sites, plant height didn't show any significant ($p < 0.05$) variation by the application of nitrogen and its interaction with phosphorus (Table 2). However, under Koka condition, phosphorus application had a significant ($p \leq 0.01$) on plant height, although it was inconsistent at Wondo Genet. The tallest mean plant height (134 cm) of Artemisia plant was recorded from 30 kg P ha^{-1} despite statistically being at par with the control treatment (Table 2). The similarity between the control treatment and 30 kg P ha $^{-1}$ could be due to higher initial P level at the experimental site.

At Wondo Genet, leaf, and stem fresh weight were significantly influenced by nitrogen rates, whereas the different levels of phosphorus didn't show any significant influence on the leaf fresh weight of Artemisia (Table 2). The maximum leaf fresh weight was recorded from 46 kg N ha^{-1}, compared with the control treatment though statistically at par with the other phosphorus levels. Similarly, the highest stem fresh weight was obtained from 92 kg N ha^{-1} even though statistically similar with 46 kg N ha^{-1}. The effect of phosphorus was not

significant on leaf fresh weight at both locations, which might be due higher initial available P in the experimental site (Table 2).

Table 2. Plant height, leaf fresh weight (LFW) and stem fresh weight (SFW) of *Artemisia annua* as affected by N and P and their interaction at Koka and Wondo Genet during 2013/2014 and 2014/2015 cropping season.

Factor	Plant height (cm)		LFW (ton ha^{-1})		SFW (ton ha^{-1})	
	Koka	W/Genet	Koka	W/Genet	Koka	W/Genet
Nitrogen levels (kg ha^{-1})						
0	123.9	130.25	4.65b	5.32^{b}	22.01	19.54^{b}
46	128.4	133.08	5.23ab	6.09^{a}	22.66	22.60^{ab}
92	127.4	133.50	5.36a	6.03^{ab}	21.53	23.58^{a}
138	128.1	126.29	4.77ab	5.96^{ab}	21.55	22.35^{ab}
LSD (0.05)	ns	ns	0.61	0.72	ns	3.10
Phosphorus levels (kg ha^{-1})						
0	127.8^{ab}	127.19	4.86	5.78	21.22b	20.48
10	126.2^{ab}	130.88	5.22	6.09	22.13ab	23.09
20	123.4^{b}	130.92	4.94	5.81	21.28b	22.12
30	130.6^{a}	134.13	4.99	5.72	23.12a	22.37
LSD (0.05)	6.19	ns	ns	ns	1.69	ns
N*P	ns	ns	**	ns	**	ns
CV	8.45	9.67	21.3	21.22	13.3	24.43

** Significant at 0.01 probability level, ns= not significant.
Means within a column followed by the same letter (s) are not statistically different from each other

At koka condition, both leaf and stem fresh weight were significantly ($p \leq 0.01$) influenced by the interaction of nitrogen and phosphorus (Table 3). The highest leaf and stem fresh weights were obtained from the interaction of 46 kg N ha^{-1} and 10 kg P ha^{-1} though it showed statistical similarity with the control N and 30 kg P ha^{-1} for stem fresh weight (Tables 3 and 4). This demonstrates that the right rate of nitrogen and phosphorus enhances efficiency of utilization of resources by Artemisia by reducing inter and- intra-specific competition. Prasad et al., (2008), in line with this study reported that foliar application of calcium chloride increased herbage yield in rose-scented geranium compared with the control. Similarly, Sajad et al, (2014) also stated that foliar application of 5g Ca $(NO_3)_2$ significantly increased fresh matter yield by an average of 68.3 and 42.7% in the first and second harvests, respectively compared with the control treatment. Regarding to our results, it was clear that nitrogen and phosphorus are considered as one of the most essential elements for growth and development of Artemisia. Many studies proved that N and P play a major role in many physiological and biochemical processes, such as cell division and elongation, enzyme activation, stabilization of the native conformation of enzymes and possibly turgor, stomata movement, metabolism of carbohydrates, and protein compounds (Espinosa et al., 1999; Khalid, 2001; Marschner, 1995; Fawzy et al., 2007).

Effect of N and P on above ground biomass and leaf dry weight

At Wondo Genet, above ground-biomass was significantly influenced by different rates of nitrogen, but not by phosphorus rate (Table 5). In contrast to above-ground biomass, N application and its interaction with phosphorus did not show any significant effect on leaf dry weight (Table 5). On the other hand, leaf dry weight was significantly ($p \leq 0.05$) affected by different levels of phosphorus although this was against the initial soil available P content at the testing site.

At Koka, nitrogen by phosphorus interaction significantly ($p \leq 0.001$) affected above-ground biomass (Table 3). The maximum above-ground biomass was obtained from the interaction of 46 kg N ha^{-1} and 10 kg P ha^{-1}. Previous studies also showed that application of KNO_3 fertilizer increased fresh matter yield by an average of 60.5% compared to the control (Singh and Ganesha Rao, 2009; Singh, 2008; Jeliazkova et al., 1999). The positive effect of N and P on above-ground biomass could be due to the efficiency of the plant for the utilization of nitrogen and phosphorus. On the other hand, the role of N and P in increasing the yield of Artemisia could be attributed to their function in plants, which include synthesis of the plant constituents through the action of different enzymes activity and protein synthesis (Jones et al.,1991), energy metabolism and enzyme activation on exchange rate and nitrogen activity as well as enhanced carbohydrate movement from the shoot to storage organs (Mengel and Kirkby, 1980).

Table 3: The interaction effects of nitrogen and phosphorus rates on mean above-ground biomass and leaf fresh weight

Nitrogen Level	Above-ground biomass				Leaf fresh weight			
	Phosphorus				Phosphorus			
	0	10	20	30	0	10	20	30
0	28384.0[abcde]	22469.0[g]	25065.9[efg]	30719.3[ab]	4822.2[bcde]	3899.9[de]	4420.7[cde]	5455.4[abc]
46	26877.4[bcde]	31390.8[a]	25856.3[defg]	27648.5[abcde]	5250.0[abc]	6203.6[a]	4636.3[cde]	4836.5[bcde]
92	26258.4[cdefg]	29948.6[abc]	26442.3[cdef]	24900.3[efg]	5638.9[abc]	6037.5[ab]	5057.8[abcd]	4692.7[cde]
138	22963.1[fg]	25595.0[defg]	27523.6[abcde]	29201.6[abcd]	3716.4[e]	4742.5 [cde]	5635.3[abc]	4998.5[abcd]
LSD	***				**			
CV	12.5				21.3			

Table 4: Mean comparison of stem fresh weight and essential oil yield as affected by the interaction of nitrogen and phosphorus rates

N level (kg ha^{-1})	**Stem fresh weight**				**Essential oil yield**			
	Phosphorus level (kg ha^{-1})				Phosphorus level (kg ha^{-1})			
	0	10	20	30	0	10	20	30
0	23561.8[abcd]	18569.1[e]	20645.2[cde]	25263.9[a]	13.5[abc]	9.3[c]	9.8[bc]	12.2[ab]
46	21433.0[bcde]	25187.2[a]	21219.9[bcde]	22812.1[abcd]	13.6[ab]	13.9[ab]	10.1[abc]	9.4[abc]
92	20619.5[cde]	23911.1[abc]	21384.5[bcde]	20207.5[de]	14.6[a]	12.3[abc]	12.2[ab]	11.8[abc]
138	19246.6[e]	20852.5[bcde]	21888.3[abcde]	24203.2[ab]	8.02[bc]	9.0[abc]	10.6[abc]	12.85[ab]
LSD	*** 13.3				** 24			

Table 5. Above-ground biomass (AGB), leaf dry weight (LDW), essential oil yield (EOY) and essential oil content (EOC) of *Artemisia annua* as affected by nitrogen and phosphorus at Koka and Wondo Genet during 2013/2014 and 2014/2015 cropping season.

Treatments	AGB (ton ha^{-1})		LDW (ton ha^{-1})		EOY (kg ha^{-1})		EOC (W/W, wet based)	
	Koka	W/Genet	Koka	W/Genet	Koka	W/Genet	Koka	W/Genet
N levels (kg ha^{-1})								
0	26.66	24.85^{b}	1.86	1.58	11.2^{ab}	8.54	0.25^{a}	0.16
46	27.94	28.78^{a}	2.11	1.83	11.8^{a}	9.69	0.22^{ab}	0.16
92	26.89	29.58^{a}	2.16	1.74	12.7^{a}	9.52	0.24^{a}	0.16
138	26.32	28.31^{a}	2.08	1.80	10.1^{b}	9.60	0.21^{b}	0.15
LSD (0.05)	Ns	3.31	ns	ns	1.58	ns	0.03	ns
P levels (kg ha^{-1})								
0	26.12^{b}	26.24	1.96	1.62b	12.4^{a}	9.56	0.25^{a}	0.17
10	27.35^{ab}	29.24	2.10	1.93a	11.1^{ab}	9.31	0.25^{b}	0.16
20	26.22^{ab}	27.94	2.00	1.75ab	10.67^{b}	9.46	0.22^{b}	0.16
30	28.12^{a}	28.10	2.16	1.64b	11.58^{ab}	9.04	0.24^{ab}	0.16
LSD (0.05)	1.95	Ns	Ns	0.27	1.58	ns	0.03	ns
N*P	***	Ns	Ns	Ns	**	ns	ns	ns
CV	12.5	20.61	26.8	27.28	24	31.1	20.9	23.82

***, **significant at 0.001and 0.01 probability level respectively, ns= not significant
Means within column followed by the same letter (s) are not statistically different from each other

Effect of N and P on essential oil yield (EOY) and essential oil content (EOC)

At Wondo Genet, both EOY and EOC did not significantly respond to the applications of nitrogen and phosphorus and their interaction (Table 5). In contrast, at Koka, essential oil yield was significantly ($P \leq 0.01$) affected by the interaction of nitrogen and phosphorus rate (Table 5). Essential oil content was also significantly affected by the two main effects. The maximum essential oil content of Artemisia was obtained from the control treatment, compared to fertilized plots. Essential oil content decreased as the rate of nitrogen and phosphorus increased. In line with this research, Robert (1986) reported that N fertilization reduced essential oil content in creeping juniper (*Juniperus horizontalis*). In contrast, Baranauskienne et al. (2003) indicated that application of N increased total essential oil yield in thyme (*Thymus vulgaris* L.). Furthermore, different researchers reported that the increase in $CaCO_3$ application decreased essential oil content of *S. hortensis* L. (Mumivand et al., 2011), *Ch. boreale*M. (Lee and Yang, 2005) and *Ch. coronarium* L. (Supanjani et al., 2005).

The maximum essential oil yield (14.6 kg ha^{-1}) was recorded from 92 kg N ha^{-1} without phosphorus application, although it was statistically at par with 46 kg N ha^{-1} and 10 kg p ha^{-1} (Table 5).Similarly, Rao (1989) reported that application of 100 kg N and 26 kg P ha-1 produced the highest biomass and essential oil yields of davana (*Artemisia pallens* Wall.). Sharafzadeh, (2011) also found that NP treatments produced the highest growth and essential oil of garden thyme (*Thymus vulgaris* L.) compared with the control treatment. Generally, an increase in oil yield of Artemisia was more evident when P level was lower and N level was higher up to 92 kg N ha^{-1}, after which any further increase decreased essential oil yield. Khalid (2012) reported that N and P nutrients positively affect oil yield, growth, and chemical constituents of some medicinal apiaceae (anise, coriander, and sweet fennel) plants. Malik et al. (2009, 2012) also stated that *Artemisia annua* responds well to chemical, organic and biofertilizers. These results are in accordance with the findings of Singh et al. (2007) on rosemary (*Rosmarinus officinalis* L.).

Conclusions

Nitrogen and phosphoruss play a vital role in improving agronomic traits and economic yield of Artemisia. The results of the study at Koka revealed that essential oil content of *Artemisia annua*was higher in the unfertilized plots of N and P, while fertilized plots increased above-ground biomass, leaf fresh weight, stem fresh weight and essential oil yield. Therefore, it could be concluded that the combined application of nitrogen and phosphoruss at the rate of 46 kg N ha^{-1} and 10 kg P ha^{-1} are ideal to maintain maximum economic yield of *Artemisia annua L.* at Koka area and other similar soil types and agro-ecologies of Ethiopia. Since the findings of the agronomic traits of Artemisia and the initial available P content of the soil for both testing sites contradict to each other, the soil analysis should be repeated for further investigation and scientific information. Further demonstration of this result is recommended around the study area through the involvement of investors and farmers working on this plant. In addition, further research on integrated soil fertility management approach is recommended in the area to enhance the yield and quality of Artemisia. At Wondo Genet, most of the parameters did not show significant variation due to the application of N and P and their interaction, except leaf and stem fresh weights, which are at par with the soil analysis result of the center. Thus, at Wondo Genet, production of Artemisia without nitrogen and phosphorusis recommended. Moreover, further fertilizer trials should not be conducted at the center unless there was N and P gradient created before the start of the actual field experiment.

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Response of Spearmint (*Mentha spicata* L.) to Nitrogen and Phosphoruss Application at Koka

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Introduction

Spearmint (*Mentha spicata* L.) is perennial aromatic plant and productive up to 15 years, and primarily cultivated mainly for its aromatic oil. The essential oil is used for flavoring of different foods, alcoholic and non-alcoholic drinks, gum and dental hygiene products, perfumes, hygiene products, pesticides, and pharmaceutical products as medicinal purpose. Moreover, the herbage yield can be used as tea. Spearmint leaves have a synergistic action of antioxidant phyto-chemicals, arotinoids and flavonoids. Consuming spearmint leaves used to combat oxidative stress that causes chronic disease like diabetes (Rajeshwari et al., 2012). Growth, development and quality of aromatic plants are affected by the genetic background, environment and management practices as well as the processing and storage of plant tissues (Clark and Menary, 1980a).

Among many plant growth factors, the nutritional requirements of the crop are considered to be the most important factor (Singh et al., 1989). For healthy growth and optimal yield, nutrients must be available to plants in correct quantity, proportion and in a usable form at the right time. To fulfill these requirements, chemical fertilizers and/or organic manures are needed. Fertilization has been reported to have an influence on the nutritional quality of crops. Inorganic fertilizer is said to reduce the antioxidant levels, while organic fertilizer has been proven to enhance antioxidant content in plants (Dumas et al., 2003)

Nitrogen (N) is the most recognized element in plants for its presence in the structure of the protein molecule. In addition, N is found in such important molecules as purines, pyrimidines, porphyrins, and coenzymes. Purines and pyrimidines are found in the nucleic acids RNA and DNA, which are essential for protein synthesis. Accordingly, N plays an important role in the synthesis of plant constituents through the action of different enzymes (Saber and Khalid, 2011). A high rate of N application increases leaf area development and increases overall crop assimilation, thus contributing to increased seed yield (Bhardwaj and Kaushal, 1998). Patra et al. (1993) reported that straw mulching significantly affected the fertilizer nitrogen use efficiency and essential oil yield in Japanese mint (*Mentha arvensis* L.) Previous studies indicated that concluded that N increases essential oil yield of peppermint by influencing a variety of growth parameters such as tillers per plant, the total plant dry weight, and the leaf area index (Alkire and Simon, 1996; Piccaglia et al. 1993). Robert and Francis (1986) reported that N fertilization reduced essential oil content in creeping juniper (*Juniperus horizontalis*), although it has been reported to increase total essential oil yield in thyme (*Thymus vulgaris* L.) (Baranauskienne et al., 2003).

Phosphorus also plays an important role in various metabolic processes. It activates coenzymes for amino acid production used in protein synthesis. Phosphorus also aids in root development, flower initiation, seed and fruit development. According to Emongor (1990), high P rates (more than 7.47 kg P ha^{-1}) decreased chamomile essential oil yield. Based on the findings of previous studies, it is essential to apply N and P to medicinal plants in soils, which are deficient in these nutrients. If spearmint is a recently cultivated crop in Ethiopia, there is a gap with regard to specific agronomic recommendations for the spearmint producing areas of the country. This urges that a lot has to be done on spearmint agronomic experiments so as to have appropriate spearmint croP management recommendations. Hence, the objective of this research was to determine optimum nitrogen and phosphorus rate for some selected agronomic characteristics, essential oil yield, and oil content of spearmint.

Materials and Methods

A field experiment was carried out under irrigated condition for two consecutive years (2013 and 2014 cropping season) at Koka experimental station. Koka is geographically located at 08° 26.1' North latitude, 39° 0.1' East longitude and at altitude of 1617 m.a.s.l. The texture of the top soil (0-25cm) was sandy clay loam with a pHvalue of 8.01 (1:2.5 soil water ratios). Factorial combinations of four nitrogen levels (0, 30, 60 and 90 kg N ha^{-1}) and four levels of phosphorus (0, 10, 20, 30 kg P ha^{-1}) were laid out in a randomized complete block design (RCBD) with three replications. The plot size for each treatment was 4.80 m x 4m.

An auger was used to take soil samples randomly at a depth of 25 cm from different spots to make a composite sample before fertilizer application. A sizeable quantity of composite soil sample was air-dried and sieved through a 2-mm mesh and subjected to chemical analysis, including soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable K, Na and Ca. Urea and triple superphosphate (TSP) were used as source of nitrogen and phosphorous fertilizer, respectively. Full dose of phosphorous was applied as the basal dressing during transplanting. Nitrogen was applied in split form (1/3 during planting, 1/3 after first harvest and the remaining 1/3 after second harvest). All the recommended agronomic practices were applied as required.

Plants from the center were harvested by excluding border rows to collect yield and yield contributing characters, such as leaf fresh weight, stem fresh weight, leaf dry weight, stem dry weight, above-ground fresh biomass, essential oil content (w/w, wet/dry based). Essential oil yield analysis was done using gas chromatography-mass spectrophotometer or modified Clevenger collector apparatus. The data were subjected to analysis of variance using SAS computer software version 9.0, and the significancedifference between any two treatments means were tested using leastsignificant difference (LSD) at 5% probability level.

Result and Discussion

Soil physicochemical properties before planting

The results of physical and chemical analyses of the soil at the experimental site before planting are presented in Table 1. The average soil pH of the trial site was 8.01, which is slightly alkaline. Based on the results of soil analysis, the organic carbon content (1.4%) and total nitrogen content (0.08%) of the experimental soil were low (Table 1), in accordance with Landon (1991), who classified the organic carbon content of soil < 4%, 4-10%, and >10% as low, medium and high respectively. According to his classification, total nitrogen content < 0.1, 0.1-0.15, 0.15-0.25 and > 0.25 are rated as very low, low, medium, and high respectively. Similarly, Tekalign (1991) also classified total nitrogen content, i.e., < 0.05, 0.05-0.12, 0.12-0.25, and > 0.25 as very low, low, medium, and high respectively. This indicates that, the soil was deficient in nitrogen possibly due to continuous cultivation and lack of incorporation of organic materials. Thus, based on the categories of soil characteristics, both nutrient values fall in the low ranges (Jones, 2003). The Olsen extractable available phosphorus was 18.0 ppm, which is above the critical level (8 ppm) for most crop plants, which was established by Tekalign and Haque (1991) for some Ethiopian soils. This was probably due to high amount of P received during the past years, indicating that P is not a limiting nutrient for optimum crop growth and yield in the experimental site. The CEC of the soil for the experimental site was 170 cmol kg^{-1} soil (Table 1), which was very high (Landon, 1991), and appropriate for crop production.

Table 1: Soil physicochemical properties of the experimental site

Location	Particle Size Analysis (%)				pH 1:25	ECE $microsm^{-1}$	OC (%)	Total N (%)	C:N ratio	Avail P (ppm)
	Sand	Silt	Clay	Class						
Koka	42	32	26	Loam	8.01	170	1.4	0.08	17.6	18

Effects of N and P on plant growth

Analysis of variance showed that N application had a significant ($P < 0.05$) effect on leaf fresh weight and essential oil content of spearmint, but not on leaf dry weight (Tables 2). The highest mean leaf fresh weight was recorded from the application of 30 kg N ha^{-1}, which is statistically at par with control and 90 kg N ha^{-1}, while the lowest was recorded at the highest rate of N application. However, the findings of this study were not in agreement with previous findings (Saber et al., 2014; Khalid et al., 2015; Minu et al., 2016), where they reported that N fertilization in general increased the various growth characters compared with unfertilized plants.

Table 2: Main effect of nitrogen and phosphorus rate on Leaf fresh weight, Steam fresh weight, Leaf dry weight and Essential oil content

Treatments	Parameters			
N-level (kg ha^{-1})	Leaf fresh weight (kg/ha)	Stem fresh weight (kg/ha)	Leaf dry weight (kg/ha)	Essential oil content
0	19210.8^{ab}	9194.5	7514.4	1.09^{ab}
30	20081.5^{a}	9548.8	7345.5	0.98^{b}
60	19816.6^{ab}	9571.4	7707.5	0.94^{b}
90	18537.7^{b}	9618.3	7036.9	1.16^{a}
LSD	1354.8	NS	NS	0.1
P-level(kg ha^{-1})				
0	18868.1^{b}	8867.1^{bc}	7328.1	1.02
10	19456.4^{b}	8646.9^{c}	7554.2	1.04
20	20822.6^{a}	9758.7^{ab}	7671.3	1.07
30	18499.5^{b}	10660.3^{a}	7050.7	1.04
LSD	1354.8	1012.2	NS	NS
N*P	NS	NS	NS	NS
CV	8.37	12.8	10.9	11.77

LSD = Least significant difference

Application of P had a significant ($P < 0.05$) effect on spearmint leaf and stem fresh weights, but not on leaf dry weight and essential oil content (Table 2). The highest mean leaf fresh weight was recorded from the application of 20 kg P ha^{-1}, but it was statistically at par with other treatments. Similarly, the highest mean stem fresh weight was recorded from the application of 30 kg P ha^{-1}, but it was statistically at par with P applied at 20 kg ha^{-1}. The lowest stem fresh weight was obtained from the application of 10 kg P ha^{-1}, which was statistically at par with the control, i.e., unfertilized plot. Nitrogen by phosphorus interaction had no significant effect on fresh and dry weight of spearmint leaves and stems as well as essential oil content.

Pooled mean analysis results also showed that above-ground biomass was significantly ($P < 0.05$) influenced by the different levels of N, P and their interaction. This indicates that the effects of different levels of N were affected by the different levels of P. The highest aboveground biomass (30110 kg ha^{-1}) was obtained from the combination of 30 kg N and 20 kg P ha^{-1} (Table 3). About 29% increment was achieved in spearmint aboveground biomass due to the combined application of N and Ps at the rate of 30 kg N and 20 kg P ha^{-1}, followed by 21% from the application of 90 kg N and 30 kg P ha^{-1}, compared to the control. The lowest biomass yield (24504 kg ha^{-1}) was recorded from the control treatment.

Effects of N and Ps on essential oil yield and essential oil content

As shown in Table 2, P levels had no significant effect on essential oil content of spearmint. In contrast, N levels had a pronounced effect on essential oil content of spearmint. The highest essential spearmint oil content (1.09%) was recorded from the application of 90 kg N ha^{-1}, but not significantly different from the control plots, while the lowest mean essential oil content was recorded from 60 kg N ha^{-1}. As the fertilizer application rate increased the essential oil content decreased relative to the control. A similar result was reported for mint by Mahmoud and Younis (2009). In contrast, the works of other investigators indicated that N fertilization increased the vegetative growth and essential oil content of *Nigella sativa* L. and Lovage plants (Saber et al., 2014; Khalid et al. 2015).

The interaction effect of N and Ps was significant for essential oil yield (Table 3). The application of 30 kg N ha^{-1} and 20 P kg ha^{-1} significantly ($P < 0.01$) increased the essential oil yieldof spearmint from 51.13 to 71.07 kg ha^{-1} in comparison to the control. The second highest essential oil yield (64.30 kg ha^{-1}) was recorded from the combined applications of 0 kg N and 30 P ha^{-1}. This clearly indicates as the NP rate increases the essential oil yield decreases significantly. The lowest essential oil yield (44.38kg h^{-1}) was obtained from 60 kg N and 30 kg P ha^{-1}. In general, in the present study, significant difference was not observed in essential oil yield from different rates of N application compared to control. A similar trend was also observed in essential oil content of spearmint for different fertilizer application rates. The maximum essential oil yield of 71.07 kg ha^{-1} achieved in this study is slightly lower than the yield reported by Mahmoud and Younis (2009).

Table 3: Pooled mean comparison of above ground biomass and Essential oil yield as affected by the interaction effects of nitrogen and phosphorus rates

Nitrogen Level	**Above ground-biomass**					**Essential Oil Yield**			
	Phosphorus					Phosphorus			
	0	10	20	30		0	10	20	30
0	24504^{cd}	26020^{cd}	25778^{cd}	26562^{bcd}		63.37^{abc}	61.28^{bcd}	54.32^{cdef}	64.30^{ab}
30	25195^{cd}	26315^{cd}	30110^{a}	26245^{cd}		51.13^{efg}	52.97^{defg}	71.07^{a}	45.86^{fg}
60	24965^{cd}	25471^{cd}	26826^{bc}	29572^{ab}		51.53^{efg}	52.73^{defg}	58.56^{bcde}	44.38^{g}
90	25685^{cd}	25690^{cd}	27159^{abc}	23759^{d}		60.77^{bcd}	59.2^{bcde}	63.12^{abc}	63.02^{abc}

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Integrated Nutrient Management on Maize Grown on Acid Soils

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Introduction

Increasing maize production through expansion of cultivable land is no more possible (Tolesa *et al.*, 2001). Therefore, productivity of the crop on less fertile acidic soils can only be improved by integrated use of soil amendments like lime, compost as well as farm yard manure and proper fertilizer management (Asrat *et al*., 2014).

Problems associated with soil acidity are well recognized by farmers in the region. But, it is difficult to manage as it occurs slowly and is not easily recognized. It is an ongoing natural process which can be exacerbated by anthropogenic activities or can be made productive by appropriate soil management practices such as liming (Haynes, 1984), organic matter amendment (Haynes and Mokolobate, 2001) and judicious fertilizer use. Therefore, the study was initiated with the aim of finding out the effects of integrated nutrients sources on maize productivity and properties of acid soil in south western Ethiopia.

Materials and Methods

The study site

The study was conducted at Jimma Agricultural Research Center. The Center is found in the Southwestern part of the country in Oromia National Regional State. It is located at coordinates of 7^0 46' N latitude and 36^0 0'E longitudes at an elevation 1750 meters above sea level. The center receives an average annual rainfall of 1529 mm with the mean maximum and minimum temperatures of 25 and 11.2 ^{0}C, respectively. The predominant soil of the center is *Eutric Nitosols* with an average pH of 5.2 (Paulos, 1994).

Experimental design and procedure

The treatments consisted of control (without amendment), compost, farmyard manure (FYM), mineral fertilizers and their combination as follows: (1) Recommended NP mineral fertilizers N 92 and P_2O_5 46 kg ha^{-1} (2) Compost based on mineral N fertilizer equivalency (3) FYM based on mineral N fertilizer based on mineral N fertilizer equivalency (4) 50% recommended N from FYM + 46 and 23 kg N and P_2O_5 ha^{-1} (5) 50% recommended N from compost + N46 and P_2O_5 23 kg ha^{-1} mineral fertilizer (6) Recommended N from FYM + 1440 kg ha^{-1} Lime (7) Compost based on mineral N fertilizer equivalency + 1440 Lime kg ha^{-1} (8) Recommended NP N 92 and P_2O_5 46 kg ha^{-1} + 1440 Lime kg ha^{-1} (9) 50% recommended N from FYM + N 46 and P_2O_5 23 kg ha^{-1} + 1440 kg ha^{-1} Lime (10) 50% recommended N from compost + N 46 and P_2O_5 23 kg ha^{-1} + 720 kg ha^{-1} lime (11) control without any amendments.

The experiment was conducted for four consecutive cropping seasons (2010 – 2013) using randomized complete block design with three replications. The different rates of compost and FYM were applied based on inorganic N equivalency that was calculated on dry weight basis. Each rate was applied to the respective experimental unit one month before sowing maize seeds and incorporated manually in the upper 15 -20 cm soil depth. Compost, FYM and lime were manually uniformly broadcasted to the experimental plots at once in the first year and incorporated into the soil one month before planting. Hybrid maize, BH 660, seeds were sown in the month of April/May. Two seeds per hill in rows were planted at a spacing of 80 cm between rows and 50 cm between plants. Lime treatment having a calcium carbonate equivalent (acid neutralizing value) value of 102% was calculated based on the soil exchangeable acidity of the experimental site using the following formula

$$LR\,(CaCO_3\ \ kg/ha) = \frac{EA\,(cmol/kg\ of\ soil) * 0.15\,m * 10^4\ m^2 * BD\,(Mg/m^3) * 1000}{2000} * 1.5$$

Where LR = Lime requirement of the soil based on exchangeable acidity and EA = Exchangeable acidity.

The different rates of mineral N fertilizers were applied as urea twice with half dose at planting and the remaining half at 30 to 40 days after emergence (knee height stage). Phosphorus was applied as in the form of TSP (46% P_2O_5) in the respective experimental plots at planting. Half of the Urea and the whole TSP were applied at side dressing and mixed with the soil manually. All other cultural practices were applied uniformly to all experimental units as per the requirement of the crop.

Sampling and analysis

Composite soil samples were collected using an auger at 0 - 20 cm depth from different places in the experimental field before planting. After harvesting, soil samples were collected from each experimental plot. The collected soil samples were air dried in wooden tray, ground and sieved to pass through a 2 mm sieve. The samples were analyzed for soil pH, exchangeable acidity, available P, cation exchange capacity and organic carbon. Soil pH was determined using digital pH meter in 1:2.5(H_2O) soil to solution ratio (Van Reedwijk, 1992). Exchangeable acidity was determined by extracting the samples with 1 M KCl solution and titrating with NaOH as described by McLean (1965). Cation exchange capacity of the soil was determined according to Chapman (1965). Organic carbon was determined following the wet digestion method (Walkley and Black, 1934). Organic matter content was calculated by multiplying the percent OC by 1.724. Available P was determined with Bray II (Bray and Kurtz, 1945) extraction methods. One kilogram of a well decomposed compost and FYM was sampled separately from their respective decomposed pile after mixing the heap of the different organic sources. Then, the samples were oven dried at 105 ^{0}C for 24 hours to a constant weight. The moisture content of the samples was determined gravimetrically (Hillel, 2004) and this was used for determination of the amount of organic sources that was applied in the respective experimental units based on mineral N equivalency.

Data analysis

Yield and soil data were subjected to analysis of variance using SAS statistical software (SAS version 9.1, 2008). Means were separated using Duncan's Multiple Range Test whenever the 'F' test was significant.

Result and Discussion

Soil analysis for selected physico-chemical properties after harvesting

The result showed that application of organic, inorganic fertilizers and lime significantly affected soil properties such as pH, exchangeable acidity, available phosphorus, organic carbon content and cation exchange capacity (Table 1). Accordingly, the use of FYM alone, compost alone, ½ compost + NP, FYM + lime, compost + lime and ½ compost + NP + lime significantly improved soil pH as compared to other treatments. It is well known that the organic manure and lime applied in acid soil conditions are increasing the degree of base saturation in the same time increasing the buffering capacity of the soil. On this way is possible to avoid unfavorable effect of chemical fertilizers with acid potential. The ameliorating effect of lime on soil acidity has been recorded by Obiri-Nyarko (2012). Continuous addition of FYM along with NPK also increased the soil pH as compared to the use of NPK alone (Sharma *et al.* 2013).The increase in soil pH following of application of manure and lime either sole or combined can be attributed to the release of organic acids (during mineralization of manure), which in turn may have suppressed Al content in the soil through chelation (Onwonga et al., 2008; Okwuagwu et al., 2003). Moreover, lime when applied in the soil reacts with water leading to the production of OH^- ions and Ca^{2+} ions which displace H^+ and Al^{3+} ions from soil adsorption sites resulting in an increase in soil pH (Kisinyo et al., 2012). These findings are similar to those of Adeniyan et al. (2011) and Verde et al. (2013) who found increased soil pH with application of organic fertilizer and lime either sole or combined.

However, the use of NP alone, ½ (FYM + NP), NP + lime and ½ (FYM + NP) + lime did not significantly improve soil pH. This might be due to the negative contributions of N fertilizers to the soil acidity. Generally, treatments that received compost alone and compost with other fertilizer sources significantly lowered exchangeable acidity of the soil (Table 1). Haynes and Molokobate (2001) also reported that the application of organic residues decreased exchangeable acidity and increased the available P of acidic soils. In contrary, the highest exchangeable acidity was observed from control and recommended NP treatments (Table 1). Except control and FYM + lime, available

P was found to be statistically at par in all treatments. This outcome is in agreement with Poulton et al. (2013) who reported application of organic fertilizer to upper soil surface increases plant available P. Abera et al. (2005) also found higher soil extractable P with higher application of manure. It was also observed that application of compost alone and simultaneously with lime improved CEC and organic carbon stock of the soil.

Table 1. Effect of inorganic and organic fertilizers and lime on chemical properties of soil

Treatment	pH	Exc. Acidity (Cmol kg^{-1})	Available P (mg kg^{-1})	CEC (Cmol kg^{-1})	OC (%)
Control	4.6c	3.4a	0.9bc	35.9a	1.5b
NP	4.6c	2.9ab	1.4a	27.1ab	1.8ab
FYM	4.8ab	2.5bc	1.1abc	29.0ab	1.9a
Compost	4.9a	1.6ed	1.2abc	34.1a	1.8a
½ (FYM+NP)	4.6c	3.0ab	1.2abc	33.3ab	1.7ab
½ (compost+ NP)	4.8ab	2.0cde	1.4a	33.9a	1.7ab
FYM + Lime	4.8ab	2.3bc	0.9bc	30.3ab	1.8a
Compost + lime	5.0a	1.6e	1.4a	34.7a	1.9a
NP + lime	4.7bc	2.3bcd	1.1abc	23.1 b	1.9a
½ (FYM+NP) + Lime	4.7bc	2.6bc	1.1abc	28.4ab	1.9a
½ (compost+ NP + lime)	4.8ab	2.0cde	1.3ab	31.5ab	1.9a
$LSD_{0.05}$	**0.2**	**0.7**	**0.4**	**10.6**	**0.3**
CV (%)	**2.5**	**17.9**	**20.1**	**20.0**	**8.8**

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.

Grain yield of maize

Combinations of organic, inorganic fertilizers and lime significantly ($P \leq 0.05$) influenced maize grain yield in all cropping seasons (Table 2). Combined analysis over years indicated that recommended NP, 50% FYM + 50% NP, recommended NP + lime and 50% FYM + 50% NP +50% lime gave significantly ($P \leq 0.05$) superior grain yield of maize as compared to the other organic fertilizers. This could be due to the provision of readily available plant nutrients from chemical fertilizers. Application of organic fertilizers along with recommended doses of fertilizers increased the maize productivity to the maximum level, which might be due to the improvement in soil health and release of organic acids that bind aluminum (Al) and iron (Fe), thereby reducing P fixation and increasing its availability (Manjhi *et al*. 2014). Application of NP, lime and FYM, either alone or in combination, had significant influences on the maize yield. These results are in conformity with the findings of Sharma et al. (2006) and Manoj-Kumar et al. (2012). More over; the result suggests that increasing soil pH is only partly responsible for improving crop production on acid soils, and organic fertilizer applications promote plant growth by buffering soil acidity and by providing plant-available nutrients. This result was in agreement with Joann et al. (2001) report. The results recommend the use of organic fertilizer alongside with lime and mineral fertilizers to increase maize yields. Similar results reported by Verde et al. (2013) who found that the use of manure alongside with lime and mineral fertilizers to increase soybean yields The high yields observed under combination of manure, NP fertilizer and lime application might be as a result of its ability for improving soil biological and physical properties which increase soil water retention and enhance nutrient uptake (Nwachukwu and Ikeadigh, 2012).

Table 2.Grain yield of maize (kg ha^{-1}) as influenced by combinations of lime, organic and inorganic fertilizers at Jimma

Treatment	Grain yield (q ha^{-1})				Mean
	2010	2011	2012	2013	
Control (no amendment)	20.73d	17.64c	14.39d	26.22e	19.75f
Recommended NP	50.83a	36.51b	31.91a	38.20abc	39.36ba
100 % FYM	25.27cd	25.62bc	15.64cd	29.89de	24.11ef
100% compost	31.98bcd	25.64bc	15.95cd	37.22bcd	27.70ed
50% FYM + 50% NP	37.27bc	34.50b	28.41ab	43.95ab	36.03bac
50% comp + 50% NP	33.19bcd	41.21ab	26.90abc	40.08ab	35.35bc
FYM + 100 % lime	27.90bcd	27.45bc	16.26cd	31.63cde	25.81edf
Compost + 100 % lime	35.45bc	26.33bc	20.09bcd	41.73ab	30.90dc
NP + 100% lime	35.69bc	52.96a	35.62a	43.35ab	41.91a
50% FYM + 50% NP + 50% lime	39.18ab	32.02bc	29.54ab	44.56ab	36.33bac
50% compost + 50% NP + 50 % lime	33.73bcd	3613b	2632abc	45.38a	35.39bc
LSD (0.05)	13.33	16.39	11.68	8.15	6.41
CV (%)	23.19	29.73	28.89	12.48	13.84

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.

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Nitrogen and Phosphorus Requirements of Maize under Limed Conditions of Acid Soils

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Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world. It ranks third among other cereals after wheat and rice (FAOSTAT, 2014). Maize is classified as one of "warm weather cereal crop and widely cultivated at altitudes ranging from 1500 to 2200 meters above sea level in Western, Southern and Southwestern parts of the country (Mosisa et al., 2001). Over half of all Ethiopian farmers grow maize, mostly for subsistence, with 75% of all maize output consumed by farming households. This makes maize Ethiopia's leading cereal crop, in terms of production, with 7.15 million tons produced in 2015 by 9.5 million farmers across 2.1 million hectares of land (CSA, 2016). Among the cereals, maize and sorghum have highest proportion consumed by producers (75–76% of produce consumed by producers), followed by finger millet, oats and rice (ILRI, 2007). Though it is consumed in all regions of Ethiopia, the crop is used as stable food in western and south western part of the country.

Of all food crops covered under the extension program, maize has received the highest attention owing to its wider cultivation, significance in its share of food crops and availability of productivity enhancing technologies. Ethiopia has high production as well as enormous potential for maize production (Berhanu *et al.*, 2007). Still, there is a room to increase productivity through wide utilization of improved seeds and curbing yield limiting nutrients like phosphorus and nitrogen. Nitrogen and phosphorus are ranked first and second respectively as yield limiting macronutrients. However, crops grown on different soils need different nutrient requirements. Indeed, nitrogen and phosphorus requirement of maize was studied in the past which is 92 kg N ha^{-1} and 69 Kg P_2O_5 ha^{-1}. However, the past recommendation did not consider limed soil condition into account.

Applications of lime under acidic condition release nutrients like phosphorus (P) would be released for plant uptake after liming. The amount of additional P needed for crop production has to be determined experimentally (Waigwa *et al.*, 2003). Therefore, the experiment was conducted to determine the optimum nitrogen and phosphorus requirement of maize grown under limed soil at Jimma and Hurumu.

Material and Methods

Field experiment was conducted at Jimma and Hurumu from 2011 to 2014 using BH-660 hybrid maize variety as test crop at both locations. Factorial combinations of three levels of N (23, 46, 69, Kg ha^{-1}) and three levels of P (10, 20, 30 kg ha^{-1}) and one satellite treatment as a control without N and P fertilizer were used and laid out in a randomized complete block design (RCBD) with three replications. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 0.15m hectare-furrow-slice, bulk density and exchangeable Al^{3+} and H^{+} of each site as described in the equation below.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000}$$

The exchangeable acidity of Jimma and Hurumu sites were 1.36 meq/100g soil and 3.76 meq/100g soil respectively. Based on the above equation, 1530 kg and 4230 kg $CaCO_3$ ha^{-1} lime rates were used for Jimma and Hurumu, respectively. The rates were applied once in the first year for all plots. The above quantity of lime was broadcasted uniformly by hand and incorporated into the soil one month before planting. Urea and TSP were used as the source of N and P, respectively. Application of urea was made in two split while the entire rate of phosphorus was applied once at sowing in band.

Result and Discussion

Grain yield of Maize

At Jimma

Effect of nitrogen and phosphorus fertilizer on maize grain yield under limed condition at Jimma for three consecutive seasons was presented in Table 1. Different combinations of nitrogen and phosphorus significantly ($P \leq 0.05$) influenced grain yield of maize in 2011 and 2012 cropping seasons. Grain yield obtained from 69/10, 46/20, 46/30 and 69/20 N/P Kg ha^{-1} was statistically comparable and significantly higher than the control in 2011 at Jimma (Table 1). In the second season, maize grown with 10 kg P ha^{-1} combined with any of nitrogen nutrient rate gave similar yield with the control. However, the yield of the crop grown in 20 and 30 kg P ha^{-1} combined with 46 and 69 kg N ha^{-1} resulted in better yield than other combinations. The significant increment of maize grain yield by the combined application of NP fertilizers along with lime, and to some extent, only N and P together with lime might show liming does not only enhance soil organic N and P mineralization in acid soils but also it facilitates uptakes of the applied inorganic N and P fertilizers by the crop.

Oluwatoyinbo et al. (2005) also indicated the possibility of increasing the crop yield by improving soil acidity through the application of lime, N and P fertilizers. According to this author the increase in crop yield through the application of lime may be attributed to the neutralization of Al, supply of Ca and increasing availability of some plant nutrients like P. Significant maize yield increment by combined application of lime along with NP fertilizers was also reported in Araka, south Ethiopia (Abay, 2011).The explanation is in agreement with that of Kamprath and Foy (1985). Fageria and Baligar (2003) who also reported that organic N and P mineralization in acid soils are stimulated mainly through liming and resulted in significant crop production increment.

Table 1. Effect of nitrogen and phosphorus on maize yield (kg ha^{-1}) under limed soil at Jimma in three consecutive seasons.

N (kg ha^{-1})	P (kg ha^{-1})	Season			Mean
		2012	2013	2014	
0	0	2888^{c}	2856^{e}	2386	2710.0
23	10	4207^{abc}	3227^{e}	2615	3349.7
46	10	4218^{abc}	3485^{e}	3066	3589.7
69	10	5035^{ab}	3718de	3239	3997.3
23	20	3902^{abc}	4550^{bdc}	2551	3667.7
46	20	5231^{ab}	5477^{a}	2958	4555.3
69	20	5331^{a}	4416^{dc}	3150	4299.0
23	30	3719^{bc}	4483^{bdc}	3369	3857.0
46	30	4701^{ab}	4760^{abc}	2670	4043.7
69	30	5244^{ab}	5337^{ab}	3249	4610.0
LSD (0.05)		1593	883	Ns	
CV (%)		20.87	12.16	20.99	

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =non significant

At Hurumu

The effect of Nitrogen and phosphorus on maize grain yield under limed soil at Hurumu is presented in Table 2. Throughout the investigation period, application of nitrogen and phosphorus fertilizers significantly affected grain yield of maize. In this regard, any of N and P combinations resulted in significantly ($P \leq 0.05$) higher yield than the control in the first cropping season. In the other cropping seasons, P played its determinant role regardless of N amount. The overall mean confirmed that supplying of the highest dose of nitrogen and phosphorus that is (P_{30} + N_{69}) Kg ha^{-1} to the soil of Hurumu on which BH-660 was grown gave the highest maize grain yield (Table 2). In line with this, Tadesse (1990) who reported that maize grain yield increased in Wellega by the application of nitrogen and phosphorus fertilizers along with the use of calcium Carbonate at 3 t ha^{-1}.

Effects of N and P under limed soil on economic feasibility of Maize production

The economic analysis results for effects of N and P fertilizer under limed condition on maize production at Jimma and Hurumu are indicated in table 4 and 5. The highest net benefit of BIRR 15921 ha^{-1} and marginal rate of return 266.5% and BIRR 14329.9 ha^{-1} and marginal rate of return 3248 % was obtained from application of 46 N and 20 kg P ha^{-1} and 23 N and 20 kg P ha^{-1} of maize production at Jimma and Hurumu, respectively. Therefore, combined application of 46 N and 20 kg P ha^{-1} and 23 N and 20 kg P ha^{-1} under limed soil at Jimma and Hurumu, respectively; are economical feasible for maize production.

Table 2. Effect of nitrogen and phosphorus on maize yield (kg ha^{-1}) under limed condition at Hurumu

N (kg ha^{-1})	P (kg ha^{-1})	Season			Mean
		2012	2013	2014	
0	0	2075^{c}	2850^{c}	2630^{b}	2740^{d}
23	10	5390^{ab}	4030^{ab}	3170^{b}	4200^{bc}
46	10	5790^{ab}	3680^{bc}	3380^{ab}	4290^{bc}
69	10	5810^{ab}	4690^{ab}	3310^{ab}	4600^{bac}
23	20	6390^{ab}	4860^{a}	3060^{b}	4770^{a}
46	20	5160^{b}	3840^{bc}	3150^{b}	4050^{c}
69	20	5780^{ab}	4280^{ab}	3320^{ab}	4460^{bac}
23	30	6540^{a}	4240^{ab}	3070^{b}	4620^{bac}
46	30	5780^{ab}	4180^{ab}	3640^{ab}	4530^{bc}
69	30	6230^{ab}	4590^{ab}	4360^{a}	5060^{a}
LSD (0.05)		124	103	107	68
CV (%)		12.94	14.52	18.92	14.79

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.

Table 3. Effects of N and P fertilizer under limed soil on economic feasibility of maize at Jimma

N (kg ha^{-1})	P (kg P_2O_5 ha^{-1})	AGYM	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	2439.0	3519	12195.0	8676.0	2.47	0
23	10	3014.7	4844	15073.7	10229.7	2.11	117.3
46	10	3230.7	5469	16153.7	10684.7	1.95	72.8
69	10	3597.6	6094	17987.9	11893.9	1.95	169.7
23	20	3300.9	5544	16504.7	10960.7	1.98	368.0
46	20	4099.8	6169	20498.9	14329.9	2.32	3248
69	20	3869.1	6794	19345.5	12551.5^{D}	1.85	
23	30	3471.3	6244	17356.5	11112.5^{D}	1.78	
46	30	3639.3	6869	18196.7	11327.7^{D}	1.65	
69	30	4149.0	7494	20745.0	13251.0^{D}	1.77	

The price of DAP Birr=14 kg^{-1} N Urea Birr=12.5 kg^{-1}, lime Birr=2.3 kg ha^{-1}, Seed maize EB=5 kg^{-1}, D= dominated, AGYM=Adjusted Grain yield of Maize (kg ha^{-1}) and TVC= Total variable cost

Table 4. Effects of N and P under limed soil on economic feasibility of maize at Hurumu

N (kg ha^{-1})	P (kg ha^{-1})	AGYM	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	2466	3519	12330	8811.0	2.50	0
23	10	3780	4844	18900	14056.0	2.90	395.9
46	10	3861	5469	19305	13836.0	2.53^{D}	
69	10	4140	6094	20700	14606.0	2.40^{D}	
23	20	4293	5544	21465	15921.0	2.87	266.5
46	20	3645	6169	18225	12056.0	1.95^{D}	
69	20	4014	6794	20070	13276.0	1.95^{D}	
23	30	4158	6244	20790	14546.0	2.33^{D}	
46	30	4077	6869	20385	13516.0	1.97^{D}	
69	30	4554	7494	22770	15276.0	2.04^{D}	

The price of DAP Birr=14 kg^{-1} N Urea Birr=12.5 kg^{-1}, lime Birr=2.3 kg ha^{-1}, Seed maize Birr=5 kg^{-1}, D= dominated, AGYM=Adjusted Grain yield of Maize (kg ha^{-1}) and TVC= Total variable cost

Conclusions

At least application of 46 kg N ha^{-1} combined with 20 kg P ha^{-1} and 23 kg N ha^{-1} combined with 20 kg P ha^{-1} should be considered for BH-660 maize variety production after liming at Jimma (Melko) and Hurumu, respectively. The result confirmed that phosphorus and nitrogen rates less than these amounts could give almost similar yield to the unfertilized fields and has no advantage for growers. The partial budget analysis also indicates that applications of 46 kg N and 20 P kg ha^{-1} and 23 kg N and 20 P kg ha^{-1} at Jimma and Hurumu, respectively are the most economical fertilizer rates to maize growers compared to the other levels in the study area.

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Determination of Nitrogen and Phosphorus Rates for Wheat under Limed Acid Soils of Banja District, North Western Ethiopia

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Introduction

In Ethiopia, about 41 % of the total land mass is affected by soil acidity and 33% of this area has Al-toxicity (Schlede, 1989) which extends from southwestern to northwestern with east-west distribution but is concentrated in the western part of the country (Mesfin , 2007). The highlands of Ethiopia (areas >1500 m above sea level) are the most affected region by the problem due to removal of ample amount of nutrients by leaching, crop mining and runoff as compared with grazing and forest lands. Moreover, continuous application of acid forming chemical fertilizers on highly weathered tropical soils increase soil acidity problem (Nekesa, 2007). The Ethiopian highlands have a great potential for crop production, contributing 95% of the cultivated land and 90% of the economic activities of the country (FAO, 1986). However, the potential in most of these areas is heavily affected by soil degradation. The problem has been aggravated in magnitude and degree from year to year. Besides, highly weathered tropical soils have strong P sorption capacities which intensify limitation of land suitability. Hence maintenance of soil fertility at levels which are economically optimal in the long run, given the productive potential of the land as determined by water availability and other climatic factors are essential for essential for sustainable agriculture.

In Amhara, National Regional State, about 24% of the region is affected by acidity and 23% has been severely eroded (ANRSI, 2006). The previous studies unequivocally, revealed severity of soil related problems that can affect agricultural sustainability of the Banja District in Amhara Region. Particularly soil acidity problem has forced most farmers to grow acid tolerant crops at the expense of economically important crops and/or allocate their productive cultivated lands to eucalyptus plantation for the last five decades.

Liming increases soil pH and availability of P, and Mo while it reduces exchangeable acidity (Caires *et al.*, 2005 and Nekesa, 2007). The fixed P would be released for plant uptake after liming and the amount of additional P needed has to be determined experimentally (Waigwa *et al*., 2003). Very limited information is available in about the effects N/P fertilizers under limed condition on wheat grain yield in Banja District in Amhara region. Therefore, the aim of this study was to evaluate the optimum rate of NP fertilizer under liming for wheat grown under acid soil.

Materials and Methods

The study site

This study was conducted for two consecutive seasons (2013 and 2014) at Banja District. Banja district is located at a distance of 447 kilometers in the Northwest direction from Addis Ababa. The site is located at latitude of 11° 10´ North and longitude of 36° 15´ East and at an altitude of 2501 masl. The mean annual rainfall of the district is 1300mm. The annual mean temperature also varies from 12°C to 25°C with mean value of 18.5°C. The district is classified into one agro- climatic zone, which is highland with wet and cool weather condition (Ethiopian Mapping Agency, 1982).

Treatment and experimental design

The treatments consisted of three levels of N (23, 46 and 69 kg N ha^{-1}), three levels Phosphorous (10, 20 and 30 kg P ha^{-1} and one satellite control treatment laid out in randomized complete block design with three replications. A high yielding wheat varieties named Danda'a was used as a test crop at a seed rate of 120 kg ha^{-1}.

Experimental procedure

Land preparation and field management

Land preparation was uniformly performed across all plots by tractor mounted moldboard plough to 30 cm soil depth. Subsequent tilling operations were done by harrowing to about 10 cm depth by conventional tillage in mid-April, May and June 2013. The field layout was maintained at a path of 1.5 m between each block and 1m path between each plot. Bread wheat was planted on gross plot area of 5 m x 4 m (20 m^2), and a net plot area of 18 m^2 was harvested. Wheat was planted at spacing of 20 cm between rows and 5 cm between plants by hand drilling. All recommended cultural practices of wheat production were adopted for the management of the experiment.

Methods of lime and fertilizer application

Lime was applied uniformly broadcasted by hand and incorporated into the soil by using hoe at least a month before planting. A high quality limestone (98 % CaCO3, 99.5 % <250 µm in diameter) were used. The amount of lime that was applied was calculated on the basis of exchangeable acidity concentration of the site (Kamprath, 1984). The amount of lime applied considered the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+1} as described in Eq. 1. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The full recommended lime dose was applied at once.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000} \qquad Eq.1$$

The whole doses of phosphorus was applied in band at planting in all representative plots at the depth of 3-5 cm below and around the wheat seed at the time of sowing. Nitrogen was applied in two splits; 1/2 at sowing and 1/2 after the first hand weeding of wheat.

Soil sampling and analysis

Two composite soil samples were collected to determine selected soil physiochemical properties before treatment application, and one composite sample per treatment after harvest of the second season crop to evaluate effect of the treatments on status of residual soil P. The collected samples were air-dried, ground and sieved with 2 mm sieve size. The soil physico-chemical properties were described by FAO procedure (FAO, 2006). Soil pH (H_2O) solution was measured at 1:2.5 soil to water ratio. The value was read using a combined glass electrode pH meter. Exchangeable acidity was determined by saturating the soil samples with 1M KCl solution and titrating with 0.01 M NaOH as described in (Rowell, 1994). Exchangeable Al was determined from aqueous solutions extracted by 1M KCl and NaF and titrated with 0.01M HCl. Cation exchange capacity was determined by extracting the soil by 1M NH_4OAc at 7 pH; while the adsorbed ammonium ions in soil were displaced with NaCl. Then the ammonium liberated from the distillation was titrated using 0.1M NaOH for CEC determination. Effective cation exchange capacity was calculated as the sum of exchangeable basic cations and Al (USDANRCS, 1995). Available P was extracted by Mehlich solution after shaking for 5 minutes on a reciprocating shaker according to Mehlich-III method (Mehlich, 1984), then phosphorus was quantified colorimetrically with spectrometer.

Statistical analysis

Analysis of variance was performed using SAS statistical software version 9.1 (SAS Institute, 2001). A Proc GLM model was constructed to compare the measured agronomic parameters for both years separately as well as combined over years. Significance differences were set at $p \leq 0.05$. When the effects were found significant, further analysis was made using Tukey multiple comparison test.

Results and Discussion

Physico-chemical properties of experimental soil

The mean soil analysis results before liming and after harvesting indicated that the applications of recommended lime drastically decreased the exchangeable acidity from 2.1 to 0.6 meq/100g soil; aluminum concentration from 1.5 to 0.4 meq/100g soil. The pH of the soil after liming increased from 5.1 to 5.4 (Table 1). Lime application at an appropriate rate brings several chemical and biological changes in soil. Upon liming numerous authors, have reported decreases in Al^{3+} in the soil solution as well as exchangeable complex (Delhaize et al., 2007; Prado et al., 2007; Alvarez and Fernadet 2009, Temesgen et al.,2016).

Table 1. Selected soil chemical properties before liming and after harvesting.

Parameter	Values	
	Before Liming	After harvesting
pH-H2O (1:2.5)	5.1	5.4
pH-KCl (1:2.5)	3.9	4.2
Exch.Acidity (meq/100g soil)	2.1	0.6
Exch.Aluminium (meq/100g soil)	1.5	0.4
Bray II P (ppm)	28.9	30.5
Total N (%)	0.2	0.2
O.C %	2.7	2.7
C:N	11.5	12.0

Table 2 shows seasonal variations in terms of exchangeable acidity, exchangeable aluminum, soil pH and available phosphorus. The lowest exchangeable acidity 0.78 (meq/100g soil), aluminum concentration 0.48 (meq/100g soil) and available phosphorous (16.9 ppm) were observed in the first as compared to the second season. While soil pH was found to be higher pH-H_2O (1:2.5) 5.53 in the first season as compared to the second season.

Table 2. Selected soil chemical properties of the experimental field during the two seasons.

Season	Exch. Acidity (meq/100g soil)	Exch.aluminum (meq/100g soil)	pH- H_2O (1:2.5)	pH- KCl (1:2.5)	AV. P (ppm)
1st Season	0.78b	0.48b	5.53a	3.99a	16.9b
2nd Season	1.00a	0.76a	5.08b	4.02a	20.7a
LSD (0.05)	0.25	0.27	0.04	0.04	2.3
CV (%)	27.78	43.22	0.77	0.93	

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Table 3. Soil exchangeable acidity, exchangeable aluminum, soil pH and available phosphorus as affected by different N/P treatments under liming

Treatment	Exch. Acidity (meq/100g soil)	Exch. Al^{3+} (meq/100g soil)	pH-H_2O (1:2.5)	pH-KCL (1:2.5)	Av. P (ppm)
Control (0P + 0N)	1.247a	0.791a	5.20c	3.91c	16.37cd
10 P + 23 N kg h^{-1}	0.602b	0.442a	5.32ab	4.05ab	19.16abcd
10 P + 46 N kg h^{-1}	1.165a	0.843a	5.26bc	3.99abc	15.04d
10 P + 69 N kg h^{-1}	0.713ab	0.482a	5.35a	4.07a	22.57a
20 P + 23 N kg h^{-1}	0.914ab	0.643a	5.31ba	3.99abc	20.86abc
20 P + 46 N kg h^{-1}	0.873ab	0.643a	5.35a	4.00ab	18.26abcd
20 P + 69 N kg h^{-1}	0.894ab	0.693a	5.33ab	4.00ab	22.40ab
30 P + 23 N kg h^{-1}	0.693ab	0.412a	5.32ab	4.04ab	17.24cd
30 P + 46 N kg h^{-1}	1.014ab	0.683a	5.30ab	3.98bc	18.84abcd
30 P + 69 N kg h^{-1}	0.773ab	0.522a	5.32ab	4.03ab	17.31bcd
LSD $_{(0.05)}$	0.559	NS	0.09	0.08	5.14
CV (%)	27.780	43.22	0.77	0.93	12.08

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Grain and biomass yield of wheat

Results revealed that the grain and biomass yield of wheat were found to be statistically significant by the application of N and P during 2013 and 2014 cropping seasons (Table 3).In 2013, the highest significant wheat grain yield was obtained by application of 69 kg N ha^{-1} in combination with 20 kg P ha^{-1}. While, in 2014 cropping season, grain yield of wheat obtained by application of 69 kg N ha^{-1} along with 10 kg P ha^{-1} and 69 kg N ha^{-1} along with 20 kg P ha^{-1} were statistically comparable. However, these two treatments were found to be significantly ($p\leq0.05$) superior in terms of wheat grain yield as compared to the other treatments. As expected, in both seasons, the lowest grain yield of wheat was recorded in control plot. Over all, the two years mean revealed that the highest grain yield of wheat (2922.35 kg ha^{-1}) was recorded by the combined application of 69 N + 20 P kg ha^{-1}. This combination brought about 2302.55 kg ha^{-1} (78.8%) additional grain yield as compared to the control treatment. These findings are in agreement with those of Bereket *et al.* (2014) who obtained the highest grain yield of wheat at a rate of 69 kg P_2O_5 ha^{-1}, which was not statistically different than the preceding lower rate (46 kg P_2O_5 ha^{-1}). Similarly, Fekadu (2016) reported the maximum grain yield of triticale by application of 30 kg P ha^{-1} followed by 20 kg P ha^{-1}. The highest mean grain yield was obtained from the maximum N rate (69 kg N ha^{-1}) with an increment of 15% and 86% yield advantage over the next higher N rate (46 kg N ha^{-1}) and the control plot, respectively.

Table 3 shows biomass yield (BMY) of 2013 and 2014 years as affected by different levels nitrogen and phosphorus fertilizer. In 2013, the highest biomass yield of wheat was obtained by application of 69 N with 20 P kg ha^{-1} and 69 N with 30 kg P ha^{-1}. These two treatments were at par, and significantly superior to the other N/P combinations. In 2014, biomass yield obtained by applications 69 N with 30 kg P ha^{-1}, 69 N with 20 P kg ha^{-1} and 69 N with 10 P kg ha^{-1} were significantly higher than the rest of the treatments. However, these treatments did not differ in terms of biomass yield from each other.

This is supported by Mengel. and Kirkby (1996). Highest straw yield was obtained at the highest phosphorus rate (92 kg P_2O_5 ha^{-1}) though it was not statistically different than the preceding lower rate (69 kg P_2O_5 ha^{-1}). Similarly, optimum biomass yield 6041.7 kg h^{-1} was achieved by application of 20P + 69N kg h^{-1} rates. Similarly, it showed 3876.2 kg h^{-1} (64%) additional biomass yield as compared to the control treatment. As expected, the lowest biomass yield 2164.9 kg h^{-1} was recorded in control plot.

The two years mean indicated that the highest biomass yield of wheat 8687.4 kg ha^{-1} was recorded by combination application of 69N + 20P kg ha^{-1}. This combination gave 6271.4 kg h^{-1} (72 %) additional biomass yield as compared to the control treatment. Over all, based on the two years mean showed that 69 kg N ha^{-1} and 20 kg P ha^{-1} consistently gave the highest grain and biomass yield of wheat i.e. 2922.35 and 6271.4 kg ha^{-1}, respectively. Similar to this finding, Abreha et al. (2013) reported that the applications NP fertilizers along with Wukro and Sheba lime revealed significant augmentation over control by giving grain yield advantage of 239 and 233% and biomass yield advantage of 174 and 172%, respectively. Abay (2011) also found significant maize yield increment by combined application of lime along with NP fertilizers around Areka area, South Ethiopia.

Table 4. The effects of nitrogen and phosphorus on grain and biomass yield of wheat on two years

Treatment	2013		2014		Mean	
	GY (kg ha^{-1})	BMY (kg ha^{-1})	GY (kg ha^{-1})	BMY (kg ha^{-1})	GY (kg ha^{-1})	BMY (kg ha^{-1})
Control (0P + 0N)	513.5^{c}	2164.9^{f}	726.1^{f}	2667^{f}	619.80	2415.95
10 P + 23 N kg h^{-1}	1162.6^{b}	3577.9^{de}	1773.8^{ed}	5800^{ed}	1468.20	4688.95
10 P + 46 N kg h^{-1}	1157.8^{b}	3849.6^{de}	2530.9^{dc}	8100^{dc}	1844.35	5974.80
10 P + 69 N kg h^{-1}	1609.7^{ab}	4936.6^{bc}	3751.5^{a}	11167^{ba}	2680.60	8051.80
20 P + 23 N kg h^{-1}	1240.4^{b}	3867.8^{de}	1635.6^{e}	5433^{e}	1438.00	4650.40
20 P + 46 N kg h^{-1}	1720.2^{ab}	5018.1^{bc}	2781.7^{c}	8667^{bc}	2250.95	6842.55
20 P + 69 N kg h^{-1}	2178.4^{a}	6041.7^{a}	3666.3^{ba}	11333^{a}	2922.35	8687.35
30 P + 23 N kg h^{-1}	1328.8^{b}	3387.7^{e}	1594.1^{e}	5300^{e}	1461.45	4343.85
30 P + 46 N kg h^{-1}	1341.0^{b}	4501.8^{cd}	2860.4^{bc}	8667^{bc}	2100.70	6584.40
30 P + 69 N kg h^{-1}	2063.0^{a}	5760.9^{ab}	3096.9^{bac}	9600b^{ac}	2579.95	7680.45
LSD (0.05)	627.4	948.1				
CV (%)	25.55	12.82	19.3	19.4		

Means followed by different letters in the same column are significantly different from each other at 5% level of significance.

Effects of nitrogen and phosphorus rates on economic feasibility of wheat production

The economic analysis results for effect of N and P fertilizer rate under limed soil are indicated in (Table 5). The highest net benefit of EBT 21121 ha^{-1} and marginal rate of return 226.4 % of wheat was obtained from application of 69 Kg N ha^{-1} combined with 20 kg P ha^{-1}. Therefore, combined application of N with P fertilizer rates (69/20 N/ P) fertilizer is economical feasible for wheat production.

Table 5. Effects of N and P rates under limed soil on economic feasibility of wheat

N (kg ha^{-1})	P (kg)	AGYW	TVC	Revenue	Net Benefit	Value to cost ratio	Marginal Rate of Return (%)
0	0	557.8	0	5020	5020.4	0.0	0.0
23	10	1321.4	1050	11892	10842.4	10.3	554.5
46	10	1659.9	1500	14939	13439.2	9.0	577.1
69	10	2412.5	1950	21713	19762.9	10.1	1405.3
23	20	1294.2	1650	11648	9997.8^{D}	6.1	
46	20	2025.9	2100	18233	16132.7^{D}	7.7	
69	20	2630.1	2550	23671	21121.0	8.3	226.4
23	30	1315.3	2250	11838	9587.8^{D}	4.3	
46	30	1890.6	2700	17016	14315.7^{D}	5.3	
69	30	2322.0	3150	20898	17747.6D	5.6	

The price of DAP BIRR=12 kg^{-1}, N Urea BIRR=9 kg^{-1}, Seed wheat EB=9 kg^{-1}, D= dominated, AGYW=Adjusted Grain yield of wheat (kg ha^{-1})

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Response of Sorghum and Soybean to Lime and Phosphorus, Application and its Subsequent Effect on Acidity of Soils in Assosa Area

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Introduction

Soil acidity has become a serious threat to crop production in most highlands of
Soil acidity is becoming a serious threat to crop production in the areas of the western, southern, and central highlands of Ethiopia (Wassie *et al.*, 2009). This low availability of P under most soils of Ethiopia is due to the impacts of P fixation by acidic cations, abundant loss of P by crop harvest, erosion, and the inherent P deficiency of the soils by application of little or no P source fertilizers (Asmare, 2014). Numerous studies demonstrated the synergetic effect of lime and P fertilizers. Studies in this regard are scarce on major crops grown on acid soils of Benishangul Gumuz Region.

Putting the above points in view, the present study was initiated to evaluate the response sorghum and soybean to lime and P fertilizer rate and its effect on acid properties of the soil around Assosa area.

Materials and Methods

The study area

This experiment was conducted at Assosa District during the main rainy season of 2012 to 2015. The study sites are found in the altitude ranging between 1300 and 1470 m with mean minimum and maximum temperatures of 14.38 and 28.55 ^{o}C, respectively. The area receives an average annual rainfall of 1291.2 mm of which 1041.7 mm were received between May and October during the cropping season.

The experiment consisted of factorial combination of five levels of lime (0, 1.88, 3.76, 5.64 and 7.52 t ha^{-1}) and four levels of P (0, 23, 46 and 69 kg ha^{-1}) laid out in randomised complete block design (RCBD) with three replications. The site exchangeable acidity of the area was 2.36 which is above the critical permissible level. The amount of lime is determined on the basis of the mass of soil per 20 cm hectare-furrow-slice, soil bulk density, and exchangeable Al^{+3} and H^{+} as described in Eq. 1 below. It has been assumed that one mole of exchangeable acidity is neutralized by equivalent mole of $CaCO_3$. The full dose of lime was applied at once in the first year according to the rate. The recommended rate of N was applied uniformly to all treatments. Lime was uniformly broadcasted by hand and incorporated into the soil one month before planting. Urea and triple super phosphate were used as the source of N and P, respectively. Application of urea was in two split while the entire rate of phosphorus was applied at sowing in band. The plots were kept permanent for the duration of the experiments to observe the carry-over effects of the lime.

$$LR, CaCO_3\,(kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000} \qquad Eq. \quad 1$$

Soil sampling and analysis

Initially one composite soil sample from the experimental site was collected before lime application and subjected to analyses of soil acidity attributes and other soil physic-chemical properties. Samples were randomly collected from surface layer of the experimental field i.e. 0-20 cm soil depth to form composite and analyzed for the soil pH, bulk density, exchangeable acidity, exchangeable aluminum, available P, calcium, magnesium, potassium, sodium, CEC and acid saturation. The pH of the soil was determined according to FAO (2008) using 1:2.5 (weight/volume) soil sample to water solution ratio using a glass electrode attached to digital pH meter. Available phosphorus was determined by the Bray method. The cation exchange capacity (CEC) was measured after saturating the soil with in ammonium acetate (NH_4Ac) and displacing it with in NaAc (Chapman, 1965).

Statistical analysis

All the generated data were subjected to analysis of variance (ANOVA) using SAS computer software version 9.3 (SAS, 2002) and the least significant difference between means (LSD) used to separate the treatment means at statistical significance level of $p \leq 0.05$. Partial budget analysis was carried out following CIMMYT (1988) procedure based on local market price.

Results and Discussion

Soil physico-chemical properties

Analysis of soil physico- chemical properties before planting and after harvesting is presented in table 1 and 2. Soil sample analysis before planting indicated that the bulk density was 1.06 g/cm^{3}which is low according to (Baruah *et al*., 1997), according to Bruce and Rayment (1982) soil pH (H_2O) was strongly acid (5.02), available $Ca^{2+,}$ Mg^{2+}, K^+ and Na^+ analysis results were 2.63 (Low), 0.78 (Low), 0.06 (very low) and 0.08 (very Low), respectively (Metson ,1961); cation exchange capacity was 8.25 Cmolkg^{-1} which was low according to Metson (1961).

Soil sample analysis after harvesting showed that soil pH value was significantly increased due to lime application as compared to control. The higher soil pH was obtained when soil is limed while the lowest soil pH was observed at control (0 level of lime). These changes of soil pH of soil might be attributed to the neutralizing of acid soil due to application of lime at increasing rates (Tisdale et al., 1993). Responses of pH to lime application were also observed in tropical soils in several regions of the world (Caires et al., 2006) and in Ethiopia by Alemayehu (1999) and Desta (1987).

Table 1. Soil sample result before planting

pH (1:2.5 H_2O)	Cmol/kg soil							CEC	% AS*	BD
	Exch. acidity	Exch. Al	Av. P (ppm)	Ca%	Mg %	K%	Na%			
5.02	2.27	2.48	3.2	2.63	0.78	0.06	0.08			

**AS=Acid saturation*

Table 2. Soil chemical properties as influenced by lime level

Lime level (t ha^{-1})	pH (1:2.5 H_2O)	Av. P (ppm)	Exchangeable acidity (C mol/kg soil)
0	5.04^{b}	3.68^{a}	1.22^{a}
1.88	5.65^{a}	3.77^{a}	0.57^{b}
3.76	5.69^{a}	3.77^{a}	0.39^{c}
5.64	5.69^{a}	3.74^{a}	0.48^{bc}
7.52	5.81^{a}	3.81^{a}	0.36^{c}
LSD (0.05)	0.16	NS	0.14
CV (%)	6.2	31.5	27.6

The available P value was slightly increased due to lime application as compared to the control. However, the increase was not statistically significant at 0.05 probability level. Fageria and Baligar (2008) indicate that liming can increase, decrease, or have no effect on soil P availability. On the other hand; the application of lime significantly reduced the exchangeable acidity compared to the treatments. This decrease might be ascribed to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as $Al(OH)_3$, as the soil was limed (Havlin et al., 1999). Moreover, an increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides thus reducing concentration of Al in soil solution (Ritchie, 1989).

Interaction effects of lime and phosphorus on yield of sorghum

The analysis of variance showed that grain yield of sorghum was significantly ($P \leq 0.05$) influenced by interaction effect of lime and phosphorous rate (Table 3). The highest grain yield of sorghum was obtained from 5.65 t lime $ha^{-1}$with application of 23, 46 and 69 kg P_2O_5 ha^{-1} and 7.54 t lime ha^{-1} with applications of 0, 23 and 46 kg P_2O_5 ha^{-1} treatments. However; the lowest grain yield (554.8 kg ha^{-1}) was recorded for control (no lime and no P_2O_5) application. Grain yield was increased with the increasing of levels of lime and phosphorus fertilizer. The observed increase in grain yield with increasing P rate, in treatments with no lime application, confirmed that P was limiting factor to sorghum production. The positive effect of lime on sorghum grain yield was therefore likely due to its effect in increasing the soil pH, increasing availability of nutrients and reducing exchangeable acidity. The increase in the grain yield of sorghum due to liming of acidic soils under different land use systems may be attributed to the reduction in acidity (H^+ and Al^{3+}) ions and reduction in nutrient deficiency of Ca and P (Curtin and Syers, 2001). Oluwatoyinbo (2005) also indicated the possibility of increasing crop yield by improving soil acidity through the application of lime, and P fertilizers.

Table 3. Grain yield of sorghum as influenced by interaction effect of lime and phosphorus

Phosphorus ($kg\ P_2O_5\ ha^{-1}$)	Lime ($t\ ha^{-1}$)					
	0	1.88	3.76	5.64	7.52	Mean
0	554.8^{g}	1016.7^{cdef}	726.2^{fg}	1292.7^{c}	2236.5^{a}	1197.4
23	856.9^{efg}	1536.2^{bc}	1089.3^{cde}	2193.2^{a}	2323.9^{a}	1559.9
46	944.1^{def}	1361.9^{c}	1815.5^{b}	2469.1^{a}	2237.5^{a}	1725.6
69	1047.4^{cdef}	1234.6^{c}	1859.1^{b}	2232.2^{a}	1678.6^{b}	1630.4
Mean	875.8	1287.3	1372.5	2046.8	2159.1	
LSD L*PR (0.05) =328.04			CV (%)=18.7			

Interaction effects of lime and phosphorus on yield of soybean

Seed yield is one of the most important and phenomenal yield components which describe the overall potential of crop genotypes. The analysis of variance indicated that highly significant ($P \leq 0.05$) effects on seed yield of soybean due to interaction effect of lime and phosphorus rates (Table 4). Accordingly, the highest significant seed yield was obtained by application of no lime with 23 kg P_2O_5 ha^{-1}, 1.88 t lime $ha^{-1}$with application of 23 kg P_2O_5 ha^{-1}, 3.76 t lime $ha^{-1}$with application of 46 and 69 kg P_2O_5 $ha^{-1}$and 5.65 t lime $ha^{-1}$with application of 0, 23 and 46 kg P_2O_5 ha^{-1}. The lowest seed yield (639.5 kg ha^{-1}) was recorded from control (no lime and no P_2O_5) application. The response of soybean to lime application was not conspicuously observed. In line with this result, Angaw and Desta (1988) reported that soybean and haricot bean showed no significant response due to lime at Nedjo though yields were increased. Similarly, Adane (2014) also reported that the seed yield of haricot did not significantly affect due to the application of lime above the control at Sodo Zuria district. Similar findings have been reported by other researchers who found non-significant effects of P fertilizer and lime on grain yields (Kamara *et al*., 2008, 2011; Mabapa *et al*., 2010; Andric *et al*., 2012). Liming affects the solubility and availability of most of the plant nutrients, raises the level of exchangeable base status of calcium, neutralize the effect of Al^{3+} and H^{+}(raising the soil pH), improves soil structure, and promotes root distribution (Nekesa *et al*., 2005). These yields trend also to explain that liming alone cannot serve to achieve the maximum potential of an acid soil.

Table 4. Seed yield of soybean as influenced by interaction effect of lime and phosphorus

Phosphorus rate ($kg\ P_2O_5\ ha^{-1}$)	Lime level ($t\ ha^{-1}$)					
	0	**1.88**	**3.76**	**5.64**	**7.52**	**Mean**
0	639.5^{f}	859.6^{de}	896.8^{cde}	1011.9^{abcd}	887.3^{cde}	859.02
23	999.7^{abcd}	1069.8^{ab}	863.3^{de}	1005.2^{abcd}	903.8^{bcde}	968.4
46	883.7^{cde}	1006.4^{abcd}	1042.52^{abc}	1024.5^{abcd}	966.3^{abcde}	984.7
69	877.4^{cde}	982.5^{abcde}	1100.6^{a}	975.5^{abcde}	818.9^{e}	950.9
Mean	850	979.6	975.8	1004.3	894.1	
LSD L*PR (0.05) =172.9			CV (%)=19.74			

Subsoil acidity might be found in the study area. Lime applied to the surface of a soil is generally ineffective in ameliorating subsoil acidity. Conyers et al. (2003) reported that the application of lime to the surface of a soil is generally ineffective in ameliorating subsurface acidity. Therefore; acid-resistant cultivars and organic amendments will be used for maintaining production on acid soils. Mean seed yield ranged from 859.0 kg ha^{-1} for the control treatment to 984.7 kg $ha^{-1}$for the rates of 46 kg P_2O_5 ha^{-1}. The highest seed yield of soybean gave yield advantage of 14.6 and 12.7 % over control and application of 23 kg P_2O_5 ha^{-1}, respectively. Increased in seed yield with the increase in rate of P_2O_5 for all levels of lime might be due the importance of phosphorus in a number of metabolic functions and is especially important for grain formation. For that reason, application of 23 kg P_2O_5 ha^{-1} alone is sufficient for remunerative soybean production in the study site.

Partial budget analysis

Partial budget analysis was carried out following CIMMYT (1988) procedure based on local market price. The study revealed that except 4 and 2 treatments on sorghum and soybean, respectively, all the other treatments were dominated. Because these treatments have net benefits, less than treatments with lower variable costs. Such dominated treatments were dropped from economic analysis. As a result, only marginal rate of return of 4 and 2 treatments on sorghum and soybean, respectively were computed (Tables 5 and 6). The highest net benefit of BIRR 7057.3 ha^{-1} and marginal rate of return 102.8 % and was obtained from application of 1.88 t lime ha^{-1} along with 23 kg P_2O_5 ha^{-1} for sorghum production. Twenty-three kg P_2O_5 ha^{-1} without lime application gave the highest net benefit of BIRR 9173.5 ha^{-1} and marginal rate of return 238.2 % of seed yield of soybean at Assosa District. Therefore, combined application of 1.88 t lime ha^{-1} along with 23 kg P_2O_5 ha^{-1} for sorghum production and 23 kg P_2O_5 ha^{-1} alone for soybean production are economical feasible.

Table 5. Effects of lime and P on economic feasibility of sorghum grain yield at Assosa District

Lime (t ha^{-1})	P (kg P_2O_5 ha^{-1})	AGYS	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	499.32	0	4493.88	4493.9	1.00	0.0
0	23	771.21	723.5	6940.89	6217.4	0.90	238.2
0	69	942.66	2170.5	8483.94	6313.4	0.74	6.6
1.88	23	1382.58	5385.9	12443.22	7057.32	0.57	102.8

The price of DAP Birr =14.47 kg^{-1} N Urea Birr =13.87 kg^{-1}, lime Birr =2.48 kg ha-1, Seed sorghum EB=9 kg^{-1}, AGYS=Adjusted Grain yield of sorghum (kg ha^{-1}) and TVC= Total variable cost

Table 6. Effects of lime and P on economic feasibility of soy bean seed yield at Assosa District

Lime (t ha^{-1})	P (kg P_2O_5 ha^{-1})	AGYSy	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	575.55	0	6331.05	6331.1	1.00	0
0	23	899.73	723.5	9897.03	9173.5	0.93	238.2

The price of DAP Birr =14.47 kg^{-1} N Urea Birr =13.87 kg^{-1}, lime Birr =2.48 kg ha-1, Seed sorghum EB=9 kg^{-1}, AGYSy =Adjusted seed yield of soybean (kg ha^{-1}) and TVC= Total variable cost

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Response of Maize and Soybean to Lime and Phosphorus Application and its Subsequent Effect on Acidity of Soils in Jimma Zone

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Introduction

In southwestern Ethiopia, even though maize is the major staple food crop, the crop is rarely rotated with other food and forage legume crops. This practice, thus, exhausts most of plant nutrients and severely reduces soil N pools. Moreover, continuous application of chemical fertilizers with N and/or P nutrients only in the form of DAP and urea, has adversely affected soil physical properties such as soil structure and bulk density (Brady and Weil, 2008). It also aggravated soil acidification and depletion of macro and micro plant nutrients to amounts below critical level needed for optimal crop growth and production (Sposito, 2008; Marschner and Rengal, 2007; Fageria *et al*., 2011).

Because of the above circumstances, a number of adverse effects are observed such as loss of crop diversity, decline in yield of existing crops, lack of response to ammonium phosphate and urea fertilizers, complete failure of cropping land (Desta and Angaw, 1988). A recent study on the two important plant growth-limiting nutrients, namely nitrogen and phosphorus showed that acid soils dominate most of the southern and southwestern parts of the country. Reports also indicate that soils in the south and southwestern part including Sidamo, Ilubabor and Keffa have high N_2 content and low P content (NFIA, 1993). These studies was therefore, planned and executed with the aim of identifying optimum levels of lime and P fertilizer for maize grown on acid soils and understand its subsequent effect on acid properties of soils in South western regions of Ethiopia.

Materials and Methods

Experimental treatment, design and procedure

The study was conducted on soybean-maize rotation system in two sets from 2009 – 2013 cropping seasons in Ilubabor zones at Hurumu research sub-station. In each season maize and soybean crops were planted at a time in different sets in the same block. Prior to the commencement of the trial, composite soil samples were collected from the upper 20 cm depth and analysed for soil pH and exchangeable acidity. In this regard, initial exchangeable acidity of the site was 3.76 Cmol kg^{-1}. In this study, five levels of lime (0.0x, 0.5x, 1.0x, 1.5x and 2.0x, exchangeable Al^{+3} and H^{+1}) with corresponding lime rate of 0, 1.41, 2.82, 4.23, and 5.64 tons ha^{-1} and four rate of phosphorus (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) within randomised complete block design with three replications. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil bulk density and exchangeable Al^{+3} and H^{+} of each site assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$ as described in equation below.

$$LR\,(CaCO_3\ kg/ha) = \frac{EA}{}\frac{(cmol/kg\ of\ soil) * 0.15\,m * 10^4\ m^2 * BD\,(Mg/m^3) * 1000}{2000}$$

Where LR = Lime requirement of the soil based on exchangeable acidity and EA = Exchangeable acidity

The different lime rates in the form of powdered lime having a calcium carbonate equivalent (acid neutralizing value) of 102 % were weighted, and uniformly broadcasted, and incorporated into the soil one month before planting. Phosphorus was applied in band as triple super phosphate (TSP) once at seed sowing while the recommended N rate (92 kg N ha^{-1}) was applied uniformly to all experimental plots as urea in two split; half at seed sowing for both crops and the remaining half when the seedlings attained knee height for maize and one month after sowing for soybean. Maize variety BH-660 and soybean variety Clarck 63K were used as attest crops. Maize was sown at the rate of two seeds per hill in seven rows per plot at spacing of 75 cm between rows and 50 cm between hills. On the other hand, soybean was hand drilled in rows of four meter long and 60 cm wide, and thinned to a recommended five centimeters spacing between plants. In the course of the study, the recommended cultural practices for maize and soybean production were applied uniformly for the management of the experimental plots.

Soil sample and analysis

Composite soil samples were taken from experimental fields prior to the commencement of the trial and from each experimental plot of the study location at the end of crop harvest. The samples were air dried on wooden tray, ground and sieved with a 2-mm sieve. The samples were analysed for pH and exchangeable acidity. Soil pH was measured potentiometrically using pH meter in 1:2.5 soil to water ratio (Page, 1982). Exchangeable acidity was determined by extracting the samples with 1 M KCl solution and titrating with NaOH as described by McLean (1965). Finally, economic yield and soil analysis data were subjected to analysis of variance using SAS statistical software (SAS version 9.1, 2008). Means were separated using Duncan’s Multiple Range Test whenever the ‘F’ test was significant.

Results and Discussion

Effect of lime and phosphorus on acid properties of soil after harvesting

Application of lime significantly influenced soil pH and exchangeable acidity while application of different phosphorus levels did not bring any significant change on both parameters (Table 1). Accordingly, soil pH gradually increased with increasing the levels of lime. The findings observed on soil pH changes in soil agree with the findings of Kayitare (1989), Hartmann (1993) and Ruganzu (2009) who reported the increase of soil pH after limes application in acidic soils. This is might be due to the hydroxyl concentration is increased, and the H^+ concentration in the soil solution is decreased by the application of materials to correct acidity; consequently, the soil pH is increased (Castro and Crusciol, 2013). The rise in pH and reduction of soil exchangeable acidity is associated with the presence of basic cations (Ca^{2+} and Mg^{2+}) (Fageria *et al.*, 2007) and anions (CO_3^{-2}) in lime that are able to exchange H^+ from exchange sites to form $H_2O + CO_2$. Cations occupy the space left behind by H^+ on the exchange leading to the rise in pH. On contrary, increasing lime rate from 1.41 to 5.64 t ha^{-1} decreased exchangeability acidity of the soil. Effiong and Okon (2009) reported that incubation of acidic soils with various liming materials for one month generally reduced exchangeable acidity among which $CaCO_3$ used as a liming material showed up to 68% reduction of exchangeable acidity of the soils. The effects observed on exchangeable Al are corroborated by the findings of Crawford and Su (2008 who reported reduction of exchangeable Al and Aluminum saturation to adequate levels following application of lime in acidic soil. Other authors such as Conyers et al. (2003), Caires et al. (2008) and Awkes (2009) have reported a decrease of exchangeable Al following liming of acidic soils.

Table 1. Effect of lime and phosphorus on acidity of soil at Hurumu.

Lime (t ha^{-1})	pH (1:2.5 H_2O)	Exchangeable acidity (Cmol kg^{-1})
0	4.55c	3.34a
1.41	4.56bc	3.37ab
2.82	4.59abc	2.72abc
4.23	4.79a	2.52bc
5.64	4.82a	2.19c
LSD (0.05)	0.21	0.90
P (kg ha^{-1})		
0	4.56	2.80
10	4.70	2.95
20	4.61	2.91
30	4.62	2.80
LSD (0.05)	Ns	Ns
CV (%)	5.68	32.90

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

Grain yield of maize

The analysis of variance revealed that individual year as well as combined over years brought about significant ($P \leq 0.05$) interaction effect on grain yield of maize due to different levels of lime and P fertilizer (Table 2). The combined data over years showed that as the level of P increased, grain yield of maize considerable increased. The observed increase in grain yield with increasing P rate, in treatments with no lime application, confirmed that P was limiting factor to maize growth in this soil. Similar responses to application of P fertilizers on P-deficient have been reported by other researchers (Ademba et al., 2015; Opala et al., 2015; and Ahmat et al., 2014). Generally, maize grain yields increased due to liming of the acid soils and improved nutrition of added N and P (Nekesa, 2007). However, there is no statistical evidence that shows increasing in lime level increased grain yield of maize at the study site. Generally, the applications of 20 and 30 P kg ha^{-1} with and without lime gave significantly the highest grain yield of maize as compared to the other treatments except 1.41, 4.23 and 5.64 t lime ha^{-1} with 10 kg P ha^{-1}. The lowest grain yield of maize was obtained in treatments that received low or no phosphorus fertilizer. From the data in could be argued that application of lime for maize at Hurumu could not benefit the crop. Similar result was reported by Brown et al. (2008). The lack of yield response due to liming can probably be attributed to the anticipated high acid buffer capacity exerted by the high soil carbon content and rendering the lime application levels relatively ineffective (Bache, 1988).

Table 2. Effect of lime and phosphorus rates on Maize grain yield (t ha^{-1}) at Hurumu from 2009-2013

Lime (t ha^{-1}) and P (kg ha^{-1}) rate	2009	2010	2011	2012	2013	Mean
$L_0 P_0$	2.72^{d-f}	4.64^{d-f}	4.93^{ab}	2.21	1.71^{e}	3.24^{f}
$L_0 P_{10}$	2.56^{f-h}	4.77^{c-f}	5.50^{ab}	4.23	4.29^{a-d}	4.27^{c-e}
$L_0 P_{20}$	3.63^{a-d}	4.34^{ef}	6.42^{ab}	6.05	3.98^{a-d}	4.88^{a-e}
$L_0 P_{30}$	3.31^{a-f}	5.43^{b-e}	5.27^{ab}	6.83	3.34^{b-e}	4.84^{a-e}
$L_{1.41} P_0$	2.29^{gh}	4.08^{f}	5.21^{ab}	2.31	1.72^{e}	3.12^{f}
$L_{1.41} P_{10}$	2.28^{gh}	5.49^{b-e}	7.19^{a}	6.52	3.57^{b-d}	5.01^{a-d}
$L_{1.41} P_{20}$	3.09^{b-g}	5.34^{b-e}	5.18^{ab}	6.81	5.39^{a}	5.16^{a-b}
$L_{1.41} P_{30}$	4.03^{a}	6.74^{a}	5.48^{ab}	6.61	4.14^{a-d}	5.40^{ab}
$L_{2.82} P_0$	2.11^{h}	4.57^{d-f}	6.06^{ab}	4.91	3.26^{b-e}	4.18^{de}
$L_{2.82} P_{10}$	2.66^{e-h}	5.43^{b-e}	5.07^{ab}	6.17	4.13^{a-d}	4.69^{b-e}
$L_{2.82} P_{20}$	3.79^{ab}	5.68^{a-d}	5.08^{ab}	7.65	4.03^{a-d}	5.24^{ab}
$L_{2.82} P_{30}$	3.59^{a-e}	6.22^{ab}	6.05^{ab}	6.48	4.97^{ab}	5.46^{ab}
$L_{4.23} P_0$	2.72^{d-h}	5.33^{b-e}	3.94^{b}	5.79	2.81^{de}	4.12^{e}
$L_{4.23} P_{10}$	2.85^{c-h}	5.44^{b-e}	5.99^{ab}	7.19	2.84^{c-e}	4.86^{a-e}
$L_{4.23} P_{20}$	3.75^{a-c}	5.99^{ab}	6.77^{ab}	6.62	4.64^{a-c}	5.55^{a}
$L_{4.23} P_{30}$	3.66^{a-c}	5.86^{a-c}	6.18^{ab}	6.66	4.89^{ab}	5.44^{ab}
$L_{5.64} P_0$	2.61^{f-h}	5.99^{ab}	6.74^{ab}	6.17	2.49^{de}	4.80^{a-e}
$L_{5.64} P_{10}$	2.51^{f-h}	5.56^{a-d}	5.49^{ab}	6.82	4.84^{ab}	5.05^{a-c}
$L_{5.64} P_{20}$	3.76^{a-c}	6.08^{ab}	6.64^{ab}	6.93	4.31^{a-d}	5.54^{a}
$L_{5.64} P_{30}$	3.19^{a-f}	6.03^{ab}	5.07^{ab}	6.52	4.83^{ab}	5.12^{ab}
LSD(0.05)	0.93	1.21	3.17	Ns	1.82	0.83
CV(%)	18.4	13.4	33.5	25.7	28.9	23.9

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns = Not significantly different.

Seed yield of soybean

The analysis of variance showed that in individual years as well as combined over years significantly ($P \leq 0.05$) influenced seed yield of soybean due to interaction effect of lime and phosphorus fertilizer (Table 3). Accordingly, the highest significant seed yield of soybean was obtained by application of 1.41, 2.82, 4.23 and 5.64 t lime ha^{-1} along with 30 kg P ha^{-1}; 2.82, 4.23 and 5.64 t lime ha^{-1} along with 20 kg P ha^{-1} and 5.64 t lime ha^{-1} along with 10 kg P ha^{-1}. These treatments are statistically at par and significantly superior to the other lime and phosphorus combinations. As expected, the lowest significant seed yield of soybean was obtained from control. So, this result indicated that liming improves availability of P for crops and also external P application improved crop yield performance. The result may be attributed to the fact that applying phosphorus fertilizer increases crop growth and yield on soils which are naturally low in P and in soils that have been depleted (Mullins, 2001; Hammond *et al*., 2004).

Table 3. Effect of lime and phosphorus rates on soybean grain yield (ton ha^{-1}) at Hurumu

Lime (t ha^{-1}) and P (kg ha^{-1}) rate	2009	2010	2011	2012	2013	Mean
$L_0 P_0$	1.44	1.16	0.38^{h}	0.57^{g}	0.62^{i}	0.84^{g}
$L_0 P_{10}$	1.73	1.54	1.21^{fg}	1.63^{a-d}	1.39^{e-g}	1.50^{e}
$L_0 P_{20}$	1.37	1.34	1.78^{a-e}	1.84^{a-c}	2.25^{ab}	1.72^{b-e}
$L_0 P_{30}$	1.60	1.55	1.93^{a-d}	1.73^{a-d}	1.74^{c-e}	1.71^{b-e}
$L_{1.41} P_0$	1.84	1.51	0.61^{h}	0.92^{fg}	0.73^{hi}	1.12^{f}
$L_{1.41} P_{10}$	1.83	1.88	1.54^{d-f}	1.49^{c-e}	1.81^{b-e}	1.71^{b-e}
$L_{1.41} P_{20}$	1.57	1.34	1.38^{ef}	1.71^{a-d}	2.16^{a-d}	1.63^{c-e}
$L_{1.41} P_{30}$	1.57	1.47	2.05^{ab}	1.78^{a-d}	2.17^{a-d}	1.81^{a-c}
$L_{2.82} P_0$	1.43	1.28	0.57^{h}	0.73^{g}	1.21^{f-h}	1.05^{fg}
$L_{2.82} P_{10}$	1.89	1.64	1.69^{b-e}	1.21^{ef}	1.78^{b-e}	1.64^{c-e}
$L_{2.82} P_{20}$	1.68	1.28	1.86^{a-d}	1.79^{a-d}	2.16^{a-d}	1.76^{a-e}
$L_{2.82} P_{30}$	1.72	2.09	1.89^{a-d}	1.86^{a-c}	2.16^{a-d}	1.95^{ab}
$L_{4.23} P_0$	1.74	1.53	0.79^{gh}	0.67^{g}	1.02^{g-i}	1.15^{f}
$L_{4.23} P_{10}$	1.55	1.49	1.59^{c-f}	1.40^{de}	1.53^{ef}	1.51^{de}
$L_{4.23} P_{20}$	1.76	1.21	2.09^{ab}	1.65^{a-d}	2.23^{a-c}	1.79^{a-d}
$L_{4.23} P_{30}$	1.79	1.94	2.00^{a-c}	2.03^{a}	2.30^{a}	2.01^{a}
$L_{5.64} P_0$	1.46	1.23	1.21^{fg}	0.68^{g}	0.91^{g-i}	1.10^{fg}
$L_{5.64} P_{10}$	2.28	2.02	1.79^{a-e}	1.54^{b-e}	1.68^{d-f}	1.86^{a-c}
$L_{5.64} P_{20}$	1.55	1.71	2.11^{ab}	1.90^{ab}	2.11^{a-d}	1.88^{a-c}
$L_{5.64} P_{30}$	1.72	1.39	2.13^{a}	1.97^{a}	2.13^{a-d}	1.87^{a-c}
LSD at 5%	Ns	Ns	0.44	0.41	0.49	0.29
CV %	22.65	42.57	17.22	16.86	17.43	25.1

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

Effects of lime and P on economic feasibility of maize and soybean production

The economic analysis results for effects of lime and P fertilizer on maize and soybean production at Hurumu are indicated in table 4 and 5. The study revealed that except 3 treatments on both crops all the other treatments were dominated. Because these treatments have net benefits less than treatments with lower variable costs. Such dominated treatments were dropped from economic analysis. The highest net benefit of BIRR 20560 ha^{-1} and marginal rate return of 292.14 % with value to cost ratio of BIRR 14.7 per unit of investment was obtained from plant 20 kg P ha^{-1} for maize production while the lowest net economic return was recorded from application of 5.64 t lime ha^{-1} along with 30 kg P ha^{-1} (BIRR 7968 ha^{-1}). The highest net benefit of BIRR 15628ha^{-1} and marginal rate return of 211.14 % with value to cost ratio of BIRR 11.2 per unit of investment was obtained from application of 20 kg P ha^{-1} without lime for soybean production while the lowest net economic return was recorded from application of 5.64 t lime ha^{-1} without P fertilizer (BIRR -2082 ha^{-1}). The second best net benefit of BIRR 14150 ha^{-1} and marginal rate return of 833.43 % with value to cost ratio of BIRR 20.2 per unit of investment was obtained from 10 kg P ha^{-1} without lime for soybean production. Therefore, 10 and 20 kg P ha^{-1} alone for soybean and maize production, respectively are economical feasible at Hurumu area.

Table 4. Effects of lime and P on economic feasibility of maize production at Hurumu

Lime (t ha^{-1})	P (kg P_2O_5 ha^{-1})	AGYM	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	2916	0	14580	14580	0	0
0	10	3843	700	19215	18515	26.5	562.14
0	20	4392	1400	21960	20560	14.7	292.14
0	30	4356	2100	21780	19680^{D}	9.4	
1.41	0	2808	3243	14040	10797^{D}	3.3	
1.41	10	4509	3943	22545	18602^{D}	4.7	
1.41	20	4644	4643	23220	18577^{D}	4.0	
1.41	30	4860	5343	24300	18957^{D}	3.6	
2.82	0	3762	6486	18810	12324^{D}	1.9	
2.82	10	4221	7186	21105	13919^{D}	1.9	
2.82	20	4716	7886	23580	15694^{D}	1.9	
2.82	30	4914	8586	24570	15984^{D}	1.8	
4.23	0	3708	9729	18540	8811^{D}	0.9	
4.23	10	4374	10429	21870	11441^{D}	1.1	
4.23	20	4995	11129	24975	13846^{D}	1.2	
4.23	30	4896	11829	24480	12651^{D}	1.1	
5.64	0	4320	12972	21600	8628^{D}	0.7	
5.64	10	4545	13672	22725	9053^{D}	0.7	
5.64	20	4986	14372	24930	10558^{D}	0.7	
5.64	30	4608	15072	23040	7968^{D}	0.5	

The price of DAP BIRR=14 kg^{-1} N Urea Birr *=12.5 kg^{-1}, lime* Birr *=2.3 kg ha-1, Seed maize EB=5 kg^{-1}, D= dominated, AGYM=Adjusted Grain yield of Maize (kg ha^{-1}) and TVC= Total variable cost.*

Table 5. Effects of lime and P fertilizer on economic feasibility of soybean production at Hurumu

Lime (t ha^{-1})	P (kg ha^{-1})	AGYM	TVC (Birr ha^{-1})	Revenue (Birr ha^{-1})	Net Benefit (Birr ha^{-1})	Value to cost ratio	Marginal Rate of Return (%)
0	0	756	0	8316	8316	0	0
0	10	1350	700	14850	14150	20.2	833.43
0	20	1548	1400	17028	15628	11.2	211.14
0	30	1539	2100	16929	14829^{D}	7.1	
1.41	0	1008	3243	11088	7845^{D}	2.4	
1.41	10	1539	3943	16929	12986^{D}	3.3	
1.41	20	1467	4643	16137	11494^{D}	2.5	
1.41	30	1629	5343	17919	12576^{D}	2.4	
2.82	0	945	6486	10395	3909^{D}	0.6	
2.82	10	1476	7186	16236	9050^{D}	1.3	
2.82	20	1584	7886	17424	9538^{D}	1.2	
2.82	30	1755	8586	19305	10719^{D}	1.2	
4.23	0	1035	9729	11385	1656^{D}	0.2	
4.23	10	1359	10429	14949	4520^{D}	0.4	
4.23	20	1538	11129	16919	5790^{D}	0.5	
4.23	30	1809	11829	19899	8070^{D}	0.7	
5.64	0	990	12972	10890	-2082^{D}	-0.2	
5.64	10	1674	13672	18414	4742^{D}	0.3	
5.64	20	1692	14372	18612	4240^{D}	0.3	
5.64	30	1683	15072	18513	3441^{D}	0.2	

The price of DAP Birr *=14 kg^{-1} N Urea* Birr *=12.5 kg^{-1}, lime* Birr *=2.3 kg ha-1, Seed maize EB=11 kg^{-1}, D= dominated, ASYSy=Adjusted seed yield of soybean (kg ha^{-1}) and TVC= Total variable cost*

Conclusion

Based on the results of this study, application of lime raised soil pH and significantly reduced exchangeable acidity thereby creating conducive soil environment for crop growth. The applications of 20 and 30 P kg ha^{-1} with and without lime gave significantly the highest grain yield of maize as compared to the other treatments except 1.41, 4.23 and 5.64 t lime ha^{-1} with 10 kg P ha^{-1}. While, the highest significant seed yield of soybean was obtained by application of 1.41, 2.82, 4.23 and 5.64 t lime ha^{-1} along with 30 kg P ha^{-1}; 2.82, 4.23 and 5.64 t lime ha^{-1} along with 20 kg P ha^{-1} and 5.64 t lime ha^{-1} along with 10 kg P ha^{-1}. From the data, there is no enough evidence that shows the beneficial effect of liming in enhancing the grain yield of maize at Hurumu. Therefore, 10 and 20 kg P ha^{-1} alone for soybean and maize production, respectively are economical feasible and investigate alternative strategies (other than lime) for increasing or maintaining soil pH, reduce the offsite impacts from acidifying processes, and maintain or improve productivity with minimal soil pH decline at Hurumu area.

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Response of Sorghum and Soybean to Split Application of Lime

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Introduction

Numerous agricultural practices have been recommended to overcome soil acidity problems in crop production. Among them, the most common and widely used practice is liming (Edmeades and Ridley, 2003). The direct benefits of liming include: enhanced soil physical, chemical and biological properties. However, the indirect benefits include mobilization of plant nutrients, immobilization of toxic heavy metals, and improvements in soil structure. It also causes optimal conditions that enhance biological activities like N_2 fixation and mineralization of N, P and S in soils. However, the cost of lime is prohibitive due to large amounts required per hectare of land. In addition to its high cost, over liming may reduce crop yield by inducing P and micronutrient deficiencies (Fageria, 1984). Thus, there are alternative application strategies such as split application of lime in a band that may allow lower rates of lime to be used and thereby offset economic constraints posed by high application rates.

In view of the above points, this study was initiated with the aim of investigating the response of sorghum and soybean to split application of lime in Assosa District, Benishangul Gumuz Regional state.

Materials and Method

The study area

This experiment was conducted at Assosa District during the main rainy season of 2012 - 2015. The study sites are found in the altitude ranging between 1300 and1470 m. with the mean minimum and maximum temperatures of 14.38 and 28.55^{o}C, respectively. The average annual rainfall of 1291 mm of which 1042 mm were received between May and October during the cropping season.

Experimental design

The experiments were placed on the basis of cereal-legume crop rotation system in two sets. In each season the selected cereal and legume (sorghum/soybean) crops were planted at a time in different sets in the same block. The treatments included in the experiment were; control, full dose of recommended lime applied at once during the cropping season; two splits in which 50% of the total dose was applied in the first year and the rest 50% in the second year; three splits in which 33% of the total dose was applied in the first year, 33% in the second year and the rest 33% in the third year; and four splits in which 25% of the total dose was applied in the first year, 25% in the second year, 25% in the third year and the rest 25% in the fourth year. Lime was uniformly broadcasted by hand and incorporated into the soil one month before planting. The experiments were laid out in randomised complete block design (RCBD) with three replications.

The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil bulk density and exchangeable Al^{+3} and $H^{+}$of each site. Assuming that one mole of exchangeable acidity would be neutralized by equivalent mole of $CaCO_3$. The recommended rate of NP was uniformly applied to all treatments. Urea and DAP was used as the source of N and P, respectively. Application of urea was in two split, while the entire rate of phosphorus was applied at sowing in band for row planted sorghum. The plots were kept permanent for the duration of the experiments to observe the carry-over effects of lime.

Soil sample and analysis

Initially, one composite soil sample from the experimental site was collected before lime application and subjected to analyses of soil acidity attributes and other soil physico-chemical properties. Samples were randomly collected from surface layer of the experimental field i.e. 0-20 cm soil depth to form a composite and analyzed for soil pH, bulk density, exchangeable acidity, exchangeable aluminum, available P, calcium, magnesium, potassium, sodium, CEC and acid saturation. The pH of the soil was determined according to FAO (2008) using 1:2.5 soil to watersolution ratio using a glass electrode attached to digital pH meter. Available phosphorus was determined by the Bray-II method. The cation exchange capacity (CEC) was measured after saturating the soil with in ammonium acetate (NH_4Ac) and displacing it with in NaAc (Chapman, 1965).

Data analysis

Data collected from the experimental field were analyzed using SAS software version 9.3 (SAS, 2002). Mean comparison of treatment was done using least significant difference at 5% probability level.

Results and Discussion

Soil physico-chemical properties before planting and after harvesting

Analysis of soil physico- chemical properties before planting and after harvesting is presented in table 1 and 2. Soil sample analysis before planting indicated that the soil pH of the area was 5.02 which was very strong acidic (Bruce and Rayment, 1982) with low available P and 2.36 exchangeable acidity. The bulk density was 1.06 g/cm^3 which is low according to (Baruah *et al*., 1997), according to Bruce and Rayment (1982) available Ca^{2+}, Mg^{2+}, K^+ and Na^+ analysis results were 2.63 (Low), 0.78 (Low), 0.06 (very low) and 0.08 (very Low), respectively cation exchange capacity was 8.25 Cmol kg^{-1} which was low according to Metson (1961).

Soil sample analysis after harvesting showed that soil pH significantly ($P \leq 0.05$) increased due to the application to different lime as compared to control. The increase in soil pH under lime treatment was due to addition of CaO which reacts with water leading to production of OH^- ions which forms $Al(OH)_3$ and H_2O thus raising the soil pH and decreasing exchangeable acidity. In addition, Kisinyo *et al*. (2012) attributed the soil pH increase in lime treatment as a result of H+ and Al^{3+} ions displacement from soil adsorption sites by Ca^{2+} ions contained in lime. Soil pH increases ranged from 0.04 to 1.98 after liming on soybean (Agustín and Antonio, 2011). The same results reported by Woodard and Bly (2010) and Haby et al. (1978). Available P values were found to be higher in treatments that received 25 % of lime every year as compared to other split application and control. Full application of lime at once, 33% of split application and control did not show any difference in terms of available P. Benvindo (2014) reported that lime applied alone significantly increased soil available P. Liming of acid soils raises soil pH, which in turn releases phosphate ions precipitated with Al and Fe ions thus making P available for plant uptake (Chimdi *et al*., 2012). However, application of different splits of lime significantly reduced exchangeable acidity to the minimum level. Application of lime, irrespective of the rate used, significantly reduced the exchangeable acidity compared to the control. This is to be expected because lime is known to increase the soil pH, hence precipitating Al as $Al(OH)_3$ (Peter, 2017 ; Hue, 2004). Elsewhere, studies conducted revealed also that lime application lead to increased soil pH and decreased soil exchangeable acidity (The *et al*., 2001; Nekesa *et al*., 2005).

Table 1.Soil sample analysis result before planting

pH (1:2.5 H_2O)	(Cmol$_{(+)}$/kg soil)						CEC	% AS*	BD
	Exch. acidity	Exch. Al	Ca	Mg	K	Na			
5.02	2.36	2.48	2.63	0.78	0.06	0.08	8.25	57.21	1.06

**AS= Acid saturation*

Table 2. Soil pH, available phosphorus, and exchangeable acidity as influenced by split application of lime

Treatment	pH (1:2.5 H20)	Av. P (ppm)	Exchangeable acidity ($Cmol_{(+)}$/kg soil)
Control	5.0b	2.2c	1.4a
Full dose of lime	5.7a	2.8bc	0.8b
50% lime each year	5.9a	3.2b	0.4c
33% lime each year	5.8a	2.9bc	0.6bc
25% lime each year	5.8a	4.2a	0.7bc
LSD (0.05)	0.4	0.9	0.4
CV (%)	5.82	24.5	39.3

Ns= not significant difference at 0.05 probability level.

Plant height and grain yield of sorghum as affected by split application of lime

The Analysis of variance result showed that plant height of sorghum significantly ($P \leq 0.05$) affected due to the applied treatments in 2015 (Table 3). The over years combined analysis of plant height brought about inconsistent results. Generally, all lime treatments gave significantly higher grain yield of sorghum as compared to control. Grain yield analysis combined over three years, however, indicated that split application of 50 % lime gave significantly superior grain yield of sorghum. But, the yield obtained in this treatment was statistically comparable with full dose of lime and 25 % lime applied every year. Similarly, grain yield of sorghum obtained by application of full dose of lime, 33 % and 25 % of split application did not differ from each other. The grain yield of sorghum obtained in each year showed inconsistent results due to terminal moisture stress and sporadic striga infestation.

Table 3. Sorghum plant height and grain yield as influenced by split application of lime

Treatment	2013		2014		2015		Combined	
	PH	GY	PH	GY	PH	GY	PH	GY
Control	117.5a	550.4c	58.4b	664.6d	136.5a	689.1d	102.5b	645.2c
Full dose of lime	121.8a	1367.2bc	68.1b	4895.8ab	118.3a	1649.6c	100.4b	2796.3ab
50% lime each year	137.0a	3153.9a	107.9a	5520.8a	128.0a	1879.7b	122.7a	3563.7a
33% lime each year	120.3a	1925.0bc	69.6b	4583.3bc	129.0a	1667.2c	104.5b	2575.2b
25% lime each year	129.8a	2447.3bc	81.4b	4010.4c	123.7a	2065.6a	109.4ab	2890.3ab
LSD (0.05)	Ns	1466.5	25.1	863.5	Ns	150.5	15.7	838.7
CV (%)	8.9	31.3	17.3	11.6	12.1	5.02	14.3	32.9

***Ns=** not significant, PH= Plant height (cm) and GY= Grain yield (kg ha^{-1})*

Seeds per pod and seed yield of soybean as affected by split application of lime

Seeds per pod and seed yield of soybean of affected by split application are presented in table 3. Analysis of variance showed that seeds per pod were significantly higher in 2014 as compared to control. Generally, seed yield of soybean obtained by application of different splits of lime gave significantly ($P \leq 0.05$) superior as compared to control. However, 50% split application of lime consistently gave the highest significant seed yield of soybean during individual years and combined over three years. The seed yield of soybean obtained by full dose of lime, 50 % and 25 % split application was not statistically different. Combined over three years, seed yield of soybean recorded from control was significantly lower than the other treatments. From this result, it could be inferred that modest application of lime could give better economic yield of soybean around Assosa area.

Table 4. Soybean seeds per yield and Seed yield (kg ha^{-1}) as influenced by split application of lime

Treatment	2013		2014		2015		Combined	
	SPP	SY	SPP	SY	SPP	SY	SPP	SY
Control	2.5^{a}	938.8^{b}	2.2^{b}	580.4^{b}	2.4^{a}	584.9^{b}	2.3^{b}	701.3^{c}
Full dose of lime	2.4^{a}	1075.0^{ab}	3.6^{a}	979.8^{a}	2.37^{a}	1040.0^{a}	2.8^{ab}	1031.6^{ab}
50% lime each year	3.1^{a}	1253.7^{a}	4.0^{a}	1251.8^{a}	2.4^{a}	1028.4^{a}	3.2^{a}	1178.0^{a}
33% lime each year	2.4^{a}	986.2^{b}	3.9^{a}	1006.9^{a}	2.37^{a}	785.3^{ab}	2.9^{a}	926.1^{b}
25% lime each year	2.2^{a}	906.8^{b}	4.0^{a}	1212.6^{a}	2.4^{a}	807.2^{ab}	2.9^{a}	975.5^{ab}
LSD (0.05)	Ns	197.7	0.77	340.2	Ns	428.5	0.54	216.7
CV (%)	20.6	10.2	11.7	17.9	5.5	26.8	20.2	23.5

** Ns= not significant, SPP= Seeds per pod , SY= Seed yield*

Conclusion

Based on this finding, application of lime improved soil pH and drastically reduced the toxic effect of aluminum. As the result, grain yield of sorghum and seed yield of soybean improved due to application of lime. Consequently, split application of 50 % lime gave significantly superior grain yield of sorghum, which was comparable with full dose of lime and 25 % lime applied every year. Hence, 25 % split application of lime every year seems to be sufficed for sorghum production around Assosa area. Similarly, the highest seed yield of soybean obtained by application of 25 % of split application of lime gives comparable yield with full dose of lime and 50 % of split-applied lime. Therefore, modest application of lime could give better economic yield of soybean around study site.

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Response of Maize and Soybean to Split Application of Lime

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Introduction

Soils of Jimma and Illubabor Zones are dominated by Nitisols/Oxisols. These soils are predominantly acidic and have been found that more than 80% of the landmasses originated from Nitisol are acidic. Liming is an important and commonly used acid soil management practices nowadays. Liming acid soil makes the soil environment better for plants and soil fauna by raising its pH and precipitating exchangeable aluminum (Pearson, 1975). As many small scale farmers in Ethiopia dwell in acid prone areas, the management of these soils through liming has been given the highest research priority. However, lime is not obtained free and a large quantity may be needed for highly affected areas. Hence, resources poor farmers may not afford full dose application of lime required at once. Besides, the locations of lime resources are very far from the problem area that makes transportation very difficult.

Therefore, splitting the required amount of lime in to equal split might be equally important for remunerative crop production. Hence, this activity was conducted with the objectives of determining the efficiency of split application on maize and soybean productivity.

Materials and Methods

Field experiments were conducted with maize and soybean for five consecutive cropping seasons on acid soils of Doyo and Hurumu of South western Ethiopia. The activity was conducted on the basis of maize-soybean rotation system in two sets. Before the commencement of the experiment, experimental fields were analysed for soil bulk density, soil pH and exchangeable acidity. Accordingly, the exchangeable acidity of Doyo and Hurumu sites were 0.61meq/100g soil and 3.76meq/100g, respectively. Maize variety BH 660 and Soybean variety clark 63K were used as test crops. Maize seeds were sown in 80 cm x 50 cm with two seeds per hill whereas soybean seeds were sown in 60 cm x 5 cm spacing. The experiment was laid out in randomised complete block design with three replications. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 0.15m hectare-furrow-slice, soil sample density and exchangeable acidity of each site based on the following formula.

$$LR, CaCO_3\ (kg/ha) = \frac{cmolEA/kg\ of\ soil * 0.15\,m * 10^4\ m^2 * B.D.(Mg/m^3) * 1000}{2000}$$

The treatments included in the experiment were; control, full dose of recommended lime applied at once during the cropping season; two splits in which 50% of the total dose was applied in the first year and the rest 50% in the second year; three splits in which 33% of the total dose was applied in the first year, 33% in the second year and the rest 33% in the third year; and four splits in which 25% of the total dose was applied in the first year, 25% in the second year, 25% in the third year and the rest 25% in the fourth year. Lime was uniformly broadcasted by hand and incorporated into the soil one month before planting.

Recommended rate of N, 46kg N ha^{-1} and 92kg N ha^{-1} were uniformly applied for soybean and maize, respectively. However, 20kg P ha^{-1} was uniformly applied for all treatments and for both test crops. Urea and TSP were used as source of N and P, respectively. Application of urea was made in two splits, half at sowing and half at knee height; while the entire rate of phosphorus was applied at sowing by band. Data collected from the crop and soil were subjected to analysis of variance using SAS software packages and mean separation was done using LSD (Gomez and Gomez, 1984) at 5% probability level.

Results and Discussion

Influence of split application of lime on soil pH and exchangeable acidity

At Doyo site

Split application of lime significantly affected soil pH and exchangeable acidity at Doyo site. In this regard, 50% application of lime for two consecutive years and application of full rate at once significantly ($P \leq 0.05$) increased soil pH, but significantly ($P \leq 0.05$) decreased exchangeable acidity of the soil (Table 1). The increase in soil pH and reduction of soil exchangeable acidity following application of lime can be attributed to the release of organic acids which in turn may have suppressed Al content in the soil through chelation (Onwonga et al., 2008; Okwuagwu et al., 2003). Moreover, lime when applied in the soil reacts with water leading to the production of OH^- ions and Ca^{2+} ions which displace H^+ and Al^{3+} ions from soil adsorption sites resulting in an increase in soil pH (Kisinyo et al., 2012). At this location, 50% lime application in consecutive years improved the pH of the soil similar to full rate application at once. Hence choosing either the former or the later depends on farmers' capacity of buying the lime. This is in agreement with Anetor and Ezekiel (2007) who indicated that lime increased pH and decrease exchangeable acidity.

Table 1. Effect split application of lime on soil pH and exchangeable acidity at Doyo

Treatment	pH	Exchangeable Acidity ($Cmol_{(+)}$ kg^{-1})
Control	4.10c	0.84a
25% every year	4.31c	0.66ab
33% every year	4.36bc	0.60abc
50% every year	4.63ab	0.37bc
Full dose at once	4.87a	0.31c
LSD (0.05)	0.30	0.29
CV (%)	13.61	28.23

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level.

At Hurumu site

Hurumu soil on the other hand, changes in soil pH and exchangeable acidity due to the split application was minimal as compared to full dose application (Table 2). This is due to the fact that Hurumu soil is strongly acidic with an initial pH value of less than 5 and exchangeable acidity of about greater than 3. The application of lime to acid soils can affect biological, chemical, and physical properties of the soils. The increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity (Suryantini, 2014). Even though, application of lime in 25%, 33% and 50% splits significantly lowered exchangeable acidity, there were no significant differences observed among them. However, the highest significant decrease in exchangeable acidity was observed by application of full dose of lime at once. Lime increased soil pH because of the likely displacement of $Al^{3+,}$ H^{+} and Fe^{3+} ions by Ca^{2+} ions it contains. This led to the observed reduction in P sorption at all the sites. Similar studies have reported increased soil pH, available P, reduction in Al levels and P sorption in acid soils due to lime application (Bado et al., 2004; Kanyanjua et al., 2002; The et al., 2006). Therefore, lime application is important for the management of soil acidity related constraints in the main maize growing areas of Hurumu.

Table 2. Effect split application of lime on acidic properties of soil at Hurumu.

Treatment	pH	Exchangeable Acidity ($Cmol_{(+)}kg^{-1}$)
Control	4.73b	3.72a
25% every year	4.88ab	2.24b
33% every year	4.93ab	2.13b
50% every year	4.97ab	2.12b
Full dose	5.1a	1.06c
$LSD_{0.05}$	0.26	0.62
CV (%)	12.87	28.98

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level

Grain yield of maize and seed yield of soybean

At Doyo site

Over the years mean showed that split application of lime significantly affected maize and soybean yield at Doyo (Tables 3 and 4). Results revealed that splitting lime into two and applying in two consecutive years as well as splitting of lime into three and applying in three consecutive years statistically gave similar yield with full rate application of lime for maize. Application of lime into four equal split gave similar maize grain yield with Splitting lime into two and three. This might be due to the less acidity of Doyo area. The lowest maize grain yield was obtained from control without lime application. Result of this experiment revealed that splitting the required amount of lime into 33% and 50% is possible if maize to be grown on this soil. Split application and full dose application gave almost similar soybean seed yield at Doyo testing site except control (Table 4). Therefore, resource poor farmers who cannot afford the price of full dose lime can split in to two, three and four and apply every year without significant yield loss for soybean crops as compared to full dose application at once.

Table 3. Effect of split application of lime on maize grain yield (kg ha^{-1}) at Doyo

Treatment	2009	2010	2011	2012	2013	Mean
Control	1656b	2524b	4259	2762c	1910	2622c
25% every year	1730b	3370ab	4464	3671ab	1792	3005bc
33% every year	1756b	3412ab	4677	4221a	2180	3249ab
50% every year	2176ab	3640ab	4936	3491ab	2256	3300ab
Full dose	2798a	4163a	5101	3192bc	2149	3481a
LSD (0.05)	780	1441	Ns	784	Ns	466
CV (%)	20.48	22.36	14.83	12.01	35.88	11.09

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

Table 4. Effect of split application of lime on soybean seed yield (kg ha^{-1}) at Doyo

Treatment	**2009**	**2010**	**2011**	**2012**	**2013**	**Mean**
Control	1259	1185	1219b	1705	2416	1557b
25% every year	1454	1541	1978a	1977	2441	1878a
33% every year	1674	1662	2270a	1739	2441	1957a
50% every year	1848	1694	2275a	1880	2108	1961a
Full dose	1944	1780	2286a	1850	2408	2054a
LSD (0.05)	Ns	Ns	638	Ns	Ns	294
CV (%)	22.86	20.77	16.91	8.92	7.91	11.62

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

At Hurumu

Similar to Doyo site, Hurumu soil was also responsive to split lime application (Table 5 and 6). Results indicated that all splits gave statistically comparable seed yield with full dose of lime application. Depending on the availability of lime and affordability of maize and soybean growers, it is possible to use either of the above application frequencies. The lowest grain and seed yield of maize and soybean were recorded from control plots.

Table 5. Effect of split application of lime on maize grain yield (kg ha^{-1}) at Hurumu

Treatment	2009	2010	2011	2012	2013	Mean
Control	5226c	4654b	6804	5868d	5993	5709b
25% every year	5851bc	5082ab	7115	6975b	5643	6133ab
33% every year	6579ab	5337ab	7127	7875a	5755	6535a
50% every year	7157ab	5812ab	7914	6678bc	5794	6671a
Full dose	7439a	5864a	8069	6204c	5616	6638a
LSD (0.05)	1337	1202	Ns	485	Ns	725
CV (%)	11.01	11.94	9.96	3.85	12.96	8.60

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

Table 6. Effect of split application of lime on seed yield of soybean (kg ha^{-1}) at Hurumu

Treatments	2009	2010	2011	2012	2013	Mean
Control	1382b	1530	1344b	1436b	2077	1554b
25% every year	1421b	1539	1953a	1766ab	2390	1814ab
33% every year	1674ab	1631	2024a	1858a	217 0	1871a
50% every year	1848ab	1709	2004a	1752ab	2327	1867ab
Full dose	1944a	1734	2050a	1727ab	2188	1929a
LSD (0.05)	497	Ns	470	384	Ns	218
CV (%)	15.97	10.06	13.33	11.86	10.17	8.98

Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. Ns =Not significantly different

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Response of Sorghum and Soybean to Furrow Application of Lime and its Effect on the Acidity of Soils

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Introduction

Liming is considered as a management practice to reduce the soil acidity. Most plants grow well at a pH range of 5.5 – 6.5 and liming is aimed at maintain the pH at this range and several other benefits. However, the cost of lime is prohibitive due to large amounts required. In addition to its expensiveness, over liming may reduce crop yield by inducing P and micronutrient deficiencies (Fageria, 1984).

There are alternative applications strategies such as furrow application of lime in a band may allow lower rates of lime to be used and thereby offset economic constraints posed by high application rates. Furrow application integrated with appropriate cropping systems may not only improve soil pH, but also improve soil structure for sustained crop yields. Thus, this study was initiated with the aim of evaluating the response of sorghum and soybean to localized furrow application of lime and its effect on acid soil amelioration in Assosa area.

Materials and Methods

The study area

This experiment was conducted in the 2012 to 2015 cropping seasons at Assosa District Megele-33 Kebele of western Ethiopia in main rainy season of. The research sites were found in the altitude ranging between 1300 and 1470 m. with the minimum and maximum temperatures of 14.5 and 28.55^{o}C, respectively and an average annual rainfall of 1291.2mm of which 1041.7mm were received between May and October during the cropping season. The soil pH of the area was 5.02, which was very strongly acidic with low available P and 2.36 exchangeable acidity.

Treatments and experimental design

The treatments consisted of control, Recommended NP, Recommended lime broadcasting, Furrow application EA 1/20 + NP, Furrow application EA 2/20 + NP, Furrow application EA 3/20 + NP and Furrow application. The experiment was laid in randomized complete block with three replications. The amount of lime that was applied at each level was calculated on the basis of the mass of soil per 15 cm hectare-furrow-slice, soil sample density and exchangeable Al^{+3} and H^{+} of each site. It has been assumed that one mole of exchangeable acidity is neutralized by equivalent mole of $CaCO_3$.

The recommended rate of NP was applied uniformly to all treatments. Lime was uniformly applied in furrow by hand and incorporated into the soil one month before planting. Urea and DAP were used as the source of N and P, respectively. Application of urea was in two split, while the entire rate of phosphorus was applied at sowing in band for row planted sorghum crops. The plot size was also based on the specific crop recommendation. Data on biomass, yield and yield components of the crop was collected. The plot was kept permanent for the duration of the experiments to observe the carry-over effects of the lime.

Soil sampling and analysis

A composite initial soil sample before planting and Plot based after harvesting soil sample of 0-20 cm soil depth was taken from the experimental site following the procedures of surface soil sampling. Uniform slices and volumes of soil was obtained in each plot was taken in a diagonal pattern through vertical insertion of the auger. Then, the sample was air-dried, grinded using a pestle and mortar, and allowed to pass through a 2mm sieve and analyzed for selected physical chemical properties mainly for soil pH, bulk density, exchangeable acidity(EA), exchangeable aluminum (EAl), total nitrogen (TN), available phosphorous (P), exchangeable potassium (K), calcium, sodium and cation exchangeable capacity (CEC) using standard laboratory procedures. Analysis of total nitrogen of the soil was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Soil reaction (pH) was analyzed using a pH meter with 1:2.5 soil to solution ratio via a glass electrode attached, and Cation Exchange Capacity (CEC) was determined by leaching the soil with neutral 1 N ammonium acetate (FAO, 2008). Available phosphorous was determined by the Bray II method and exchangeable potassium by flame photometer.

Data analysis

Data collected from the experimental field were analyzed using SAS computer software version 9.3 (SAS, 2002). Mean comparison of treatment was done using least significant difference at 5% probability level of significance.

Results and Discussions

Physico-chemical properties of soils before planting and after harvesting

Analysis of soil physico- chemical properties before planting and after harvesting is presented in table 1 and 2. Soil sample analysis before planting indicated that the bulk density was 1.06 g/cm^3 which is low according to (Baruah et al., 1997), according to Bruce and Rayment (1982) soil pH (H_2O) was strongly acid (5.02), available Ca^{2+}, Mg^{2+}, K^+ and Na^+ analysis results were 2.63 (Low), 0.78 (Low), 0.06 (very low) and

0.08 (very Low), respectively (Metson ,1961); cation exchange capacity was 8.25 Cmol kg^{-1} which was low according to Metson (1961).

Soil sample analysis after harvesting showed that soil pH and available P values were significantly increased due to lime application as compared to control. The higher soil pH and available P were obtained when soil was limed while the lowest soil pH and available P were observed at control (0 lime) It is generally known that reducing of soil acidity leads to increased phosphorus availability (Gaume et al., 2001). On the other hand, the application of lime significantly reduced the exchangeable acidity as compared to the other treatments. Generally, there was no significant difference among different furrow application of lime in terms of soil pH, available P and exchangeable acidity. However, furrow applied lime gave significantly higher values of the above soil parameters as compared to control and recommended NP. These results are similar to those reported by Brown et al. (2008), Anetor et al. (2007) and Caires et al. (2002) who reported that liming at various levels had highly significant effects on increasing soil pH, whereas exchangeable acidity decreased significantly with an increase in lime application. In control plot, the great variation in exchangeable acidity before planting and after harvesting is difficult to explain. However, this could be due to soil sampling or error during soil analysis.

Table 1. Soil sample result before planting

pH (1:2.5 H_2O)	Cmol(+) /kg soil						CEC	% AS*	BD
	Exch. acidity	Exch. Al	Ca	Mg	K	Na			
5.02	2.36	2.48	2.63	0.78	0.06	0.08	8.25	57.21	1.06

**AS= Acid saturation*

Table 2. Soil pH, available phosphorus and exchangeable acidity as influenced by split application of lime

Treatment	pH (1:2.5 H_20)	Av. P (ppm)	Exchangeable acidity (Cmol(+) /kg soil)
Control	5.42^{c}	4.18^{bc}	0.38^{a}
Recommended NP	6.01^{b}	4.12^{c}	0.19^{b}
Recommended lime by BC	6.34^{ab}	4.73^{abc}	0.19^{b}
Furrow application EA 1/20	6.33^{ab}	5.15^{a}	0.18^{b}
Furrow application EA 2/20	6.35^{ab}	5.15^{a}	0.14^{b}
Furrow application EA 3/20	6.46^{a}	4.68^{abc}	0.18^{b}
Furrow application EA 4/20	6.45^{ab}	5.03^{ab}	0.16^{b}
LSD (0.05)	0.35	0.85	0.06
CV (%)	4.8	15.4	25.5

**BC= Broadcasting*

Effect of furrow application of lime on plant height and grain yield of sorghum.

The analysis of variance result showed that the plant height and grain yield of sorghum significantly ($P \leq 0.05$) affected due to the applied treatments in all years except 2014 (Table 3). The combined analysis indicated that significantly higher mean plant height was obtained with application of recommended lime by broadcasting and furrow application EA 1/20. However, the lower plant height of sorghum was recorded in other treatments. The increase in plant height with increasing lime rates on acidic soils is highly likely related to the increase in soil fertility and reduction of the toxic concentration of acidic cations. Lime should improve growth conditions for crops and increase crop yields in acidic soils by increasing pH and nutrient levels and reducing the exchangeable acidity. Liming might have reduced the detrimental effect of soil acidity on plant growth due to high concentration of H^+ and Al^{3+} ions in the acid soils (Achalu et al., 2012). Corroborating the results of this study, Oluwatoyinbo *et al*. (2005) reported that plant height was significantly increased by the application of lime. Like plant height, the grain yield of sorghum was increased by the application of lime. The highest grain yield was recorded on the full dose of lime applied by broadcasting. But there was no significant difference with different furrow applied lime every year. The application of lime increased the grain yield of sorghum as compared to the control. This might be due to the capacity of lime to enhance the availability of nutrient such as P. It also reduced soil acidity and prevented P fixation in the soil thus increasing its uptake (Benvindo, 2014). Grain yield of sorghum obtained by application recommended NP was comparable with that of control. Therefore, before application of chemical fertilizer soil acidity problem as to be solved.

Table 3. Sorghum plant height and grain yield as affected by furrow application of lime

Treatment	2013		2014		2015		Combined	
	PH	GY	PH	GY	PH	GY	PH	GY
Control	114.7^{c}	3894.3^{d}	124.1^{a}	3208.3^{a}	108.7^{c}	680.5^{c}	115.8^{b}	2594.4^{c}
Recom.NP	117.1^{c}	3733.4^{d}	124.3^{a}	3720.9^{a}	135.0^{ab}	1594.8^{a}	125.4^{b}	3016.3^{bc}
Recom. Lime by BC	167.0^{a}	6533.9^{a}	135.4^{a}	3597.9^{a}	120.5^{bc}	1600.8^{a}	140.9^{a}	3910.9^{a}
Furrow app. EA 1/20	152.6^{b}	4792.4^{bc}	138.5^{a}	3281.3^{a}	139.3^{a}	1431.8^{ab}	143.5^{a}	3168.5^{abc}
Furrow app. EA 2/20	120.2^{c}	5607.0^{b}	121.8^{a}	3837.5^{a}	113.7^{c}	1009.1^{bc}	118.6^{b}	3484.6^{ab}
Furrow app. EA 3/20	123.1^{c}	4202.1^{cd}	127.6^{a}	3671.9^{a}	123.0^{abc}	1662.3^{a}	124.6^{b}	3178.8^{abc}
Furrow app. EA 4/20	115.2^{c}	4879.4^{b}	126.6^{a}	3494.8^{a}	120.9^{bc}	1743.2^{a}	120.9^{b}	3372.5^{abc}
LSD (0.05)	14.4	881.8	Ns	Ns	16.4	562.1	12.4	830.3
CV (%)	6.2	10.3	9.8	27.5	7.5	22.74	10.3	27.1

Ns= not significant, BC= Broadcasting, PH= Plant height (cm) and GY= Grain yield (kg ha^{-1})

Effect of furrow application of lime on seeds per pod and seed yield of soybean

The seeds per pod and seed yield of soybean were significantly ($P \leq 0.05$) influenced by furrow application of lime during all years (Table 4). The combined over three years analysis indicated that all treatments except the control gave the highest seeds per pod of soybean. This showed that seeds per pod of soybean was improved by application of lime and recommended fertilizer. On the other hand, the highest seed yield of soybean was obtained from recommended lime by broadcasting, recommended NP, furrow application EA 2/20 and furrow application EA 3/20 treatments. Rahman *et al.* (2002) reported that application of lime influenced the nutrient availability of soil, resulting increased the yield and yield components of crops.It seems that application of lime to soybean around Assosa area is not beneficial.

Table 4. Soybean seeds per pod and seed yield affected by furrow application of lime

Treatment	2013		2014		2015		Combined	
	SPP	SY	SPP	SY	SPP	SY	SPP	SY
Control	1.6[b]	951.8[d]	1.8[b]	308.6[b]	1.9[b]	898.7[bc]	1.8[b]	719.7[c]
Recom.NP	2.8[a]	1342.7[ab]	2.2[a]	754.2[a]	2.5[a]	970.8[bc]	2.7[a]	1021.6[ab]
Recommended Lime	2.6[a]	1407.0[a]	2.0[a]	568.2[a]	2.7[a]	1478.1[a]	2.4[a]	1151.1[a]
Furrow app. EA 1/20	2.6[a]	1111.9[cd]	2.2[a]	727.1[a]	2.5[a]	729.9[c]	2.4[a]	856.3[bc]
Furrow app. EA 2/20	2.1[a]	1377.8[ab]	2.2[a]	605.0[a]	2.7[a]	1200.5[ab]	2.3[a]	1061.1[a]
Furrow app. EA 3/20	2.5[a]	1207.0[bc]	2.3[a]	740.4[a]	2.4[a]	1043.5[bc]	2.4[a]	997.0[ab]
Furrow app. EA 4/20	2.5[a]	1071.4[cd]	2.0[a]	644.9[a]	2.5[a]	774.2[c]	2.3[a]	830.2[bc]
LSD (0.05)	0.75	196.8	0.38	226.8	0.35	360.3	0.29	201.1
CV (%)	17.8	9.14	10.1	20.5	7.93	19.9	13.1	22.4

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Effect of Integrated Organic and Inorganic Fertilizer Application on Growth and Yield of Wheat

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Introduction

Wheat is one of the most important cereal crops in Ethiopia in terms of area coverage and production (Tesfaye, 1991). The area under wheat cultivation was estimated at 1.67 million ha with an average yield of 2543 kg ha^{-1} (CSA, 2015). With the rapid increase in population and urbanization, the demand for wheat as a staple grain food is increasing. Though Ethiopia is among the largest wheat producer in Sub-Saharan Africa, consumers' demand far exceeds domestic production and wheat imports are costing the country millions of dollars in foreign exchange every year.

Depletion of soil fertility and poor crop management practices are among the major constraints responsible for the low productivity of wheat in Ethiopia (Gete et al., 2010; Getachew et al., 2014). The use of mineral fertilizers to avert soil fertility depletion in wheat production is still at suboptimal level (Nyamangara et al., 2001). About190631 tons of organic and inorganic fertilizers have been used for the production of wheat in 2014 cropping season (CSA, 2015). The average fertilizer use for wheat production in Ethiopia is 115 kg ha^{-1}, which was by far below the research recommended rate of 250 kg ha^{-1} (KARC, 2014). Continuous production of crops against a backdrop of little fertilizer use over decades (Sanchez et al., 1997) has aggravated the decline in soil fertility and crop yield (Getachew et al., 2014; Gete et al. 2010).

The integration of organic fertilizers, such as vermicompost and conventional compost with inorganic fertilizers may improve and sustain crop yields without degrading soil fertility status. Integration of organic and inorganic fertilizers improved the crop yield compared to application of inorganic NP fertilizers alone (Getachew and Taye, 2005; Getachew et al., 2014). Integrated soil fertility management plays important role in restoring soil fertility and availability of plant nutrients, enhancing crop growth and productivity (Gete et al., 2010; Vanlauwe et al., 2010; Getachew and Tilahun, 2017). Therefore, the objective of this study was to determine the effect of the separate and combined application of vermicompost, conventional compost, and inorganic fertilizers on the yield and yield components of bread wheat.

Materials and Methods

Description of the study area

The experiment was conducted at Kulumsa Agricultural Research Center in 2014 to 2015 cropping seasons. The dominant soil type is vertic-luvisol at Kulumsa is (Sahlemedhin et al., 2003). The experimental site lies at 8.08°N latitude and 39.08°E longitude, at an altitude of 2300 m.a.s.l. It receives mean annual rainfall of 811 mm, which starts in June and continues to September. The mean minimum and maximum annual temperatures are 10.5 and 24.5°C, respectively.

Preparation of conventional compost and vermicompost

The inputs used for the preparation of conventional compost were wheat and maize crop residues, chopped green alfalfa leaves, animal manure, wood ash, forest soil and water. While the vermicompost was prepared from indigenous earthworms, using mixtures of vegetables and food wastes, and bedding materials as feeding stocks for the vermiworms. The vermicasts were collected and used for the experiment. Prior to application, the total nitrogen and moisture contents of the conventional and vermicomposts were determined. The conventional compost rates used to maintain the recommended amount of nitrogen (73 kg ha^{-1}) for bread wheat production at Kulumsa were 11 and 12 t ha^{-1} in 2014 and 2015, respectively. The corresponding rates for vermicompost were 4 and 7 t ha^{-1}, respectively (Table 1).

Table 1. Total amount of conventional and vermicomposts used to maintain the recommended nitrogen rate for bread what production at Kulumsa in 2014 and 2015

Sample	Total nitrogen (%)		Moisture (%)		Fresh matter (t ha^{-1})		Dry matter (t ha^{-1})	
	2014	2015	2014	2015	2014	2015	2014	2015
Compost	0.67	0.60	65	44	18.0	17.5	11	12
Vermicompost	1.79	1.05	29	66	5.3	11.5	4	7

Experimental set-up and procedure

The experiment consisted of eight treatments of sole and various combinations of inorganic NP fertilizers and organic amendments (conventional and vermicomposts). Table 2 shows the details of the treatments. While N being the most limiting nutrient, applications was adjusted to a homogeneous N rate of 73 kg ha^{-1}. The treatments were arranged in randomized complete block design with three replications.

The seedbed was ploughed and harrowed using tractor mounted mould board plough and disk harrow before planting. The gross plot size was 2.6 m by 4 m. Bread wheat variety (*Kakaba*) was planted by hand at a seed rate of 125 kg ha^{-1} during the first week of July each year. Conventional compost and vermicompost treatments were applied to plots two weeks before planting. Phosphorus fertilizer was applied to the respective plots as basal dose at planting as diammonium phosphate (DAP) while nitrogen fertilizer was applied in splits, half at planting and the remaining half at tillering stage as urea. Weeds were controlled using PALAS OD-45 supplemented with hand weeding.

Table 2. Treatments descriptions of conventional compost, vermicompost and inorganic NP fertilizers at Kulumsa in 2014 and 2015

No.	Treatment
1	Control (no input)
2	Recommended N and P (RNP) as inorganic fertilizers (IF) (73/30 kg N/P ha^{-1})
3	Recommended vermicompost (RVC) based on N equivalence (4 and 7 t ha^{-1} for 2014 and 2015)
4	Recommended compost (RC) based on N equivalence (11 and 12 t ha^{-1} for 2014 and 2015)
5	50: 50% RVC: RNP from IF
6	50: 50%RC: RNP from IF
7	50:50% RVC:RC
8	33: 33: 33%RVC:RC: RNP from IF

Data collection and analysis

Number of spikes were determined from each plot from of 0.5 m length and then converted to m^2. Plant height was measured from ten plant samples per plot from the ground surface to the tip of the spike, excluding awns. The length of spikes was determined from ten spike samples per plot, and number of seeds from ten spike samples per plot. Plants were harvested from 2 m by 3 m net plot area, and air dried at normal temperature of 18-22^oC. The dried samples were threshed manually and the biomass and grain and weights were determined. The data were subjected to analysis of variance using SAS - version 9.0 statistical software (SAS Institute, 2004). The differences among treatment means was compared using least significant difference (LSD test).

Results and discussion

The mean yield and yield components of bread wheat are indicated in Table 3. Application of organic and inorganic fertilizers significantly affected most of the bread wheat parameters measured, except for spike length, hectoliter weight and thousand grain weight (Table 3). Year had a significant effect on yield and yield components of bread wheat, indicating temporal variations across cropping seasons.

Table 3. Significance of year, organic and inorganic fertilizers application on yield and yield components of bread wheat at Kulumsa in 2014 and 2015.

Sources of variation	Yield and yield component parameters								
	Spike m^{-2}	Plant height (cm)	Spike length (cm)	No of seeds/ spike	HI (%)	Grain yield (kg ha^{-1})	Total biomass (kg ha^{-1})	HLW (kg hl^{-1})	TGW (g)
Treatment (Trt)	***	***	Ns	***	***	*	***	ns	ns
Year (Y)	***	***	***	***	***	***	***	*	***
Y*Trt	*	**	Ns	**	***	ns	**	ns	ns
Mean	355	87	6.76	43.77	41.51	4424	10758	75.57	35.30
CV (%)	5.78	1.75	5.51	5.20	6.24	7.97	12.09	1.60	5.79
LSD (5%)	24.17	1.80	0.44	2.68	3.06	415.90	1533.50	1.42	2.41

Note: HI = Harvest index; HLW = Hectoliter weight; TGW = Thousand grain weight

The application of organic and inorganic fertilizers significantly ($P<0.05$) increased mean grain yield of bread wheat (Table 4). The highest grain yield of bread wheat (4695 kg ha^{-1}) was obtained from the application of half dose of the recommended rate of vermicompost and the remaining half dose from inorganic NP fertilizer (Table 4). Application of 50% vermicompost and 50% of the recommended rate of NP fertilizer gave grain yield advantage of 504 kg ha^{-1} compared to application of full dose of the recommended rate of vermicompost alone as N equivalence (4191 kg ha^{-1}). Application of the recommended dose of inorganic NP fertilizers produced 4677 kg ha^{-1} of wheat grain yield (Table 4). Application of half dose of the recommended rate of N and P from conventional compost and the remaining half dose from inorganic fertilizer gave 4640 kg ha^{-1} of wheat grain yield. Application of half the recommended rate of conventional compost and half the recommended rate of inorganic NP fertilizers resulted in grain yield advantage of 440 kg ha^{-1} compared to application of compost alone (Table 4). Hence, application of vermicompost or compost alone did not result significant increase in mean grain yield of wheat, indicating the slow release of nutrients from organic fertilizer sources.

The integrated use of organic and inorganic fertilizers resulted in a significant ($P<0.001$) increase in the total biomass of bread wheat (Table 4). The highest total dry biomass (13430 kg ha^{-1}) was obtained from the application of the recommended dose of inorganic NP fertilizers followed by application of 50% of the recommended rate of vermicompost and half the recommended rate of inorganic NP fertilizers (12509 kg ha^{-1}), but statistically significant differences were not observed between them (Table 4). The highest number of spikes (387) and plant height (90 cm) were obtained from the application of 50% of the recommended rate of conventional compost and half the recommended rate of inorganic fertilizer (Table 4). Application of full dose of either vermicompost or conventional compost or their combination resulted in lower plant height, which might be due to the slow release and unavailability of important nutrients from organic sources. In contrast, despite statistically insignificant, the highest number of seed $spike^{-1}$ of bread wheat was recorded from the combined application of 33% of the recommended rate of inorganic N and P fertilizer, 33% of the recommended rate of vermicompost and 33% the recommended rate of compost (Table 3 and Table 4).

The mean grain yields and total biomass of bread wheat recorded in 2015 were statistically superior over the yields in 2014 cropping season (Table 4). This was mainly attributed to the very high rainfall in 2014 and low in 2015 (Fig. 1). Since the soil of Kulumsa is vertic-luvisol (Sahlemedhin et al., 2003), the excess rainfall in 2014 induced waterlogging problem, and thus resulted in underperformance of bread wheat roots and consequently reduced yield compared to 2015 copping season. Although the rainfall condition in most of the main cropping season in 2015 was relatively lower than the long-term average, the soil could conserve and efficiently utilize the available moisture; and hence it resulted in better yield.

Table 4. Effects of year, inorganic and organic fertilizers application on yield and yield components of bread wheat at Kulumsa in 2014 and 2015

Factor	Yield and yield components parameters					
	Spike m^{-2}	Plant height (cm)	Number of seeds $spike^{-1}$	HI (%)	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})
Year						
2014	381[a]	89.5[a]	46[a]	38.89[b]	3680.8[b]	9509.5[b]
2015	328[b]	84.5[b]	42[b]	44.14[a]	5166.3[a]	12007[a]
Integrated nutrient						
No input	331[cd]	85.4[d]	41[bc]	42.37[ab]	4217.6[c]	9869.6[b]
Recommended NP from inorganic fertilizers (DAP and Urea) (RR IF)	382[a]	88.5[ab]	46[a]	35.61[c]	4677.4[a]	13430[a]
Recommended vermicompost based on N equivalency (RR VC)	324[d]	85.8[cd]	43[abc]	41.98[b]	4191[c]	9966[b]
Recommended compost based on N equivalency (RR C)	330[cd]	86.1[cd]	44[ab]	43.36[ab]	4200[c]	9601[b]
50: 50 % RR VC: RR IF	363[ab]	87.3[bc]	45[a]	38.22[c]	4695[a]	12509[a]
50: 50 % RR C: RR IF	387[a]	89.8[a]	45[a]	42.15[ab]	4640[ab]	10944[b]
50: 50 % RR VC: RR C	351[bc]	86.2[cd]	41[c]	43.22[ab]	4241[bc]	9818[b]
33:33: 33 % RR VC: RR C: RR IF	371[ab]	87.3[bc]	46[a]	45.19[a]	4526[abc]	9929[b]

Conclusion

To maintain soil fertility, reduce cost of inorganic fertilizers and sustain bread wheat production, farmers need to be advised to apply the integrated use of organic and inorganic fertilizers. Therefore, application of half of the recommended rate of N and P from vermicompost/ conventional compost and the remaining half from inorganic fertilizers could be recommended as the best management option.

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Effect of Inorganic and Organic Fertilizer Application on Growth and Yield of Maize and Soil Fertility in Assosa Zone

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Introduction

Maize is an important cereal crop, which ranks third after wheat and rice in the world (Rasheed and Mahmood, 2004). Maize was originated in Mexico (Dowswell*et al*., 1996) and introduced to Ethiopia in the late 16th and early 17thcentury by the Portuguese (Orkaido, 2004). Maize is among the main stable food crops in Ethiopia (Wonde et al., 2013). According to CSA (2013), maize is the first crop in terms of production (6,158,317.6 t) with an average yield of 3.1 t ha^{-1}, and second in area coverage (2,730,272.9 ha) after tef. Low soil fertility is one of the constraints to sustain agricultural production and productivity in Ethiopia. Anthropogenic factors such as inappropriate land use systems, monocropping, and nutrient mining and inadequate supply of nutrients aggravated the situation (Gete et al., 2010). To alleviate the problem, integrated nutrient management is an option as it utilizes available organic and inorganic nutrients to build ecologically sound and economically viable farming system (Gruhn et al., 2000; Getachew and Tilahun, 2017). Gruhn et al. (2000) stated that organic inputs influence nutrient availability by the total nutrients added and controlling the net mineralization-immobilization patterns. Organic materials are also precursors to soil organic matter fractions that interact with soil minerals in complexing phosphorus (P) fixing cations thereby reducing P sorption capacity. Wakene et al. (2002, 2003, 2007) demonstrated that the integrated use of farmyard manure (FYM), compost, and bone meal with low dose of NP fertilizers gave comparable maize grain yield compared to the yield obtained from the recommended rate of NP fertilizers (110/20 kg ha^{-1}) in Bako area.

Compost improves soil physical properties and increasing soil organic carbon, N, S and P nutrients (Saison *et al*., 2006). However, the use of manure for domestic energy consumption and removal of crop residues for animal feeding greatly affect soil fertility in the study area. Research findings showed that neither inorganic nor organic fertilizers alone can result in sustainable productivity (Tadesse et al., 2013; Getachew and Tilahun, 2017). These scenarios necessitate the use of integrated nutrient management in crop production since the combined use of organic and inorganic fertilizers builds ecologically sound and economically viable farming systems (Wakene et al., 2007).

Composting has been recognized as a low cost and environmentally sound process for treatment of many organic wastes. A process related to composting which can improve the beneficial utilization of organic wastes is vermicomposting. It is a non-thermophilic process by which organic materials are converted by earthworms and microorganisms into rich soil amendments with greatly increased microbial activity and nutrient availability. Vermicomposting offers a solution to tones of organic wastes that are being burned by farmers and to recycle and reuse these refuses to promote agricultural development in more efficient, economical and environmentally friendly manner. There is a need, however, to bridge the gap between controlled vermicomposting within the laboratory and the broader field utilization of vermicomposts in organic resource management. There are several reasons why farmers will choose to practice vermicomposting. Vermicomposts have excellent chemical and physical properties that compare favorably to traditional composts. Therefore, the objective of this study was to determine the effect of the separate and combined application of organic and inorganic fertilizers on growth and yield of maize in Assosa District.

Materials and Methods

Description of the study area

The experiment was conducted at Assosa Agricultural Research Center which is located in Assosa district of Benishangul-Gumuz Regional State. Assosa District is characterized by hot to warm moist lowland plain with unimodal rainfall pattern. The rainy season commonly starts at the end of April and lasts at the end of October with maximum rainfall in the months of June, July, August, and September. The total annual average (2007-2014) rainfall is 1316 mm. The annual mean minimum and mean maximum temperatures of the district for the periods from 2007 to 2014 are 16.75 and 27.92 ^{O}C, respectively.

Experimental procedure

The experiment was conducted in 2013 and 2014 cropping seasons. The treatments included recommended inorganic NP fertilizer (46/92 kg ha^{-1}), recommended N from conventional compost (12.34 t ha^{-1}), recommended N from FYM (17.5 t ha^{-1}), recommended N from vermicompost (10 t ha^{-1}), 50% recommended N from vermicompost (VC) + 50% N from conventional compost, 50% recommended N from VC + 50% N from FYM, 33:33: 33 33% recommended N from VC + 33% N from conventional compost + 33% N from FYM, 50% recommended N from VC + 50% N from inorganic fertilizer, 50% recommended N from conventional compost + 50% N from inorganic fertilizer, and 50% recommended N from FYM + 50% N from inorganic fertilizer. The volume of organic sources was calculated from their N equivalence of inorganic fertilizer on dry weight basis. The plot size was 3 m × 4 m. Soil bunds were constructed around each plot and around the entire experimental field to minimize nutrient and water movement from plot to plot. Improved maize variety (*BH-540)* was used as test crop. Nitrogen was applied in split as urea, i.e. half at planting as basal and the remaining half as top dressing at 35 to 45 days after planting which occurred 40 days after germination. Urea was hand drilled to the side of plant rows at 5-10 cm depth of the soil. The total dose of P was applied basal as triple super phosphate (46% P_2O_5) during sowing. The field was hand weeded five times after sowing.

Data collection

Ten random soil samples from 0-20 m depth were collected before planting to make one composite soil sample. Similarly, post crop harvest soil samples were collected from each plot from 0-20 cm soil depth. The soil samples collected were prepared following the standard procedures and analyzed for selected soil physical and chemical properties.

Agronomic parameters, including plant height, ear weight per plot and cob weight per plot, cob length and grain yield were collected. The grain yield was adjusted to 12.5 % grain moisture content.

Result and Discussion

Soil physical and chemical properties of the experimental site

The textural classes of the soils were clay, with varying proportions of sand, silt and clay. The soil pH was 5.8 (Table 1). The exchangeable K of the soil before application of the treatments was 0.1443 cmol (+) kg^{-1}, which is very low, indicating the depletion of cations or plant nutrients in the area. Available soil P was 3.47 ppm, which is rated in very low range (London, 1991).

Table 1. Major characteristics of the experimental soil

Soil character	Values	Remark
Soil pH (1:2.5 soil water ratio)	5.8	Moderately acidic
Total Nitrogen (%)	0.28	High
Organic matter content (%)	2.46	Moderate
Available phosphorous (ppm)	3.47	Very Low
Cation exchange capacity (cmol (+) kg^{-1})	22.6	Low
Exchangeable potassium (meq/100 g soil)	0.1443	Very low
Soil texture (%)	Clay (60.4); Sand (30.5); Silt (9.1)	
Textural class	Clay	

The total N was found in medium range (London, 1991). The organic carbon content of the soil was also found low range London (1991). The low OC and medium N content in the study area indicate low fertility status of the soil. This could be due to continuous cultivation and lack of incorporation of organic materials. (Table 1)

Grain yield

Year had a significant ($P < 0.01$) effect on grain yield and yield components of maize, indicating seasonal variation of environmental factors (Table 2). In 2014, the highest mean maize grain yield of 4992 kg ha^{-1} was obtained from the application of 50% of the recommended N from VC and 50% NP from inorganic fertilizer. While in 2015, the highest grain yield of 5842 kg ha^{-1} was obtained from the application of same treatment combinations in 2014 (Table 3). This indicates that application of 50% of the recommended N from VC and 50% from the recommended inorganic NP fertilizer has been found superior in terms of enhancing maize grain yield in both successive years over the rest treatments. The increase in mean grain yield of maize was mainly due to better performance in yield attributing factors, better nutrient use efficiency and better grain development. Similarly, Ayoola and Makinde (2006) reported the prevalence of higher nutrient use efficiencies with the combined application of organic and inorganic fertilizers.

Table 2. Mean square of yield and yield components of maize on Nitosol of Asossa district

Source of variation	DF	Mean squares			
		Ear length (cm)	Number of cob per plant	Plant height (cm)	Grain yield (kg ha^{-1})
Replication	2	7.69081	0.01867	863.9	41327.4
Treatment	9	50.917	0.02519	103.9	5091.7*
Year	1	1.22694	0.32267***	15507.6**	80908.8 ***
Year*Treatment	9	1.54138	0.05007	457.1	22054.0 ***
Error	38	1.29186	332.0	332.0	7457.9

**, **, ***significant at 5, 1% and 0.01 probability level*

High doses of inorganic and organic fertilizers increased yield as N and P are the main driving force to produce high yields of maize. Compost, vermicompost and FYM improve soil physical, chemical and microbial conditions. Similarly, Shah and Ahmad (2006) reported higher wheat grain yield in the treatments receiving inorganic and organic fertilizer. Likewise, Ahmad et al. (2006) found statistically similar grain yield of sorghum between (enriched compost and 50% of recommended N fertilizer) and inorganic fertilizer. Abunyewa et al. (2007) found higher maize grain yield from smaller amounts of manure and light fertilizer application than sole heavy fertilization, which was due to the efficiency in terms of crop utilization and sustainable productivity. Rajeshwari et al. (2007) also found higher mean yield from the integrated application of organic and inorganic fertilizers. The integrated use of low dose of NP fertilizers with FYM significantly increased maize grain yield in Bako area (Wakene et al., 2002).

Integrated use of organic fertilizers, such as compost, vermcompost and FYM and inorganic fertilizer could be the potential alternative in improving crop yield and soil fertility, particularly on acidic soils of Assosa district where boron, molybdenum, copper and zinc deficiencies are common (ETHIOSIS, 2014). As there is no fertilizer sources for micronutrients currently used in the region, the integrated use of organic and inorganic fertilizers in Benshalgul Gumuz Region will have paramount importance. Sole vermicompost application across both years produced statistically similar grain yield as inorganic fertilizers and integrated fertilizers in 2015 (Table 3), which might be due to the residual effects of organic fertilizer sources applied in 2014 cropping season. Lampkin (1992) indicated that use of compost over several seasons increased maize yields by 40-60%, but 80-95% in combination with inorganic fertilizers.

Table 3. Effect of organic and inorganic fertilizers on yield and yield components of maize in Asossa zone

Source	Ear length (cm)	Number of cob per plant	Plant height (cm)	Grain yield (t ha^{-1})
Year				
2015	15.31	1.24A	196.22A	4.550A
2014	15.03	1.09B	164.07B	3.815B
LSD	0.59	0.10	9.52	451
2014				
Treatments				
Recommended NP inorganic fertilizer	16.66	1.33	185.33b	4.695a
Recommended N conventional compost (CC)	15.26	1.20	184.33c	3.4.67c
Recommended N FYM	15.60	1.53	202.00a	3.743bc
Recommended N vermicompost (VC)	14.46	1.13	207.33a	4.089b
50: 50 % recommended N VC: CC	15.40	1.13	182.67cd	3.549c
50: 50 % recommended N VC: FYM	15.20	1.20	200.00ab	3.950bc
33: 33:33 % recommended N VC: CC: FYM	14.80	1.26	190.67ab	3.911bc
50: 50 % recommended N VC: inorganic fertilizer	17.66	1.20	208.53a	4.992a
50: 50 % recommended N CC: NP inorganic fertilizer	16.10	1.26	205.33ab	3.671bc
50: 50 % recommended FYM: NP inorganic. Fertilizer	16.00	1.13	179.00d	3.919.bc
LSD	1.87	0.4144	23.62	0.518
CV%	7.49	19.48	20.65	7.5
2015				
Recommended NP inorganic fertilizer	14.640	1.066	176.33e	5.050ab
Recommended N conventional compost (CC)	14.833	1.066	200.00bc	4.810a
Recommended N FYM	15.20	1.00	181.67de	4.452ab
Recommended N vermicompost (VC)	15.00	1.26	209.67ab	5.110a
50: 50 % recommended N VC: CC	15.46	1.13	208.67ab	4.960a
50: 50 % recommended N VC: FYM	14.30	1.06	200.67bc	5.136a
33: 33:33 % recommended N VC: CC: FYM	14.20	1.00	210.20ab	4.157ab
50: 50 % recommended N VC: inorganic fertilizer	16.80	1.06	221.00a	5.842a
50: 50 % recommended N CC: NP inorganic fertilizer	15.267	1.26	191.67cd	4.126ab
50: 50 % recommended FYM: NP inorganic. fertilizer	14.600	1.00	190.80cd	4.123ab
LSD	1.87	2.33	48.35	1.700
CV%	9.06	12.50	13.63	22.92

Plant height, number of cobs per plant and ear length

Plant height of maize was significantly (P <0.05) influenced by organic and inorganic fertilizer application. Application 50% recommended N from VC and 50% from NP inorganic fertilizer in resulted in the highest plant height of 209 cm in 2014 and 221 cm in 2015 (Table 3). The lowest plant height of maize was recorded from 50% of the recommended N from FYM and 50% from inorganic NP fertilizer in 2014 cropping season, and from the recommended inorganic NP fertilizer in 2015 cropping season (Table 3). The integrated fertilizer application resulted in a similar plant height of maize with the recommended inorganic fertilizer rate in 2014 cropping season. In contrast, the integrated fertilizer application gave statistically similar plant height with the recommended N from organic fertilizers in 2015 (Table 3). Similarly, Ayoola and Makinde (2009) reported that taller plant height of maize was obtained from the application of organic and inorganic fertilizer sources than sole application of either organic or inorganic nutrient sources.

Conclusion

Integrated use of organic fertilizers, such as compost, vermcompost and FYM and inorganic fertilizer could be the potential alternative in improving crop yield and soil fertility, particularly on acidic soils of Assosa district. The use of half recommended N from vermicompost and NP from inorganic fertilizer could produce better mean grain yield of maize in Assosa district. Soil physico-chemical changes through use of organic and inorganic fertilizer integration should be explained by comparing pre-planting and post-harvest soil analysis data. Therefore; use of half recommended N from vermicompost and NP from inorganic fertilizer was recommended for increasing the production and productivity of maize crop for the study area.

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Evaluation of Different Earth Worm Species and Food Sources for their Vermiculture and Vermicompost outputs in Raya Azebo District, South Tigray

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Introduction

Soil degradation and declining crop yields, agricultural sustainability with respect to maintenance of soil fertility and stabilized crop production year after year are the main concern. Besides, rapid growth of urbanization, industrialization, population increase, and change in life style has led to generation of huge amount of wastes over the whole world. Accordingly, solid wastes at low capital, in eco-friendly and energy saving basis has attracted much attention worldwide. Ever increasing cost of energy would be an important constraint for increased use of chemical fertilizers in achieving production targets coupled with its deleterious effect on soil environment. Vermicomposting has been considered as a way to transform wastes into useful compost for plant and soil, while diminishing their negative environmental impact. The technology, therefore, has two benefits, i.e. producing good quality organic fertilizer, and reducing the volume of organic waste by converting it into organic fertilizer.

Vermicompost promotes plant growth from 50-100% over conventional compost and 30-40% over chemical fertilizers. In addition to providing soil organic carbon and NPK, vermicompost also provides enzymes and hormones which stimulate plant growth. It significantly stimulates the growth of a wide range of plant species such as tomato (Gutiérrez-Miceli et al., 2007), pepper (Arancon et al., 2005), garlic (Argüello et al., 2006), aromatic and medicinal plants (Anwar et al., 2005), sorghum and rice (Sunil et al., 2005), and banana and papaya (Cabanas-Echevarria et al., 2005). It enhances soil biodiversity by promoting the beneficial microbes which, in turn, enhances plant growth, plant health and crop yield by producing growth regulating hormones and enzymes, controlling plant pathogens, nematodes and other pests. Wastes are degraded by over 75% faster than conventional systems and compost produced are cleansed of harmful microorganisms and toxic substances, and enriched with nutrients and beneficial soil microbes.

Vermicomposting technology is new to Ethiopia. However, Arancon and Edwards (2006) reported that application of vermicompost in different locations in Tigray National Regional State doubled grain yield of several crops compared to the check (non-fertilized). Nevertheless, despite the positive effects of vermicompost on plant growth and yield, there is also strong evidence that these effects are not general or constant, and there is great variability in the magnitude of the effects reported in different studies. Vermicompost may decrease growth and even cause plant death (Lazcano et al., 2010). The variability in the effects of vermicompost may depend on the cultivation system into which it is incorporated, as well as on the physical, chemical and biological characteristics of vermicompost, which vary widely depending on the original feedstock, the earthworm species used, the production process, and the age of vermicompost (Warman and Anglopez, 2010).

Vermicomposting efficiency is measured by the worm number and biomass produced and by the vermicompost yield in a certain period of time. To get the maximum efficiency of vermicomposting, the compost worms must be provided with the five basic things that they need. These are favorable living environment, usually called "bedding", food source, correct moisture of the substrate, adequate aeration, and protection from too high or too low temperatures. Since moisture holding capacity and aeration are characteristics of bedding, the selection of bedding materials is a key to successful vermicomposting. Fortunately, the materials that can be used for good bedding mixtures are generally available and mostly abundant in the farm and even in the backyard and households. It is suggested that selection of substrate materials is a key to efficient vermicomposting process. Different organic materials that can be used as a food sources for the worms have different characteristics. Likewise, different worms have different efficiency of vermicompost production. The differences can affect directly the reproduction and growth of worms, and the amount of substrate that can be broken down by worms into compost. Therefore, the objective this study was to evaluate the effect of different worms and feedstock types on the quality of vermiculture and vermicompost.

Materials and Methods

The experiment was conducted in 2015 and 2016 cropping seasons at Fachagama Research station of Mehoni Agricultural Research Center, Raya Azebo district located in Southern zone of Tigray region, northern Ethiopia. The topography is gentle slope. Mehoni is located 668 km from Addis Ababa and about 120 km south of Mekelle. Geographically it is located at 12.70° North latitude and 39.70° East longitude at an altitude of 1574 m.a.s.l. It receives a mean annual rainfall of 539 mm with an average minimum and maximum temperature of 12.81 and 23.24°C, respectively (MeARC, 2016). The soil textural class of the experimental site was clay with a pH of 8.5. The study area, Raya Azebo district, is under sub-moist lowlands (SM1-3a). The area receives bimodal rainfall with low and erratic distribution. The main rain season is from end of June to early September and the highest amount of rain is in July and August, whereas the short rain season starts in February and ends in March.

Earthworms and feedstocks were collected for the determination of the dry matter of each feedstock. A soil sample of 100 g was collected and oven dried at 70^{O}C for 48-72 hrs. Worm cages had 1m length, 0.5 width and 0.5m depth. The treatments were factorial combination of 3 worm types (LOCALa, LOCALb and *E. fetida*) and 5 feed stocks (sorghum straw, tef straw, industrial waste, fruit waste and chat). The two local worms are our own collections and have been phenotypically characterized once while *E. fetida* was brought from Ambo Plant Protection Research Center. The experiment was laid in randomized complete block design in factorial arrangement with three replications. The straws and wastes were air-dried and shredded with aiding tools as smaller size of the feed particles is favorable to worm action and also provides more surface area per volume, which facilitates microbial activities as well as moisture availability. The bedding material used for all treatments was composite of dried cattle manure, sorghum straw and soil. Pre-composting decomposition was done for 15 days to the 65 kg mixture of bedding material and feedstock at 3:2 ratio. After, stirring and drying the mixture, 200 adult worms (close to 100 g) were introduced to each treatment. The mixed substrate was sprayed on the surface with water every day or whenever drying was observed to maintain moisture at approximately 60-70%.

At the 30^{th} and 60^{th} days of vermicomposting, the total worm biomass was determined by weighing and the number by counting the individual worm of any size. The worms were first taken from the substrate by hand, and the substrate materials were gently removed. To facilitate removal of the adhering material on the earthworm body, the hands are moistened first. Data on the increase in number and weight were obtained by subtracting the initial measurements from the measurements at day 30 and 60. The data were collected and recorded on bin base. At the end of the experiment, the un-composted portion of the substrate was separated from the composted part. The harvested vermicompost was then mixed thoroughly and then air-dried for one day. The air-dried weight was lastly determined.

Result and Discussion

Number of worms

The mean numbers of worms are shown in Table.1. The number of worms showed significant differences among combinations of worms and feeding sources. The mean worm numbers were consistently highest when exotic worms were fed with sorghum compared to local worms fed with any of the feed sources. The local worms fed with sorghum, fruit, industrial waste, tef or chat had no statistically significant difference on mean number of worms produced. Feeding exotic worms (*E. fetida*) either with sorghum, fruit, industrial waste, tef or chat did not show statistically signifacnt response for mean worm number. Feeding exotic (*E. fetida*) worms with sorghum straw resulted in 34.53 and 52.43% increment in worm numbers over the same feed to the LOCALa and LOCALb worms, respectively. This implies that exotic worms can be cultured fast by feeding sorghum straw under Mehony climatic condition.

The superiority of sorghum feed might be due to the supply of easily metabolizable organic matter, non-assimilated carbohydrates, and even low concentration of growth-retarding substances, which favor earthworm growth in waste system (Suthar, 2007). Similarly, growth rate (worm/day) has been considered as a good comparative index to compare the growth of earthworms in different waste or food (Edwards et al., 2004). The increment in worm numbers up to the fourth month is inconsistent and varies from treatment to treatment particularly for the local worms (Fig. 1). This might be due to the time taken by worms to adapt themselves with the condition and to enter to the normal reproductive situation. When monthly growth rate is computed, the minimum was 0.34 and the maximum was 0.69, indicating that exotic worms had still relatively high monthly population growth rate at Mehony condition.

Table 1. Effect of different bedding and waste feeds on mean values of average amount of vermicompost yield and average number of earthworms

Treatment	Worm no. at harvest*	Vermiompost dry matter (kg)
LOCALa EW*Sorghum	2392^bcde^	29.88^cde^
LOCALa EW*Teff	2089 ^de^	27.13^ed^
LOCALa EW*Chat	2345^bcde^	28.13^ed^
LOCALa EW*Industrial wastes	2041^de^	28.75^ed^
LOCALa EW*Fruit wastes	2361^bcde^	26.88^ed^
LOCALb EW* Sorghum	2111^cde^	27.38^ed^
LOCALb EW* Tef	1717^e^	22.38^e^
LOCALb EW*Chat	1734^e^	19.5 e
LOCALb EW*Industrial wastes	2107^cde^	25.0^ed^
LOCALb EW* Fruit wastes	2405^bcde^	35.38^bcd^
Exotic EW* Sorghum	3218^a^	51.5^a^
Exotic EW* Tef	2807^abcd^	45.38^ab^
Exotic EW* Chat	3098^ab^	46.38^ab^
Exotic EW* Industrial wastes	2815^abcd^	45.88^ab^
Exotic EW* Fruit wastes	2882^abc^	41.25^abc^
CV (%)	15.29	16.87
LSD (*p≤0.05)*	789.12	12.08

**Worm number is on the 22th month. Means with same letter(s) in same column are not significantly different at p ≤ 0.05; LSD= least significant difference; CV= coefficient of variance.*

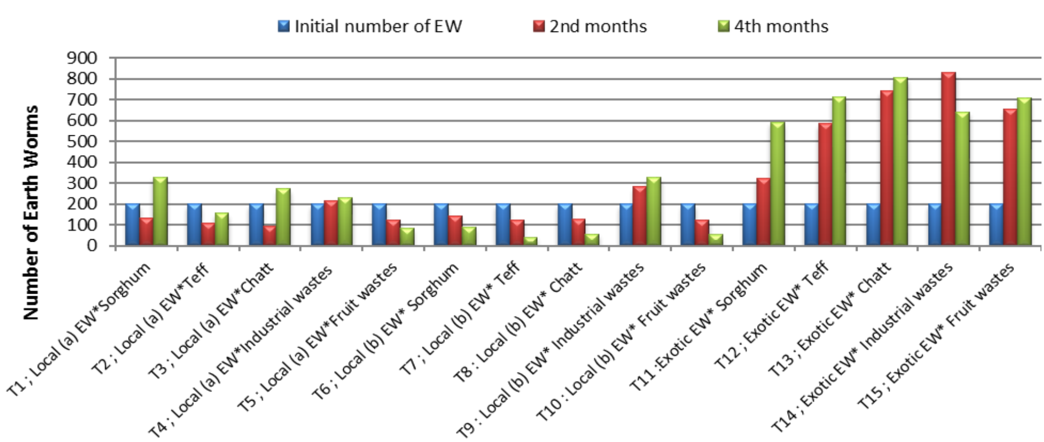

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Fig. 1. Growth of earthworms as affected by different feedstock types

Vermicompost dry matter

Data on the vermicompost weights are shown in Table 1. The treatment showed statistically significant (P ≤0.05) variation for vermicompost yield. Based on vermicompost yield and dry matter, exotic worms fed with sorghum straw was the best followed by chat and then tef. Exotic worms fed with sorghum resulted in statistically significant vermicompost yield compared to the local worms fed with different feeds. However, feeding the same worm with different feedstock sources had no significant (p ≤ 0.05) difference on the vermicompost yield. Similarly, the final weight and volume of vermicompost varies with original feedstock or substrate type (Elina, 2016) and worm species (Rajendran and Thivyatharsan, 2013). Materials with high C:N ratio give higher vermiconpost yields than low C:N ratio as they create a more hospitable habitat for worms due to higher absorbency and bulking potential. The high N content of worm food is favorable to worm growth but high N content of bedding and the associated heating during decomposition could kill the worms or retard normal reproduction.

Another important characteristic of bedding material is its high bulking and water-holding capacity. It was observed that bulk of substrates was reduced after pre-composting and dried easily when placed in vermiculture boxes so that it required more frequent moistening. A little drying of the skin can kill worms because their bodies have very high water content. Therefore, the ability of worms to consume and convert the waste into vermicast varies according to the substrate and hence, the differences in vermicompost yield.

Conclusion and Recommendation

There are different numbers of worms in different type of bedding material. The maximum number of Exotic EW (*Eisenia fetida*) on sorghum resulted height bedding that is 3218 worms and the minimum number of worms (1734) in (Local (b) EW* Teff) which is end of vermi-composting period. With respect to vermi-compost yield, it was significantly (P<0.05) affected by bedding materials. The highest vermi-compost yield (51.5 kg) was obtained at a bedding Exotic EW* Sorghum, whereas the lowest numerical result (19.5 kg) was recorded from a Local (b) EW* Chat (Table 2).

Therefore the research result indicated that the exotic earth worms (*Eisenia fetida*) showed highest in multiplication in numbers of worms and producing vermicompost in period of time.

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Determination of Biochar Applicaton Rate for Improved Production of Lemmon grass (*Cymbopogon citratuc* L.)

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Introduction

Lemongrass (*Cymbopogon citratuc* L.) belongs to the family of Poaceae (Graminae). Lemon grasses grow well in a variety of soils with good drainage under sunny, warm and humid conditions. The oil yield is correlated to the rainfall, a well distributed rainfall, which is native to southern India, ceylon, indonesia and Malaysia (Tashi, 2008). Lemongrass oil has a wide range of applications in the cosmetic, perfume, pharmaceutical and food industry. Local people use lemon grass oil to subdue toothache. Lemon grass oil can help to accelerate the healing of scratches and cuts. However, when pure lemon grass oil comes into direct contact with the skin, it causes a burning sensation. In Asia, such as Thailand, Indonesia and Vietnam, lemon grass is frequently used as a spice to flavor meat dishes and soups (Tashi, 2008).

Farmers need better technologies, more sustainable practices, and fertilizers to improve and sustain their crop productivity. Fertilizers play a vital role in raising the agricultural productivity in Ethiopia over a period of time (Samuel, 1981). However, the cost of chemical fertilizers and their associated risks on the environmental safety was becoming unaffordable (Mahajan *et al*., 2008). To alleviate these problems, easily available and an environmental friendly soil amendment like biochar is of very high significance to increase agricultural productivity and ensure food security. Biochar is a fine grained highly porous charcoal (carbon) that can be formed as a result of the pyrolysis of biomass in a complete or absence of oxygen and it is different from other charcoals for intended use as a soil amendment (Gaunt and Lehmann, 2008).

Currently, biochar has widely been accepted and given great attention not only due to its contribution in mitigating climate change but also as a desirable soil amendment material that can enhance fertility. Therefore, biochar serves as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and provide a habitat for beneficial microorganisms to flourish (Warnock et al., 2007). Biochar has agronomic as well as environmental impact for it is a good soil amendment. It improves water holding capacity and aggregate stability, CEC and soil pH (Abebe *et al.*, 2012; Getachew et al., 2016). Therefore, the objective of this study was to evaluate the effects of different rates of biochar amendment on growth and yield of lemon grass and soil fertility.

Materials and Methods

Description of the experimental area

The experiment was conducted during the main season of 2013 and 2014 cropping season at Wondo Genet Agricultural Research Center. It is geographically located at 07° 03' 19.1" to 07° 04' 00.2" N latitude and from 38° 30' 08.4" to 38° 31' 01.8" E longitude. It receives mean annual rain fall of 1128 mm, with minimum and maximum temperature of 11 and 26°c, respectively. The soil textural class of the experimental area is clay loam with pH of 6.4.

Treatments and experimental design

The biochar types used in this study wer prepared from Coffee husk, and bagasse from sugar factor. The biochars were crushed into particles of different sizes ranging between 2 mm to 2.5 mm. Each biochar type was applied at rates of 5, 10, 15 and 20 tons ha^{-1}, and a control without amendment, with a total of nine treatments. The treatments were laid out in randomized complete blocked design with three replications (Table 4). The plot size used was 3m x 3m= $9m^2$. The biochars were applied manually by mixing it into the surface soil a week before planting.

Planting lemmon grass for better quality and yield of oil was recommended to grow by slips obtained by dividing well-grown clumps at Wondo Genet Agricultural Research Center planting materials multiplication site. Top of clumps was cut off within 20 to 25 cm of the root and the latter should be divided into slips and panting was done manually with panting distance of 60 cm between plant and 60 cm between rows. Proper hoeing, weeding and irrigation of the experimental field were carried out uniformly when required.

Soil sampling, growth and yield parameters

Soil samples were collected from the experimental site at a depth of 0-20 cm before biochar application and one year after biochar amendment. Plant growth and yield data was collected by randomly sampling five plants from central rows of each plot. Plant height, fresh biomass, and number of leaves per hill, essential oil content and oil yield were collected and analyzed.

The collected soil samples were prepared following the standard procedures and analyzed for selected soil physic-chemical properties (Carter, 1993). Essential oil content was determined by taking 300 g fresh leaves of composite samples using hydro-distilled in a Clevenger apparatus according to Guenther (1972). The oils were collected, dehydrated, measured and expressed in w/w dry basis.

Data analysis

The collected agronomic data were subjected to analysis of variance using SAS (version 9) computer software (SAS inst., 2004). Least significant difference (LSD) was used to compare means at 5% probability level.

Results and Discussion

Biochar chemical properties

The results of boichar properties are indicated in Table l. The carbon content of biochar was high and the available P and total N were also high. Exchangeable K, Ca and Mg concentrations of biochar were medium to high. The CEC of the biochars is in the medium range. There are nutrients in boichar rather than its action as soil conditioner, but it is better to apply it together with additional nutrients to enhance its function (Steiner et al., 2008). Other studies indicated that biochar has been shown to retain nutrients against leaching (Getachew et al., 2015; Lehmann et al., 2003), potentially improving the efficiency of nutrients applied alongside biochar (Getachew et al., 2016; Major et al., 2010). The chemical properties of biochar vary based on the type of feedstock types used for charring; the charring environment (e.g. temperature, air) and additions during pyrolysis process (Glaser et al., 2002). The source of biochar material strongly affects the content and availability of nutrients in the soil after amendment. The soil chemical properties after amendment will strongly be affected by source of biochar applied.

Table 1: The selected physicochemical properties of the experimental soil and biochars used.

Parameters	
Soil	
Textural class	clay loam
pH-H_2O	6.4
Organic C (%)	1.82
Total N (%)	0.20
Available P (ppm)	9
CEC (meq/100g)	19.78
Exchangeable K (cmol/kg)	_
Exchangeable Na (cmol/kg)	0.08
Exchangeable Ca (cmol/kg)	9.15
Exchangeable Mg (cmol/kg)	2.51
Coffee husk biochar	
Organic C (%)	
Total N (%)	44.95
Available P (ppm)	0.59
CEC (meq/100g)	36
Exchangeable K (cmol/kg)	15
Exchangeable Na (cmol/kg)	
Exchangeable Ca (cmol/kg)	0.77
Exchangeable Mg (cmol/kg)	6.47
Bagasse drived boichar	**2.37**
Organic C (%)	
Total N (%)	29.58
Available P (ppm)	0.25
CEC (meq/100g)	50
Exchangeable K (cmol/kg)	33.15
Exchangeable Na (cmol/kg)	_
Exchangeable Ca (cmol/kg)	8.49
Exchangeable Mg (cmol/kg)	3.82
	0.62

Note: C = carbon; N= nitrogen; P = phosphorous; CEC = cation exchange capacity

Soil properties

Soil organic C and pH were increased one year after biochar application. Similar trends were observed for total N, available P, CEC and exchangeable bases; such increases were due to biochar application (Table 2). The increase in soil pH due to application of biochar could be because of high surface area and porous nature of biochar, which increase the CEC of the soil. Agusalim et al. (2010) reported the decrease in exchangeable Al and soluble Fe in biochar-amended soils. Other studies also indicated that Al and soluble Fe were decreased in biochar-amended soil due to the increase in CEC (Lehmann et al., 2006; Agusalim et al., 2010). The increase in organic C and total N due to addition of biochar could be resulted from the presence of high amount of C and N in the biochar. Higher values of organic C in biochar treated soils indicate the recalcitrance of C-organic in biochar (Lehmann, 2007; Getachew et al., 2017).

The increase in available P could be due to the presence of high P in the biochar and the increase in soil pH and CEC due to biochar application, which reduce the activity of Fe and Al. Similarly, Previous studies also indicated the increase in available phosphorous after the application of biochar (van Zwieten et al., 2010; Chan et al., 2008). The increase in CEC due to application of biochar could be resulted from the inherent characteristics of biochar, such as high surface area, and porousity, and variable charge organic material that has the potential to increase soil CEC, surface sorption capacity and base saturation when added to soil (Glaser et al., 2002). Therefore, soil amended with biochar had high CEC (Agusalim et al., 2010; Chan et al., 2008; Getachew et al., 2016). Higher values of exchangeable bases with biochar treated soils might be attributed to the presence of ash in the biochar. The ash content of biochar helps for the immediate release of the occluded mineral nutrients like Ca, K and N for crop use (Scheuner et al., 2004). The results of the present study also agree with Lehmann et al. (2003) who reported the highest exchangeable bases in biochar amended soils.

Table 2. Chemical properties of soil samples before and after one year amendment in 2013 and 2014 cropping season

Soil properties	Before amendment	After one year amendment
Textural class	clay loam	clay
pH-H_2	6.40	6.80
Organic C (%)	1.81	2.00
Total N (%)	0.20	0.27
Available P (ppm)	9.00	24.74
CEC (meq/100g)	19.78	29.90
K (Cmol/kg)	-	1.32
Na (Cmol/kg)	0.08	0.63
Ca (Cmol/kg	9.15	9.53
Mg (Cmol/kg)	2.51	6.60

Yield and yield components

In 2013 cropping season, statistically significant differences were not observed among biochar rates for all parameters (Table 3). Numerically higher lemongrass number of leaf per hill (112 kg ha^{-1}) and fresh biomass (5695 kg ha^{-1}) was obtained from application of 15 t ha^{-1} rate coffee husk biochar, while higher moisture content (73.3%) and essential oil yield (28.2 kg ha^{-1}) were recored from bagasse biochar with the same rate compared to other biochar rates. However, in 2014 cropping season, application of biochar had significant ($p<0.001$) effect on lemongrass fresh biomass, number of leaf per hill ($p<0.01$) and essential oil yield ($p<0.05$), but not on moisture content (Table 3). The highest lemongrass number of leaf per hill (207.2 kg ha^{-1}) was obtained from addition of 15 t ha^{-1} from coffee husk biochar, while the hihest essential oil yield (72.2 kg ha^{-1}) and fresh biomass (10845 kg ha^{-1}) were obtained from bagasse biochar with the same rate (Table 3). The significant difference in biochar rates in 2014 may be because of the positive effect of biochar on soil properties thorough time, which agrees wit the findings of Stephanie et al. (2005). Steiner et al. (2008) also indicated that application of biochar and fertilizer improved plant growth and doubled grain yield in comparison to fertilizer alone. The result was in agreement with the works of Chan et al. (2008) and Major et al. (2010), indicating that positive effects of biochar application on crop yields with application of 5-50 t ha^{-1} biochar, with appropriate nutrient management. Since biochar is recalcitrant, single application of it can provide beneficial effects for several seasons in the field (Steiner et al., 2008; Major et al., 2010).

Analysis of variance over two years indicated that lemmon grass fresh biomass and number of leaves per hill significantly ($p<0.05$) differed among biochar rates (Table 4). The highest fresh biomass, number of leaf per hill and moisture content were obtained from application of 15 t ha^{-1} from coffee husk biochar followed by the application of 15 t ha^{-1} bagasse biochar with the same rate (Table 4). Lemmon grass fresh biomass and number of leaf per hill increments of 20 and 13% were obtained from application 15 t ha^{-1} biochar, respectively compared to the control. Malisa et al. (2011) also showed that application of 10 ton ha^{-1} biochar increased yield of Kenaf (*Hibiscus cannabinus L.*) andsoil physic-chemical properties in Malaysia. Several studies demonstrated crop yield improvements due to biochar application on acidic and highly weathered tropical soils (Getachew et al., 2015; Lehmann et al., 2003; Rondon et al., 2006).

Table 3. Effect of biochar application on yield and yield components of lemon grass at W/Genet in 2013 and 2014 cropping season

Treatments	2013			
	FBM kg ha^{-1}	NLPH	MC (%)	EOY kg ha^{-1}
0 (control)	4674.2	90.90	76.90	21.9
5 t ha^{-1} CHB	4944.2	100.90	77.30	24.7
10 t ha^{-1} CHB	5058.9	98.00	77.70	25.5
15 t ha^{-1} CHB	5694.6	111.7	77.80	26.0
20 t ha^{-1} CHB	5459.3	97.20	78.00	27.0
5 t ha^{-1} SBB	5236.4	96.60	77.90	26.0
10 t ha^{-1} SBB	5093.3	92.00	78.00	23.7
15 t ha^{-1} SBB	4950.9	95.20	78.32	28.2
20 t ha^{-1} SBB	4610.9	99.00	78.31	23.0
$LSD_{0.05}$	NS	NS	NS	NS
CV (%)	19	18.9	2.2	22
Treatments	2014			
	FBM kg ha^{-1}***	NLPH**	MC (%)	EOY kg ha^{-1}*
0 (control)	8564.3^{d}	190.5^{bc}	71.3	57.0^{c}
5 t ha^{-1} CHB	8975.1^{cd}	188.8^{bc}	72.0	63.8a^{bc}
10 t ha^{-1} CHB	9978.6^{ab}	194.7^{bc}	71.3	61.7^{bc}
15 t ha^{-1} CHB	10298.2^{ab}	207.22^{a}	72.8	66.96^{ab}
20 t ha^{-1} CHB	9063.3^{c}	183.5^{c}	72.0	63.3^{bc}
5 t ha^{-1} SBB	9986.2^{ab}	191.9^{bc}	71.8	67.0^{ab}
10 t ha^{-1} SBB	9686.1^{bc}	190.35^{bc}	71.4	62.2^{bc}
15 t ha^{-1} SBB	10844.8^{a}	200.4^{ab}	72.1	72.2^{a}
20 t ha^{-1} SBB	10185.5^{ab}	200.4^{ab}	71.7	68.9^{ab}
$LSD_{0.05}$	876.8	12.28	NS	8.73
CV	9.3	6.9	2.6	14

** Significant p<0.05, **significant p<0.01, ***significant p<0.001, Ns= not significant. Means with the same letter in column are not significantly different at 5% level for Least Significant Difference Test. CH - biochar from coffee husk, SBB- sugarcane bagasse biochar, FBM –fresh biomass, NLPH-no of leaf per hill, MC-moisture content, EOY-essential oil yield.*

Table 4. Effect of biochar application on yield and yield components of lemon grass at W/Genet combined over years

Treatments	FBM kg ha^{-1}*	NLPH*	MC (%)	EOY kg ha^{-1}
0 (control)	6619.66^{c}	140.756^{b}	74.05	39.52
5 t ha^{-1} CHB	6959.6^{bc}	144.856^{b}	74.68	44.28
10 t ha^{-1} CHB	7611.3^{ab}	146.356^{b}	74.72	43.60
15 t ha^{-1} CHB	7996.4^{a}	159.456^{a}	75.28	46.75
20 t ha^{-1} CHB	7261.3^{abc}	140.344^{b}	74.95	45.83
5 t ha^{-1} SBB	7611.3^{ab}	144.856^{b}	74.79	46.72
10 t ha^{-1} SBB	7389.7^{abc}	141.256^{b}	74.75	42.97
15 t ha^{-1} SBB	7897.9^{a}	147.856^{b}	75.23	49.70
20 t ha^{-1} SBB	7398.2^{abc}	149.744^{ab}	75.01	46.13
LSD (5%)	887.31	11.36	NS	NS
CV (%)	18.18	11.80	2.22	20.82

*significant p<0.05, **significant p<0.01, ***significant p<0.001, ^{ns} not significant.

Means with the same letter in column are not significantly different at 5% probability level.

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Evaluation of Vermicompost Production using Different Bedding Materials and Waste Feeds

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Introduction

Earthworms have been identified as one of the major tools to process the biodegradable organic materials (Julka and Senapati, 1987; Smith et al., 1992). The utilization of waste materials through earthworms has given the concept of vermicomposting. The vermitech approach utilizes waste management process by involving earthworms (Satchell, 1967). Improvement of soil through vermiculture has now become a popular part of organic farming. Vermicmpost is accepted as humus biofertilizer, soil fertility booster, soil activator and soil conditioner with required plant nutrients, vitamins, enzymes, growth hormones and beneficial microbes like nitrogen fixing, phosphate solubilizing, denitrifying and decomposing bacteria (Satchell, 1967).

Numerous organic materials have been evaluated for growth and reproduction of earthworms since these materials directly affect the efficacy of vermicompost (Nogales et al., 1999). Worms need bedding in addition to food. Shredded paper or newspaper, coir (coconut husk fiber), and shredded cardboard are common bedding materials used for worm composting. Normally, the bedding will soak well with clean water and then squeeze it to remove excess liquid. Selection of bedding and feeding materials is a key to successful vermicomposting process. Therefore, the objectives this study were to establish functional vermiculture /vermicompost production units; to evaluate earthworm reproduction on different beds and waste feeds and to evaluate vermicompost produced as a fertilizer.

Materials and Methods

The experiment was conducted in 2013 and 2014 cropping seasons at Wondo Genet Agricultural Research Center. It is geographically located at 07° 03' 19.1" to 07° 04' 00.2" North latitude and from 38° 30' 08.4" to 38° 31' 01.8" East longitude. It receives mean annual rain fall of 1128 mm and minimum and maximum temperature of 11 and 26°c, respectively. The technology was practiced under shade or special constructed house for the process. Thus, the methods used for mass rearing and maintaining of earthworms were used for vermicompost preparation (cast harvest). The materials were produced using the same inputs – cattle manure, with straw used as bedding for the vermicomposting and bulking in the composting process (Table 1). The products were dried, screened, and applied as a treatment. Adding soil to the worms, they need the grit to aid their digestion and provide sufficient moisture. The bedding material should be moist but not soggy. Moistened bedding was prepared two days prior to adding worms, as it may heat initially and harm the worms.

Table 1. Source of bedding and feed materials for vermicompost production

Locations	Beds made of	Treatments/feed materials on top
W/Genet	Cow dung + Soil + Stevia leaves	Stevia leaves Maize stalk Fresh food scraps Khat /Chat/ wastes

This activity was started in special constructed bins or divided cement constructed pool (up to 35 cm long × 60 cm width × 45 cm depth) for each earthworm type, and the worms were predetermined by number. The earthworms included three species, i.e. *Eisenia fetida* (Ambo exotic) and two local earthworm collections (Meskan and Zeway local). There were three earthworm species to be fed with four feeding materials listed in Table 1. Each earthworm species was tested on a uniform bedding material. Treatment arrangements were three earthworm species by four feeding materials, with the total number of 12 bins. Predetermined numbers (70) of each earthworm species were introduced into the bin management work. The required data, such as amount of cast produced, weight of bedding and feeding materials, number of earthworms in each alternative method, and the amount of water used were collected three times in three month intervals. Cast nutrient analysis were performed for N, P, K, OC, CEC, S, pH and Mn in the cast harvested from each bin.

Result and Discussion

The earthworm population and size increased during incubation for 90 days (Table 2). The Meskan local worms increased from 70 to 6233, Zway local worms to 6198 and Ambo exotic worms increased to 6041when grown individually using maize stalks, chat and stevia leaves, and fresh food scraps (Table 2). Meskan local and Zway local worms performed better than exotic Ambo worms (Table 2). Maize stalk, chat and stevia leaves, and fresh food scraps were best to least feed materials for earthworm multiplication. The stigher number of worms (2067) was obtained by feeding worms on maize stalk, whereas the lowest worm number (713) was obtained on fresh food scraps. Likewise, maize straw was found to be the most suitable feed material compared to soybean (*Glycine max*) straw, wheat straw, chickpea (*Cicer arientinum*) straw and city refuse for the tropical epigeic earthworm, *Perionyx excavatus* (Manna et al., 1997). The highest cast was also produced (13.3) from worms fed with maize stalk, while the lowest cast was produced (9.3) from worms fed with fresh food scraps (Table 2). Therefore, maize stalk, chat wastes, stevia and fresh food scraps were also best to least bedding materials for cast production.

Table 2. Comparative performance of three different species of earthworm in relation to different bedding materials and change in amount of cast produced

Treatment	Initial no. of EWs	Weights of initial bedding materials (kg)	Weights of feeds added (kg)	No. of EWs at 3 months	Amount of cast produced (kg)
Ambo + stevia leafs	70	7	2	1509	12
Meskan + maize stalk	70	7	2	1810	13.3
Ambo + maize stalk	70	7	2	2067	12.8
Zway + chat wastes	70	7	2	1663	10.2
Meskan + chat wastes	70	7	2	2056	12.3
Zway + stevia leafs	70	7	2	1934	9.8
Zway + maize stalk	70	7	2	1760	12.3
Ambo + FF	70	7	2	717	10.8
Meskan + stevia leafs	70	7	2	1450	11.3
Ambo + chat wastes	70	7	2	1750	11.8
Zway + FF	70	7	2	840	11.3
Meskan + FF	70	7	2	897	9.3

Ambo=Ambo exotic worm, Meskan = Meskan local worm, Zeway =Zeway local worm and FF= Fresh food scraps

Table 3. Comparative performance of three different species of earthworm in relation to the different bedding material and change in cast nutrient analysis

Treatment	TN %	Available p (ppm)	OC %	CEC (Cmol/kg)	Na	K	Mg	Ca	Mn	pH
Ambo + stevia leafs	2.06	12.083	3.33	35.2	1.38	15.44	11.25	16.38	47.22	6.85
Meskan + maize stalk	1.58	14.962	3.94	35.0	1.67	17.5	12.50	40.50	60.50	7.00
Ambo + maize stalk	1.76	23.447	4.65	38.3	1.75	17.65	11.62	36.71	58.54	7.21
Zway + chat wastes	1.74	20.038	4.12	39.1	1.53	16.11	11.34	50.39	69.20	6.86
Meskan + chat wastes	1.82	17.841	4.68	37.1	1.17	13.85	14.36	45.51	107.52	6.03
Zway + stevia leafs	1.88	22.310	4.75	34.8	1.30	17.99	11.85	39.56	89.28	7.17
Zway + maize stalk	1.51	20.038	3.46	31.4	1.64	15.58	12.39	40.61	49.60	7.28
Ambo + FF	1.60	19.583	2.16	31.4	2.58	17.17	10.56	17.35	31.20	7.36
Meskan + stevia leafs	1.67	21.670	4.68	37.1	1.44	16.76	12.71	48.58	81.72	7.00
Ambo + chat wastes	1.86	16.375	4.25	37.9	1.38	13.80	12.19	47.99	114.84	6.40
Zway + FF	1.87	27.593	3.19	28.9	2.33	18.34	14.21	38.73	35.84	7.28
Meskan + FF	1.85	31.565	3.27	28.3	3.19	18.38	12.28	43.73	41.92	7.42

Ambo=Ambo exotic worm, Meskan = Meskan local worm, Zeway =Zeway local worm and FF= Fresh food scraps, Ca & Mn are calcium and manganese in (C mol/kg)

Lower multiplication of earth worms, and lower cast production in the fresh food scraps might be due to the creation of unfavorable environment related to suffocation, which may cause death of worms. Excessive moisture combined with poor aeration conspire to cut off oxygen supplies, areas of the worm bed, or even the entire system, can become anaerobic, and may kill the worms very quickly.

The nutrient contents of vermicomposts prepared from different crop residues and waste materials are indicated in Table 3. Higher nutrient concentration was obtained from vermicompost. Application of organic matter including vermicompost favorably affects soil pH, microbial population and soil enzyme activities (Maheswarappa et al., 1999). The pH of all the vermicomposts prepared from the wastes ranged from slightly acidic to neutral, which is in conformity with Fares et al. (2005). Higher N content was found in Ambo + stevia leaves followed by Zeway + stevia leaves, while P, K and Na contents were higher in Meskan + FF, followed by Zway + FF. The highest CEC, Mg, Mn and Ca contents were recorded from chat leaf vermicompost, followed by maize stalk waste vermicompost (Table 2).

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Effect of Different Earthworm Feedstocks on Vermicompost Quality and Local Earthworm Performance

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Introduction

Earthworms normally live in decaying organic wastes, and they can degrade organic wastes into fine particulate materials, which were rich in available nutrients to enhance crop productivity and soil fertility. The earthworm cast increases the soil nutrients and microbial population that directly promotes the plant growth and increases the yield. They play an important role in increasing porosity, aeration, drainage and water holding capacity, increase nutrient availability of soil, and enhances natural biodegradation and decomposition of organic matters (Rasool *et al.*, 2008; Sinha *et al.*, 2010a). To enhance growth, reproduction and health of earthworms, certain minimum care requirements are needed for their survival in the soil. However, human activity decreases earthworm population by deep and frequent tillage can reduces earthworm populations by as much as 90% (Steven *et al.*, 2009). Earthworm abundance is strongly affected by the availability of organic residue in the field after harvesting the crop. The amount of organic matter in the soil strongly influences abundance and distribution of earthworms, and soils that are poor in organic matter do not usually support large number of earthworms (Addisu, 2007). Organic mulches enhance earthworm habitat by moderating microclimate and supplying a food source (Steven *et al.*, 2009). Heavy application of commercial fertilizer also decreases the number of earthworms in the soil. Application of pesticides can increase mortality (22%-100%) on different earthworms' species (Mahanthaswamy and Patil, 2003; Addisu, 2007). Therefore, the farmers can be benefited if they avoid extensive use of chemical fertilizers. For this it is necessary to establish worm farm or a vermitechnology. Hence, the objective of this study was to evaluate earthworm species and to select best feedstock for worms from agricultural wastes for vermicompost production.

Materials and Methods

This experiment was conducted at Debre Zeit agricultural research center. It is located at an altitude of 1900 m.a.s.l. and mean annual temperature of 18.5 ^{o}C. Bins were made from wood and iron sheets with the size of 60 cm×45 cm×57 cm (depth × width × length) and were placed in special constructed house for vermiculture. Each bin was used for mass rearing and maintaining earthworms. The bedding materials were made uniformly from the same inputs (cow dung, soil and shredded paper/cartoons), with the total height of 39 cm. Bedding was moistened for 2 days prior to adding worms in the bin to remove the bad and sniffing ammonia gas. Then worms were provided with sufficient amount of moisture every week. The experimental materials used in this experiment were three earthworm species, namely *Eisenia fetida* (control), Wereta collection (We-02-11) and Adet collection (AD-20-2004); and four feed-stock types: wheat straw, chickpea straw, khat waste and *Prosopis julifera*. Wheat and chickpea straw were obtained from DZARC experimental field; which were chopped into 1-2 cm size. Whereas, the khat waste was collected from streets and khat shops in Adama. Khat waste was used after drying for 5 days under shade and chopped to the same size as other feed materials (1-2 cm). *Prosopis julifera* was collected from Welenchity district and chopped to 1-2 cm before use. Equal amount of different feeding materials was dried, screened, and applied as a treatment to each bin. Twenty treatment combinations were arranged in completely randomized design with 3 replications.

Amount of vermicompost produced by the earthworm species after feeding on the different agricultural wastes was measured at the end of experiment. Number and biomass weight of earthworms were recorded at the initial and end of the experiment. The different vermicompost types were analyzed for N, P, K, S, Ca and Mg, OC, CEC. The pH of the earthworm casts was sampled every 15 days interval until day 90. The vermicomposting efficiency of local earthworm (EW) species fed with different feedstocks was compared using two factors, i.e., the first factor (factor A) being the feed materials at four levels and the second factor (factor B) was earthworm species at three levels. The treatment combinations were replicated three times and arranged in completely randomized design. The management practices, such as addition amount of water, bin size, grinding of the feeding materials, number of EW added and environmental conditions were maintained similarly to all experimental units.

Results and Discussion

Two local earthworm (EW) species (Ad-02-11 and Wereta 02) and the exotic earthworm (*Esenia fetida)* were selected for this study. The *E. fetidia* species had Russian origin and brought through the then phyto-pathological laboratory at Ambo. The Adet EW species were collected from around Bahir Dar, Yilmana Densa district of West Gojam near Adet Agricultural research center (2400 masl). The Wereta EW species were collected from around Wereta town 60 km North of Bahir Dar, Fogera district (1900 masl). These earthworm species have unique characters as indicated in Table 1.

Total weight of earthworms

The interaction effects of earthworm species and different feeds provided to the earthworm showed significant differences ($p < 0.05$) on weight of earthworm. The maximum mean TWE (452.5g) was recorded for Wereta (We-02-11) earthworms fed with wheat straw. This did not show significant difference with TWE recorded for *E. fetida* fed on *Prosopis julifera* (400.3g). The lowest TWE recorded for *E. fetida* provided with khat waste (192.3g), which showed no significant TWE with *E. fetida* fed on wheat straw (198.7g) and chickpea straw (203.0g). The chickpea straw used for *E. fetida,* the three feedstocks (wheat straw, chickpea straw and khat waste) used for

Adet (Ad-02-11) earthworms and the chickpea straw used for Wereta (We-02-11) earthworms did not show significant TWE differences (Table 2).

Table 1. Characteristic of earthworm species used in the experiment

Characters	*Esenia fetida*	*AD-02-11*	*WE-02-11*
Total length	9.93cm	7.7cm	11.67cm
Length of head to culitulem	2.667cm	1.51cm	2.5cm
Length of culitulem	0.7cm	0.467cm	0.83cm
Length of culitulem to end	4.767cm	4.95cm	6.67cm
Total Segment number	164	136	196
Segment number of head to culitulem	26	25	28
Segment number of culitulem	13	10	18
Segment number of culitulem to end	125	101	150
Color of total body	Red	Red	Red
Color of culitulem	Pink	Deep pink	Very light pink
Culitulem type	Invisible	Visible	Invisible
Body size comparatively	Moderate	Small	Larger
Coelumic fluid	Less	Less	More
Escaping capacity	High	Normal	Normal

Table 2. Total weight of earthworms as affected by the different feedstock

Earthworm (EW) types	EWs weight in vermicompost of			
	wheat straw	chickpea halm (straw)	khat waste	*Prosopis julifera*
E. fetida	198.67c	203.00a	192.33^{c}	400.33^{ab}
Ad-02-11	249.00b	203.67a	225.33^{b}	343.67^{bc}
We-02-11	452.50a	249.17a	269.00^{ab}	316.67^{c}
CV (%)	16.16			

The highest total weight of earthworms recorded for Wereta (We-02-11) earthworms, Esenia fetida and Adet (Ad-02-11) earthworms when they fed on wheat straws, and *Prosopis julifera* respectively. The TWEs recorded for the previous two EWs did not show significant differences. All worms fed on chickpea straws showed intermediate TWEs, which did not show significant differences. *Prosopis julifera* was the favorable feedstock that increased TWEs in comparison to the rest three feedstocks (chickpea straws, wheat straws and khat wastes). Esenia fetida and Ad-02-11 earthworms showed the minimum TWEs when they fed on wheat straws and khat waste. The weight of Esenia fetida doubled when they fed on *Prosopis julifera* alone. According Algabr et al. (2014) khat plants has nearly 0.9% oil content. Naturally earthworms don’t prefer oily/greasy feed materials unless it was partially decomposed. Kale et al. (1982) suggested that decomposition of cellulose and lignin present in organic wastes was known to enhance the total weight of earthworm. Accordingly, earthworms used in this study had different response or feedstock preference, even though they ingested /consumed all feedstocks provided with in the study period.

Individual earthworm body weight (IEBW): Table 4 shows the interaction effects of earthworm species and different feedstocks indicated significant difference of IEBW at P>0.05 probability level. Maximum IEBW (0.3g) was recorded for Wereta EW (We-02-11) when they fed on wheat straws. The lowest IEBW of 0.12g was recorded for Adet EW (Ad-02-11) when fed on chickpea straw. This was statistically at par when *E. fetida* was fed on wheat straw (0.114g), chickpea straw (0.132g), and khat waste (0.13g). When Adet EW (Ad-02-11) fed on wheat straw, khat waste and prosopis julifera the IEBW respectively were 0.143g, 0.1442g, and 0.138g. When Wereta EW (We-02-11) was fed on prosopis julifera the IEBW was 0.1473g (Table 3). In general, the highest IEBW was recorded equally when Wereta EW (We-02-11) fed on wheat straw, chickpea straw, and khat waste. Both local earthworm collections (Ad-02-11 and We-02-11) showed the least IEBW when they fed on prosopis julifera. The total weight of *Esenia fetida* in vermicompost made of prosopis julifera was the highest.

Table 3. Average individual body Weight (g) of EW species as affected by feed-stocks

EW species	Feedstocks			
	wheat straw	chickpea straw	khat waste	*Prosopis julifera*
E. fetida	0.1137[c]	0.1317[b]	0.1267[b]	0.1614
Adet collection	0.1426[b]	0.1171[b]	0.1442[b]	0.1383
Wereta collection	0.2937[a]	0.1848[a]	0.1962[a]	0.1473
LSD (0.05) 0.0393; CV (%)=14.74				

We -02-11 EW showed the highest IEBW when fed on wheat straw. Indeed this could be true due to the fact that wheat straw has the highest organic carbon content, which increases the IEBW insead of earthworms' reporoduction /multiplication. This was in agreement with Hailu Kebede (2009) work, which showed increased individual weight of easrthworms with an increase in the C:N ratio of earthworm feedstocks. Contrary to this when feedstocks have higher proportion of nitrogen content high fecundity of earthworm population or increased reproduction rate than body building.

Growth performance rates of earthworms (GPE): Earthworms fed on different feedstocks showed non-significant difference (p > 0.05) on growth percentage of earthworm. However, the main effect of earthworms were significantly different (P<0.05) in terms of GPE. Table 5 shows the highest mean earthworm numbers (3769.3) across all feedstocks were observed for Adet (Ad-02-11) EWs. The minimum mean earthworm numbers (3293.4) across all feed stocks were observed for Wereta (We-02-11) EWs. There was no significant mean earthworm number difference between Ad-02-11 and *E.fetida* species (3578.3) (Table 4). The mean earthworm numbers for each feedstock type was increased from khat waste, chickpea straw, wheat straw, and *prosopis julifera*. The highest mean growth percentage of earthworms was recorded when EWs were fed on *prosopis julifera* (4089.4). The least mean number of earthworms (3202.0) was recorded for khat waste, eventhough there was no significant difference with mean numbers of earthworms (3341.6) for chickpea straw. Chickpea straw have large amount of protein and less content of organic carbons compared to wheat straw.

Table 4. Growth rates of EW species as affected by feedstock

EW species	Feedstock				Means of EW species
	wheat straw	chickpea straw	khat waste	*Prosopis julifera*	
E. fetida	3521.4	3350.2	3391.1	4050.4	3578.3a
Adet collection	3764.6	3778.4	3236.3	4297.8	3769.3a
Wereta collection	3378.5	2896.4	2978.5	3920.0	3293.4b
Means of feedstock	3554.8b	3341.6bc	3202.0c	4089.4a	
LSD (0.05) feedstock: 295.69 ; EW species: 256.08 CV (%) = 8.57					

Growth performance of earthworms is affected with the earthworm species and feedstock types provided to them. The best feedstock that increased the GPE was prosopis julifera for all EW species. As it was indicated by Manna et al. (1997) different EW species has different prefer the different kind of feedstocks. The result obtained from this study agrees with that of Suthar (2007), who reported the waste decomposition and earthworm production strongly associated with the quality of the substrate, especially with substrate chemical composition as well as biological composition. Suthar and Singh (2008), observed increased growth rate and reproduction activity of earthworms. According to Manna et al. (1997) for *P. excavates,* earthworm species was chronologically increased for soybean straw < chickpea straw < wheat straw < city garbage < maize stover. In this study indiscriminately, all earthworm species showed decreasing preference prosopis julifera < wheat straw < chickpea straw < khat straw. Prosopis julifera has high organic carbon content which attract EWs, while khat waste contains 0.9% oil in its leaves (Algabr *et al*., 2014) which which is less attractive for EWs. However, there was no significant difference in the number of EWs between chickpea straw and wheat straw (Figure 1). Inoculation of feedstock with earthworms accelerated the decomposition process, which resulted in a reduction in the duration of decomposition. Adet (Ad-02-11) earthworms exhibited the highest growth rate when compared with *E. fetida* and Wereta (We-02-11) earthworms (Figure 1). Probably the vermiculture condition and microclimate was very conducive for Adet earthworm than the other earthworms used in the study. Bisen et al. (2011) compared three different EW species collected from different environmental conditions. They observed faster multiplication of the local EW as opposed to earthworm species collected from other environment.

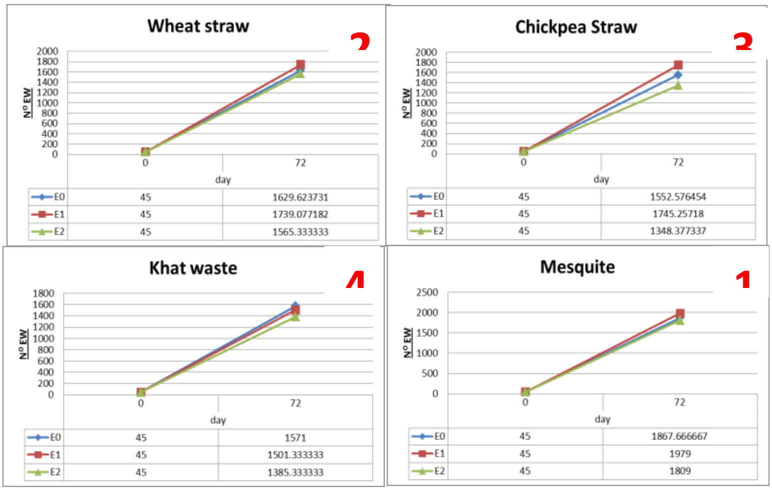

Fig. 1. Effect feedstock on number of earthworm species

Vermicompost Quality: The quality of vermicompost samples was determined for plant nutrients, hormones, microorganisms, enzymes and humus. Sharma et al. (1999) reported that vermicompost contains more plant growth promoters, high vitamin B12, inorganic P and exchangeable K as well as trace elements. Vermicompost is rich in ammonium and nitrate. It does not contain any disease pathogens because pathogenic bacteria in the worms gut. The casts are also rich in humic acids which condition the soil, have a perfect pH balance. The pH determines both quality and quantity determinants of nutrient contents in the vermicompost. The vermicompost quality can be variable due to process types and raw feeding materials used for composting (Edwards and Arancon, 2004). However, the interaction effects of earthworm species and different feedstock showed no significant difference ($p<0.05$) on pH value (Table 6). Whereas, the main effects of the earthworm species and feedstocks' were significantly different ($p<0.05$) in terms the vermicompost pH. The highest mean value of pH (8.38) was recorded for vermicompost made of Wereta EW collection was inoculated to the feeds, which was at par with *E. fetida* earthworm species (8.19). The least pH value, 8.08, was documented from Adet EW collections. Similarly, there was a significant difference ($p < 0.05$) in terms of pH value when the main effect of feedstock was assessed. The highest mean pH value, 8.57, for the vermicompost was observed when chick pea straw was provided to the earthworms, which were statically similar with khat waste (8.48). On the other hand, the least pH value (7.52) was obtained for prosopis julifera feed. Decomposition of organic matter leads to formation of two different components, these are ammonium ions and humic acids, and these have exactly opposite effects on the value of pH. The pH of vermicompost from prosopis julifera was near neutral, but higher pH value was recorded for vermicompost made of chickpea straw, followed by vermicompost of khat waste and vermicompost of wheat straw (Table 5).

The pH of vermicompost from *Prosopis julifera* was near neutral, but higher pH value was recorded for vermicompost made from chickpea straw, followed by vermicompost from khat waste and wheat straw. Therefore, the pH value of vermicompost also depends on a substrate utilized. Similarly, Gutierrez-Miceli et al. (2007) observed a pH value of 8.6 from sheep manure, while Lazcano et al. (2008) documented pH of 7.73 for vermicompost made from cattle manure. Also, Atiyeh *et al*. (2002) recorded a pH value of 5.3 for vermicompost made from pig manure. They justify that differences in the substrates used for compositing would result in the formation of vermicompost with different pH values.

Total nitrogen and available phosphorus: The interaction of earthworm species and different feeds fed to the earthworm had no significant ($p < 0.01$) effect on available phosphorus, but not on total nitrogen. The highest available phosphorus (151.47) was obtained from Wereta earthworm collection fed with chickpea straw. This was statistically at par with *E. fetida* fed with wheat straw (140.56), and khat waste (138.72). However, the lowest available phosphorus (105.21) was obtained from Adet EW collection provided with wheat straw. This was statistically similar with *E. fetida* fed with *Prosopis julifera* (120.35); Adet EW collection fed with khat waste (107.29), *Prosopis julifera* (114.07g); and Wereta EW collection fed with khat waste (120.24) (Table 6).

Table 5. Phosphorus (ppm) content of vermicompost produced by interaction effect of different EW species and feed materials

EW species	Feedstocks			
	wheat straw	chickpea straw	khat waste	*Prosopis julifera*
E. fetida	140.565[ab]	127.529[bcd]	138.725[abc]	120.352[def]
Adet collection	105.206[f]	123.671[dc]	107.288[ef]	114.072[def]
Wereta collection	121.760[ed]	151.474[a]	120.238[def]	128.583[bcd]
LSD (0.05)= 15.28; CV (%) =7.255				

The mineralization of P during vermicompost depends on both the feed-stocks and EW species. *E. fetida* had higher mineralization of phosphorus nutrient from the wheat straw, chickpea straw and khat waste than the other earthworms. This is due to high cast (faecal) of *E.fetida.* This shows that during vermicomposting (Table 5) the concentration of P in the composted material (vermicompost) varies with the type of the material and the earthworm species. Based on the type of feed-stocks available, different EW species can be selected for different feedstock sources. Therefore, the availability different EWs could be helpful in vermicomposting of different materials at different locations. Garg *et al.* (2006) and Nedunchezhiyan et al. (2011) reported that phosphorus mineralization and mobilization was a result of bacterial and faecal phosphatase activity of earthworms. Yan *et al* (2012) also reported that the initial organic waste materials affect the final nutrient contents of vermicompost.

Carbon to nitrogen ration (C: N)

The interaction effect of earthworm species and different feedstock fed to the earthworm indicated was not significant for C: N ratios. Main effects of feedstock were significantly ($P < 0.05$) different on C: N ratios, when the different feeds were inoculated with different earthworm species. The highest C: N ratio of 3.25 was recorded when wheat straw was provided to the earthworms. On the other hand, the least C: N ratio of 2.63 was obtained when *Prosopis julifera* was provided as feed to the EWs which were statistically similar with khat waste (2.72) and chickpea straw (2.77) (Table 6).

Table 6. C: N ratio content of vermicompost produced from different feed materials

Feedstocks	wheat straw	chickpea straw	khat waste	*Prosopis julifera*
Means of feedstock	3.2499a	2.7662b	2.72b	2.63b
Initial C: N ratio	126.81	52.80	39.07	70.11
LSD (0.05) for Feed:0.455; CV (%) 16.473				

F: Feedstock; F_0: wheat straw, F_1: chickpea straw, F_2: khat waste, F_3: *Prosopis julifera*.

The C: N ratios of vermicompost treatments were lower than the C:N ratios of the initial feed treatments due to the process of mineralization by earthworm and microorganisms. The final C: N ratios of all treatments were between 2.33:1 and 3.42:1, whereas the initial feed was 39.07-130. Moreover, the gradual decrease in C: N ratio with time may be explained by the loss of organic carbon as CO_2 (Bisen *et al*., 2011) due to microorganisms and earthworm in process of mineralization. Higher C: N ratio indicates slower mineralization of substrate by the species (Haug, 1993).

Conclusion

Earthworms need well organized feed-stock for vermiculture and vermicast production. All earthworms showed different and significant response / preference to the different feedstocks except on chickpea straws. Comparatively Adet (Ad-02-11) local earthworms produced quality vermicompost and highest earthworm growth rate when fed on all feedstocks. Prosopis juliflra was found to be best feedstock material in terms of earthworm multiplication. Prosopis julifera was the favorable feedstocks that increased total earthworm weights (TWE) when fed the three feedstocks. The weight of *Esenia fetida* doubled when they fed on prosopis julifera alone. We -02-11 earthworms showed the highest individual earthworm body weight (IEBW) when fed on wheat straw. IEBW of Wereta (We-02-11) earthworms fed on wheat straw, chickpea straw, and khat waste was statistically at par. Both local earthworms (Ad-02-11 and We-02-11) showed the least IEBW when they fed on *Prosopis julifera*. In general, the standard (*Esenia fetida*) and local earthworms showed feedstocks preference in decreasing tendency for *Prosopis julifera* < wheat straw < chickpea straw < khat straw.

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Survey of Azolla Fern in Ethiopia as a Source of Nitrogen Fertilizer

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Introduction

Azolla ferns are often found floating in water, providing the benefit of nitrogen fertilization because the ferns always live in association with a nitrogen-fixing cyanobacteria in the genus *Anabaena*. Parallel to the N-fixing ability of Azolla fern, it reduces water pollution by changing strategies of mineral use and by integrating organic fertilizers in rice production system. The fern is either incorporated into the soil before rice transplanting or grown as a dual crop along with rice. It may not be possible to find many research reports on Azolla in Ethiopia except the works of Tesfaye et al. (2006) who applied azolla in rice production in Fogera plain. They used two azolla species (*Azolla filiculoides and Azolla microphylla*) introduced from India in 2004. Inoculation of *Azolla filiculoides* and *Azolla microphylla* incorporated once to soil has increased rice yield by 911 kg ha^{-1} (19%) and 721 kg ha^{-1} (15%) over the control, respectively. Azolla is distributed worldwide. Seven species are recognized in temperate and tropics, viz. *Azolla filiculoides, A. rubra, A. caroliniana, A. mexicana, A. microphylla, A. pinnata* and *A. nilotica* (Dhar *et al.*, 2003). All these species has *Anabaena* as symbiont in their leaves (Singh, 1998). According to Fransisco et al. (2000), Azolla species have been distributed in wide ecologies from temperate to tropical regions. No one indicated that either azolla is available or not in Ethiopia. Fransisco was reporting Azolla only in neighboring countries like Sudan and Kenya. Hence, conducting a baseline survey for native *Azolla* is paramount importance for further study. Even though there was no evidence study on the invasive nature of Azolla fern left to the fields. The survey study was conducted to reinitiate Azolla research in Ethiopia with the following justifications and aspirations to assess all water bodies in Ethiopia and look for native Azolla fern and relay on our own resource; farmers in Ethiopia use several water ponds and water harvesting structures for their agriculture, which were taken as a good opportunity for Azolla multiplication; azolla may serve as a means to reduce evapourating water from the ponds and water structures; and azolla may serve as a feeding sources to farm animals in the community. Azolla must be grown in nurseries so that farmers will have the opportunity to utilize it as organic source for horticultural crops.

Materials and Methods

The survey was conducted around lakes and ponds found in the country. All water bodies are summarized in Table 1 with the necessary information. All Azolla and Azolla like ferns were collected from the shores of each water body using their morphological and growth characteristics. All Azolla and Azolla like specimens were brought to Debre Zeit agricultural research center and multiplied in special bucket/bowls under shed for further observation. A lobe of Azolla leaves (upper leaves) was placed in drops of water on a microscope slide with a cover slip and gently applied enough pressure with thumb. The filaments of *Anabaena* were observed amongst the crushed leaf tissue. The cells can be examined form the filaments of well-defined shape (cells that are round and thick-walls) and generally predictable size. Two to eight mg of dry Azolla samples were analyzed for total **N, C** and **P** concentrations. These specialized cells, called heterocyst's, are the sites of nitrogen fixation.

Results and Discussion

Azolla fern has many advantages in agriculture. It is important to look for native Azolla through baseline survey before embarking on detail and extensive research in the country. The surveyed water bodies had Azolla like species but not precisely Azolla (Table 1). Out of surveyed the14 water bodies only one lake (Lake Ziway) was found to harbor Azolla species (Table 1). Tesfaye *et al*. (2008) also indicated that few Azolla species were found around Lake Tana from research conducted in low land rice producing area of Fogera by introducing Azolla from abroad or indigenous Azolla. These exotic Azolla species might have the probability to spread throughout Lake Tana shoreline.

The Azolla species harboring the shoreline of Lake Ziway were found in the south-west of the lake, where fishermen anchor their boats and big birds look for fish scraps. Probably these tiny algal species might have been adapted this shoreline for long without gaining any attention to anybody until our team reached there.

Azolla fern multiplied on a plastic bowl had multiple branches and roots as long as 10 cm. Each leaf had clearly visible ventral and dorsal lobes. The fern had a dark green color with proper growth development. According to IRRI (1988), apart from leaf trichomes and possibly root anatomy, vegetative features provide little assistance in taxonomic separation. Despite variations, features of the megaspore apparatus are the most reliable means of separating taxa within Azolla (IRRI, 1988). Azolla is heterosporous, producing a corn-shaped megasporocarps (~1 mm in length) and larger microsporocarps which rupture when ripe, release microspores embedded within massulae.

Morphological characteristics of the ferns were recorded (Table 2). The ferns were well adapted and showed better performance, survived and multiplied for two harvests. Azolla fern grows very well in a tap water with neutral pH and little amount of phosphorus. Whereas the water samples collected from the boggy shoreline where Azolla was sampled had a pH 7.9. Azolla fern reproduced rapidly and doubled its initial surface coverage within five days. The Azolla species found in Lake Ziway had a vegetative cell and hetrocysts dimensions as indicated by Singh (1977). Therefore, based on the morphological and growth performance, the Azolla species found in the shoreline of Lake Ziway is *Azolla pinnata*. This Azolla could be considered as native to the area and Ethiopia at large, which can be easily propagated by vegetative means and utilized by farmers as organic nitrogen source for many agricultural crops.

Table 1. The different water bodies assessed for the native *Azolla* habitat

Water bodies	GPS	Altitude (m)	Native Azolla
Hora	8°45'32.29"N 38°59'42.89" E	1932	Not present
Bishoftu Guda	8°47'05.20"N 38°59'35.58"E	1928	Not present
Arenguade Wuha	8°41'54.08"N 38°58'47.92" E	1967	Not present
Kuriftu	8°47'05.20"N 38°59'35.39"E	1930	Not present
Bishoftu	8°44'30.28"N 38°58'59.27"E	1952	Not present
Cheleqleqa	8°45'25.53"N 38°58'03.95"E	1967	Not present
Lake Langano	7°40'52.60"N 38°43'13.44" E	1684	Not present
Koka	8°28'03.18"N 39°02'58.14" E	1656	Not present
Lake Ziway	7°55'03.08"N 38°43'32.49" E	1667	Present
Lake Abyata	7°35'42.17"N 38°43'13.41" E	1650	Not present
Arba Minch	6°02'26.21"N 37°34'21.91" E	1336	Not present
Around Lake Tana	11°38'46.98"N 37°25'43.11" E	1853	Present *
Zengena	10°54'29.42"N 36°57'21.32" E	2493	Not present
Hayk	11°18'35.64"N 39°39'41.20" E	2450	Not present

** Most probably not native to the area.*

This Azolla species produced 0.21kg per sq. meter in 5 days. The dry Azolla fern we propagated from Azolla specimen had 4 % nitrogen content. *A. pinnata* gave 12,600 kg biomass per ha per month (Table 3. The Azolla biomass obtained was better as compared to others findings. Similarly, Watanabe and Berja (1983) reported that *A. pinnata* showed a maximum biomass of 100 kg N ha^{-1} and *A. filiculoides* gives 140 kg N ha^{-1} at an optimum temperature of 22°C. Azolla multiplies vegetatively (i.e., it does not produce seeds). Thus, live Azolla (inoculum) is maintained throughout the year by growing in small ponds or water filled ditches. According to Lumpkin (1985), Azolla grown in nurseries are more tolerant of adverse conditions than sporophytes. It is a potential source of biofertilizer by fixing N to the plant. Further maintenance and multiplication of this fern requires construction of appropriate artificial pond and shades.

Table 2. Azolla species identified as native to Lake Ziway, in Ethiopia

Section	Species	Source	Megasporocarps	Microsporocarps	Others
Azolla	*Azolla pinnata*	Asia, Oceania, Africa	9-Float	No hook-like tip in glochidia of Massulae	a pair of sporocarps

Table 3. Elemental contents of dry Azolla fern biomass

Elements	%
Nitrogen	4.1
Phosphorus	0.18
Potassium	0.23
Calcium	0.55
Magnesium	0.29
Sulphur	0.27
Copper (ppm)	2.0
Zinc (ppm)	2.3

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Organic and Inorganic Fertilizers Application for Chickpea (*Cicer arietinum*) Production on Vertisols in Central Highlands of Ethiopia

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Introduction

Integrated soil fertility management is an approach for sustainable and cost- effective management of soil fertility and attempts to make the best use of inherent soil nutrient stocks, locally available soil amendments and mineral fertilizers to increase land productivity, while maintaining or enhancing soil fertility.

Rong *et al*. (2001) reported that organic and inorganic fertilizers when combined, increased yields significantly over inorganic fertilizers mainly because these materials decompose, and hence release nutrients gradually over the crop growth period and they also build up organic carbon content essential for maintaining soil structure and the water holding capacity of soils. The use of organic amendments in farming have proven to be effective means of improving soil structure, enhancing soil fertility and increasing crop yields. Traditional composting of organic matter wastes has been known for many years but new methods of thermophilic composting have become much more popular in organic waste treatment recently since they eliminate some of the detrimentally effects of organic wastes in the soil. Composting has been recognizing as a low cost and environmentally sound process for treatment of many organic wastes (Hoitink, 1993).

A process related to composting which can improve the beneficial utilization of organic wastes is vermicomposting. It is a non-thermophilic process by which organic materials are converted by earthworms and micro-organisms into rich soil amendments with greatly increased microbial activity and nutrient availability. Vermicomposts have excellent chemical and physical properties that compare favorably to traditional composts (Paoletti, 1991).

Girma and Gebreyes (2014 and 2017) have reported that wheat and tef yields were improved due to application of vermicompost integrated with inorganic fertilizer application. They also reported that this approach had significantly reduced the need for the chemical fertilizers and able to improve some soil chemical properties. According to Arancon and Edwards (2005), the use of vermicompost in different location in Tigray region doubled the grain yield of several crops in comparison to each respective check (not fertilized). Bationo *et al.* (1993) found that the use of mineral fertilizers, without recycling of organic materials resulted in higher yields, but this increase was not sustainable without inclusion of soil amendments.

Chemical fertilizers are also costly for farmers to apply in the recommended rates. On the other hand, sole application of organic matter is constrained by access to sufficient organic inputs, low nutrient content, high labor demand for preparation and transporting. For instance, the low P content of most organic materials indicates the requirement of external sources of P to sustain crop productivity.

Chickpea (*Cicer arietinum* L.) is the second most important cultivated food legume after faba bean (*Vicia faba* L.), with in an annual total production of about 122,496 tons and a total cultivated area of about 175,050 hectares (CSA, 2016). It is mainly grown under rainfall condition particularly on residual soil moisture due to its drought tolerance. Besides its importance as food and source of cash income to the farm household, it has an additional advantage of restoring and ameliorating soil fertility by the virtue of its capacity of biological nitrogen fixation through rhizobial microorganisms.

The use of agrochemical inputs with legumes remains limited in Africa (Chianu et al., 2011), and chickpea is grown without fertilizer often on marginal lands in Ethiopia, with a common notion among farmers that legume crops do not need nutrient inputs. Yet poor legume yields are often a reflection of poor soil fertility. Thus, the integration of organic and inorganic sources can improve and sustain crop yields without degrading soil fertility status. This experiment was carried out on farmers' field and Ginchi sub site in 2013 and 2014 cropping seasons with objectives of determining the effect of organic and inorganic fertilizers and their combinations on growth and yield of chickpea in central highlands of Ethiopia.

Materials and methods

Experimental site

The experiment was conducted in 2013 and 2014 cropping seasons at Ginchi, West Showa, in the central highlands of Ethiopia. Chickpea is widely grown in these areas and the environment is seasonally humid; the soil type is Vertisols with low N, P and OM contents. Ginchi is located between 09^0 02'N latitude and 38^0 12'E longitude, at an altitude of about 2200 matter above sea level, with the long-term average annual rainfall of 1080 mm, of which about 85% is received from June to September. The average minimum and maximum air temperatures are 9 and 24^{0c}, respectively (Getachew and Amare, 2004). The treatments combinations were as indicated in the Table 1 below.

The experimental design was Randomized Complete Block Design (RCBD) with three replications. Compost was prepared following the standard procedure for compost preparation (Getechew *et al*., 2012). Similarly, earthworms and the same inputs- cattle manure and straw as bedding materials for the vermicomposting and bulking in the composting process produced vermicompost (VC). Samples were collected for nutrient content analysis from well- decomposed manure, compost, and vermicompost before they were applied to the field. The level of application was determined based on the recommended P equivalent rate for the test crop. The treatments were applied three weeks before sowing and thoroughly mixed in the upper 15-20cm soil depth. The source of inorganic N and P was DAP fertilizer where the full dose was applied at planting time. Chickpea (Shasho) was used as test crop at the recommended seed rates of 100 kg ha^{-1} by row planting and sowing dates were 18 and 22 September for 2013 and 2014, respectively. All recommended agronomic management practices were applied during the crop growing period as per needed.

Table 1. Treatments set up and their description

Treatment	Description
Control	Without fertilizer
Recommended NP (100 kg DAP)	18 kg ha^{-1} N + 20 kg ha^{-1} P
Conventional Compost (CC)	13.9 t ha^{-1} (based on equivalent recommended P rate)
Farmyard manure (FYM)	8.9 t ha^{-1} t ha^{-1} (based on equivalent recommended P rate)
Vermicompost (VC)	3.5 t ha^{-1} (based on equivalent recommended P rate)
50% VC + 50% CC	1.75 t ha^{-1} VC + 6.95 t ha^{-1} CC
50% VC + 50% FYM	1.75 t ha^{-1} VC + 4.45 t ha^{-1} FYM
33% VC + 33% CC + 33% FYM	1.06 t ha^{-1} VC + 4.21 t ha^{-1} CC + 2.70 t ha^{-1} FYM
50% VC + 50% NP	1.75 t ha^{-1} VC + 9 kg ha^{-1} N + 10 kg ha^{-1} P
50% CC + 50% NP	6.95 t ha^{-1} CC + 9 kg ha^{-1} N + 10 kg ha^{-1} P
50% FYM + 50% NP	4.45 t ha^{-1} FYM + 9 kg ha^{-1} N+ 10 kg ha^{-1} P

Soil sample collection and analysis

Composite soil samples were collected from the experimental site at 0-20cm soil depth before treatment application and immediately after harvesting for analysis of soil pH, total organic carbon (OC), total N, and available P. The contents of N and P in the analyzed samples before application were 0.86 % N and 1.72 % P for vermicompost, 0.97 % N and 0.43 % P for conventional compost both on 55% dry-weight basis, and 1.67 % N and 0.67 % P for farmyard manure on 50% dry weight basis. Soil pH was determined in 1:2.5 soil: water ratio (FAO, 2008). Organic carbon was determined according to Walkley and Black method (Walkley, 1947) and total nitrogen using Kjeldahl method (Jackson, 1958). Available P was determined using the Bray-II method (Bray and Kurtz, 1945). Exchangeable cations and CEC were also analyzed using ammonium acetate method (Chapman, 1965). Plant parameters collected were grain yield, above ground total biomass, plant height, thousand seed weight and pod numbers per plant (average 5 plants). Mature plant height was measured from the ground level to the tip of the plant at physiological maturity stage. To measure total biomass and grain yields, the entire plot was harvested at maturity in February 2013 and 2014. After threshing, the seeds were cleaned and weighed, and the moisture content was measured. Total biomass (dry matter basis) and grain yields (adjusted to a moisture content of 12.5%) recorded on plot basis were converted to kg ha^{-1} for statistical analysis. The SAS statistical software package (SAS, 2002) was used to test for presence of outliers and normality of residuals. The total variability for each trait was quantified using separate and pooled analysis of variance over years using the following model (Gomez and Gomoz, 1984). Mean separation was done using Duncan's Multiple Range Test (DMRT) at 5% probability level. Linear regression was performed between grain yield and some relevant component parameters.

Results and Discussion

Effects of Organic and Inorganic Fertilizers application on Soil Chemical Properties

Soil chemical properties like pH, OC, total N and available P measured after harvesting were significantly affected ($P<0.001$) by the application of different rate of organic and inorganic fertilizers sources either in combination or alone (Table 2).

The soil pH has been improved through application of conventional compost, farmyard manure and vermicompost either alone or in combination with each other as compared to the control plot. Thus, the lowest pH value was recorded from the control (6.07) while the highest value was from conventional compost (6.59). But, all the values of pH fall in the range of moderately acidic soil reaction condition (5.8-6.5) which is suitable for most field crop production. Mahler *et al*. (1988) reported that in terms of nutrient availability pea, lentil, chickpea and faba bean grow best in soils with pH values between 5.7 and 7.2 and require between 13 and 35 kg P ha^{-1} for adequate yields. He further indicated pulse crops grown on soils with a pH value of 5.6 and less give low yield. Thus, it is a good strategy to apply organic fertilizer which raises the pH level for production of chickpea.

The level of N also varies with application of treatments ranging from 0.22 % N to 0.32% N and it lies in the range of medium N level. It also showed that application of organic fertilizers either alone or in combination with inorganic fertilizer has significantly affected the soil N level (Table 2). Most of the time it is evident that N is low in highland waterlogged Vertisols ascribed to denitrification and leaching loses of N in the form of ammonia. But in this case, the soil had medium N level most probably due to atmospheric N fixation by rhizobial bacteria through its symbiotic association with chickpea and the high N level contained in the organic fertilizers added.

The available P in the soil after treatment application has also significantly improved where the lowest value was recorded from control plot (12.19 ppm) and the highest from organic fertilizer addition especially from vermicompost (30.83 ppm). Application of organic materials increase P availability in the soil and its uptake by plants not only by directly adding P to the soils, but also indirectly through the release and production of organic anions and stimulation of microbial activity during the decomposition process which increase P mobilization and decrease P fixation (Ayaga *et al*,. 2006; Fuents *et al*. 2006). According to Sikora and Enkiri (2000) and Cornish (2009) combined application of compost with inorganic fertilizers can increase efficiency of inorganic fertilizers and reduce the cost. However, the increase in P availability from organic inputs application depends on type of feedstock, P concentration, particle size, C: P and C:N ratio and environmental conditions. Thus, it could be concluded that application of organic fertilizer alone or integrated with inorganic fertilizer can increase the available P content of the soil significantly (Table 2).

The level of OC was generally rated as medium (ATA, 2016) where the highest organic carbon 3.40 and 3.36% were recorded from application of full doses of farmyard manure and compost, respectively and the lowest was from the control plot as usual (Table 2). Therefore, in all the cases, nutrient concentration in the soil had significantly increased in response to organic nutrient source applications, which has great contribution in improving the overall condition of the soil and its productivity.

Table 2: The effect of organic and inorganic fertilizer application on different soil parameters at Ginchi, during 2013 and 2014.

Treatment	pH (H_2O)	Total N (%)	Avail. P (ppm)	OC (%)
Control	6.07^{c}	0.22^{b}	12.19^{c}	2.24^{e}
Recommended N and P	6.3^{d}	0.24^{b}	24.15^{b}	2.83^{d}
Conventional Compost (CC)	6.59^{a}	0.31^{a}	30.45^{a}	3.36^{ab}
Farmyard manure (FYM)	6.56^{ab}	0.32^{a}	30.43^{a}	3.40^{a}
Vermicompost (VC)	6.55^{ab}	0.29^{a}	30.83^{a}	3.12^{cd}
50% VC + 50% CC	6.4^{bcd}	0.29^{a}	29.05^{ab}	3.0^{cd}
50% VC + 50% FYM	6.47^{abc}	0.28^{a}	28.9^{ab}	3.04^{cd}
33% VC + 33% CC + 33% FYM	6.54^{ab}	0.28^{a}	29.44^{ab}	3.06^{cd}
50% VC + 50% NP	6.4^{bcd}	0.29^{a}	29.03^{ab}	3.26^{abc}
50% CC + 50% NP	6.38^{cd}	0.30^{a}	26.71^{ab}	3.02^{cd}
50% FYM + 50% NP	6.48^{abc}	0.29^{a}	30.19^{a}	3.05^{cd}
Overall mean	6.44	0.28	27.39	3.04
DMRT (5 %)	0.15	0.04	5.77	0.30
CV (%)	1.34	7.71	12.37	5.66

Means in a column with different letters are significantly different at $P<0.05$.

Effects of integrated nutrient application on chickpea yield and yield components

The combined analysis of variance over two years revealed that the effect of cropping season was highly significant ($p<0.01$) on all the parameters considered plant height, biomass and grain yield of chickpea. The highest mean plant height, grain and biomass yields of chickpea were recorded during 2014 cropping season (Table 3) due to the fact that the plots were fixed during the study period and there was carry over effect of the application of the organic fertilizers in the previous year (2013). This study has clearly indicated that productivity of chickpea was significantly affected by different treatments applied. Thus, applications of inorganic and organic nutrient sources either alone or in combination had a significant ($p<0.05$) effect on all the parameters i.e. plant height, grain yield and biomass yield (Table 3).

The highest chickpea plant height (47.8cm) biomass (10030 kg ha^{-1}) and grain yield (2712 kg ha^{-1}) were obtained from the application of 50% vermicompost plus 50% the recommended NP rate. The second higher results for plat height (46 cm) was recorded from the application of 33 % of each organic inputs; whereas biomass yield (9152 kg ha^{-1}) and grain yield (2454 kg ha^{-1}) were recorded from the plot treated with conventional compost. As usual, the list values were recorded from the control plot where no input is applied (Table 3).

Table 3. Effects of organic and inorganic fertilizers application on chickpea yield and yield components

Year	PHT (cm)	BY (kg ha^{-1})	GY (kg ha^{-1})
2013	41.7^{b}	3591.0^{b}	1615.2^{b}
2014	44.4^{a}	10780.3^{a}	2435.9^{a}
F-Probability	*	***	**
DMRT $_{0.05}$	1.9	660.9	161.42
Treatments			
Control	38.2^{d}	3680.3^{e}	964.7^{d}
Conventional Compost (CC)	44.0^{abc}	9152.0^{ab}	2454.5^{ab}
Farmyard manure (FYM)	41.3^{cd}	6280.8^{d}	1901.0^{c}
Vermicompost (VC)	40.2^{cd}	6679.5^{d}	1997.3^{c}
Recommended N and P	44.2^{abc}	6805.7^{d}	1889.3^{c}
50% VC + 50% CC	43.5^{abc}	6310.3^{d}	1831.3^{c}
50% VC + 50% FYM	41.5^{bcd}	6672.5^{d}	1869.3^{c}
33% VC + 33% CC + 33% FYM	46.0^{ab}	7223.3^{cd}	2082.0^{bc}
50% VC + 50% NP	47.8^{a}	10030.0^{a}	2712.2^{a}
50% CC + 50% NP	44.7^{abc}	8542.7^{abc}	2197.7^{bc}
50% FYM + 50% NP	42.0^{bcd}	7664.5^{bcd}	2381.7^{ab}
DMRT $_{0.05}$	4.5	1549.9	378.6
Y x T	*	***	**
CV (%)	9.02	18.50	16.04

**, **= significant at 5 and 1 % probability levels respectively, ns= Non-significant. Means in a column with the same letter are not significantly different (P<0.05), plant height (PHT), biomass yield (BY), grain yield (GY)*

Application of 100% recommended rate of compost, farmyard manure and vermicompost at recommended inorganic P equivalent rate had increased chickpea grain yield by 154%, 97% and 107% when compared to non-treated control plot respectively (Table 3). However, the yield advantage for the best treatment in this experiment that is 50% VC and 50% NP had resulted in 44% yield increase as compared to the application of recommended N and P fertilizer. Thus, the result of this study has clearly indicated that, the application of different fertilizer sources either as inorganic, organic or in combination has improved chickpea grain yield significantly as compared to the farmers' practice. This result is in line with Tolanur and Badanur (2003) indicating that the combined application of organic and inorganic N sustained the productivity of the soil. Soil available nutrients like N, P and K increased significantly with the application of various organic sources of nutrients in combination with fertilizers over the fertilizer alone. Other research findings revealed that growth and yields of chickpea have responded differently to application of P on different soil types (Mamo *et al*., 2001; Ayalew, 2011; Agegnehu, 2014).

Effects of organic and inorganic fertilizers on economic feasibility of chickpea production

As farmers attempt to evaluate the economic benefits of shift in practice, partial budget analysis was done to identify the rewarding treatments. Yield from on–farm experimental plots was adjusted downward by 15%, i.e. 10% for management difference and 5% for plot size difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Three years average market grain price of chickpea (9.5 birr/kg), farm-gate price of DAP fertilizer (15 birr/kg) respectively and labour valued at 40 birr/person-day were used. Labour for chickpea field management was 30 person-day per hectare. The result of the partial budget analysis is given in Table 4.

The economic analysis further revealed that the application of 50% of vermicompost plus 50% N and P fertilizers provided the highest marginal rate of the return (MRR) of 4653% (Table 5) suggesting for one birr invested in wheat production, the producer would collect birr 46.53 after recovering his investment. Since the MRR assumed in this study was 100%, the treatment with application of 50% of vermicompost and 50% N and P gave an acceptable MRR. Therefore, the application 50% VC (based on P equivalent rate) and 50% N and P fertilizers mentioned above is found economical to be recommended on Vertisols of the study area and similar locations in the central highlands of Ethiopia.

Table 4. Partial budget analyses of organic and inorganic fertilizers for chickpea production

Treatment	Average yield (kg/ha)	Adjusted yield-15% (kg/ha)	Gross benefits (birr/ha)	Costs that vary (birr/ha)			Net benefit (birr/ha)	Dominated
				Fertilizer	Labour	Total cost		
Control	964.7	819.9	9164.65		2200	2200	6964.65	D
Recom. N and P	2454.5	2086.3	23317.75	2300	2000	4300	19017.75	D
CC	1901.5	1616.3	18059.5		3850	3850	14209.50	D
FYM	1997.3	1697.7	18974.35		3550	3550	15424.35	D
VC	1889.3	1605.9	17948.35		4100	4100	13848.35	
50% VC + 50% CC	1831.3	1556.6	17397.35		4050	4050	13347.35	D
50% VC + 50% FYM	1869.3	1588.9	17758.35		3950	3950	13808.35	D
33% VC + 33% CC + 33% FYM	2082.0	1769.7	19779		3800	3800	15979.00	D
50% VC + 50% NP	2712.2	2305.4	25765.9	1250	1835	3085	22680.90	
50% CC + 50% NP	2197.7	1868.1	20878.15	1950	2850	4800	16078.15	
50% FYM + 50% NP	2381.7	2024.5	22626.15	1750	2650	4400	18226.15	

Grain price of Chickpea =BIRR 9.50 kg^{-1}, DAP price= BIRR 13 9.50 kg^{-1} (1USD = 20.40 Ethiopia birr; D= Dominated

Table 5: Marginal analysis of organic and inorganic fertilizer effects on chickpea at

Particulars	Vermicompost	50% CC + 50% NP	50% FYM + 50% NP	50% VC + 50% NP
Average yield (kg/ha)	1889.3	2197.7	2381.7	2712.2
Adjusted yield-15% (kg/ha)	1605.9	1868.1	2024.5	2305.4
Gross benefit (birr/ha)	17948.35	20878.15	22626.15	25765.9
Cost of fertilizer (birr/ha)	0	1950	1750	1250
Cost of labour (birr/ha)	4100	2850	2650	1835
TVC (birr/ha)	4100	4800	4400	3085
NB (birr/ha)	13848.35	16078.15	18226.15	22680.9
MC (birr/ha)		50	50	85
MB (birr/ha)		2229.8	2148	3954.75
MRR (%)		4459.6%	4296%	4652.7

TVC= total variable cost; NB= net benefit; MC= marginal cost; MB= marginal benefit and MRR= marginal rate of return

Conclusion and Recommendation

The result of this experiment showed that the two years result were significantly different from each other most probably attributed to season differences and the carry over effect of the previous year fertilizer application as the plots were fixed during the experimental period. Results of soil analysis after harvesting revealed that application of organic fertilizer improved soil pH, OC, total N and available P. Therefore, from the results of this study, it can be concluded that chickpea crop could reasonably be produced using 50% vermicompost (based on N equivalent rate) plus half doses of the recommended N and P fertilizers from inorganic sources. Hence, combined or multiple use of chemical fertilizer and locally available organic fertilizer application is the best approach for achieving higher fertilizer-use efficiency, maximum yield and economic return of input than the sole application of either of the input types.

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Organic and Inorganic Fertilizer Application and its Effect on Yield of Wheat and Soil Chemical Properties of Nitisols

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Introduction

Most smallholder farmers in Ethiopia appreciate the value of fertilizers, but they seldom able to apply them at the recommended rates and at the appropriate time because of high cost, lack of credit, delay in distribution to the site, and low and variable returns (Heisey and Mwangi, 1996). On the other hand, organic inputs are often proposed as alternatives to mineral fertilizers. However, the traditional organic inputs such as crop residues and animal manures cannot meet crop nutrient demand over large areas because of their limited availability, low nutrient content of the materials, and requiring high labour for processing and application to meet the crop demand, even where they are available in sufficient quantity. Thus, soil fertility management which combines the use of both inorganic and organic fertilizer to increase crop yield, rebuild depleted soils and protect the natural resource base is very important (Palm *et al.*, 1997).

Traditional composting of organic wastes has been known for many years. But new methods of thermophilic composting have become much more popular since it eliminates some detrimental effects of organic wastes in the soil. It is also cost effective and environmentally sound process for treatment of many organic wastes (Hoitink and Keener, 1993). When the composting process is assisted by the presence of the earthworms in the compost heap, it is named vermicomposting, which is non-thermophilic process that the organic materials are converted by earthworms and micro-organisms into rich soil amendments with greatly increased microbial activity and nutrient availability. Vermicomposting can significantly improve the chemical and physical properties of soils preferably as compared to traditional composts (Paoletti, 1991).

Nitrogen and phosphorous are the most limiting nutrients for wheat production that affect the rapid plant growth and improves grain yield. Under most field conditions, the amounts of soluble and readily mineralized soil N are insufficient to meet the crop requirement. Therefore, to obtain better growth of high yielding crops, N as chemical fertilizer, manure, crop residue, or other source, must be added. Asnakew Woldeab *et al*. (1991) also reported that increased usage of N fertilizer is considered as one of the primary means of increasing wheat grain yield in Ethiopia. This experiment was, therefore, carried out with objective of determining the effects of farmyard manure, compost, vermicompost, and N and P fertilizers and their combinations on the yield of wheat and soil chemical properties.

Materials and Methods

Experimental Site

The experiment was conducted in the District of Welmera, West Shewa Zone of Oromia National Regional State for two consecutive cropping seasons (2014 and 2015). The experiment site is located at 09^0 03′ N latitude and 38^0 30′ E longitude, 30 km west of Addis Ababa, at an altitude of about 2400m above sea level. The mean annual rainfall of the study area was 1100mm of which about 85% falls from June to September and the rest from March to May. The mean annual temperature is about 14.3^0c, with the mean maximum and minimum temperatures of 21.7^0c and 6.9 ^{0}c respectively.

The major soil types of the trial sites are Eutric Nitisols (FAO-WRB, 2006). Wheat variety (*digelu*) was used as test crop in the experiment. The rates of organic fertilizers applied were calculated based on the recommended N equivalent rate of the inorganic source for the test crop. This means samples of each organic fertilizers listed below were taken and analyzed for their N content and then the rate to be applied for the crop (on hectare basis) was determined as indicated in Table 1.

These treatment combinations were laid down in Randomized Complete Block Design (RCBD) with three replications. Compost was prepared following the standard procedure for compost preparation (Getachew Agegnehu *et al*., 2012).

Table 1: Treatment Combinations

No.	Treatments	Description
1	Recommended N and P	60 kg/ha N and 30 kg/ha P
2	Conventional Compost (CC)	6.2 ton/ha
3	Farmyard manure (FYM)	3.6 ton/ha
4	Vermicompost (VC)	8.3 ton/ha
5	50% VC + 50% CC	4.2 ton/ha VC + 3.1 ton/ha CC
6	50% VC + 50% FYM	4.2 ton/ha VC + 1.8 ton/ha FYM
7	33% VC + 33% CC + 33% FYM	2.8 ton/ha VC + 2.1 ton/ha CC + 1.2 ton/ha FYM
8	50% VC + 50% NP	4.2 ton/ha VC + 30 kg/ha N + 15 kg/ha P
9	50% CC + 50% NP	3.1 ton/ha CC + 30 kg/ha N +15 kg/ha P
10	50% FYM + 50% NP	1.8 ton/ha FYM + 30 kg/ha N + 15 kg/ha P

Similarly, vermicompost (VC) was produced by using earth worms and the same inputs i.e. cattle manure and straw as bedding materials for the vermicomposting and bulking in the composting process. The vermicompost was prepared from organic materials such as green plants, animal dung, pulse straw, leaves and ash. The decomposition process was facilitated by earth worm (*Eisenia foetida)* collected from Ambo Agricultural Research Centre and fresh organic matters incorporated in the compost bin and above 75% moisture was maintained for free motility and breathe of the worms. Three months later, the important end product vermicompost (the worm casting) was ready for fertilization.

Samples were collected from well decomposed farmyard manure, compost and vermicompost before they are applied to the field. Then their N and P contents were analyzed in the laboratory to determine the rate of application of each treatment, which was based on recommended N equivalent rate for the test crop. The contents of N and P before application in the analyzed samples were 0.86% N and 1.72% P for vermicompost, 0.97% N and 0.62% P for conventional compost both on 55% dry weight basis and 1.67% N and 0.78% P for farm yard manure on 50% dry weight basis. Manure and compost were applied to the field three weeks before sowing and thoroughly mixed in the upper 15 to 20 cm soil depth. Nitrogen and P fertilizers were applied in the form of Urea and DAP respectively. To minimize the loss and increase its efficiency half rate of N was applied as split at planting and the remaining half was side dressed at tillering stage of the crop whereas all P rates were applied as basal application during planting time. The seed was drilled at the recommended seed rate of 150 kg/ha in row. All recommended agronomic management practices were carried out during the crop growth period as per needed.

Data Collection and Analysis

Composite surface soil samples before planting and from the whole experimental field and from each treatment plots (0-20 cm depth) after harvest were collected and analyzed for the determinations of pH, organic carbon (OC), total N and available P following the standard procedure for each parameter. The crop parameters collected were grain yield and above ground total biomass. Grain yield was adjusted to a moisture content of 12.5%.

The agronomic data were subjected to analysis of variance (GLM procedure) using SAS statistical computer package (SAS, 2002). Duncan multiples range test (DMRT) at 5% probability level was used to detect differences among means.

Economic data was collected to assess the costs and benefits associated with different treatments, partial budget, dominance and marginal analyses following technique as described by CIMMYT (1988). The average yield was adjusted downwards by 15% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is because, experimental yields even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. The two years (2014-2015) average price of wheat was used to convert the adjusted yields into gross yield benefits. The costs of fertilizer and daily labour were also taken from the study areas.

Results and Discussion

Effects of fertilization on soil chemical properties

The results for the soil analysis indicated relatively higher pH levels, OC and nutrient concentrations for plots treated with manure, conventional compost and vermicompost or combinations of these organic nutrient sources among themselves or with inorganic nutrient fertilizers. But, application of inorganic fertilizer alone gave the lowest value in all the soil parameters tested (Table 2). Accordingly, the lowest pH value recorded from inorganic fertilizer was 4.14 (very strongly acidic) while the pH values from the rest treatments were ranging from 4.7 to 5.06 and are rated as strongly acidic indicating that there is a tendency of improving the soil acidity when organic fertilizers added alone or combined with inorganic fertilizers. This result is in line with Ano and Ubochi (2007) and Eghball *et al*. (2004) which reported that application of animal manure and compost increased soil pH.

On the other hand, the values of OC were generally rated as low (Jones, 2003). The results of total N and available P determined after harvest are also generally rated as medium and it is somehow in line with the change in OC and pH values respectively (Table 2). According to Agbenin and Igbokwe (2006) and Gichangi and Mnkeni (2009) organic supplements have been reported to increase P availability in P-fixing soils and humic substances enhance the bioavailability of P fertilizers in acidic soils (Hua et al., 2008).

Table 2: The effect of organic and inorganic fertilizer application on soil chemical properties analyzed for samples after harvest of the crops 2014 and 2015

Treatments	pH(H_2O)	Nitrogen (%)	Phosphorous (ppm)	OC (%)
Recom.N and P	4.14^{de}	0.17^{de}	10.17^{de}	1.18^{d}
Conventional Compost (CC)	5.0^{abc}	0.25^{ab}	14.69^{cd}	1.61^{abc}
Farmyard manure (FYM)	5.06^{a}	0.27^{a}	16.26^{abc}	1.75^{a}
Vermicompost (VC)	5.03^{ab}	0.24^{bc}	17.1^{ab}	1.67^{ab}
50% VC + 50% CC	4.89^{abcd}	0.22^{cd}	13.75^{d}	1.46^{c}
50% VC + 50% FYM	4.8^{bcd}	0.22^{cd}	14.15^{cd}	1.58^{abc}
33% VC + 33% CC + 33% FYM	4.85^{bcd}	0.25^{ab}	17.37^{a}	1.69^{ab}
50% VC + 50% NP	4.8^{bcd}	0.22^{cd}	15.38^{abcd}	1.63^{abc}
50% CC + 50% NP	4.7^{d}	0.20^{d}	13.43^{d}	1.55^{bc}
50% FYM + 50% NP	4.8^{bcd}	0.23^{bc}	15.03^{bcd}	1.61^{abc}
Overall mean	4.75	0.22	14.15	1.53
DMRT(0.05)	0.21	0.025	2.14	0.18
CV (%)	2.59	6.58	8.88	6.9

Means in a column with different letters are significantly different at P<0.05, P< 0.05and P<0.001 probability level, respectively; NS= not significant.

Effects of integrated nutrient application on wheat yield

The combined analysis of variance over two years revealed that the effect of cropping season was highly significant ($p<0.01$) for biomass yield of wheat and significant ($p<0.05$) for grain yield. The highest mean grain yield and biomass of wheat were recorded in 2015 cropping season, while the lowest values were recorded in 2014 cropping season (Table 3). This is due to the fact that the plots were fixed during the study period and there was residual effect of the application of the organic fertilizers in the previous year (2014). This study clearly indicated that productivity of wheat was significantly affected by different treatment applied. Thus, applications of inorganic and organic nutrient sources either alone or in combination had a significant ($p<0.05$) effect on parameters such as grain yield and biomass yield.

The highest wheat grain and biomass yield (6698 kg/ha and 19417 kg/ha respectively) were obtained from the application of 50% VC and 50% N and P followed by full dose of recommended rate N and P from inorganic fertilizer resulting in 6241 kg/ha grain and 18917 kg/ha biomass yields respectively (Table 3). The rest set of treatments gave inferior yields under all tested parameters and the result from the application of farmyard manure was the least with regard to grain yield (Table 3).

Table 3: Effects of organic and inorganic fertilizers application on wheat yield

Year	GY(kg/ha)	BY(kg/ha)
2014	5177.3[b]	14651.5[b]
2015	5749[a]	17174.2[a]
F-Probability	*	**
DMRT (0.05)	485.96	1048.3
Treatments		
Recommended N and P	6241[a]	18917[ab]
Conventional Compost (CC)	5790[abc]	14500[cde]
Farmyard manure (FYM)	4635[d]	13667[d]
Vermicompost (VC)	5144[cd]	15333[cd]
50% VC + 50% CC	5213[bcd]	15583[cd]
50% VC + 50% FYM	5189.3[cd]	15125[cd]
33% VC + 33% CC + 33% FYM	5923[abc]	17000[abc]
50% VC + 50% NP	6698[a]	19417[a]
50% CC + 50% NP	5940.7[abc]	17000[abc]
50% FYM + 50% NP	6148.3[ab]	16583[bc]
DMRT $_{0.05}$	951.8	2584.1
Y x T	*	**
CV (%)	14.4	13.6

*, **= significant at P< 0.05 and P< 0.001, respectively; ns= not significant. Means in a column with the same letter are not significantly different from each other; BY= biomass yield; GY= grain yield

Therefore, the results of this study has clearly indicated that it is possible to fairly increase wheat yield through combined or multiple nutrient application approach, rather than applying nutrient from one source. In line with the current result, research findings of Tekalign Mamo *et al*. (2001) and Getachew Agegnehu *et al.* (2012) indicated that wheat has showed significance response to the combined soil fertility management treatments containing both organic and inorganic forms under farmers' field condition that they could be considered as alternative options for sustainable soil and crop productivity in the degraded highlands of Ethiopia. Moreover, the crop has responded differently to application of N and P on different soil types.

Economic Analysis

As farmers attempt to evaluate the economic benefits of shift in practice, partial budget analysis was done to identify the rewarding treatments. Yield from on–farm experimental plots was adjusted downward by 15%, i.e. 10% for management difference and 5% for plot size difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment. Three years average market grain price of wheat (9 birr/kg), farm-gate price of N and P fertilizers (12 and 14 birr/kg) respectively and labour valued at 40 birr/person-day were used. Labour for wheat field management was 30 person-day per hectare. The result of the partial budget analysis is given in Table 4.

Table 4: Partial budget and dominance analyses of organic and inorganic fertilizers trial on wheat

Treatments	Average yield (kg/ha)	Adjusted yield-15% (kg/ha)	Gross benefits (birr/ha)	Costs that vary (birr/ha)				Net benefit (birr/ha)	Dominated
				Fertilizer	Seed	Labour	Total cost		
Control	3172.3	2696.5	24268	-	2500	3850	6350	17918	
Recom. N and P	6241	5304.9	47744	3500	2500	3850	9850	37894	
CC	5790	4921.5	44293	-	2500	6500	9000	35293	D
FYM	4635	3939.8	35458	-	2500	6200	8700	26758	
VC	5144	4372.4	39351	-	2500	6400	8900	30451	D
50% VC + 50% CC	5213	4431.1	39879	-	2500	6650	9150	30729	D
50% VC + 50% FYM	5189.3	4410.9	39698	-	2500	6300	8800	30898	
33% VC + 33% CC + 33% FYM	5923	5034.6	45311	-	2500	6750	9250	36061	
50% VC + 50% NP	6698	5693.3	51239	1750	2500	6000	10250	40989	
50% CC + 50% NP	5940.7	5049.6	45446	1750	2500	5700	9950	35496	D
50% FYM + 50% NP	6148.3	5226.1	47034	1750	2500	5920	10170	36864	

CC= conventional compost; FYM= farmyard manure; VC= vermicompost; D= Dominated

The economic analysis further revealed that the application of 50% of vermicompost plus 50% N and P fertilizers provided the highest marginal rate of the return (MRR) of 5156% (Table 4) suggesting for one birr invested in wheat production, the producer would collect birr 51.56 after recovering his investment. Since the MRR assumed in this study was 100%, the treatment with application of 50% of vermicompost and 50% NP gave an acceptable MRR. Therefore, the application 50% VC (based on N equivalent rate) and 50% N and P fertilizers mentioned above is found economical to be recommended on Nitisols of the study area and similar locations in the central highlands of Ethiopia.

Table 5: Marginal analysis of organic and inorganic fertilizer effects on wheat at Welmera, 2014 and 2015

Particulars	Control	Rec. NP	FYM	50% VC + 50% FYM	33% VC 33% CC + 33% FYM	50% FYM + 50% NP	50% VC + 50% NP
Average yield (kg/ha)	3172.3	6241	4635	5189.3	5923	6148.3	6698
Adjusted yield-15% (kg/ha)	2696.5	5304.9	3939.8	4410.9	5034.6	5226.1	5693.3
Gross benefit (birr/ha)	24268.5	47744	35458	39698	45311	47035	51240
Cost of fertilizer (birr/ha)	-	3500	-	-	-	1750	1750
Cost of seed (birr/ha)	2500	2500	2500	2500	2500	2500	2500
Cost of labour (birr/ha)	3850	3850	6200	6300	6750	5920	6000
TVC (birr/ha)	6350	9850	8700	8800	9250	10170	10250
NB (birr/ha)	17918.5	38744.1	26758.2	30898.1	36061.4	36864.9	40989.7
MC (birr/ha)		200	2350	100	250	500	80
MB (birr/ha)		8840	8839.7	4139.9	2682.7	1223.5	4124.8
MRR (%)		4420%	376.2%	4139.9%	1073%	244.7%	5156%

TVC= total variable cost; NB= net benefit; MC= marginal cost; MB= marginal benefit and MRR= marginal rate of return

Conclusion

The result of this experiment showed that the two years result were significantly different from each other most probably attributed to season differences and the carry over effect of the previous year fertilizer application as the plots were fixed during the experimental period. Results of soil analysis after harvesting revealed that application of organic fertilizer improved soil pH, OC, total N and available P. Therefore, from the results of this study, it can be concluded that wheat crop could reasonably be produced using 50% vermicompost (based on N equivalent rate) plus half doses of the recommended N and P fertilizers from inorganic sources. Hence, combined or multiple use of chemical fertilizer and locally available organic fertilizer application is the best approach for achieving higher fertilizer-use efficiency, maximum yield and economic return of input than the sole application of either of the input types.

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Combined Application of Organic and Inorganic Fertilizers on Yield of Tef and Soil Properties in the Central Highlands of Ethiopia

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Introduction

In sustainable agricultural system, integrated soil fertility management is an approach that attempts to make the best use of inherent soil nutrient stocks, locally available soil amendments and mineral fertilizers to increase land productivity while, maintaining or enhancing soil fertility. Integrated soil fertility management strategies include the combined use of soil amendments, organic materials and mineral fertilizers to replenish soil nutrient pools and improve the efficiency of external inputs.

Rong et al., (2001) reported that combined application of organic and inorganic fertilizers decreased soil bulk density, increased soil moisture, soil fertility, and improved maize grain quality. Donovan and Casey (1998) also showed that technologies that combine mineral fertilizers with organic nutrient sources can be considered as better options in increasing fertilizer use efficiency, and providing a more balanced supply of nutrients. It is also general fact that organic fertilizers increase yields of crops significantly over inorganic fertilizers mainly because these materials decompose, and hence release nutrients gradually over the crop growth period and they also build up organic carbon content essential for maintaining soil structure and the water holding capacity of the soil.

Traditional composting of organic wastes has been known for many years but new methods of thermophilic composting have become much more popular since it eliminates some detrimental effects of organic wastes in the soil and it is also cost effective and environmentally sound process for treatment of many organic wastes (Hoitink, 1993). When the composting process is assisted by the presence of the earthworms in the compost heap, it is named Vermicomposting.

Chemical fertilizers are also becoming very costly for farmers to apply the full recommended rates. On the other hand, sole application of organic matter is constrained by access to sufficient organic inputs, low nutrient content, high labor demand for preparation and transporting. Thus, the integration of organic and inorganic nutrient sources can improve and sustain crop yields without degrading soil fertility status. This has been confirmed by different authors such as Tolessa (1999a), Wakene et al., (2004) and Teklu and Hailemariam (2009) in their recommendation of FYM combined with inorganic fertilizer for maize and tef crop production. This experiment was therefore, carried out with objective of determining the effect of farmyard manure, compost, vermicompost, and N and P fertilizers and their combinations on the yield of tef.

Materials and Methods

Experimental Site

The trial was conducted at Ginchi, West Shewa Zone of Oromiya Regional State for two consecutive cropping seasons (2013 and 2014). Geographically, the experimental site is located at 09^0 02'N and 38^0 12'E and an altitude of 2200 masl at a road distance of about 74 km West of Addis Ababa. The area is characterized by a unimodal rainfall pattern and receives an average annual rainfall of 1080 mm, about 85% of which is received from June to September. The annual average minimum and maximum air temperatures are 9 and 24°C, respectively (Getachew and Amare, 2004. Tef variety (Kuncho) was used as test crop in the experiment. The rates of organic fertilizers applied were based on the recommended N equivalent rate for the test crop.

Treatments

No.	Treatments	Description
1	Control	without fertilizer
2	Recommended N and P	69 N kg/ha and 26 P kg/ha
3	Conventional Compost (CC)	7.1 ton/ha
4	Farmyard manure (FYM)	4.1 ton/ha
5	Vermicompost (VC)	9.6 ton/ha
6	50% VC + 50% CC	4.8 ton/ha VC + 3.55 ton/ha CC
7	50% VC + 50% FYM	4.8 ton/ha VC + 2.1 ton/ha FYM
8	33% VC + 33% CC + 33% FYM	3.2 ton/ha VC + 2.36 ton/ha CC + 1.36 ton/ha FYM
9	50% VC + 50% NP	4.8 ton/ha VC + 34.5 kg/ha N + 13 kg/ha P
10	50% CC + 50% NP	3.55 ton/ha CC + 34.5 kg/ha N + 13 kg/ha P
11	50% FYM + 50% NP	2.1 ton/ha FYM + 34.5 kg/ha N + 13 kg/ha P

The above mentioned treatment combinations were laid down in RCBD with three replications. Compost and Vermicompost were was prepared following the standard procedure and then their N and P contents were analyzed in the laboratory using standard procedure to determine the rate of application of each treatment, which was based on recommended N equivalent rate for the test crop. Manure and compost were applied to the field three weeks before sowing and thoroughly mixed in the upper 15 to 20 cm soil depth. Nitrogen and P fertilizers were applied in the form of Urea and TSP respectively. To minimize the loss and increase the efficiency of N, half rate of N was applied as split at planting and the remaining half at tillering stage of the crop whereas all P rate was applied as basal application during planting time. The seed was drilled at the recommended seed rate of 12 kg ha^{-1} in row. All recommended agronomic management practices were carried out during the crop growth period as per needed.

Data Collection and Analysis

Composite surface soil samples collected from experimental fields (0-20 cm depth) before planting and soil samples collected after harvest from each treatment plots were analyzed for their content of pH, total organic carbon (OC), total N, available P. All standard procedures were employed to measure the above mentioned soil parameters.

Plant parameters collected were grain yield, above ground total biomass. Grain yield was adjusted to a moisture content of 12.5% before statistical analysis and the data were subjected to analysis of variance (GLM procedure) using SAS statistical computer package (SAS, 2002). Duncan multiples range test (DMRT) test at 5% probability level was used to detect differences among treatment means.

Results and Discussion

Effects of fertilization on soil chemical properties

All the soil parameters tested (pH, OC, N and P) measured after harvesting were significantly ($P<0.05$) affected by the application of different fertilizer inputs applied. This result indicated very little tendency rising soil pH, OM and nutrient concentrations in the plots treated with manure, conventional compost and vermicompost (Table 1). The average soil pH of the experimental field after harvest was found to be 6.40, which is nearest to neutral.

Though the values of OC were generally rated as medium(Jones, 2003), the highest OC, 3.42% and 3.39% were recorded from plots treated with full doses of farm yard manure and compost respectively and the least (2.83%) was from the plot which received recommended N and P (Table 1). Likewise, the total N and available P determined after harvesting was rated high (Tekalign, 1991). The highest soil total N (0.32% and 0.30%) were recorded from plots treated with full doses of farm yard manure and compost respectively. The lowest soil N content 0.22% was obtained from the plot which received recommended N and P as usual. Similarly, the highest soil available P (29.44 mg kg-1) was recorded from plots treated with one-third of each nutrient source (manure + conventional compost + vermicompost).

This finding is in agreement with Kaur et al. (2005) mentioning that application of farmyard manure or poultry manure improved the soil organic C, total N, P and K status. Sharma et al. (1990) also reported that the use of organic fertilizer can made the soil more porous and pulverized, to allow better root growth and development, thereby resulting in higher root cation exchange capacity (CEC). According to Vanlauwe et al. (2001) the direct interactions between chemical fertilizer and organic matter can improve soil fertility by restocking nutrients lost through leaching and by modifying the pH of the rhizosphere and making unavailable nutrients available. Generally, the above results indicate that integrated use of nutrient sources have significant improvement in the overall condition of the soil as well as agricultural productivity if best alternative option is adopted in the area.

Table 1: The effect of organic and inorganic fertilizer application on soil chemical properties analyzed for samples after harvest of tef (2013 and 2014)

Treatments	pH(H_2O)	Nitrogen (%)	Phosphorous (mg kg^{-1})	OC (%)
Recom.NP	6.3^{b}	0.23^{c}	26.48	2.83^{e}
Conventional Compost (CC)	6.53^{a}	0.30^{ab}	28.41	3.39^{ab}
Farmyard manure (FYM)	6.54^{a}	0.32^{a}	28.19	3.42^{a}
Vermi Compost (VC)	6.45^{ab}	0.28^{ab}	28.57	3.12^{bcd}
50% VC + 50% CC	6.4^{ab}	0.27^{b}	27.11	2.99^{cde}
50% VC + 50% FYM	6.42^{ab}	0.267^{bc}	28.75	3.02^{cde}
33% VC + 33% CC + 33% FYM	6.52^{a}	0.267^{bc}	29.44	3.06^{cde}
50% VC + 50% NP	6.41^{ab}	0.273^{b}	28.12	3.26^{abc}
50% CC + 50% NP	6.32^{b}	0.267^{bc}	24.44	2.9^{de}
50% FYM + 50% NP	6.48^{a}	0.267^{bc}	23.70	3.05^{cde}
Overall mean	6.40	0.245	26.14	3.03
DMRT(0.05)	0.147	0.043	NS	0.287
CV (%)	1.35	8.9	18.3	5.3

Means in a column with different letters are significantly different at P<0.05, NS= Not significant.

Effects of integrated nutrient application on tef yield and yield components

The combined analysis of variance over two years revealed that the effect of cropping season was significant ($p<0.05$) on grain and biomass yields of tef. The highest mean value of grain and biomass yield were recorded during 2014 cropping season (Table 2) due to the fact that the plots were fixed during the study period and there was carry over effect from the previous year application of organic fertilizers. This study clearly showed that productivity of tef had significantly affected by different treatments applied.

The highest tef grain and biomass yield (3144.8 kg ha^{-1} and 12562 kg ha^{-1} respectively) were obtained from the application of 50% VC and 50% recommended rate of N and P followed by full dose of recommended rate of N and P from inorganic fertilizer resulting in 2846 kg ha^{-1} grain and 11833 kg ha^{-1} biomass yields respectively, where there is no significance differences between the two treatments. The application of 50% CC with 50% N and P has also given comparable grain and biomass yield as compared to application of full dose of N and P from inorganic fertilizer. The rest set of treatments had given inferior yields under all tested parameters where the lowest grain yield was from plot treated with vermicompost alone (Table 2).

Table 2: Effects of organic and inorganic fertilizers application on tef yield

Year	BY($kgha^{-1}$)	GY($kgha^{-1}$)
2013	10780.3^{b}	1964.1^{b}
2014	17564.4^{a}	2435.9^{a}
F-Probability	**	*
DMRT $_{0.05}$	758	152.29
Treatments		
Recommended NP	11833.3^{ab}	2846^{ab}
Conventional Compost (CC)	7979.2^{d}	1941de
Farmyard manure (FYM)	8250^{d}	1920^{e}
Vermi-Compost (VC)	9020^{cd}	1904.7^{e}
50% VC + 50% CC	8500^{cd}	2027.3^{de}
50% VC + 50% FYM	8750^{cd}	1933.5^{de}
33% VC + 33% CC + 33% FYM	9145.8^{cd}	2293^{cd}
50% VC + 50% NP	12562.5^{a}	3144.8^{a}
50% CC + 50% NP	10208.3^{bc}	2516.7^{bc}
50% FYM + 50% NP	9687.5^{cd}	2420^{c}
DMRT $_{0.05}$	1940.2**	368.02
Y x T	**	*
CV (%)	16.6	13.9

*, **= significant at P< 0.05 and P< 0.001, respectively; NS= Not significant. Means in a column with the same letter are not significantly different (P<0.05).PHT= plant height; PL= panicle length; BY= biomass yield; GY= grain yield

Therefore, the result of this study has clearly indicated that it is possible to fairly produce tef through integrated nutrient application approach, rather than applying nutrient from one source. In line with the current result, research findings of Tekalign *et al*. (2001), Ayalew (2011) and Getachew *et al.* (2012) indicated that tef has showed significance response to the integrated soil fertility management treatments containing both organic and inorganic forms under farmers' field condition that they could be considered as alternative options for sustainable soil and crop productivity in the degraded highlands of Ethiopia.

Economic analysis

As farmers attempt to evaluate the economic benefits of shift in practice, partial budget analysis was done to identify the rewarding treatments. Yield from on-farm experimental plots was adjusted downward by 15% i.e., 10% for management difference and 5% for plot size difference, to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment (Getachew and Taye, 2005).

Three years average market grain price of tef (ETB 13.5kg^{-1}), farm-gate price of N and P fertilizers (ETB 12kg^{-1} and 15kg^{-1}) respectively and labour valued at ETB 40 per person-day were used. Labour for tef field management was 30 person- days per hectare. The result of the partial budget analysis is given in (Table 3). The economic analysis revealed that the highest net benefit of (birr 28588.9 ha^{-1}) was obtained from the application of 50% vermicompost plus 50% N and P fertilizers, where as the control treatment (no application of input) gave the lowest net benefit (birr 10778.9 ha^{-1}).

Table 3: Partial budget and dominance analyses of organic and inorganic fertilizers trial on tef

Treatments	Average yield (kg/ha)	Adjusted yield-15% (kg/ha)	Gross benefits (birr/ha)	Costs that vary (ETB ha^{-1})			Net benefit (birr/ha)
				Fertilizer	Labour	Total cost	
Control	1253	1065.1	14378.9		3600	3600	10778.9
Recom. NP	2846	2419.1	32657.9	4750	1850	6600	26057.9
CC	1941	1649.85	22272.9	-	4500	4500	17772.9
FYM	1920	1632.00	22032	-	5100	5100	12832
VC	1905	1619.25	21859.9	-	4800	4800	17059.9
50% VC + 50% CC	2027	1722.95	23259.8	-	4650	4650	18609.8
50% VC + 50% FYM	1934	1643.9	22192.7	-	4300	4300	17892.7
33% VC + 33% CC + 33% FYM	2293	1949.05	26312.2	-	5250	5250	21062.2
50% VC + 50% NP	3145	2673.25	36088.9	3250	4250	7500	28588.9
50% CC + 50% NP	2517	2139.45	28882.6	3250	4000	7250	21632.6
50% FYM + 50% NP	2420	2057	27769.5	3250	3500	6750	21019.5

Three years average price of tef is ETB 13.5/kg, Urea birr 12/kg and DAP birr 15/kg (1USD = 20.40 Ethiopia birr);

The economic analysis further revealed that the application of 33% of each of the nutrient sources used i.e. 3.2t ha^{-1} VC + 2.36t ha^{-1} CC + 1.36t ha^{-1} FYM (based on recommended N equivalent rate) provided the highest marginal rate of the return (MRR) of 408.7% (Table 4) suggesting for each birr invested in tef production, the producer would collect birr 4.087 after recovering his cost. Since the MRR assumed in this study was 100%, the treatment with application of 33% of VC, CC and FYM gave an acceptable MRR. Therefore, the combined application each of these organic fertilizers (based on N equivalent rate) would be economical to be recommended on Vertisols of central highlands of Ethiopia.

Table 4: Marginal analysis of organic and inorganic fertilizer effects on tef at Ginchi, 2013 and 2014

Particulars	Control	Rec.NP	50%VC+ 50% CC	33%VC + 33%CC+ 33%FYM	50%VC + 50%NP
Average yield (Kg ha^{-1})	1253	2846	2027	2293	3145
Adjusted yield-15%(Kg ha^{-1})	1065.1	2419.1	17222.95	1949.1	2673.25
Gross benefit (ETB ha^{-1})	14378.9	32657.9	23259.8	26312.2	36088.9
Cost of fertilizer (ETB ha^{-1})	0.00	4750	0.00	0.00	3250
Cost of labour (ETB ha^{-1})	3600	1850	4650	5250	4250
TCV (ETB ha^{-1})	3600	6600	4650	5250	7500
NB (ETB ha^{-1})	10778.9	26057.9	18609.8	21062.2	28588.9
MC (ETB ha^{-1})		550	550	600	900
MB(ETB ha^{-1})		4995.7	677.8	2452.4	2531
MRR (%)		370.1%	123.2%	408.7%	281.2%

Conclusion

The result of this experiment has showed that the two years result were significantly different from each other most probably attributed to season differences and the carry over effect of the previous year fertilizer application as the plots were fixed during the experimental period. Thus, the combined analysis indicated that integrated application of organic and inorganic fertilizer mix 50% VC (4.8 t ha^{-1}) and 50% recommended N and P rates (34.5 kg ha^{-1} N and 30 kg ha^{-1} P) have given the maximum grain and biomass yield of tef (3144 kg ha^{-1} and 12562 kg ha^{-1} respectively) followed by the full recommended N and P rate (2846 kg ha^{-1} and 11833 kg ha^{-1}). But, considering the economical feasibility of input use, the application of 33% of each of the organic fertilizers i.e. vermicompost, conventional compost and farmyard manure (based on N equivalent rate), has been found economical to be recommended on Vertisols of the study area and similar agro-ecologies. Moreover, the status of soil fertility has been improved where the OM is increased from 2.83% to 3.03%, TN from 0.23% to 0.25%, while P showing no significant difference. Therefore, integrated use of chemical fertilizer and locally available soil amendments is the best approach for achieving higher crop yields and economic feasibility. In order to address soil fertility problems, potential synergies can be gained by combining technical options with farmers' knowledge as well as training of farmers and development agents on integrated soil fertility management approaches.

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Performance Evaluation of Different Crops as an Option for Smallholder farmers producing on the Waterlogged Vertisols of Central Highlands of Ethiopia

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Introduction

Vertisols is a group of heavy clay soils having 2:1 expanding clay type and swell and shrink upon wetting and drying, respectively. It has produced a modified micro-environment mainly dominated by water loggings and micro-*gilgai* surface relief. With little surface modification and management most farmers allows some crops to fit with it. Thus, predominant crops like tef, wheat, chickpea, lentils and grass pea have been grown for long. Today, with improved drainage system, several attempts were made to introduce and hence possible to diversify the alternative option of crops having a high net return per hectare as compared to the predominant crop on Vertisols.

High value crops generally refer to non-staple agricultural crops such as vegetables, fruits, flowers, ornamentals and spices (Temu and Temu, 2005; CGIAR, 2005). Most high value agricultural crops are those known to have a higher net return per hectare of land than staples or other widely grown crops. They, therefore, generally have a monetary value higher than staple crops in emerging and expanding local, national, regional and global markets. High value crops and products present an ideal opportunity for the poor in many developing countries to increase their income by participation in commodity value chains, provided there is effective vertical coordination to ensure that supply is in relative balance with demand. IFAD (2008) has made a research in the role of high-value crops in rural poverty reduction in the Yemen, Syria, and Egypt and found out the positive outcome. Accordingly, they provide options for income diversification and pathways out of poverty. This consistently shows that the ratio of benefits to costs for these high value crops is at least two times higher than the corresponding ratio for predominant cereals and pulses. Similar research findings have been reported by Temu and Temu, 2005).

When we come to our scenario, according to the World Bank report in 2011, arable land (hectares per person) in Ethiopia is 0.17 ha (1700 sq m). The yield obtained from the given land is not significantly increasing and currently economic return mostly seems does not satisfy their needs. Therefore, different options have to be look into it and crop diversification and intensification is only one of them. Thus, the objective is to evaluate the performance of high value crops on Vertisols and to determine the economic rate of return by producing them on Vertisols.

Material and Methods

Ambo

Ambo site is situated on 38^o 07' E longitude and 8º 57'N latitude and 2225m altitude. The area experienced bimodal rainfall with a mean annual precipitation of 1115 mm. The mean maximum and minimum temperature of the area is 25.4^oC and 11.7^oC respectively. The soil texture has been classified as clay soil. As the graph show that the ratio between monthly precipitation (input) to output (monthly evaporation) is less than unit starting from January to May and end of September to December.

DebreZeit

DebreZeit Agricultural Research Center is located at Central highlands of Ethiopia and situated between 38'051'43'.63" to 39'004'58"E and 8'046'16.20" to 8'059'16.38"N, in the Western margin of the great East African Rift Valley, at an altitude of 1980 m above sea level. The soils are dominantly vertic in nature. The average minimum and maximum air temperature of the watershed are about 7.9 and 28.2^oC, respectively, with the mean annual value of about 18.5^oC. The area receives an annual mean rainfall of around 789 mm with medium seasonal variability and bimodal pattern. The "Meher" rain, which is quite small to support crop production, usually occurs during the periods from the second week of March to second or third week of May. The long rainy season extends from the second week of June to the last week of September.

Treatments and Experimental Design

The experiments were conducted in both locations in 2012 and 2013 cropping seasons on two land configurations-broad bed and furrow (BBF) and flat. In each land configuration, there were six to seven treatments. The available high value crops such as black and white cumin, coriander, chickpea (improved variety), Lentil, popcorn along with the major crops like tef and wheat were used as a treatment and planted on a plot size of 5 m x 5 m in RCBD with four replications. The recommended fertilizers rate and other agronomic management practices were adopted for these crops. The monetary values of these high values crops were compared among each other and with the predominant crop usually grown on Vertisols such as tef. The data were subjected to analysis of variance using SAS software program version 8.2 (SAS Institute, 2000). LSD at 0.05 probability level was employed to separate treatments means where significant differences exist (Gomez and Gomez, 1984).

Results and Discussion

Table 1 shows biomass yield, economic yield, monetary value (birr ha^{-1}) and monetary advantage (birr ha^{-1}) of crops in 2012 at Ambo. The statistical analysis revealed that highly significant ($P<0.05$) variation was observed among the treatments in the dry biomass, economic yield, and gross monetary value of the respective high value crops.

Table 1 Crop diversification and economic benefits of the introduced crops in 2012 at Ambo

Treatment	Biomass Yield	Grain Yield	Monetary Value(Birr ha-1)	Monetary Advantage (Birr ha-1)
Black cumin	4816.7^{b}	1182.7^{d}	70308.3	+42159.5
White cumin	7083.3^{a}	1861.7^{bc}	95630	+25321.7
Coriander	4200^{b}	1473.0^{cd}	55056.5	+26907.7
Chickpea	5216.7^{b}	2200.3$^{a\ b}$	29644.86	+1496.06
Teff	7416.7^{a}	2363.0^{a}	28148.8	
LSD (5 %)	1434.2	423.98		
CV (%)	13.25	12.39		

The results in Table 1 showed that producing these crops would have an economic benefits of at least 33,203 Birr/ha as compared to the traditional Vertisols dominant crops tef (*Eragrostis tef*). The highest monetary value (95,630 Birr/ha) and economic yield (1861.7 kg/ha) recorded from White cumin , followed by black cumin and coriander (Table 1). This indicates that the newly introduced crops were found to be promising in terms of economic return though the yield were a bit small as compared to the predominant crops on Vertisols such as tef and Chickpea.

Table 2 shows the status of high value crops as well as the dominant crops in 2013 cropping season at Ambo. The highest monetary value (14 6385.2 Birr/ha) and economic yield (4185.7 kg/ha) recorded from pop corn, followed by black-cumin (58,187.39 Birr/ha) and coriander (39180.5 Birr/ha). Similarly, the monetary gain was obtained (116,989 Birr/ha, 28791.19 Birr/ha and 9784.3 Birr/ha) over tef , respectively.

The results indicated that the promising high value crops like pop corn (40 Birr/kg) and black-cumin (70 Birr/ha) gave the highest economic benefit under the improved price observed in the local market of the area.

Table 2. The mean dry biomass and economic yield of high value crops grown in 2013, at Ambo

Treatment (High Value Crops)	Dry Biomass (kg/ha)	Yield (kg/ha)	Monetary Value (Birr/ha)	Monetary gain over teff (Birr/ha)
Black-cumin	4989[c]	990.3[c]	58187.39	+28791.19
Coriander	3552[c]	1081.0[c]	39180.5	+9784.3
Pop corn	20037[a]	4185.7[a]	146385.2	+116989
Tef	11065[b]	2462.0[b]	29396.2	
LSD (5%)	3470.2	805.24		
CV (%)	17.52	18.49		

Means in the same column with the same letter are not significantly different at 5% probability level. (Birr/ha) expressed in Ethiopia Birr per unit hectare, + and – are denoted for profit and loss, respectively.

Hence, the economic analysis suggests that the economic benefits of pop corn and black-cumin are profitable over the crops like tef which usually grown on highland Vertisols predominantly.

Table3 shows biomass yield, economic yield, monetary value (birr ha^{-1}) and monetary advantage (birr ha^{-1}) of crops in 2012 at Debrezeit on Flat land planting system. It shows a significant difference among treatments on grain yield as well as on the gross monitoring value. Highest grain yield (1630.20 kg/ha) was observed from the pre dominant crops while the highest monitoring value (25031.47 birr ha^{-1}) were recorded from the high value crops (Table 3). This indicates that although the yield of these high value crops are low, but the return from them is high. Table 1 also showed that the yield of the crops in 2012 cropping season were generally low. This is probably due to the high rain fall distribution of the season. The highest gross monitoring value was recorded from black cumin followed by coriander (table 3).

Table 3. The mean dry biomass, economic yield and gross monetary value of high value crops grown at Debrezeit on flat bed system in 2012 cropping season.

Treatment	Biomass Yield (kg/ha)	Economic Yield (kg/ha)	Monetary Value (Birr ha^{-1})	Monetary Advantage (Birr ha^{-1})
Black cumin	1237.5^{c}	441.78^{cb}	25031.47	7790.488
White cumin	1037.5^{c}	284.98^{c}	11888.64	-5352.34
Coriander	1400^{c}	616.35^{b}	21762.18	4521.195
Chickpea	990^{c}	558.15^{b}	4842.03	-12399
Lentil	2300^{b}	597.65^{b}	7847.125	9393.855
Wheat	5818^{a}	1630.20^{a}	10372	
Teff	5383^{a}	1497.30^{a}	17240.98	
LSD (5 %)	726.08	201.79		
CV (%)	18.83	16.9		

Means in the same column with the same letter are not significantly different at 5% probability level. (Birr/ha) expressed in Ethiopia Birr per unit hectare,
+ and – are denoted for profit and loss, respectively.

The biomass yield, economic yield, monetary value and monetary advantage of crops in 2012 on BBF planting system were shown on Table 4 bellow. Here also it showed the highest economic yield (2090.6 kg/ha) was recorded from wheat whereas the highest gross monetary value (27242.54 Birr/ha) was observed from Black cumin. The results also showed that growing of this crop under BBF and flat method of seed bed preparation makes no or little difference on yield except wheat yield which results higher yield on BBF planting method (table 3 and 4). This result is in agreement with Okada et al. (1991) which also reported that ridge and furrow system made on Vertisols at ICRISAT were better than flat seedbeds. The yield of the newly introduced crops were comparable both on BBF and flat bed planting method this is probably due to the BBF may fail to provide safe drainage in times of peak rains.

Table 4. The mean dry biomass and economic yield gross monetary value of high value crops grown at Debrezeit on BBF planting method in 2012 cropping season.

Treatment	Biomass yield (kg/ha)	Grain yield (kg/ha)	Monetary Value (Birr ha^{-1})	Monetary Advantage (Birr ha^{-1})
Black cumin	1804.4^{c}	499.1^{cd}	27242.54	+2525.98
White cumin	1272.1^{c}	336.7^{d}	13281.47	-13961.1
Coriander	1851.2^{c}	743.2^{c}	25499.6	+12218.13
Chickpea	1679.3^{c}	372.3^{cd}	431.26	-24285.3
Lentil	1500.0^{c}	424.6^{cd}	2553.5	-22163.1
Wheat	7554.4^{a}	2705.8^{a}	20052	
Teff	6443.0^{b}	2090.6^{b}	24716.56	
LSD (5 %)	634.4	382.69		
CV (%)	13.51	25.14		

Means in the same column with the same letter are not significantly different at 5% probability level. (Birr/ha) expressed in Ethiopia Birr per unit hectare, + and – are denoted for profit and loss, respectively.

Table 5 shows a significant difference ($P<0.05$) on the biomass, grain yield and monetary value of crops in flat bed planting method. The highest grain yield (2308.55 kg ha^{-1}) was recorded by wheat while the lowest is observed by lentil (587.38 kg ha^{-1}). The highest monetary value was recorded due to black cumin (49504.49 birr ha^{-1}) followed by white cumin (30199.72 birr ha^{-1}). The table also shows that, there is high monetary advantage due to the newly introduced crops as compared to tef. It can also be noted that since the general yield of the crops is good we can say that the crops are well adapted to the soil.

Table 5 The mean dry biomass and economic yield gross monitoring value of high value crops grown at Debrezeit on Flat bed planting method in 2013 cropping season.

Treatment	Biomass Yield (kg/ha)	Economic Yield (kg/ha)	Monetary Value (Birr ha^{-1})	Monetary Advantage (Birr ha^{-1})
Black cumin	2921.1^{c}	830.25^{c}	49504.49	+31885.88
White cumin	2319.0^{cde}	624.08^{cd}	30199.72	+12581.11
Coriander	2841.3^{cd}	803.95^{c}	29359.98	+11741.37
Chickpea	1619.5^{e}	446.83^{d}	3038.646	-14580
Lentil	2079.9^{de}	587.38^{d}	7616.05	-10002.6
Wheat	7935^{a}	2308.55^{a}	16477	
Teff	5560.0^{b}	1527.27^{b}	17618.6	
LSD (5 %)	813.5	206.76		
CV (%)	15.16	13.67		

Means in the same column with the same letter are not significantly different at 5% probability level. (Birr/ha) expressed in Ethiopia Birr per unit hectare, + and – are denoted for profit and loss, respectively.

A significant difference ($P<0.05$) of crops biomass yield and monetary advantage was also recorded on BBF planting methods (table 6). Although the highest grain yield (2038.2 kg/ha) was recorded due to wheat, the highest monetary value was recorded by black cumin (57633.01Birr ha^{-1}) followed by coriander (39415.4 Birr ha^{-1}) and White cumin (38158.83 Birr ha^{-1}). The monetary advantage recorded due to black cumin, coriander and white cumin was 40447.47 Birr ha^{-1} 22229.86 birr ha^{-1} and 20973.29 birr ha^{-1} respectively. Table 4 also shows planting of the newly introduced crops on BBF makes a difference in yield. It can be observed that planting the crops using BBF is advantageous where there is a good cropping season.

Table 6: The mean dry biomass and economic yield gross monitoring value of high value crops grown at Debrezeit on BBF planting method in 2013 cropping season.

Treatment	Biomass Yield (kg/ha)	Economic Yield (kg/ha)	Monetary Value(Birr ha^{-1})	Monetary Advantage (Birr ha^{-1})
Black cumin	1700.0^{c}	981.5^{cd}	57633.01	+40447.47
White cumin	3050.0^{b}	797.4^{d}	38158.83	+20973.29
Coriander	2500.0^{b}	1086.8^{c}	39415.4	+22229.86
Lentil	1050.0^{cd}	278.2^{e}	-740.5	
Wheat	5395.0^{a}	2038.2^{a}	14044^{c}	
Teff	4796.3^{a}	1492.9^{b}	17185.54	
LSD (5 %)	727.49	274.38		
CV (%)	17.95	19.10		

Means in the same column with the same letter are not significantly different at 5% probability level. (Birr/ha) expressed in Ethiopia Birr per unit hectare, + and – are denoted for profit and loss, respectively.

Conclusions and Recommendations

From the above results, it is possible to conclude that these high value crops have well adapted to the area where Vertisols are dominant. The economic analysis also suggests that the economic benefits of black-cumin, white cumin, Popcorn and coriander are profitable over the crops like tef and wheat which usually grown on highland Vertisols predominantly.

From the results, white cumin (*Cuminum cyminum* L.), black cumin (*Nigella sativa*) and coriander can be recommended for Debrezeit area while black cumin and popcorn can be recommended for Ambo area. The availability of quality seed is also decisive to guarantee good performance.

It can also be concluded that planting of these high value crops in BBF system rather than the flat bed planting method is advantageous. But care should be taken in preparing the seed bed. It should be wide enough so that the crops don't lodge during peak rainy time.

Therefore, this promising result should be scaled out/demonstrated to the farming community. In the a future, research on the fertilizer requirement and agronomic package of these high value crops on Vertisols for full package recommendation is very important .

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