EFFECTS OF LIME AND VERMICOMPOST APPLICATIONS ON MAIZE PRODUCTION IN LALO ASABI DISTRICT, WESTERN ETHIOPIA

ABSTRACT

Soil acidity is one of the major yield-limiting factors for crop production worldwide, particularly on highly weathered and leached tropical soils. Different reports have indicated that there is significant soil acidity coverage in Ethiopia. In particularly, in the western part of the country, soil acidity is a well-known problem limiting crop production and productivity. As part of the solution to such a problem in soils, the combined application of lime and VC on maize has not been investigated in the area, in which maize was one of the potential cereal crops in the area.A field experiment was conducted at Lalo Asabi district in western Wollega during the 2020 cropping season to evaluate the responses of maize to the combined application of lime and vermicompost (VC). The experimental treatments were five rates of lime ($CaCO_3$) (0, 25, 50, 75, and 100% of lime requirement (LR)) and three levels of vermicompost (0, 2.5, and 5 t ha^{-1}). The treatments were arranged in factorial combinations in a randomized complete block design with three replications. One composite surface soil samples from a depth of (0-15 cm) was collected from the experimental field before the commencement of the experiment. Maize yield and yield components were measured following standard procedures. The yield components and yield results revealed the main effects of lime and VC showed a significant effect ($p<0.05$) on the number of days to 50% tasseling and silking, ear height, number of cobs per plant, number of grains per cob, thousand grain weight, above ground biomass, and harvest index of maize. However, days to 90% physiological maturity, plant height, cob length and grain yield of maize were significantly affected ($p<0.05$) by lime and VC interactions. Even though both were statistically equal, the combined application of lime at 100% LR + 5 t VC ha^{-1} yielded the highest grain yield (7.99 t ha^{-1}) followed by the combined application of lime at 75% LR + 2.5 t VC ha^{-1} whereas the lowest grain yield (2.97 t ha^{-1}) from control plots. The results of economic analysis indicated that the combination of lime at 75% LR + 2.5 t VC ha^{-1} showed a marginal rate of return of 2322.74%, with the highest net benefit of 49980 Ethiopian Birr compared to other treatments.This study indicates combined use of lime and VC could ameliorate the adverse effect of soil acidity, and application of 75% LR + 2.5 t VC ha^{-1} enhances grain yield and produces the highest net benefit of maize grown on acidic soil of the Lalo Asabi district.

Keywords: Acidity, Lime, Vermicompost amelioration, Maize yield

1. INTRODUCTION

Soil is one of the natural resources, that arevital for the existence of life on the planet earth. It needs to be protected, conserved and enhanced. However, globally more than half (52%) of all fertile andproductive soils are now classified as degraded or severely degraded [1]. These soil fertility and productivity degradation's have been described as the most constraints to crop production for foodsecurity.Soil acidity is among the major land degradation problems that affects ~50% of the world's potentially arable soils [2]. It is a major constraint to agricultural productivity throughout Africa, where high rainfall is common, due to the deficiencies of N by leaching, P fixation and low soil OM [3]. In the tropics, substantial weathering of soils over millennia has resulted in the leaching of plant nutrients mainly K, Mg, and Ca, followed by replacement by the release of H, Al, and Mn cations that contribute to acid-related stresses on crop production [4].

Soil acidity is a major constraint to crop production, particularly maize (*Zea mays* L.) on tropical soils due to toxic levels of aluminium (Al) and concomitant phosphorus (P) deficiency [5]. Soil acidity is now a serious threat to crop production in most of the high lands of Ethiopia. Ethiopian Soil Information System [6] showsabout 43% of the Ethiopian arable land hasaffected by soil acidity, of these about 28.1% of soils are dominated by strongly acidic soils (pH 4.1-5.5). In Ethiopia, low soil fertility and nutrient availability due to acidity and low levels of input uses are among the major constraints to maize production [7]. [8] stated that achieving a high yield requires an adequate and balanced supply of plant nutrients, where declining soil fertility is a prominent constraint for maize production.

Major crops like maize and sorghum in western Ethiopia are being grown with sub-optimal inputs on extremely acidic soil [9]. In the western parts of the country such as Assosa and Wollega, soil acidity is a well-known problem thatlimits crop productivity. In these areas, 67% of soils have a pH < 6, with the range varying from extremely acidic to moderately acidic [10]. There are different conventional and non-conventional amendments to ameliorate acid soils. The general practice for ameliorating soil acidity is the application of lime. The productivity of crops in acid soils with Al toxicity and low soil availability P improved by the use of lime, lime with fertilizers and/or organic materials [11].

Lime is the most important and effective means of amending soil acidity [12]. The practice of well-planned lime application to acid soil is fundamental to improving soil fertility and increasing crop yields. This in turn helps to reduce crop production risks associated with soil acidity, as liming promotes nutrients use, especially phosphorus [13].Proper liming of acid soils has the potential to contribute to an overall increase in maize yields cultivated in such soils because of its ability to reduce exchangeable acidity and increase soil pH. By increasing soil pH, liming makes other nutrients more available, and prevents Al and Mn from being toxic to plants [14]. Liming also enhances root development, and water and nutrient uptake which are necessary for healthy plant growth [15]. Reduction of soils acidity also improves the microorganisms' proliferation and hence their activity in soils [16]. Soil acidity problems are commonly corrected by applying agricultural limestone. In low-input agricultural systems, the use of locally available liming materials could be a key management practiceto reduce soil acidity. These non-limestone liming materials could be organic residues from green and animal manures thatcan increase the pH of acid soils and improve soil fertility [17].Moreover, application of organic materials to acidic soils has been proven to be an efficient alternative to the use of lime [18]. Organic fertilizer application has been reported to improve crop growth by supplying plant nutrients as well as improving soil physical, chemical, and biological properties [19].

Vermicompost (VC) is one of the stabilized, finely divided organic fertilizers with a low C:N ratio, high porosity, and water-holding capacity. Most nutrients present in VC are in the forms readily available to plants [20]. It contains most nutrients in forms such as nitrates, phosphates, and easily soluble potassium and calcium [21]. The reported improvements in the growth and development of plants are due to the presence of humic acids and micro and macronutrients in vermicompost [22]. In a sustainable agricultural system, integrated soil fertility management is an important approach.

Many research findings have been obtained in many parts of the country. Consequently, in the western part of the country in general, and the Wollega and Lalo Asabi districts in particular, soil acidity is a well-known problem that limits crop productivity. As part of the solution to such a problem in soils, the combined application of lime and VC on maize has not been investigated in the area, in which maize was one of the potential cereal crops in the area. Therefore, by considering the beneficial effects of liming and organic matter particularly VC as amendments for soil acidity amelioration and increasing maize productivity and production this research was carried outto evaluate the response of maize yield and yield components to the application of combined rates of lime and vermicompost in the study area.

2. METHODOLOGY

2.1. Description of the Study Area

The study was conducted at Garjo Siban kebele in Lalo Asabi district, west Wollega Zone, Oromia National Regional State, Western Ethiopia (Figure 1). It is 451 kilometers west of Addis Abeba and 20 kilometers from Gimbi Town, the administrative center of the west Wollega Zone. Geographically, it is found between 9^{o} 5' 30" and 9^{o} 23' 00" N latitude,and 35^{o} 32' 30" and 35^{o} 47' 00" E longitude,with altitude ranges from 1500 to 1900 meters above sea level (masl). Agroclimatically,thedistrictis characterizedbyslightlywarmtocoolhumidmidhighlandswithauni-modalrainfallpatternandmeanmonthlyminimum,maximum,andmean airtemperaturesof12.8,26.4,and19.5°C,respectively. The rainy season starts in April and extends up to November. The predominant soil type in southwest and western Ethiopia in general and the study district in particular is Nitisols [23].

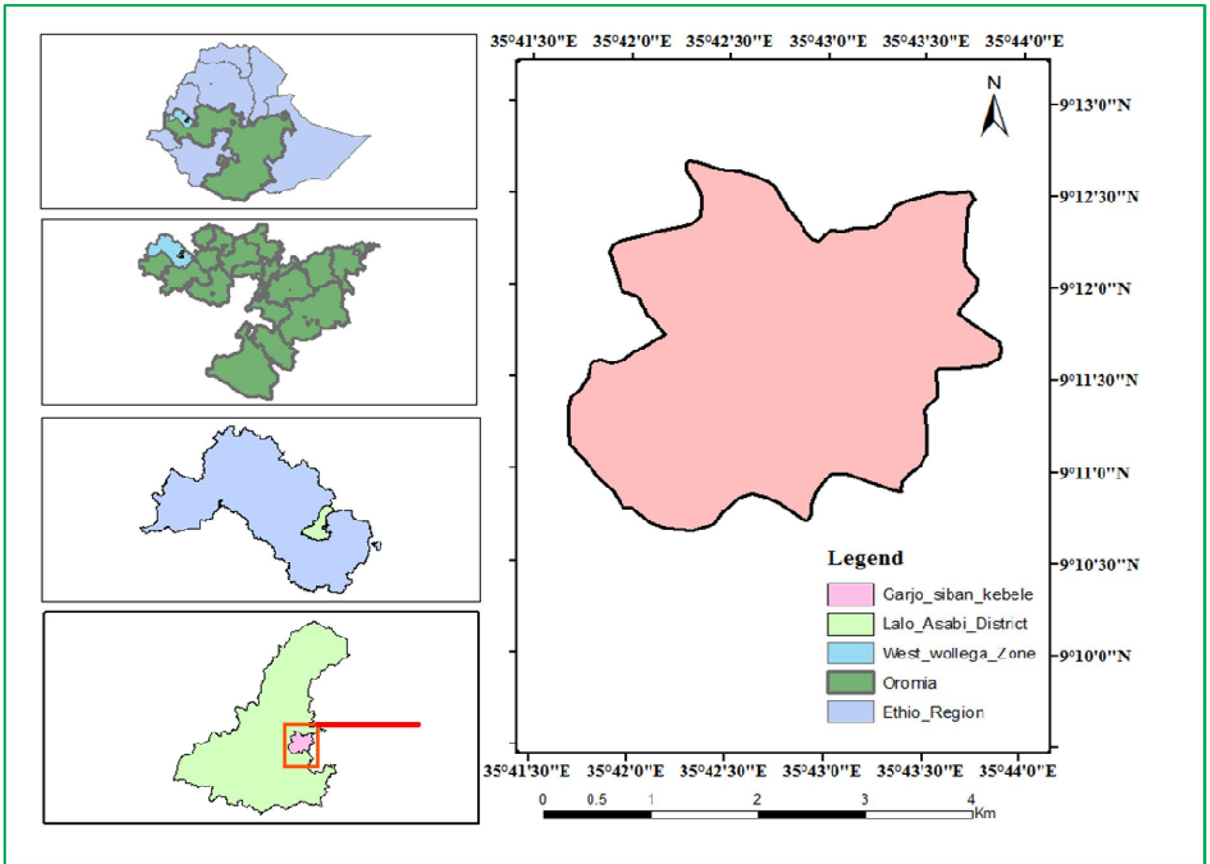

Figure 1. Location map of the study area

2.2. Experimental Design and Treatments, Procedures and Management

The treatments consisted of five rates of lime ($CaCO_3$) (0, 25, 50, 75, and 100 % LR) and three levels of vermicompost (0, 2.5, and 5 t ha^{-1}) in a factorial combination in a randomized complete block design with three replications. A total of 45 plots were prepared for the experiment. The plot size was 3.75 m × 4.2 m with a spacing of 1 m between each plot and block. The treatments included vermicompost and lime. Ground limestone with 85.5% $CaCO_3$ content and a fineness of 25% that passed through a 60-mesh screen (approved by the Oromia Agricultural and Natural Resource Bureau, at Guder Limestone Crushing Factory) was used as limingmaterials. The experimental field was ploughed by oxen three times to get a fine seedbed and leveled manually before the experimental design layout.Lime and vermicompost were uniformly applied to the plots as per treatments combination and mixed with soil to a 15 cm depth. The method of soil amendments were applied was by the manual broadcasting method. Beforeplanting,lime andvermicompost wereincorporatedintothesoil foramonthandaweek,respectively,toallowtimeforsoilreaction. Maize (variety, BH- 661), which is widely grown by farmers, was used as a test crop. The inter- and intra- row spacing were 75 and 30 cm, respectively**.** Maize seeds weresown on May 20, 2020 as per the recommended maize planting period. Two seeds were sown in rows per hill and then thinned to one plant after eight days of germination by keeping a good stand of seedlings.Toavoidseedcontactwiththefertilizers,halfoftheureaandfulldoses ofNPSwereapplieduniformlyintothemaizerows andmixedwiththesoilduringplanting. The remaining half dose of urea was applied at the knee height growth stage of maize to minimize the loss and increase N use efficiency.All other necessary agronomic practices were carried out properly and uniformly for all plots.

2.3. Soil Sampling, Preparation and Analysis

Prior to the commencement of the experiment, both disturbed and undisturbed soil samples were collected from the experimental site. Ten random disturbed composite soil samples at a depth of 0-15 cm were collected using a soil augur, and a composite soil sample was prepared by thoroughly mixing. The collected composite soil samples were shade-dried, ground and sieved to pass through a 2 mm sieve for the analysis of selected soil physicochemical properties such as particle size distribution, exchangeable acidity, soil pH, exchangeable bases,available P and cation exchange capacity (CEC) of the soil, and a 0.5 mm sieve for soil organic carbon (OC) and total nitrogen (TN) following standard laboratory procedures. Soil bulk density was measured from the undisturbed soil samples collected by a core sampler, as per the procedure described by [24]. Porosity was determined using the following equation.

Total Porosity (%) = (1-BD/PD)*100

Where: BD = Bulk density (g cm^{-3}), PD = Particle density (using the average value of mineral soils, 2.65 g cm^{-3}) for most soil components).

2.4. Determination of Lime Requirement

The amount of lime applied was determined based on the exchangeable acidity, mass per 0.15 m furrow slice and bulk density of the soil [25], considering the amount of lime needed to neutralize the acidity of the soil up to the permissible level for crop growth.

2.5. Data collection and analysis

Theyieldandyieldcomponentdatacollectedonap lot basiswereconvertedtoha^{-1}. Thecollecteddatawereenteredintoanexcelsprea dsheetandthenanalyzedusingSASsoftwareversi on9.2 [26].

Data collected for the experiment were days to 50% taseling, days to 50% silking, days to 90% physiological maturity, plant height (cm), cob length (cm),number of cobs per plant, number of grains per ear, thousand grain weight (g), grain yield (t ha^{-1}), aboveground biomass (t ha^{-1}), and harvest index (%).

3. RESULTS AND DISCUSION

3.1. Selected Soil Physicochemical Properties before Planting

Table1. Selected soil physicochemical characteristics of the experimental site

Parameters	Value	Rating	Reference
Particle size distribution			
Sand (%)	39		
Clay (%)	45		
Silt (%)	16		
Textural class	Clay		
Bulk density (g cm^{-3})	1.34	High	Barauah and Barthakulh

			[27]
Total phosphorous (%)	49.44		
Soil pH (1:2.5 H_2O)	5.2	Strongly acidic	Tekalign [28]
Exchangeable acidity ($cmol_c$ kg^{-1})	2.54		
Organic carbon (%)	1.48	Low	Tekalign [28]
Total nitrogen (%)	0.19	Medium	Tekalign [28]
Available phosphorous (mg kg^{-1})	2.26	Low	Landon [29]
Exchangeable calcium ($cmol_c$ kg^{-1})	2.48	Low	FAO [30]
Exchangeable magnesium ($cmol_c$ kg^{-1})	1.57	Medium	FAO [30]
Exchangeable potassium ($cmol_c$ kg^{-1})	0.57	Medium	FAO [30]
Exchangeable sodium ($cmol_c$ kg^{-1})	0.18	Low	FAO [30]
Cation exchangeable capacity ($cmol_c$ kg^{-1})	11.35	Low	Hazelton and Murphy [31]
Percent base saturation (%)	42.3	Moderate	Hazelton and Murphy [31]

3.2. Selected Chemical Properties of Vermicompost

Selected nutrient contents of vermicompost (VC) used in the experiment are presented in Table 2.

Table 2. Chemical composition of vermicompost

Parameters	Value
Soil pH (1:2.5 H_2O)	7.1
Electrical conductivity (dSm^{-1})	10.10
Carbon (%)	11.11
Total nitrogen (%)	1.19
Phosphorous (mg kg^{-1})	365.24
Calcium ($cmol_c$ kg^{-1})	12.22
Magnesium ($cmol_c$ kg^{-1})	6.84
Potassium ($cmol_c$ kg^{-1})	28.67
Sodium ($cmol_c$ kg^{-1})	2.10
C:N	9.34

3.3. Responses of Maize to Combined Application of Lime and Vermicompost

Days to 50% tasseling and silking

The main effects of lime and vermicompost rates showed a highly significant ($p<0.01$) differencein the number of days to tasseling and silking, but the interaction effect was not significant (Appendix Table 1). Maize plants on plots that received 100 and 75% rates of LR, had the lowest number of days to tasseling (92.77 and 93.11 days) and silking (96.11 and 96.55 days), respectively, while those on control plots showed the highest number of days to tasseling (96.66 days) and silking (100 days). Plants on control plots were delayed for 4 daysto tasseling and silking in comparison with those on plots treated with 100 and 75% rates of LR (Table 3).

The decreased number of days to tasseling and silking with increased rates of lime might be due to the lime effect reducing exchangeable acidity of the soil and thus increasing the availability of certain nutrients and improvements in soil conditions that promote plant growth.

Similarly, maize plants on plots treated with the highest rate of VC (5 t ha^{-1}) showed the lowest number of days to tasseling (94 days) and silking (97.40 days), while those on control plots showed the highest number of days to tasseling (95.46 days) and silking (98.73 days) (Table 3). The reduced number of days to tasseling and silking with the increase in the rates of VC might be due tothe availability of nutrients contained in VC and the effects of VC on other soil properties, which played a significant role in promoting crop growth.

Table 3. Main effects of lime and vermicompost rates on days to tasseling and silking of maize

Treatment	**Phenological parameters**	
Lime rate (% LR)	**Days to 50% tasseling**	**Days to 50% silking**
0	96.66[a]	100.00[a]
25	95.11[b]	98.44[b]
50	95.00[b]	98.22[b]
75	93.11[c]	96.55[c]
100	92.77[c]	96.11[c]
LSD(0.05)	0.663	0.739
VC (t ha^{-1})		
0	95.46[a]	98.73[a]
2.5	94.13[b]	97.46[b]
5	94.00[b]	97.40[b]
LSD (0.05)	0.513	0.572
CV (%)	0.726	0.782

Means followed by the same letters within column are not significantly different from each other at p ≤ 0.05. LSD = Least significant difference; CV = Coefficient of variation.

3.3.1. Days to 90% physiological maturity

The results of statistical analysis revealed that the main effect of lime rates showed a highly significant effect (p<0.01), but VC rates showed non-significant effect on days to 90% physiological maturity of maize. However, the interaction effect of the two factors showed a highly significant effect (p<0.01) on the days to 90% physiological maturity of maize (Appendix Table 1). Thecombinedapplicationof75%LR+2.5tVCha^{-1}resultedinthelongestnumberofdaystomaturity (172.66days),followedbytheapplicationof100 %LR+2.5tVCha^{-1}(169.33days),andthecontrolresultedintheshortestnumberofdaystomaturity(157.33days)(Table4).The delay in days to maturity with the combined application of lime and VC might be attributed to the improvement of soil conditions that could increase the availability of nutrients that might have boosted the vegetative growth of the plants and allowed them to stay green for a longer period of time for grain filling.

Table 4. Interaction effects of lime and vermicompost rates on days to 90% physiological maturity of maize

Days to 90% physiological maturity			
Treatments	**Vermicompost**rate (t ha^{-1})		
Lime rate (% LR)	0	2.5	5
0	157.33^{e}	157.33^{e}	159.33^{e}
25	161.33^{de}	159.66^{e}	159.33^{e}
50	166.33^{bc}	164.66^{cd}	165.6^{6bcd}
75	165.33^{bcd}	172.66^{a}	167.00^{bc}
100	165.00^{bcd}	169.33^{ab}	167.33^{bc}
LSD (0.05)	4.64		
CV (%)	1.69		

Means followed by the same letter(s) are not significantly different at $p \leq 0.05$. LSD = Least significant difference; CV = Coefficient of variation.

3.3.2. Plant height

Analysis of variance revealed that maize plant height was highly and significantly affected ($p<0.01$) due to the main effects of lime and vermicompost, and significantly affected ($p<0.05$) due to their interaction (Appendix Table 1). Combined application of lime rate at 100% LR + 5 t VC ha^{-1}resulted in the highest plant height (273.33 cm) that was not significantly different from combined applications of 100% LR + 2.5 t VC ha^{-1} (266.33 cm), 75% LR + 2.5 t VC ha^{-1} (263.06 cm) and 75% LR + 5 t VC ha^{-1} (261.26 cm), but the control plots exhibited significantly lower plant height (208.46 cm) compared to all other treatments (Table 5). In general there was a synergistic effect between the two factors which in turn favored height increments by minimizing the effect of soil acidity.

Table 5. Interaction effects of lime and vermicompost rates on height of maize

Plant height (cm)			
Treatments	**Vermicompost**(t ha^{-1})		
Lime rates (% LR)	0	2.5	5
0	208.46^{d}	252.26^{bc}	254.33^{bc}
25	239.60^{c}	256.73^{bac}	254.06^{bc}
50	252.06^{bc}	252.60^{bc}	252.46^{bc}
75	257.06^{bac}	263.06^{ab}	261.26^{ab}
100	251.5^{bc}	266.33^{ab}	273.33^{a}

LSD (0.05)	18.12
CV (%)	4.29

Means followed by the same letter (s) are not significantly different at p≤ 0.05. LSD = Least significant difference; CV = Coefficient of variation.

3.3.3. Cob length

Analysis of variance showed a highly significant effect (p≤ 0.01) of lime and VC on the cob length of maize.The interaction effect of different rates of lime and vermicompost was also a highly significant (p≤0.01) on cob length (Appendix Table 1). Accordingly, the highest cob length (23.80 cm) was recorded for maize plants on plots treated with combined application rates of 75% LR + 2.5 t VC ha^{-1} followed by 100% LR + 5 t VC ha^{-1} (23.73 cm) with the cob length of about 33.7% higher compared to those on control plots (17.80 cm) (Table 6). An increase in the cob length might be due to reduction of soil acidity and increased nutrient availability.

Table 6. Interaction effects of lime and vermicompost rates on cob length of maize

Cob length (cm)			
Treatments	**Vermicompost (t ha^{-1})**		
Lime rates (% LR)	0	2.5	5
0	17.80^{e}	21.53^{d}	22.00^{cd}
25	21.66^{d}	21.40^{d}	21.86^{d}
50	21.33^{d}	21.93^{d}	22.20^{bdc}
75	23.66^{a}	23.80^{a}	23.40^{ab}
100	22.53^{bdac}	23.33^{bac}	23.73^{a}
LSD (0.05)	1.35		
CV (%)	3.67		

Means followed by the same letter (s) are not significantly different at p≤ 0.05. LSD = Least significant difference; CV = Coefficient of variation.

3.3.4. Number of cobs per plant and number of grains per ear

The main effects of lime and VC were highly significant (p<0.01) for the number of cobs per plant of maize, but the interaction of the two factors had no significant effect on these yield components (Appendix Table 1). The highest number of cobs per plant was recorded for maize grown on plots treated with lime application of 100% LR followed by 75% LR (1.88) (Table 7), but the lowest number of cobs (1.33) per plant was recorded for the control. Similarly, the highest number of cobs (1.86) per plant was recorded for maize grown on plots treated with an application of 5 t VC ha^{-1} followed by 2.5 t VC ha^{-1} (1.73), but the lowest number of cobs (1.33) per plant was recorded for the control (Table 7).

However, analysis of variance showed a highly significant variation (p<0.01) for the number of grains per ear of maize due to lime and vermicompost main effects, but the interaction of the two factors had a non-significant effect (Appendix Table 1). The increases in the number of grains per ear following the application of lime rates, of 100%, 75%, 50%, and 25% LR ha^{-1} were about 14.95%, 11.13%, 8.78%, and 4.3%, respectively, over the control (Table 7). Similarly the increases in the number of grains per ear following the application of vermicompost rates of 2.5 and 5 t ha^{-1} were 9.90%, and 12.6%, respectively, compared to the control (Table 7). Thus, the significant increases in the number of cobs per plant and number of grains per ear with the main effects of lime and vermicompost application could be attributed to the general improvement of the soil environment in terms of decreased acidity and increased availability of plant nutrients which in turn increased the number of cobs per plant and the number of grains per plant, and thereby increased grain yield.

3.3.5. Thousand grain weight

The main effects of the application of lime and vermicompost were highly significant ($p<0.01$) for thousand grain weight. However, the interaction effect of the two factors was not significant (Appendix Table 1). Application of lime rate at 75% LR resulted in the highest thousand grain weight (461.33 g) followed by 100% LR (454.67 g), but statistically not significantly different from each other, and the lowest weight (391.33 g) resulted from the control treatment. The increased lime rates from 0 to 100% LR increased thousand grain weights by 16.18% (Table 7). Similarly, application of increased rates of vermicompost increased thousand grain weight by 8.4 to 12.6% over control (Table 7). Such an increase in 1000 grain weight over the control might be attributed to better availability of nutrients for crop growth and grain filling that contributed to relative seed weight while the lowest thousand seed weight from the control plots could be due to shriveled seeds that have small size

Table 7. Main effects of lime and vermicompost rates on number of cobs per plant, number of grain per ear, thousand grain weight, aboveground biomass and harvest index of maize

Treatment	**Yield related parameters**				
Lime rate (% LR)	NCPP	NGPE	TGW (g)	AGB (t ha^{-1})	HI (%)
0	1.33^{b}	515.89^{c}	391.33^{c}	12.03^{c}	43.66^{ab}
25	1.44^{b}	538.00^{bc}	417.44^{bc}	13.39^{b}	45.77^{ab}
50	1.55^{b}	561.16^{ab}	442.44^{ab}	13.45^{b}	47.77^{ab}
75	1.88^{a}	573.33^{a}	461.33^{a}	13.80^{ab}	52.00^{a}
100	2.00^{a}	593.03^{a}	454.67^{a}	14.80^{a}	48.55^{ab}
LSD (0.05)	0.30	33.83	30.88	1.24	7.43
Vermicompost (t ha^{-1})					
0	1.33^{b}	517.45^{b}	405.13^{b}	11.60^{b}	46.60
2.5	1.73^{a}	568.70^{a}	439.13^{a}	14.15^{a}	46.60
5	1.86^{a}	582.69^{a}	456.07^{a}	14.74^{a}	49.46
LSD (0.05)	0.234	26.20	23.92	0.96	5.75
CV (%)	19.07	6.29	7.38	9.53	16.19

Means followed by the same letter (s) within column are not significantly different at $p \leq 0.05$. NCPP = Number of cobs per plant; NGPE = Number of grains per ear; TGW = Thousand grain weight; AGB = Aboveground biomass; HI = Harvest Index; LSD = Least significant difference; CV = Coefficient of variation.

3.3.6. Aboveground biomass yield

Analysis of variance showed that the aboveground biomass (AGB) yield of maize was highly and significantly ($p<0.01$) influenced by the main effects of lime and VC; however, the interaction effect was non-significant (Appendix Table 1). The highest aboveground biomass yield (14.8 t ha^{-1}) was obtained from plots that received a lime rate of 100% LR ha^{-1} whichwasstatisticallysimilarto75%LRha^{-1}. The lowest aboveground biomass yield (12.03 t ha^{-1}) was obtained from the plots without lime, but as the rate of lime increased from 0 to 100% LR, the aboveground biomass yield increased by 23.02% (Table 7).

Likewise, the highest aboveground biomass yield (14.74 t ha^{-1}) was obtained from plots treated with a VC rate of 5 t ha^{-1} whereas the lowest (11.6 t ha^{-1}) was obtained from the control. Application of vermicompost increased aboveground biomass yield by 21.98 to 27.06% over the control (Table 7). The increase in aboveground biomass with the application of lime and vermicompost to the soil probably creates more favorable physicochemical conditions in the soil, such as reduced aluminum toxicity and increased nutrients availability, which ultimately enhances maize growth. Application of organic matter as fertilizers provide growth-regulating substances and improves the physicochemical and microbial properties of soils. Furthermore, there is reduction of Al toxicity, which restricts roots growth and creates difficulty in accessing nutrients and water from a longer distance in the soil. Finally, application of lime along with VC could improve root nutrient uptake of the plant through promoting its growth.

3.3.7. Harvest index

The harvest index was not significantly influenced by the main and interaction effects of lime and vermicompost (Appendix Table 1). Though there was non-significant effect observed, the highest harvest index (52%) was recorded for yields obtained from plots received lime rate of 75% LR ha^{-1}, whereas the lowest harvest index (43.66%) was for yields obtained from control plot. Similarly, the highest harvest index (49.46%) was recorded for yields obtained from plots treated with VC rate of 5 t ha^{-1}, whereas the lowest (46.60%) was for yields obtained from control plot even though both being statistically at par (Table 7). The possible reason could be that application of lime and VC with increased rate might have increased the efficiency of maize to partition the dry matter into the reproductive seed sinks. Integrated use of lime with organic and inorganic fertilizer significantly affected yield and yield components of barley.

3.3.8. Grain yield

Analysis of variance revealed that grain yield was significantly influenced ($p<0.01$) by the main effects of lime, vermicompost and their interaction (Appendix Table 1). Application of increased lime rates increased grain yield by 88.21 to 114.14% over the control (Table 8). Similarly, application of vermicompost without lime increased grain yield by 120.8 to 123.2% over control (Table 8). The highest grain yield (7.99 t ha^{-1}) was obtainedwith a combined application of lime rate at 100% LR ha^{-1} + 5 t VC ha^{-1} followed bylime at 75% LR ha^{-1} + 2.5 t VC ha^{-1}, which gave a (7.73 t ha^{-1}) grain yield, whereas the lowest grain yield (2.97 t ha^{-1}) was obtained from control plots with a yield difference of about 5.02 t ha^{-1} (Table 8).

Table 8. Interaction effects of lime and vermicompost rates on grain yield of maize

	Grain yield (t ha^{-1})		
Treatments	**Vermicompost (t ha^{-1})**		
Lime rates (% LR)	0	2.5	5
0	2.97^{f}	6.63^{bdec}	6.56^{bdec}
25	5.59^{e}	6.63^{bdec}	6.10^{de}

50	6.25^{de}	6.31^{de}	6.39^{dec}
75	6.19^{de}	7.73^{ab}	7.60^{bac}
100	6.36^{de}	7.07^{bdac}	7.99^{a}
Mean	5.47	6.87	6.92
LSD (0.05)	1.21		
CV (%)	11.34		

Means followed by the same letter (s) are not significantly different at $p< 0.05$. LSD = Least significant difference; CV = Coefficient of variation.

In general, separate application of both VC and lime alone was not adequate to increase the grain yield of maize significantly when compared with integration of lime and VC application (Table 8). This indicates that the synergistic effect of applied lime along with VC was significant in ameliorating soil acidity and increasing grain yield. Maximum and sustainable crop yields are only possible with the application of organic matter as a fertilizer.

3.3.9. Economic Analysis

The partial budget analysis as described by [32] was done to determine the economic feasibility of the maize production. The average yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could obtain under their management practices as described by [32]. Thus, the economic analysis was done on the basis of vermicompost preparation and lime transport costs due to the fact that lime is supplied to farmers free of charge and it was difficult to quantify the economic benefit of lime in one year as lime has a long-term effect. So, the economic analysis was done without considering the costs of lime but with consideration of vermicompost preparation and lime application as well as transportation. The average market grain price of maize (ETB 8 kg^{-1}), and labour valued at ETB 50 per day were used. The result of the partial budget analysis is given in (Table 9).

The results of this study revealed that the total grain yield significantly increased with the application of lime and VC and attained its maximum value as compared with the control (Table 8). Accordingly, the highest grain yields resulted from the combined application of lime and VC at 100% LR ha^{-1} + 2.5 t VC ha^{-1} followed by a 75% LR ha^{-1} + 2.5 t VC ha^{-1} application even though both were statistically at par. As indicated in Table 9, the highest net benefit was obtained in response to the interaction of 75% LR ha^{-1} lime with 2.5 t VC ha^{-1} (49,980 Birr). A dominance analysis was also performed to eliminate negative values. According to the guidelines of [32], for economic analysis, the marginal rate of return above the minimum level (100%) is considered economical. Thus, 75% LR ha^{-1} lime + 2.5 t VC ha^{-1} was found to be economically feasible as compared to the other treatment combinations.

Table 9. Partial budget analysis for profitability of combined rates lime and vermicompost for maize production at the study area

Lime (%LR) and VC ($t\ ha^{-1}$)	Average Yield ($t\ ha^{-1}$)	Ad GY ($t\ ha^{-1}$)	GFB (Birr ha^{-1})	TVC (Birr ha^{-1})	NB (Birr ha^{-1})	Dominance	MRR (%)
0,0	2.97	2.673	21384	0	21384		-
25,0	5.59	5.031	40248	412	39836		4478.64
50,0	6.25	5.625	45000	844	44156		1000
75,0	6.19	5.571	44568	1266	43302	D	
100,0	6.36	5.724	45792	1718	44074	D	
0,2.5	6.63	5.967	47736	4410	43326	D	
25,2.5	6.63	5.967	47736	4822	42914	D	
50,2.5	6.31	5.679	45432	5254	40178	D	
75,2.5	7.73	6.957	55656	5676	49980		2322.74
100,2.5	7.07	6.363	50904	6128	44776	D	
0,5	6.56	5.904	47232	8810	38422	D	
25,5	6.10	5.490	43920	9222	34698	D	
50,5	6.39	5.751	46008	9654	36354	D	
75,5	7.60	6.840	54720	10076	44644	D	
100,5	7.99	7.191	57528	10528	47000	D	

TVC = Total variable cost; Ad GY= Adjusted grain yield (yield was adjusted down wards by 10% to reflect yields under farmers' management practices); GFB = Gross field benefit; NB = Net benefit; MRR = Marginal rate of return

4. SUMMARY AND CONCLUSION

Application of lime and vermicompost at different rates improved phenological, growth, yield, and yield components of maize following improvement of soil properties.The highest grain yield (7.99 t ha^{-1}) was obtained from the combined application of lime at 100% LR + 5 t VC ha^{-1} followed by 75% LR+ 2.5 t VC ha^{-1} (7.73 t ha^{-1}). The lowest grain yield (2.97 t ha^{-1}) resulted from control plots that showed difference of about 5.02 t ha^{-1} compared to the highest grain yield.

The combined application of lime at 75% LR + 2.5 t VC ha^{-1} showed a marginal rate of return of 2322.74% with the highest net benefit of 49,980 Birr compared to other treatments. The results of this study clearly indicate that the combined application of lime and VC could ameliorate the adverse effects of soil acidity. Therefore, application of lime at 75% LR + 2.5 t VC ha^{-1} could be a suitable combination, from an economic benefit, to ameliorate soil acidity and improve soil fertility for sustainable maize production with improved productivity in the Lalo Asabi district. However, to draw a conclusive recommendation, the study has to be repeated over several seasons as lime and vermicompost have long-term effects on improving soil properties.

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Appendix Table 1. ANOVA results for maize phenology, growth, yield components and yield parameters as affected by lime and vermicompost rates and their interaction

		Mean squares											
Sources of variation	DF	DT	DS	DM	EH	PH	CL	NCPP	NGPE	TGW	AGB	GY	HI
Replication	2	2.066*	0.80^{ns}	61.42**	9.224^{ns}	29.91^{ns}	1.79^{ns}	0.28^{ns}	2328.60^{ns}	771.28^{ns}	0.11^{ns}	0.44^{ns}	23.62^{ns}
Lime (L)	4	22.96**	22.07**	185.81**	246.73**	886.54**	14.71**	0.74**	8169.73**	7511.66**	8.88**	5.08**	87.94^{ns}
Vermicompost (VC)	2	9.86**	8.46**	10.55ns	696.82**	1431.04**	6.48**	1.15**	17695.72**	10092.32**	41.63**	10.21**	41.08^{ns}
L*VC	8	0.53^{ns}	0.49^{ns}	14.36**	74.83^{ns}	309.36*	2.85**	0.21^{ns}	2224.01^{ns}	429.38^{ns}	2.63^{ns}	1.98**	113.72^{ns}
Error	28	0.47	0.58	3.92	34.959	124.38	0.583	0.098	1227.67	1023.28	1.65	0.53	59.28
CV (%)		0.72	0.78	1.21	4.29	4.41	3.44	19.07	6.29	7.38	9.53	11.41	16.19

** and * Significant at (1 and 5%) probability level respectively. DF = Degree of Freedom; MS = Mean Square; L = Lime; VC = Vermicompost rate; DT = Days to 50% tasseling; DS = Days to 50% silking; DPM = Days to 90% physiological maturity; EH = Ear height; PH = Plant height; CL = Cob length; NCPP = Number of cobs per plant; NGPE = Number of grain per ear; TGW = Thousand grain weight; AGB = Aboveground biomass; GY = Grain yield; HI = Harvest Index.