academicJournals

Vol. 13(10), pp. 477-489, 8 March, 2018
DOI: 10.5897/AJAR2017.12949
Article Number: BBCA0CD56253
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Effects of lime, vermicompost and chemical P fertilizer on yield of maize in Ebantu District, Western highlands of Ethiopia

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Received 23 December, 2017; Accepted 12 February, 2018

Integrated use of lime with organic and chemical fertilizers is considered as a good approach for sustainable crop production under acidic soils. Vermicompost (VC) and chemical phosphorus (P) fertilizer when used with lime play a vital role in enhancing productivity of acidic soils. Field experiments were conducted for two consecutive cropping seasons of 2015 and 2016 to evaluate the effects of lime, VC and chemical P fertilizer on yield and yield components of maize in Ebantu District, Western highlands of Ethiopia. The experiments were laid out in a randomized complete block design as a factorial combination of two lime rates (0, and 4 t $CaCO_3$ ha^{-1}), three VC rates (0, 2.5 and 5 t VC ha^{-1}) and three chemical P rates (0, 20 and 40 kg P ha^{-1}) which were replicated three times. Relevant crop parameters were measured following standard procedures. Tasseling days (102), silking days (109), highest leaf area index (5.91), plant height (3.48 m), cob length (47.83 cm), number of grain per cob (644) and above ground dry biomass yield (22 t ha^{-1}) were exhibited by 5 t ha^{-1} VC and 40 kg ha^{-1} chemical P fertilizer with lime of 0 and 4 t ha^{-1} while the highest 1000-seed weight (508 g), grain yield (4.87 t ha^{-1}) and harvest index (24%) were obtained at 2.5 t ha^{-1} VC and 40 kg P ha^{-1} with lime. Integrated application of organic and chemical fertilizers with lime amended the acidic soils and improved its fertility which in turn increased crop yields. Combined use of VC at 2.5 t ha^{-1} and chemical P fertilizer at 20 kg ha^{-1} with lime at 4 t ha^{-1} is economically optimum and could be recommended for reclaiming soil acidity and improve nutrients for maize as it enhanced grain yield and yield components of maize plant in strongly acidic soils for the two consecutive years pooled together.

Key words: Maize yield, lime, Vermicompost (VC), phosphorus (P), integrated application.

INTRODUCTION

Maize (*Zea mays* L.) is the most widely grown staple food crop in sub-Saharan Africa (SSA) occupying more than 33 million ha each year (FAO, 2015). Ethiopia is Africa's fourth biggest maize producer next to South Africa, Nigeria and Egypt but the yield of the crop was low in the country (ECEA, 2009).

In Ethiopia, maize had been growing from moisture stress areas to high rainfall areas and from lowlands to highlands of the country. Among cereals, maize is the first and second crop in terms of volume of production and area coverage followed by and next to *teff* (*Eragrostis tef*) (CSA, 2017).

Although maize is an important crop, the major constraint limiting its production in medium to high agricultural potential areas in tropical Africa is soil acidity (Kanyanjua et al., 2002; Opala et al., 2015). Low soil fertility and nutrient availability due to acidity and low level of input use are also among the major crop production constraints in Ethiopia including maize crop (Alemayehu et al., 2011; Abreha et al., 2013). Maize does well with pH of 5.5-5.7, while strongly acidic soil (pH ≤ 5.0) is unsuitable for good yield (Mbah and Nkpaji, 2010). The productivity of acid soils is limited by the presence of toxic levels of aluminium (Al) and manganese (Mn) and deficiency of nutrients such as phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo) (Brady and Weil, 2014).

Aluminium toxicity due to high exchangeable Al reduces P uptake by fixing P which in turn affects maize growth and yield on acid soils (Gaume et al., 2001). In sub-humid agro-ecosystem of Western Ethiopia, the highest maize grain yield recorded under farmers' field has been11 t ha^{-1} (Wakene et al., 2007). Surprisingly, CSA (2017) reported that the potential maize productivity on farmers' field in East Wollega is only 4.5 t ha^{-1} due to constraints related to soil acidity and nutrient deficiency problems.

Achieving high maize yield requires adequate and balanced supply of plant nutrients as declining soil fertility is a prominent constraint for maize production (Barbieri et al., 2008; Okoko and Makworo, 2012). There are different materials of conventional and non conventional sources to amend soil acidity and fertility. The general practice for ameliorating soil acidity is the application of lime. However, the key to sustainable food production in low input agricultural system is the use of locally available nonconventional liming materials to reduce soil acidity and increase soil fertility simultaneously.

Vermicompost (VC) and wood ash were reported to increase the pH of acid soils and improve soil fertility by supplying essential plant nutrients (Chaoui, 2003; Materechera, 2012). Along with this, Zeinab et al. (2014) reported that VC has large particulate surface area that provides sites for the microbial activity and retention of nutrients. Similarly, Wael et al. (2011) declared that VC can be used to increase the pH in acidic soils and reduce Al and Mn toxicity because of its alkalinity. It has been reported that application of VC increases the supply of easily assimilated as well as micronutrients to plants besides mobilizing unavailable nutrients into available form (Zeinab et al., 2014). Its application had a positive effect on yield parameters of maize (Gutiérrez-micely et al., 2008). VC contains high levels of total and available N, P, potassium (K) and micronutrients (Tesfaye, 2017), microbial activities and growth regulators (Chaoui, 2003). It significantly stimulates the growth of sweet corn (Lazcano et al., 2011).

Generally, VC can improve seed germination, growth and yield of crops (Nagavallemma et al., 2004). There is an increasing interest in the potential use of VC as soil amendment, where the addition of VC improves the soil physical and chemical properties (Angin et al., 2013; Lordan et al., 2013). Continuous and adequate use of VC with proper management can increase soil organic carbon (OC), soil water retention and permeability (Mahdavi, 2007).

Phosphorus is a critical element in natural and agricultural ecosystems throughout the world (Onweremadu, 2007) as its limited availability is often the main constraint for plant growth in highly weathered soils of the tropics (Bunemann et al., 2004). The application of mineral P fertilizers and the introduction of sustainable land management practices have amended P deficiency in some soils used for crop production. However, P deficiency remains a major constraint in rainfed upland farming systems throughout the tropics (Fairhurst et al., 1999). The high available P contents associated with the mineral P treated soils were attributed to the fact that mineral P applied in the form of TSP is a source of soluble P (Asmare et al., 2015).

Nowadays agronomists are concentrating on reducing the use of inorganic fertilizers by using biofertilizers such as VC (Darzi et al., 2011). The management practices with organic materials influence agricultural sustainability by improving physicochemical and biological properties of soils (Haj Seyed Hadi et al., 2011). Inappropriate use of chemical fertilizers is also becoming a chronic problem due to its high cost (Johannes, 2013) and effect in deteriorating soil biological properties as well as environmental impacts (Zarina et al., 2010). On the other hand, integrated and judicious use of organic sources of nutrients not only supplies nutrients but also has some positive interaction with chemical fertilizers to increase their efficiency and thereby to improve soil structure (Elfstrand et al., 2007).

Similarly, integrated use of organic matter (OM) and chemical fertilizers is beneficial in sustainably improving crop production, soil pH, OC and available N, P, and K in soils (Rautaray et al., 2003). Tilahun et al. *(*2013) also stated that neither inorganic nor organic fertilizers alone can result in sustainable productivity. This situation made the use of integrated nutrient management in maize production necessary since combined use of organic and inorganic fertilizers builds ecologically sound and economically viable farming systems (Rajeshwari, 2005; Wakene et al., 2007). In maize, significantly higher seed

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yield (7.48 t ha^{-1}) was obtained with the application of VC at 5 t ha^{-1} along with the recommended dose of fertilizer when compared with VC alone (Pawar et al., 1995).

Although Ebantu district is humid and sub-humid in its agro-ecology, maize yield is low due to very high soil acidity and low fertility caused by high rainfall, continuous cropping using acidity accelerating mineral fertilizers and crop residue removal from fields. Hence, increasing yield in maize production could be taken as an important step and actual fertilizer recommendations should be made on the basis of experimental results for different nutrients. Farmers in the district do not practice proper application of lime and organic materials integrated with inorganic fertilizers.

However, research on an integrated nutrient management for maize production has not been conducted in the study area. Due to this gap of scientific studies, logical recommendations for combined application of VC and mineral P fertilizer with recommended lime rates were not employed for maize production in the study district. Thus, it is pertinent to study the effect of an integrated use of VC and mineral P fertilizers with lime to improve nutrient availability and hence, crop yield. Therefore, the objective of this study was to evaluate the effects of lime, VC and mineral P fertilizer on maize yield and yield components at the study site.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Ebantu district, East Wollega Zone of Oromia National Regional State (ONRS), Western Ethiopia (Figure 1). It is located at approximately 483 km from Addis Ababa and around 153 km from Nekemte, the capital city of East Wollega zone. The district lies between 9°58'30" to 10°14'0" N and 36°3'0" to 36° 89'40" E and covers an estimated area of 929 km^2 with an altitude that ranges from 1994 to 2176 meters above sea level (masl).

Geologically, the study area is covered by the metamorphic basement rocks in which tertiary volcanic rocks buildup and that is characterized by fine granular rock, small crystal which is invisible by naked eye. This rock is characterized by large vesicles from where gas escaped out and used for percolation of precipitation (Amenti, 1990). The predominant soil type in southwest and western Ethiopia in general and the study area in particular, is Dystric Nitisols according to (FAO, 2001) soil classification system. On average, the soil is deep and relatively highly weathered, well drained and very strongly to strongly acidic in reaction. Nitisols are highly weathered soils in the warm and humid areas of the west and southwest Ethiopia (Mesfin, 1998). Its vernacular name is "*Biyyee Diimaa*" meaning red soil.

The district receives an annual average rainfall of 1778 mm and has monthly mean minimum, maximum and mean air temperatures of 16.6, 20 and 18.3 °C, respectively (NMA, 2015) (Figure 2). The rainfall pattern is unimodal, stretching from April to October.

In terms of topography, 30% of the total area is gentle slope, while flat and steep slope lands account for 52 and 18%, respectively. Out of the total area of the district 35% is covered by cultivated land, 19% is grazing land, 20% is natural forest land, 16% is fallow land, 8% is shrubs and about 2% is estimated to be area covered by settlement (Ebantu district Agricultural development Bureau, 2014 unpublished).

According to the local and the Ethiopian agro-climatic zonation, the study area belongs to the humid (*Baddaa)* and sub-humid *(Badda Daree)* climatic zones (FAO, 1990). The economic activity of the local society of the study area is primarily mixed farming system that involves animal husbandry and crop production. Continuous cultivation without any fallow periods coupled with removal of crop residues is a common practice on cultivated fields. All farmers in the study area use diammonium phosphate (DAP) ($(NH_4)_2HPO_4$), urea ($CO(NH_2)_2$), and cow dung as sources of fertilizers. The major crops are maize (*Zea mays* L.), teff *(Eragrostis tef),* coffee (*Coffee arabica* L*.)*, barley *(Hordeum vulgare* L*)*, potato *(Solanum tubersoum* L.) and noug (*Guizotia abyssinica*)*.* These major crops are produced usually once per year (Ebantu district Agricultural development Bureau, 2014 unpublished).

Treatments, experimental design, and procedures

The experiment consisted of factorially combined three factors namely: two rates of lime (0 and 4 t $CaCO_3$ ha^{-1}), three rates of VC (0, 2.5, and 5 t ha^{-1}) and three rates of mineral P fertilizer (0, 20, and 40 kg P ha^{-1}) as triple superphosphate (TSP) or [$Ca(H_2PO_4)_2$], while N fertilizer was applied in the form of urea (46% N) to all treatments at rate of 69 kg N ha^{-1}. The rates of lime were calculated from the lime requirement using the acid saturation method and confirmed by incubation experiment. Treatments were laid out in randomized complete block design (RCBD) with three replications. Thus, there were 2*3*3 =18 treatment combinations, which contained 54 experimental plots each season.

The field experiment was conducted for two consecutive main cropping seasons of 2015 and 2016. A land with average pH of 4.81 was selected for the study and land preparation took place well in advance before sowing maize, as lime and VC need certain incubation period to bring change in physicochemical properties of the soil. Plot size was 5.1 m by 4.5 m with an area of 22.95 m^2. Total area used for this experiment was 52.5 m by 40.6 m (2131.5 m^2) including border areas. The experimental field was prepared following the conventional farmers' practices. The field was oxen ploughed three times before sowing. The seed bed was prepared by ploughing and harrowing using oxen and then leveled manually. All agronomic practices such as hoeing and weeding, were undertaken uniformly to all plots by hand.

The treatments of lime and VC were applied to the plots as per treatment in band according to the randomization set before sowing of maize; and left for two months of incubation period for lime and three weeks for VC. A hybrid maize variety (BH-660) was used as a test crop. An inter- and intra-row spacing of 75 cm and 30 cm was used, respectively. At the time of sowing one third of N fertilizer (69 kg N ha^{-1}) and the whole mineral P rates (0, 20, and 40 kg ha^{-1}) were applied as side dressing 2 cm apart from the maize seed and 5 cm deep into the soil. The remaining two third rate of N was applied at knee height stage of the crop.

Soil sampling and analysis

Soil samples from 0 to 20 cm depth were collected prior to maize planting in 2014 to analyze selected soil physicochemical properties. A Total of three composite samples were collected from the three blocks. Soil samples were collected by auger from eighteen sub-samples in each block and thoroughly mixed to make soil bulk density (ρ_b) of the area were collected at random by taking one sample per block using core method. All the laboratory activities were undertaken at Haramaya University and Nekemte

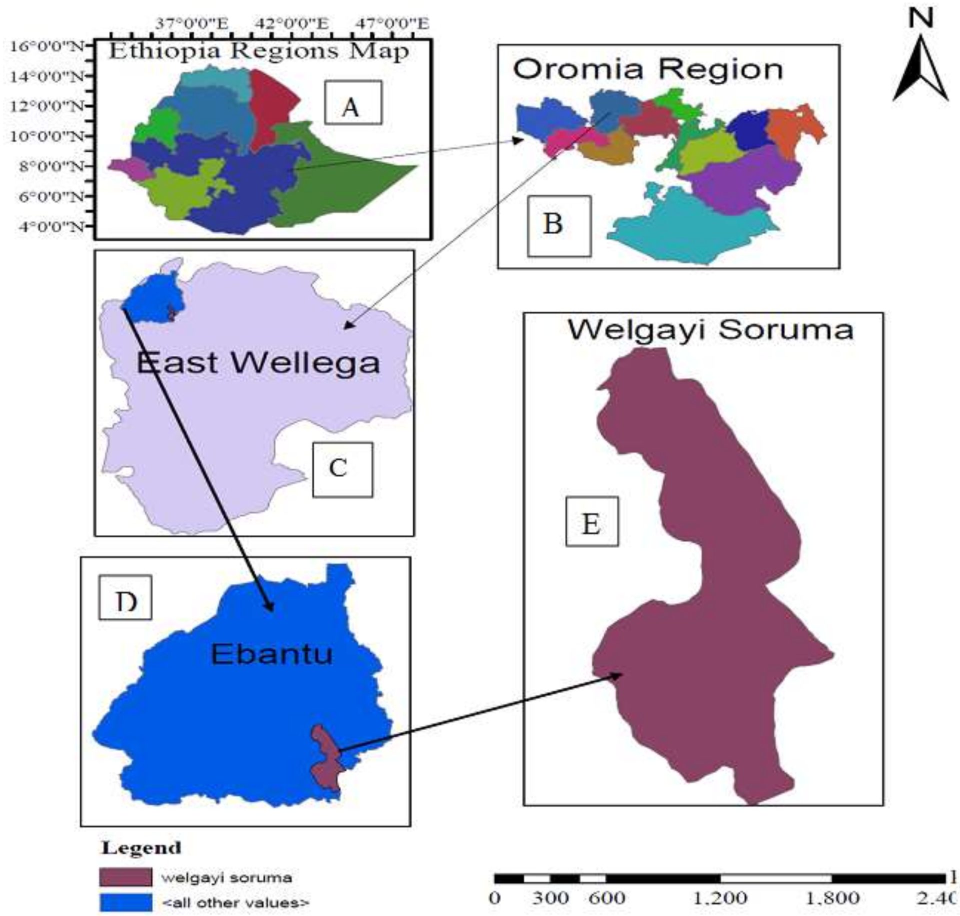

Figure 1. Location map of Ethiopian regions (A), Oromia National Regional State (ONRS) (B), East Wellega Zone (C), Ebantu district (D) and study site (E)

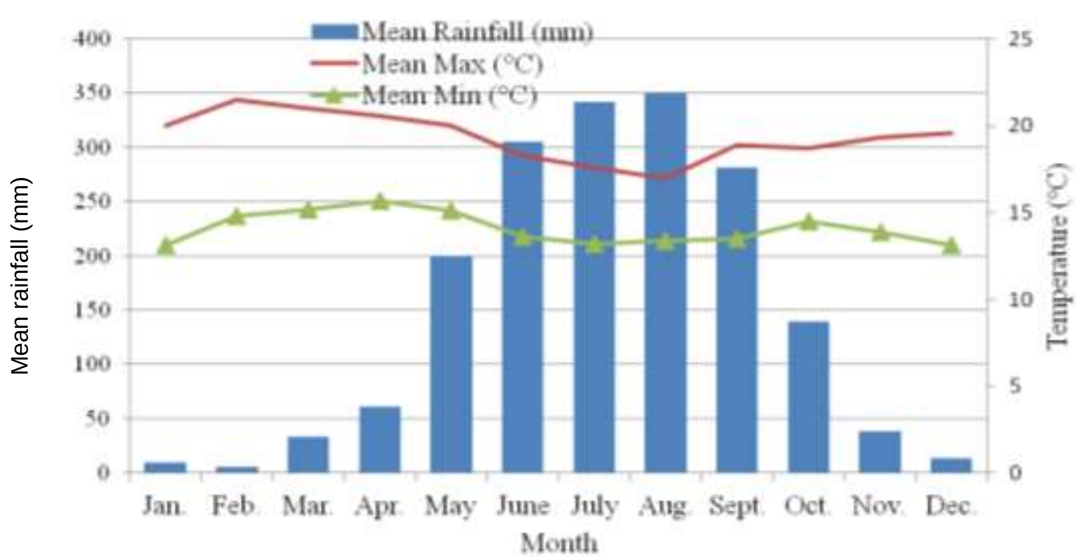

Figure 2. Mean monthly rainfall (mm), minimum and maximum temperatures (°C) of the study area recorded for the year from 2006-2015. Source: National Meteorological Agency; Gida Ayana Meteorological Station.

Soil Research Center according to standard laboratory procedures.

Soil particle size distribution was analyzed by the Bouyoucus hydrometer method (Bouyoucos, 1951). Soil ρ_b was measured from three undisturbed soil samples collected using a core sampler as per the procedure described by Jamison et al. (1950), while particle density (ρ_s) was measured using pycnometer (Barauah and Barthakulh, 1997) at the Nekemte Soil Research Center. Total porosity (ϕ) was calculated from the values of ρ_b and ρ_s (Brady and Weil, 1996) as:

$$\phi = \left(1 - \frac{\rho_b}{\rho_s}\right) * 100$$

Soil pH was measured potentiometrically in 1:2.5 soils: H_2O solution using a combined glass electrode pH meter (Chopra and Kanwar, 1976). Total exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution as described by Rowell (1994). From the same extract, exchangeable Al in the soil samples was determined by application of 1 M NaF. Acid saturation (AS) was calculated from exchangeable acidity and CEC Rowell (1994).

$$\text{AS}(\%) = \frac{\text{Excchangeable acidity (cmol}_c\text{ kg}^{-1})}{\text{CEC (cmol}_c\text{ kg}^{-1})} \text{x}\,100$$

Where:

AS = Acid saturation, CEC = Cation exchange capacity

Organic carbon (OC) content of the soil was determined by the wet combustion procedure of Walkley and Black (1934) and OM% was obtained by multiplying OC% by 1.724. The total nitrogen (N) content of the soil was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Available P was extracted by the Bray II method (Bray and Kurtz, 1945). Exchangeable basic cations (Ca, Mg, K, and Na) were determined by saturating the soil samples with 1M NH_4OAc solution at pH 7.0. Then Ca and Mg were determined by using atomic absorption spectrophotometry (AAS), while exchangeable Na and K were measured by flame photometer from the same extract. The cation exchange capacity (CEC) of the soil was determined from the NH_4^+ saturated samples that were subsequently replaced by K from a percolated KCl solution (Chapman, 1965). The extractable micronutrients (Fe, Mn, Zn, and Cu) were extracted by diethylene triamine pentaacetic acid (DTPA) as described by Sahlemedhin and Taye (2000) and all these micronutrients were measured by atomic absorption spectroscopy (AAS).

Analysis of vermicompost

Vermicompost was prepared from the raw materials like cow dung, sheep and goat faeces, dried chopped maize residues and chopped grasses by using red worm (*Eisenia fetida*). Selected parameters of VC were determined using dried samples which were ground to pass through a 2 mm sieve as described by Pisa and Wuta (2013). Electrical conductivity (EC) and pH were determined from a suspension of 1:10 VC: H_2O as described by Ndegwa and Thompson (2001). The total OC was estimated by wet combustion procedure of Walkey and Black (1934). Total OM% was obtained by multiplying total OC% by 1.8 (Emeterio and Victor, 1992). The total N content of the VC was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Total Ca, Mg, K, and Na were extracted by wet digestion using concentrated sulphuric acid (H_2SO_4), selenium (Se) powder, lithium sulphate (Li_2SO_4), and hydrogen peroxide (H_2O_2) mixture (Okalebo *et al*., 2002). Total Ca and Mg were determined from the wet digested samples by AAS while K and Na were estimated by flame photometer. Total P was extracted using concentrated H_2SO_4, Se powder, salicylic acid ($C_7H_6O_3$), and H_2O_2 mixture (Okalebo *et al*. 2002). Micronutrients (Fe, Mn, Zn, and Cu) were extracted using concentrated H_2SO_4, Se powder, $C_7H_6O_3$ and H_2O_2 mixture and their concentrations were determined from the wet digested samples by AAS (Okalebo *et al*. 2002).

Data collections and measurements

Agronomic data were collected during both growing seasons. The data collected were crop phenology, growth parameters, yield and yield components.

Crop phenology

Days to 50% tasseling (the number of days from planting to the start of shedding of pollen by 50% of maize plants in the plots) and days to 50% silking (number of days from planting to silking by 50% of the maize plants in the plots) were recorded at their respective stages. Days to physiological maturity (DPM) was recorded as the number of days after sowing to the formation of a black layer at the point of attachment of the kernel with the cob.

Growth parameters, yield and yield components

Plant height (PH) was measured in cm from the soil surface to the base of the tassel of ten randomly taken plants from the net plot area at physiological maturity. Data on leaf area (LA, cm^2) was taken to calculate leaf area index (LAI) for maize at 50% tasseling. The LA was determined using methods of McKee (1964). The width (W) and length (L) of leaves from 10 randomly taken plants in each plot was measured and LA was calculated (Uzun and Celik, 1999).

LA = W × L × 0.733

Where:

LA = Leaf area (cm^2)
W = Maximum leaf width (cm)
L = Maximum leaf length (cm)
0.73 = Correction factor for maize

Leaf area index (LAI) was then calculated by dividing leaf area per sampled ground area (Radford, 1967). Cob length (CL, cm) was measured during harvesting while number of grains per cob (NGPC) was recorded simply by counting for the ten plants picked randomly in the four central rows of the net area. Grain yield (GY) per plot was weighed in kg/plot and adjusted to12.5% moisture content and then converted to t ha^{-1} and above ground dry biomass yield (AGDBY, t ha^{-1}) for each plot were recorded after harvesting and air drying the samples to constant weight. Thousand seed weight (TSW) was weighed (g) and grain harvest index (HI) was calculated as the ratio of dried grain yield to the AGDBY.

Economic analysis

The economic analysis comprising partial budget with dominance and marginal rate of return was carried out. To estimate economic parameters, the marketable maize yield was valued based on average market price collected from the local markets during the two consecutive years of production immediately after harvest where average maize price was 8 Birr kg^{-1}. The average cost of P and VC were 15.96 and 1.00 Birr kg^{-1}, respectively. A wage rate of 40 Birr per man day^{-1} was used. In the partial budget analysis, total variable cost, gross field benefit, net benefit and marginal rate of return were employed. Total variable cost refers to the sum of all costs of variable inputs (fertilizers) and management practices. The gross field benefit ha^{-1} was obtained as the products of real price and the mean maize yield for each treatment adjusted to 10% whereas the net benefit ha^{-1} is the difference between the gross field benefit and total variable cost (CIMMYT, 1988). The dominance analysis procedure, which was used to select potentially profitable treatments, comprised ranking of treatments in an ascending order of total variable cost from the lowest to the highest cost to eliminate treatments costing more but producing a lower net benefit than the next lowest costing treatment was undertaken. For each pair of ranked non-dominated treatments, marginal rate of return was also calculated in percent. The percent marginal rate of return between any pair of undominated treatments denoting the return per unit of investment for crop production was analyzed. The marginal rate of return (%) was calculated (CIMMYT, 1988).

$$\text{MRR } (\%) = \frac{\Delta \text{NB}}{\Delta \text{TVC}} \text{ x } 100$$

According to CIMMYT (1988) for a treatment to be considered a worthwhile option to farmers, the marginal rate of return needed to be between 50 and 100% by taking the minimum acceptable rate of return to be 50%. The values of other materials used uniformly for each treatment were not considered in the budget for the partial economic analysis.

Statistical analysis

In all cases, the variations in the two consecutive years of the study were not significantly different and the error variances were homogeneous using the F-test as illustrated by Gomez and Gomez (1984). Thus, combined analysis of variance (ANOVA) for the two years data was performed using SAS 9.2 (SAS, 2004). Duncan's Multiple Range Test was employed to test the significant difference between means of treatments. Moreover, simple Pearson's correlation analysis was done to determine the association of various agronomic characters of maize with each other.

RESULTS AND DISCUSSION

Soil physicochemical properties before planting and vermicompost

The experimental soil is loamy in texture (Table 1). Soil pH of 4.81 was in the very strongly acidic soil range (Jones, 2003). The contents of exchangeable acidity and Al were relatively high. The OM content (2.15%) was low and total N (0.18%) was moderate according to Tekalign (1991). Available P was in the low range (0 – 10 $mgkg^{-1}$) (Clements and McGowen, 1994). The mean soil exchangeable Ca and K were in the low range, while exchangeable Mg was in medium range (FAO, 2006). The CEC of the soil was categorized as medium

Table 1. Selected soil physical and chemical properties of the experimental soils.

Soil parameters	Value
Sand (%)	50
Silt (%)	38
Clay (%)	12
Textural class	Loam soil
ρ_b (g cm^{-3})	1.3
ρ_s (g cm^{-3})	2.28
ϕ (%)	43
pH (H_2O) (1:2.5)	4.81
Exchangeable acidity ($cmol_c$ kg^{-1})	2.44
Exchangeable Al ($cmol_c$ kg^{-1})	2.03
AS (%)	12
OM (%)	2.15
Total N (%)	0.18
Available P (mg kg^{-1})	4.6
Exchangeable Ca ($cmol_c$ kg^{-1})	3.51
Exchangeable Mg ($cmol_c$ kg^{-1})	1.61
Exchangeable K ($cmol_c$ kg^{-1})	0.27
Exchangeable Na ($cmol_c$ kg^{-1})	0.11
CEC ($cmol_c$ kg^{-1})	21
Fe (mg kg^{-1})	35.1
Mn (mg kg^{-1})	36.7
Zn (mg kg^{-1})	2.96
Cu (mg kg^{-1})	2.73

ρ_b =Bulk density; ρ_s = Particle density; ϕ =Total porosity; AS = Acid saturation; OM = Organic matter; Total N = Total nitrogen; CEC = Cation exchange capacity.

according to Roy et al. (2006). The soil DTPA-extractable Fe, Mn, and Zn were high whereas Cu was medium (Jones, 2003). Generally, the result of pre-soil analysis showed that the soils of the study site had acidity problem and were poor in chemical fertility. Selected nutrient contents and the pH of VC are presented in Table 2. These sources of the nutrients could be decomposition of VC by the activities of microorganisms. Through its contents, the VC can decrease soil acidity and increase soil fertility status in general.

Crop phenology

Tasseling, silking, and physical maturity

The ANOVA showed that the combined application of VC, mineral P and lime significantly (P ≤ 0.01) speeded up tasseling of maize (Table 3). Early days to tasseling were recorded with the application of lime, VC, and

Table 2. Chemical characterization of vermicompost.

Vermicompost	Value
pH (H_2O) (1:10)	7.5
EC (dSm^{-1}) (1:10)	5.2
Total OM (%)	25.74
Total N (%)	1.95
Total P ($g\ kg^{-1}$)	5.3
Ca ($cmol_c\ kg^{-1}$)	36.3
Mg ($cmol_c\ kg^{-1}$)	19.8
K ($cmol_c\ kg^{-1}$)	27.7
Na ($cmol_c\ kg^{-1}$)	14.2
Fe ($mg\ kg^{-1}$)	219
Mn ($mg\ kg^{-1}$)	397
Zn ($mg\ kg^{-1}$)	152
Cu ($mg\ kg^{-1}$)	95

EC = Electrical conductivity; Total OM = Total organic matter; Total N = Total nitrogen; Total P = Total phosphorus.

mineral P fertilizer at the rate of 4 t ha^{-1}, 5 t ha^{-1}, and 40 kg ha^{-1}, respectively. The latest days to 50% tasseling was obtained for the control. The application of each factor at maximum rates decreased days to tasseling by as much as 19 days (16%) as compared to the control. This may be due to rapid physiological activities observed with high plant nutrients availability via VC and mineral P fertilizer application with lime. In line with this result, Arancon *et al*. (2008) and Ramasamy and Suresh (2011) reported that VC stimulates plant flowering, increases the number and biomass of the flowers. Silking days were also hastened with the application of 5 t VC ha^{-1} and 20 kg P ha^{-1} with lime. Contrary to tasseling and silking, time to reach physiological maturity was highly significantly ($P \leq 0.001$) prolonged by the applications of lime, VC, and chemical P fertilizer (Table 3). The application of the highest rates of all the three factors prolonged the maturity of the maize plants by as much as 17 days compared to the control. An interesting observation is that in the control it took only 33 days to reach maturity after silking, but at the application of the highest rates of all the three factors, this period was extended to 75 days. There was thus much more time for growth and development in the plots well supplied with nutrients. Late maturity in response to increasing rate of lime, VC, and mineral P fertilizer may be ascribed to the availability of optimum nutrients contained in VC and increment of available P that may have led to prolonged maturity through enhanced leaf growth and photosynthetic activities thereby increasing partition of assimilate to the storage organ. This is supported by Jolien (2014) who reported that the maturity of maize was prolonged when treated by high dose of diammonium phosphate (DAP) and compost.

Plant height and leaf area index

The highest leaf area index was recorded at the plots treated by 5 t VC ha^{-1} and 40 kg P ha^{-1} with lime which was increased by 43% over the control (Table 4). The maximized leaf area index of maize at higher rates of treatments is attributed to enhanced vegetative growth. Zeinab *et al.* (2014) and Atarzadeh et al. (2013) also stated that the highest leaf area index was observed when plants were grown under integrated VC and inorganic fertilizers management. There was highly significant ($P \leq 0.001$) interaction effect of lime, VC, and mineral P fertilizer on plant height (Table 4). The tallest mean plant height was recorded in plots treated with high doses of VC and mineral P fertilizer integrated with lime while the shortest plant was recorded for the control. Maize plants grown in plots treated with nil fertilizer rates were stunted while plant height was increased with increasing VC, mineral P fertilizer, and lime rates. Hence, there was a clear synergistic effect between the treatments. In the unlimed plots VC and chemical P fertilizer increased plant height only slightly. Vermicompost had little effect also in limed plots that did not receive P fertilization. But plant height was increased by about 1 m in plots receiving lime, VC, and chemical P fertilizer. This is in harmony with the findings of Kannan et al. (2013) who reported that integrated nutrient management has positive effect on maize height. Manish et al. (2017) also reported that the tallest plant height was observed on the plots treated by VC and cattle manure, whereas the shortest was in the control. Similarly, Atarzadeh et al. (2013) also described that VC contains many humic acids which improve morphological traits of the crop and, thus, increase plant height.

Maize yield parameters and grain yield

Cob and seed characteristics

Application of lime, VC, and mineral P fertilizer had a significant ($P \leq 0.01$) effect on cob length (Table 5). Accordingly, the highest mean cob length was recorded in plots that received the highest rates of P and VC in the limed plots, where the cob length was 2.5 times higher than that of the control. The increase in the cob length might be attributed to the reduction in acidity and increase in nutrient availability, whereas the reduction in cob length of the control might be due to unavailability of nutrients as a result of lower pH and P sorption. This is supported by Oluwatoyinbo (2005) who indicated the possibility of increasing cob length by reducing soil acidity through the application of soil acidity amendments. A perusal of data presented in Table 5 also showed highly significant ($P \leq 0.001$) interaction effects of lime, VC, and mineral P fertilizer on grain number per cob. The highest grain number per cob (644) was recorded in plots treated with the highest doses of VC and mineral P with lime,

Table 3. Days to tasseling, silking and maturity of maize receiving different rates of lime, mineral P fertilizer and vermicompost (VC).

Lime and VC (t ha^{-1})		Crop phenology								
		Mineral P fertilizer (kg ha^{-1})								
Lime	VC	Tasseling (days)			Silking (days)			Maturity (days)		
-	-	0	20	40	0	20	40	0	20	40
-	0	121^{a}	116^{e}	111.3^{i}	131.3^{a}	123.3^{c}	120.8^{d}	164.8^{h}	172.0^{efg}	173.3^{def}
0	2.5	120^{b}	113^{fg}	111.7^{ghi}	128.7^{b}	124.0^{c}	120d^{e}	170.5^{g}	174.2^{de}	174.2^{de}
-	5	117^{cd}	114^{f}	112.3^{f-i}	123.5^{c}	123.3^{c}	120.5^{de}	172.5^{d-g}	172.8^{d-g}	174.8^{cd}
-	0	118^{c}	111.5^{hi}	106.3^{j}	118.8^{ef}	118.0^{f}	110.3^{h}	171.5^{fg}	170.8^{g}	173.5^{def}
4	2.5	116de	111.2^{i}	104.2^{k}	118.0^{f}	114.3^{g}	108.5^{i}	172.2^{efg}	174.2^{de}	178.2^{b}
-	5	113^{f-h}	106.3^{j}	102.3^{l}	119.0^{ef}	113.8^{g}	109.0^{hi}	172.8^{d-g}	177.2^{bc}	181.7^{a}
CV (%)	-	-	1.28	-	-	1.29	-	-	1.17	-
F-test	-	-	**	-	-	***	-	-	***	-
SE (±)	-	-	0.52	-	-	0.63	-	-	0.83	-

Means sharing the same letter(s) are not significantly different according to DMRT at 5% level of significance. **and *** indicate significance at P ≤ 1% and 0.1%, respectively. VC = Vermicompost; CV = Coefficient of variation; SE = standard error.

Table 4. Plant height and leaf area index of maize as affected by liming, and different rates of VC and chemical P fertilizer.

Lime and VC (t ha^{-1})		Growth parameters					
		Mineral P fertilizer					
		LAI			PH (m)		
Lime	VC	0	20	40	0	20	40
-	0	3.40^{k}	3.77^{j}	3.84^{hij}	2.07^{f}	2.26^{def}	2.30^{def}
0	2.5	3.79^{ij}	4.09^{fgh}	4.11^{fg}	2.17^{ef}	2.31^{def}	2.36^{de}
-	5	4.10^{fg}	5.08^{cd}	5.05^{cd}	2.23^{def}	2.45^{d}	2.41^{de}
-	0	4.04^{ghi}	4.34^{f}	5.02^{de}	2.39^{de}	2.46^{cd}	2.44^{d}
4	2.5	4.23^{fg}	4.77^{e}	5.30^{c}	2.43^{d}	2.81^{b}	2.71^{bc}
-	5	5.11^{cd}	5.56^{b}	5.91^{a}	2.45^{d}	3.40^{a}	3.48^{a}
CV (%)	-	-	4.94	-	-	8.74	-
F-test	-	-	**	-	-	***	-
SE (±)	-	-	0.09	-	-	0.09	-

Means sharing the same letter (s) are not significantly different according to DMRT at 5% level of significance. **and *** indicate significance at P ≤ 0.01 and 0.001, respectively. VC = Vermicompost; LAI = Leaf area index; PH = Plant height; CV = Coefficient of variation; SE = Standard error.

whereas the lowest (343) was recorded in the control (Table 5), which indicated an increase of about 112%. In addition to the higher number of grains, the grains were also significantly (P ≤ 0.001) heavier in maize receiving lime, VC, and /or chemical P fertilizer (Table 5). This might in turn have improved the normal development of maize with increasing grain number per cob. This is in line with the reports of Mihiretu (2014), who stated that maize seed setting is highly dependent and responsive to the amount and availability of P fertilizer during critical growth stages mainly the reproductive phase.

Thousand seed weight

The interaction effect of lime, VC and mineral P fertilizer had highly significant (P ≤ 0.001) effect on 1000-seed weight (Table 5). The highest mean 1000-seed weight (508 g) was recorded in plots treated with 2.5 t VC ha^{-1} and 40 kg P ha^{-1} with lime, while the lowest (255 g) was in the control indicating an increase of about 99% due to the treatments. Such high increase in 1000-seed weight might be due to the synergistic effects of the combined factors for better growth and grain filling of maize as well as effects of VC and lime in improving the physicochemical and biological soil properties. Besides the high rate of mineral P fertilizer, VC may play a paramount role in improving 1000-seed weight and other yield components. This is in consent with the reports of Negasi (2014), who stated that OM plays a significant role in plant nutrition through its positive effects on

Table 5. Effects of combined application of lime, vermicompost, and mineral P fertilizers on cob length, number of grain per cob, and 1000-seed weight of maize.

Lime and VC (t ha^{-1})		Yield parameters								
		Mineral P fertilizer (kg ha^{-1})								
		CL (cm)			NGPC			TSW (g)		
Lime	VC	0	20	40	0	20	40	0	20	40
	0	19.4^{k}	21.0^{jk}	23.2^{hijk}	343^{f}	389^{e}	436^{d}	255^{i}	297^{g}	375^{f}
0	2.5	20.4^{k}	25.4^{ghi}	27.1^{efg}	374^{e}	435^{d}	445^{cd}	283^{h}	426^{e}	454^{d}
	5	20.7^{jk}	29.8^{def}	30.4^{de}	388^{e}	463^{bcd}	470^{bc}	286^{h}	453^{d}	458^{d}
	0	24.5^{ghij}	21.6^{ijk}	22.3^{ijk}	453^{bcd}	442^{cd}	448^{bcd}	455^{d}	458^{d}	468^{c}
4	2.5	26.4^{fgh}	36.5^{bc}	37.8^{b}	475^{b}	444^{cd}	624^{a}	479^{b}	454^{d}	508^{a}
	5	32.7^{cd}	45.1^{a}	47.8^{a}	467^{bc}	620^{a}	644^{a}	458^{d}	505^{a}	505^{a}
CV (%)	-	-	11.92	-	-	5.47	-	-	1.24	-
F-test	-	-	**	-	-	***	-	-	***	-
SE (±)	-	-	1.38	-	-	10.37	-	-	2.14	-

Means sharing the same letter(s) are not significantly different according to DMRT at 5% level of significance. **, *** indicate significance at P ≤ 0.01 and 0.001, respectively. VC = Vermicompost; CL = Cob length; NGPC = Number of grain per cob; TSW = Thousand seed weight; CV=Coefficient of variation; SE = Standard error.

Table 6. Effects of combination of lime, vermicompost, and mineral P fertilizers on grain yield, above ground dry biomass yield, and harvest index of maize.

Lime and VC (t ha^{-1})		Yield parameters								
		Mineral P fertilizer (kg ha^{-1})								
		GY (t ha^{-1})			AGDBY (t ha^{-1})			HI (%)		
Lime	VC	0	20	40	0	20	40	0	20	40
-	0	2.18^{g}	2.36g	3.05^{e}	16.1^{g}	16.5^{g}	16.8^{fg}	13.6^{i}	14.4^{hi}	16.9^{ef}
0	2.5	2.30^{g}	3.03^{e}	3.95^{d}	16.3^{g}	17.0^{efg}	18.4^{de}	14.3^{hi}	17.9^{ef}	21.5^{bc}
-	5	2.36^{g}	4.25^{c}	4.03^{d}	16.5^{g}	18.6^{cde}	18.7^{cd}	14.5^{ghi}	23.0^{ab}	21.5^{bc}
-	0	2.20^{g}	2.77^{f}	2.94^{ef}	16.5^{g}	17.1^{efg}	18.2^{def}	13.4^{i}	16.3^{fg}	16.2^{fgh}
4	2.5	3.13^{e}	4.07^{cd}	4.87^{a}	17.1^{efg}	18.5^{cde}	20.0^{c}	18.3^{de}	22.0^{b}	24.4^{a}
-	5	4.02^{d}	4.55^{b}	4.73^{ab}	18.3^{def}	22.7^{b}	25.9^{a}	22.0^{bc}	20.1^{cd}	18.3^{de}
CV (%)	-	-	5.52	-	-	7.40	-	-	9.01	-
F-test	-	-	***	-	-	*	-	-	***	-
SE (±)	-	-	0.08	-	-	0.55	-	-	0.67	-

Means sharing the same letter(s) are not significantly different according to DMRT at 5% level of significance. *and *** indicate significance at P ≤ 0.5 and 0.001, respectively. VC = Vermicompost; GY = Grain yield; AGDBY = Above ground dry biomass yield; HI = Harvest index; CV = Coefficient of variation; SE = Standard Error.

nutrient supply to plant roots, in improving soil structure, water holding capacity, and other soil properties.

Above ground dry biomass yield (AGDBY)

The results of ANOVA indicated that there is a significant interaction effect of lime, VC, and mineral P fertilizer (P ≤ 0.001) on AGDBY of maize (Table 6). The highest mean AGDBY (12.18 t ha^{-1}) was recorded in plots treated with the highest rates of VC and mineral P along with lime, while the minimum (5.02 t ha^{-1}) was in the control with a difference of about 7.16 t ha^{-1}. This difference might be due to synergistic effects of lime, VC, and mineral P fertilizer as well as high doses of mineral P and VC used for luxuriant vegetative growth of plants. These results are in line with that of Makinde and Ayoola (2010), who demonstrated that the application of OM as fertilizers provides growth regulating substances and improves physicochemical and microbial properties of soils.

Grain yield (GY)

The results of ANOVA showed that, the highest mean grain yield (4.87 t ha^{-1}) was recorded in plots treated with40 kg P ha^{-1} and 2.5 t VC ha^{-1} with lime, while the lowest (2.18 t ha^{-1}) was recorded in the control (Table 6).

Table 7. Partial budget and dominance analyses of lime, vermicompost, and mineral P fertilizer on maize (2-years data pooled).

Lime (t ha^{-1})	P (Kg ha^{-1})	VC (t ha^{-1})	TVC (ETB ha^{-1})	Ad GY (t ha^{-1})	GFB (ETB ha^{-1})	NB (ETB ha^{-1})	Dominance
0	0	0	0	2.18	17467	17467	UD
4	0	0	200	2.20	17573	17373	D
0	20	0	1721	2.36	18907	17186	D
4	20	0	1921	2.77	22187	20266	UD
0	0	2.5	2660	2.30	18427	15767	D
4	0	2.5	2860	3.13	25013	22153	UD
0	40	0	3282	3.05	24387	21105	D
4	40	0	3482	2.94	23533	20051	D
0	40	2.5	4381	3.03	24267	19886	D
4	40	2.5	4581	4.07	32547	27966	UD
0	0	5	5160	2.36	18880	13720	D
4	0	5	5360	4.02	32160	26800	D
0	40	2.5	5942	3.95	31613	25671	D
4	40	2.5	6142	4.88	39013	32871	UD
0	20	5	6881	4.25	33960	27079	D
4	20	5	7081	4.55	36413	29332	D
0	40	5	8442	4.03	32240	23798	D
4	40	5	8642	4.73	37827	29185	D

VC = Vermicompost; TVC = Total variable cost; Ad GY = Adjusted grain yield; GFB = Gross field benefit; NB = Net benefit; D = dominated; UD = Undominated.

The maximum grain yield is due to high plant height, cob length, grain numbers per cob, and AGDBY. This is also supported by the correlation in which grain yield had highly significant ($P \leq 0.001$) and very strong positive correlations ($r = 0.81$, 0.78 and 0.81) with AGDBY, NGPC and CL, respectively (Table 9). This high discrepancy between the highest and lowest grain yields seems also to be due to synergistic effects of these treatments. From Table 6 it is obvious that liming alone did not increase yield and neither did VC when applied without liming and chemical P fertilizer. But combined use of lime and VC almost doubled the yield compared to the control even without chemical P fertilizer. Also, the effect of chemical P fertilizer was much greater when integrated with lime and VC. This is in agreement with reports of Bayu et al. (2006) and Makinde and Ayoola (2010) who concluded that high and sustainable crop yields are only possible with integrated use of mineral fertilizers and OM. Tilahun et al. (2013) also verified that integrated fertilizers application gave the maximum grain yield compared to the control. Similarly, Dilshad et al. (2010) reported that improvement in yield can be obtained if soil fertility is maintained through the combined use of organic and inorganic fertilizers. Furthermore, high doses of VC increased grain yield since it improved soil physicochemical and microbial conditions and then facilitating maize crop growth. This is supported by the findings of Adrien et al. (2010), who reported that the application of composted paper sludge led to high maize yields. Babbu et al. (2015) also reported that the highest maize grain yield was in treatment having NPK with FYM, whereas the lowest was in non-treated plots showing the beneficial effects of manure on crop performance.

Harvest index (HI)

Results of ANOVA revealed that HI was strongly and significantly ($P \leq 0.001$) affected by the interaction effects of lime, VC, and mineral P fertilizer (Table 6). The highest mean grain HI (24.4%) was observed in plots treated by 2.5 t VC ha^{-1} and 40 kg P ha^{-1} with lime, while the lowest (13.4%) was observed when only lime was applied without VC and mineral P fertilizer (Table 6). This might be due to the increment of the availability of essential nutrients for crops when the acidic soils were treated by the integration of VC and mineral P with lime. Along with this, Hamidia et al. *(*2010) suggested that mineral P plays great role for maximum utilization of nutrients in acidified soils.

Economic return

The production of maize in two different years under fertilizer management involved different costs that affected total cost of production based on different treatments that were applied in the growing seasons (Table 7). The treatments that received 4 t $CaCO_3$ ha^{-1}, 5 t VC ha^{-1}, and 40 kg P ha^{-1} showed the highest total variable cost of 8642 Birr ha^{-1} followed by 5 t ha^{-1} of VC

Table 8. Marginal rate of return analysis of lime, vermicompost and mineral P fertilizer for maize production (2-years data pooled.

Lime (t ha^{-1})	P_2O_5 (Kg ha^{-1})	VC (t ha^{-1})	TVC (ETB ha^{-1})	Ad GY (t ha^{-1})	GFB (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
0	0	0	-	2.18	17467	17467	-
4	20	0	1921	2.77	22187	20266	146
4	0	2.5	2860	3.13	25013	22153	201
4	20	2.5	4581	4.07	32547	27966	338
4	40	2.5	6142	4.88	39013	32871	314

VC = Vermicompost; TVC = Total variable cost; Ad GY= Adjusted grain yield; GFB = Gross field benefit; NB = Net benefit; MRR = Marginal rate of return.

and 40 kg ha^{-1} of mineral P with nil lime with total variable cost of 8442 Birr ha^{-1} (Table 7).

The adjusted average maize yields obtained from a hectare of land were highest at the rate of 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1} and 40 kg P ha^{-1} fertilizer with 4.88 t ha^{-1} followed by 4 t $CaCO_3$ ha^{-1}, 5 t VC ha^{-1}, and 40 kg P ha^{-1} fertilizer with 4.73 t ha^{-1}, whereas the lowest (2.18 t ha^{-1}) was at the control. The highest net benefit (32871 Birr ha^{-1}) of maize was obtained at the rate of 4 t $CaCO_3$ ha^{-1}, 2.5 t VC, ha^{-1} and 40 kg P ha^{-1} fertilizer followed by 4 t $CaCO_3$ ha^{-1}, 5 t VC ha^{-1}, and 20 kg P ha^{-1} fertilizer with 29332 Birr ha^{-1}, while the lowest (17467 Birr ha^{-1}) was at the control as shown in Table 7. This might be due to the fact that integrated application of organic and inorganic fertilizers in general and OM such as VC together with lime in particular improved the economic advantage of the farmers cultivating acidic soil areas.

Marginal rate of return was analyzed for the treatments which indicated that the highest is observed at treatment rates of 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 20 kg P ha^{-1} followed by 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 40 kg P ha^{-1} with 338 and 314 Birr, respectively. It seems that liming alone was not very profitable. The same applies to VC alone, and chemical P fertilizer alone. The highest benefits appeared to require combined use of different additions, and the use of chemical P fertilizer.

Hence, treatment with 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 20 kg P ha^{-1} gave a rate of return above the minimum acceptable rate of return (50%) considered in this study. The treatment with 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 20 kg P ha^{-1} had also the highest net benefit (27966 Birr ha^{-1}) next to the treatment of 4t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 40 kg P ha^{-1} with the net benefit of 32871 Birr ha^{-1}. Therefore, treatment with 4 t $CaCO_3$ ha^{-1}, 2.5 t VC ha^{-1}, and 20 kg P ha^{-1} can be recommended for farmers in the study area as it can be taken as the best combination for optimum maize yield offering high marginal rate of return above the proposed minimum acceptable rate of return of 50 to 100% (CIMMYT, 1988) (Table 8).

Conclusion

Integrated nutrient management mainly use of vermicompost and mineral P fertilizers with lime has been getting attention because of its high ability to ameliorate soil acidity, improve soil fertility and eventually crop yield sustainably. The results of the study demonstrated that there was a significant increase in yield and yield components of maize due to the application of vermicompost and mineral P fertilizer with lime over the control. Since maize is a huge feeder of nutrients, application of high dose of mineral P fertilizer together with good nutrients sources of vermicompost has paramount importance in reclaiming soil acidity and enhancing soil fertility, and improving maize yield and yield components. From this study, it is possible to deduce that integrated application of organic and mineral fertilizers with lime amended the acidic soils and improved its fertility which in turn increased crop yields. Hence, combination of vermicompost at (2.5 t ha^{-1}) and mineral P fertilizer at (20 kg ha^{-1}) with lime at 4 t ha^{-1} is optimum and could be recommended for reclaiming soil acidity and improve nutrients for maize as it enhanced grain yield and yield components of maize plant in strongly acidic soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

We would like to thank Ministry of Education of the Federal Democratic Republic of Ethiopia for its financial support through Haramaya University. We also acknowledge Ebantu Woreda Agriculture Bureau for their support during field work.

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