

Responses of Acidic Soil to Lime and Vermicompost Application at Lalo Asabi District, Western Ethiopia

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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, 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 problem in soils, 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. Field experiment was conducted at Lalo Asabi district in western Wollega during 2019/20 cropping season to evaluate the responses of acidic soil 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 randomized complete block design with three replications. One composite surface soil samples from a depth of (0-15 cm) were collected from the experimental field before commencement of the experiment. A total of fifteen composited soil samples were also collected from each plot and then composited by replication to obtain one representative sample per treatments for determination of selected soil physicochemical properties. The soil analysis results revealed that soil pH increased from 5.1 (strongly acidic) to 5.8 (moderately acidic) while exchangeable acidity decreased from 2.44 to 0.31 cmol_c kg⁻¹ under combined application of lime at 75% LR+2.5 t VC ha⁻¹, which resulted in improvement of others selected soil physicochemical properties. This study indicates combined use of lime and VC could ameliorate the adverse effect of soil acidity at Lalo Assabi district.

Keywords: Acidity, Lime, Vermicompost, Amelioration, Selected Soil Properties

1. Introduction

Soil is one of the natural resources, which are vital 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 and productive soils are now classified as degraded or severely degraded [1]. These soil fertility and productivity degradations have been described as the most constraints to crop production for food security.

Soil acidity is among the major land degradation problems, which affects ~50% of the world potentially arable soils [2]. It is a major yield-limiting factor for crop production

worldwide and in many developing countries where food production is critical [3]. Acid infertility factors limit crop growth and yield as well as soil productivity in highly weathered soils of humid and sub-humid regions of the world due to deficiency of essential nutrient elements [4]. Crop productivity on such acid soils is low and declining, particularly where acid forming fertilizers, such as ammonium based fertilizers have been applied continuously over years [5]. As these soils suffered multi-nutrient deficiencies, application of mineral fertilizers has become mandatory to increase crop yields. However, mineral fertilizers are commonly scarce and cost in developing countries. Their nutrient contents mostly limited to two to

three elements. This may result in imbalanced nutrition and their uses could aggravate the problem of soil acidity [6]. Continuous cropping with inorganic fertilizer application has led to development of soil acidity due to toxic levels of aluminum (Al) and the concomitant phosphorus (P) deficiency that hinders plant growth [7].

Soil acidity is now a serious threat to crop production in most high lands of Ethiopia. Ethiopian Soil Information System [8] shows about 43% of the Ethiopian arable land has affected by soil acidity, of these about 28.1% of soils are dominated by strongly acidic soils (pH 4.1-5.5). In Ethiopia, vast areas of land in the Western, Southern, Southwestern, Northwestern and even the Central highlands, which receive high rainfall, have been affected by soil acidity [9]. Areas dominated by Nitisols/Oxisols are mainly affected by soil acidity. These soils predominantly cover more than 80% of the landmasses of the western and central highlands. Acid Nitisols (pH <5.5) occur widely in Ethiopian highlands where the rainfall intensity is high and crop production has gone for many years [10].

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 the concomitant phosphorus (P) deficiency [7]. In Ethiopia, low soil fertility and nutrient availability due to acidity and low level of input uses are among the major constraints to maize production [11]. Major crops like maize and sorghum in western Ethiopia are being grown under suboptimal inputs on extreme acid soil. In the western part of the country such as Assosa and Wollega, soil acidity is a well-known problem that limiting crop productivity. Smallholder farmers in different districts in East and West Wollega zones have also reported crops yield's stagnation and even decline with no responses to application of urea and DAP fertilizers. This suggests for requirements of additional amendments to improve soil fertility and productivity [12]. 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 use of lime, lime with fertilizers and/or organic materials [13].

Lime is the most important and effective means of amending soil acidity [14]. Proper liming of the acid soils has the potential of contributing to an overall increase of maize yields cultivated in such soils because of reducing exchangeable acidity and increasing soil pH. By increasing soil pH, liming makes other nutrients more available, and prevents Al and Mn from being toxic to plant [15]. This in turn helps to reduce crop production risks associated with soil acidity, as liming promotes nutrients use efficiency especially phosphorus [16]. Liming also enhances root development, water and nutrient uptakes which are necessary for healthy plant growth [17]. Reduction of soils acidity also improves the microorganisms' proliferation and hence their activity in soils [18]. Soil acidity problems are commonly corrected by applying agricultural limestone.

In low-input agricultural system, use of locally available

liming materials could be a key management practice to reduce soil acidity. These non-limestone liming materials could be organic residues from green and animal manures that can increase the pH of acid soils and improve soil fertility [19]. Organic fertilizer application has been reported to improve crop growth by supplying plant nutrients as well as improving soil physical, chemical, and biological properties [20].

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 plant [21]. Soil organic carbon, pH, CEC, porosities and water-holding capacities, microbial populations and dehydrogenase activity of soils increased while soil bulk density decreased, in response to vermicompost application [22]. The reported improvements in growth and development of plants are due to the presence of humic acids and micro and macronutrients in vermicompost [23]. In sustainable agricultural system, integrated soil fertility management was an important approach.

Several researchers have demonstrated the beneficial effects of combined organic materials and ground lime on ameliorating soil acidity and mitigating deficiency of several macro- and micro-nutrients [24]. Consequently, in the western part of the country in general, Wollega and Lalo district in particular, soil acidity is a well-known problem that limiting crop productivity. As part of the solution to such problem in soils, 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 VC as amendments for soil acidity amelioration and increasing maize productivity and production this study was carried out with the following objectives.

To assess response of acidic soil to the application of combined rates of lime and vermicompost in terms of selected soil physicochemical properties.

2. Materials and Methods

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 located about 451 km away from Addis Ababa to the west and 20 km from Gimbi town, administration center of west Wollega Zone. Geographically, it is found in between 9° 5' 30" and 9° 23' 00"N latitude, and 35° 32' 30" and 35° 47' 00"E longitude and altitude ranges from 1500 to 1900 meter above sea level (masl).

Agro-climatically, the district has been characterized by slightly warm to cool humid mid highlands with uni-modal rainfall pattern with average annual rainfall of 1889 mm and has mean monthly minimum, maximum and mean air temperatures of 12.8, 26.4 and 19.5°C, respectively (Figure

2). 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 [25].

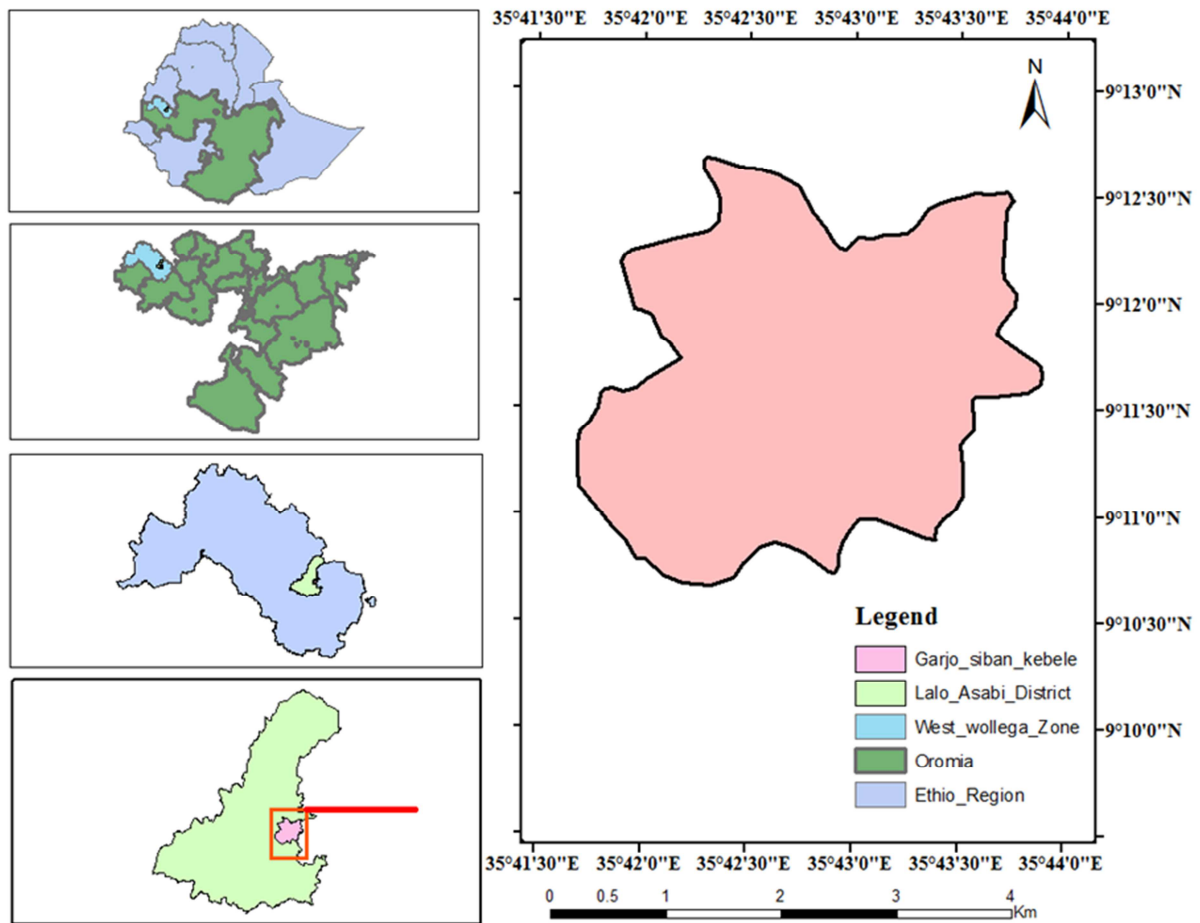


Figure 1. Location map of the study area.

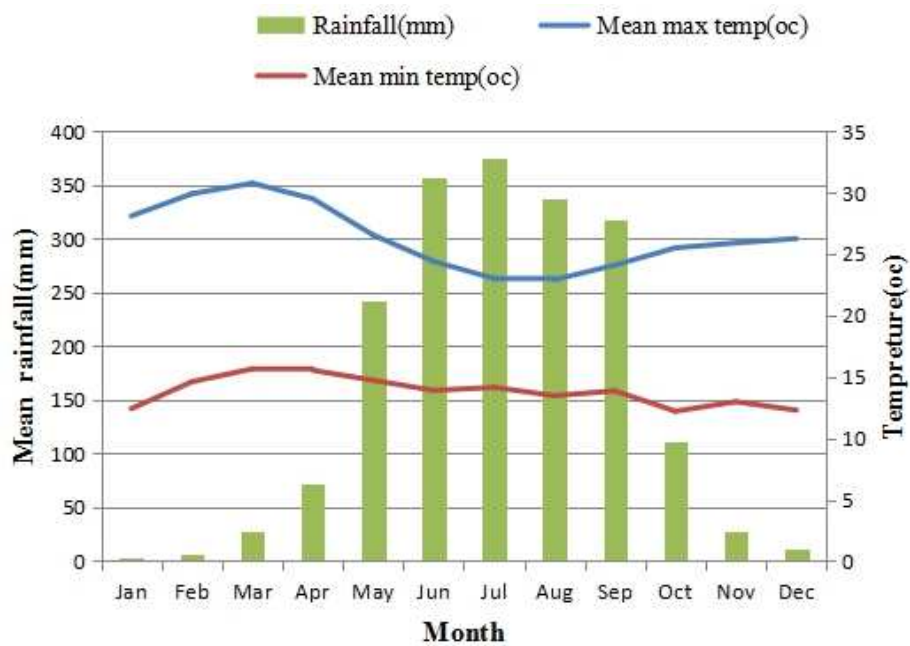


Figure 2. Mean monthly rainfall, minimum and maximum temperature of the study area from 2006-2018 (National Meteorological Service Agency, Assosa Head Office (NMSA)).

2.2. Soil Sample 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 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 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 core sampler, as per the procedure described by [26]. Porosity was determined using the following equation.

$$\text{Total Porosity(\%)} = (1 - \text{BD}/\text{PD}) \times 100$$

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).

$$\text{LR, CaCO}_3(\text{kg/ha}) = \frac{\text{CmolEA/kg of soil} \times 0.15 \text{ m} \times 104 \text{ m}^2 \times \text{B.D}(\text{gcm}^{-3}) \times 1000}{2000}$$

Where:

BD = Bulk Density

EA = Exchangeable acidity (H^+ + Al^{3+}) LR = Lime Requirements,

0.15 m = plow depth/depth of lime incorporation.

2000 = Conversion factor to convert exchangeable acidity per kg of soil to per hectare.

2.5. 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 randomized complete block design with three replications. A total of 45 plots were used for the experiment. Plot size was $3.75 \text{ m} \times 4.2 \text{ m}$ with the spacing of 1 m between each plot and block. Vermicompost and lime were used as treatments. Ground Limestone with 85.5% CaCO_3 content and fineness of 25% pass a 60-mesh screen (approved by Oromia Agricultural and Natural Resource Bureau, at Guder Limestone Crushing Factory) was used as liming materials. The experimental field was plowed by oxen three times to get a fine seedbed and

2.3. Vermicompost Preparation, Sampling and Analysis

Vermicompost was prepared from crop residues of maize and soya bean, cow dung and top soil by using red earthworm (*Eisenia fetida*). Sixty percent of the straw was air dried and chopped, into pieces of 3 to 5 cm, and mixed well with 30% cow dung and 10% of topsoil following sequence according to [27]. Above 75% moisture was maintained for free motility and breathe of the worms. The vermicompost obtained was mixed, shade dried, sieved and then, it was subjected to the analysis of pH, C, N, P, Ca, Mg, and K following standard procedures adopting the same methods described for the soil. The C:N ratio was estimated from C and N contents of the vermicompost.

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 [28], considering the amount of lime needed to neutralize acidity of the soil up to the permissible level for crop growth.

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 15 cm depth. The method of application was manually broadcasting. Vermicompost and lime were incorporated into the soil before planting to a depth of 15 cm for a months for lime and one week for vermicompost (time allowed for soil reaction). Maize (variety, BH-661), which is widely grown by farmers was used as a test crop. Inter- and intra-row spacing's of 75 and 30 cm were used, respectively. Maize seeds were planted on May 20, 2019 as per the recommended maize planting period. Two seeds were sown in rows per hill and then thinned to one plant after 8 days germination by keeping a good stand seedling. At planting of maize, half of urea and full doses of NPS were applied uniformly into the maize rows and mixed with the soil to avoid contact of the seed with the fertilizers. The remaining half dose of urea was applied at 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.

Table 1. Treatments combination and description.

| Trt. No. | Lime Requirement (%) | Vermicompost rate (t ha^{-1}) | Treatment description |
|----------|----------------------|--|---|
| 1 | 0 | 0 | Control |
| 2 | 0 | 2.5 | 0 Lime + 2.5 t ha^{-1} Vermicompost |
| 3 | 0 | 5 | 0 Lime + 5 t ha^{-1} Vermicompost |
| 4 | 25 | 0 | 25% LR of Lime + 0 Vermicompost |
| 5 | 25 | 2.5 | 25% LR of Lime + 2.5 t ha^{-1} Vermicompost |
| 6 | 25 | 5 | 50% LR of Lime + 5 t ha^{-1} Vermicompost |

| Trt. No. | Lime Requirement (%) | Vermicompost rate (t ha ⁻¹) | Treatment description |
|----------|----------------------|---|--|
| 7 | 50 | 0 | 50% LR of Lime + 0 Vermicompost |
| 8 | 50 | 2.5 | 50% LR of Lime + 2.5 t ha ⁻¹ Vermicompost |
| 9 | 50 | 5 | 50% LR of Lime + 5 t ha ⁻¹ Vermicompost |
| 10 | 75 | 0 | 75% LR of Lime + 0 Vermicompost |
| 11 | 75 | 2.5 | 75% LR of Lime + 2.5 t ha ⁻¹ Vermicompost |
| 12 | 75 | 5 | 75% LR of Lime + 5 t ha ⁻¹ Vermicompost |
| 13 | 100 | 0 | 100% LR of Lime + 0 Vermicompost |
| 14 | 100 | 2.5 | 100%LR of Lime + 2.5 t ha ⁻¹ Vermicompost |
| 15 | 100 | 5 | 100% LR of Lime + 5 t ha ⁻¹ Vermicompost |

2.6. Post-Harvest Soil Samples Collection

Soil samples were collected after harvest from each plot and then composited by replication to obtain one representative sample per treatments to have a total of fifteen soil samples and analyzed for the following parameters such as bulk density, exchangeable acidity (H⁺ and Al³⁺), soil pH, OC, TN, avail. P, CEC, Exchangeable bases (Ca, Mg, K and Na) and Percent base saturation (PBS) following standard procedures.

3. Results and Discussion

3.1. Selected Soil Physicochemical Properties Before Planting

The particle size distribution analysis showed that the soil of the study area contains 39, 45 and 16% of sand, clay and silt, respectively (Table 2). Based on the soil textural triangle of United State Department of Agriculture (USDA) system, textural class of the soil is clayey. Bulk density value of the soil was 1.34 g cm⁻³. According to [26], soil bulk density rating of this soil has moderate compaction (Table 7). The moderate compaction of the soil could be due to continuous cultivation which causes disintegration of the soil structure and exposure of surface soil to the direct raindrops. The total porosity of this soil was 49.44% which was classified as high according to the rating of [29]. The soil pH (H₂O) was 5.2 and falls under strongly acidic according to [30]. This indicates the possibility of Al toxicity and deficiency of certain plant nutrients. Low pH value of the soil could be due to the leaching of basic cations such as Ca²⁺, Mg²⁺, K⁺ and Na⁺, from the top soil and replaced with Al ions since the area receives high rainfall [12]. Soil pH is probably the most important master chemical soil parameter and it reflects the overall chemical status of the soil and influences the whole range of chemical and biological processes occurring in the soils [31]. For example, most plants and soil organisms prefer pH range between 5.5 and 7.5 [32]. The results obtained show that the pH of the soil is out of this normal pH range. Under such low pH, the availability of essential nutrients could be critically affected. In contrast, toxicity of aluminum to plants greatly affects root and shoot growth as well as nutrients and water absorption. Moreover, the activities of microorganisms which play pivotal roles in nutrient cycling in agro-ecosystems are affected. Since the soil of the experimental area was strongly acidic, and under

which many plant macronutrients are fixed and not available for crop growth, amending with lime and organic sources such as compost and vermicompost in combination with lime is necessary to improve soil acidity and boost crop productivity in the study area.

Exchangeable acidity of the experimental soil was 2.54 cmolc kg⁻¹, which indicates presence of toxicity of some metal elements that might affect growth of most crops [33]. This soil exchangeable acidity might be associated with lower soil pH value. Under such acidic conditions, the exchange sites and the soil solution are concentrated mostly with aluminum and hydrogen ions. Therefore, liming is a mandatory management option to use this soil for crop production.

The soil organic carbon (SOC) content of the experimental site soil was 1.48%. This value of SOC content is low as per the rating established by [30] for OC content of soil. Low organic carbon content of the soil might be due to low input of organic sources such as animal manure, compost and household wastes. Farmers of the area also remove crop residues from the cultivated fields for fuel and animal feeds. In addition to complete removal of crop residues from cultivated fields and burning during tillage practice, high soil erosion might also attributed to low soil organic matter content. Organic carbon in soils influences physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in the soil. Nitrogen content of the soil was 0.19%, which is medium according to [30]. Available phosphorus of the soil was 2.26 mg kg⁻¹ (Table 2), which is low according to [33]. This low soil available phosphorus could be due to low pH and presence of exchangeable acidity. Hence, P in the soil solution could be fixed by Al and Fe due to high P fixing potential of cations and oxides of these elements in acid soils. [34] reported that availability of P in most soils of Ethiopia decline by the impacts of fixation as a result of low pH and higher concentration of acidic cations on soil exchange sites and in soil solution. This might also be because of low OM content of the soil which is also in agreement with the suggestion of [35] who indicated that soil OM influences P availability to crops directly by contributing to P pool. [36] reported that high aluminum content and acidity in soil could contribute to low amounts of macro-nutrients such as P. This happens through precipitation of the element into insoluble compounds hence rendering it unavailable to the crops. Therefore, application of organic matter like compost,

farmyard manure and lime is necessary to increase soil pH and subsequently to improve P availability.

The experimental soil had exchangeable bases of (2.48, 1.57, 0.57 and 0.18 cmol_c kg⁻¹) for Ca²⁺, Mg²⁺, K⁺ and Na⁺, respectively, which were low for Ca, medium for Mg and K, and low for Na as ratings by [37]. Low and medium contents of exchangeable bases might be due to leaching by rainfall. According to [37], soil of the study area requires external

application of these nutrients as per the recommendations of the respective nutrients for crop production. Similarly, CEC of the soil was low (11.35 cmol_c kg⁻¹), according to [32] rating. Low CEC of the soil might be due to low organic matter content and high soil acidity. [31] reported low CEC for strongly acidic soil. Percent bases saturation of the soil was also low (42.3%).

Table 2. Selected soil physicochemical characteristics of the experimental site.

| Parameters | Value | Rating | Reference |
|--|-------|-----------------|-------------------------------|
| Particle size distribution | | | |
| Sand (%) | 39 | | |
| Clay (%) | 45 | | |
| Silt (%) | 16 | | |
| Textural class | Clay | | |
| BD (g cm ⁻³) | 1.34 | High | Barauah and Barthakulh (1997) |
| TP (%) | 49.44 | | |
| pH (1:2.5 H ₂ O) | 5.2 | Strongly acidic | Tekalign (1991) |
| Exchangeable Acidity (cmol _c kg ⁻¹) | 2.54 | | |
| OC (%) | 1.48 | Low | Tekalign (1991) |
| TN (%) | 0.19 | Medium | Tekalign (1991) |
| Avail. P (mg kg ⁻¹) | 2.26 | Low | Landon (1991) |
| Exchangeable Ca (cmol _c kg ⁻¹) | 2.48 | Low | FAO (2006) |
| Exchangeable Mg (cmol _c kg ⁻¹) | 1.57 | Medium | FAO (2006) |
| Exchangeable K (cmol _c kg ⁻¹) | 0.57 | Medium | FAO (2006) |
| Exchangeable Na (cmol _c kg ⁻¹) | 0.18 | Low | FAO (2006) |
| CEC (cmol _c kg ⁻¹) | 11.35 | Low | Hazelton and Murphy (2007) |
| PBS (%) | 42.3 | Moderate | Hazelton and Murphy (2007) |

BD = Bulk density; TP = Total porosity; OC = Organic carbon; TN = Total nitrogen; Avail. P = Available phosphorous; CEC = Cation exchange capacity.

Table 3. Chemical composition of vermicompost.

| Parameters | Value |
|--|--------|
| pH (1:2.5 H ₂ O) | 7.1 |
| EC (dSm ⁻¹) | 10.10 |
| C (%) | 11.11 |
| TN (%) | 1.19 |
| P (mg kg ⁻¹) | 365.24 |
| Ca (cmol _c kg ⁻¹) | 12.22 |
| Mg (cmol _c kg ⁻¹) | 6.84 |
| K (cmol _c kg ⁻¹) | 28.67 |
| Na (cmol _c kg ⁻¹) | 2.10 |
| C:N | 9.34 |

EC = Electrical conductivity; C = Carbon; TN = Total nitrogen; P = phosphorus; C:N = Carbon to nitrogen ratio.

3.2. Selected Chemical Properties of Vermicompost

Selected nutrient contents of vermicompost (VC) used in the experiment are presented in Table 3. Vermicompost used for the study had pH (H₂O) 7.1, total phosphorus content 365.24 mg kg⁻¹. Organic carbon and total nitrogen content 11.11 and 1.19%, respectively with narrow C:N ratio of about 9.34. This indicates that vermicompost applied to experimental field is well mineralized for nutrients such as NPK and therefore enhances their availability in soil for plant use. [38] Recommended C:N ratio of below 20 to have expected impact from application of compost. The average concentrations of basic cations, such as Ca²⁺, Mg²⁺, K⁺ and Na⁺ were 12.22, 6.84, 28.67, and 2.10 cmol_c kg⁻¹, respectively (Table 3). These nutrients could be come up by

the activities of microorganisms during decomposition of VC elevated contents of salts it can be utilized to raise the pH of acid soils. Therefore, this VC could decrease soil acidity and increase soil fertility status.

3.3. Responses of Acidic Soil to Application of Lime and Vermicompost

The effects of lime, vermicompost and their combinations on selected soil properties are presented in Tables 4, 5, and 6.

3.3.1. Bulk Density

Analysis of variance revealed that the main effect of lime and vermicompost on soil bulk density was highly significant (P<0.01), whereas their interaction effect was significant (P<0.05) (Table 7). Bulk density is of greater importance than particle density in understanding the physical behavior of the soil [39]. Application of lime alone decreased soil bulk density over the control with increasing lime rates (Table 4). Similarly vermicompost application alone also decreased soil bulk density over the control with increasing rates. The lowest soil bulk density value (1.04 g cm⁻³) was recorded from the plots treated with the highest combined application of lime and vermicompost at the rates of 100% LR with 5 t VC ha⁻¹. This resulted in decreasing of soil bulk density by 28.3% over that of the control. This lowest bulk density could be due to the positive effects of lime and the availability of organic matter to the soil at the proper time and in the proper proportions and this improves soil physical and chemical properties due to increased soil organic matter.

[40] Reported improvements in soil structures and water holding capacity, which are directly associated with bulk density, as a result of cattle manure application with mineral fertilizer. Similarly, [41] reported that decrease in bulk density of soil treated with manure due to increased organic matter, which played a significant role in reducing compaction. This suggests, organic amendments promote the activity of soil organisms that play a major role in the buildup and stabilization of soil structure.

Table 4. Interaction effects of lime and vermicompost on soil bulk density.

| Lime rate (% LR) | Soil bulk density (g cm ⁻³) | | |
|------------------|---|---------------------|---------------------|
| | Vermicompost (t VC ha ⁻¹) | | |
| | 0 | 2.5 | 5 |
| 0 | 1.45 ^a | 1.25 ^{dfe} | 1.29 ^{dc} |
| 25 | 1.40 ^{ba} | 1.22 ^{dfe} | 1.18 ^{gf} |
| 50 | 1.34 ^{bc} | 1.21 ^{fe} | 1.24 ^{dfe} |
| 75 | 1.28 ^{dcc} | 1.12 ^g | 1.17 ^{gf} |
| 100 | 1.19 ^{gf} | 1.17 ^{gf} | 1.04 ^h |
| LSD (0.05) | 0.083 | | |
| CV (%) | 4.029 | | |

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

3.3.2. Soil pH and Exchangeable Acidity

Exchangeable acidity is presence of $\text{Al}^{3+} + \text{H}^+$ ions in soils that cause soil acidity. Application of lime rates increased soil pH from 5.1 (control) to 5.7. The increases in soil pH over the control were 0.3, 0.3, 0.4 and 0.6 units for application of 25, 50, 75 and 100% of LR, respectively. This value of soil pH is increased from strongly acidic to moderately acidic range as per the rating established by [30] for soil pH. When lime added to acid soils, it dissociates to yield Ca^{2+} and OH^- ions, Ca^{2+} replaces Al^{3+} and H^+ from the exchange sites. The Al^{3+} and H^+ ions react with hydroxyl ions forming Aluminum hydroxide ($\text{Al}(\text{OH})_3$) and water, respectively. This causes decreasing in the activity of Al^{3+} and H^+ ions and thereby, increasing pH of the soil solution. [41] also reported increased soil pH and reduction of exchangeable acidity and attributed this to the replacement of Al^{3+} by Ca^{2+} from the exchange site and subsequent precipitation of Al as $\text{Al}(\text{OH})_3$, due to liming.

Crop response to lime is principally a response to soil pH. The results clearly showed that liming visibly raised the pH of the experimental soils, and thus indirectly favor the creation of more suitable medium for nutrient uptake by plants. The result is in agreement with [43] who stated that lime application to acidic soils is one of the solutions to address soil acidity problem. Similarly application of VC alone showed change in soil pH from 5.1 (control) to 5.5 by 0.3 - 0.4 units. [44] also reported that addition of organic manures to acid soils increased soil pH, decreased Al saturation, and thereby improved conditions for plant growth. The rise of soil pH through addition of farm yard manure (FYM) could be caused by consumption of H^+ by the humic-type substances which have a large number of carboxyl, and phenolic functional groups [45] and corroborated with the

findings of [46]. These humic substances are formed during decomposition processes and are relatively stable against further decomposition. Their capacity to consume H^+ , therefore, indicates their buffer characteristics and ability to neutralize soil acidity.

The combination of lime with vermicompost at higher rates (75 and 100% LR with 2.5 and 5 t VC ha⁻¹) mostly increased the soil pH from 5.1 (strongly acidic) to 5.8 (moderately acidic) (Table 6). This raise in soil pH by the combined application of lime and VC might be due to reduction in H^+ and Al^{3+} concentration in the soil solution by the neutralizing and buffering ability of lime and VC. [47] Also reported that lime and compost significantly increased soil pH and reduced exchangeable acidity.

In response to all the treatments, except the control, soil pH progressively increased while the exchangeable acidity decreased with increased rates of lime and vermicompost. The application of lime reduced soil exchangeable acidity with increasing lime rates and the effect was more pronounced at higher rate. The percentage reduction in soil exchangeable acidity was 60.24, 70.49, 79.09 and 83.19% with the application of 25, 50, 75 and 100% of LR, respectively. Such significant reduction in soil exchangeable acidity has been reported when lime was applied which leads to precipitation of Al as $\text{Al}(\text{OH})_3$. Similarly, application of 2.5 and 5 t VC ha⁻¹ reduced soil exchangeable acidity by 59.83 and 61.06%, respectively. Adsorption of organic anions on hydrous Fe and Al surfaces and the corresponding release of hydroxyl ions increased soil pH and reduced exchangeable acidity [44]. [48] also reported that addition of organic manures to acid soils increased soil pH, decreased Al saturation, and thereby improved soil conditions for plant growth. The lowest exchangeable acidity values were recorded for combined application of lime at 75% LR + 2.5 t VC ha⁻¹ (0.31 cmol_c kg⁻¹) followed by 100% LR + 5 t VC ha⁻¹ (0.33 cmol_c kg⁻¹) and 100% LR + 2.5 t VC ha⁻¹ (0.35 cmol_c kg⁻¹) while the highest was recorded for the control (2.44 cmol_c kg⁻¹) (Table 6). Similarly, [49] reported reduction of exchangeable acidity due to combined application of VC and lime to acid soils.

3.3.3. Organic Carbon, Total Nitrogen and Available Phosphorous

Application of lime increased soil organic carbon (OC) from 1.61% at 25% to 1.69% at 100% LR (Table 6). This value of OC content is medium as per the rating established by [30] for OC content of soil. The increment of soil OC in response to lime alone was about 4.73% over the control (1.57% of OC) (no lime applied soil). [50] Reported that lime applications have a short term stimulating effects on soil biological activity leading to acceleration of organic matter turnover rates in soil. Similar observations were reported by [51]. Vermicompost also increased soil OC from 1.65% at 2.5 t VC ha⁻¹ to 1.76% at 5 t VC ha⁻¹ (Table 6), which increased about 10.79% OC over the control (1.57% OC). [50] Also reported that vermicompost increased soil OM and decreased soil acidity to make the environment conducive for microbial

activity. Combined application of lime and VC increased OC from 1.58% to 1.94% OC under different combined rates of lime and VC at 50% LR + 2.5 t VC ha⁻¹ and 100% LR + 5 t VC ha⁻¹, respectively, which was about 14.43% increment over the separate effects of lime and vermicompost and hence, about 19.07% over control. The highest OC was recorded at the higher rates of combined application of lime and vermicompost, 75 and 100% LR with 2.5 and 5 t VC ha⁻¹ than other combined rates.

Total nitrogen (TN) contents of the experimental soil were also increased to a slight extent due to the application of lime and VC in combined or independently compared to the control (Table 6). This slight improvement in TN could be due to the increased soil pH that might have encouraged microbial activity in the soil, and thus, increased mineralization of nitrogen from OM [52].

Available phosphorous (P) was higher in soil of all plots treated with lime and VC in combination or alone compared to that of the control plot (Table 6). Application of lime alone increased available P of the soil from 5.61 to 12.17 mg kg⁻¹, which was about 53.9% increment over the control (Table 6). This value of available P content is increased from close to

low to medium as per the rating established by [33]. Liming of acidic soils could increase soil pH, which enhances the release of phosphate ions fixed by Al and Fe ions into the soil solution. Substantial increase in concentration P might be as a result of quick action of lime in improving soil acidity, and hence, increase bio-availability of P [53]. Similarly, application of vermicompost alone increased available P contents of the soil by 17 to 26% over the control plot. This might be due to the release of organic substances that can form complex with ions of Fe and Al in soil solution consequently, prevents phosphorus fixation. [54] also reported a positive effect of OM on available P contents of soil. The highest available P (13.27 mg kg⁻¹) was obtained under the combined application of lime and VC at 75% LR with 2.5 t VC ha⁻¹ which was about 72.34% increment over the control. The increase in available P after harvesting maize might be due to synergistic effects of high doses of VC with lime which enhance mineralization of P from OM. Some anions and organic acids produced during decomposition of VC blocks the adsorption site for P and increase concentration of P in soil solution which could be readily available to plant [50].

Table 5. Influences of combined application of lime and vermicompost on soil pH, exchangeable acidity, organic carbon, total nitrogen and available phosphorous.

| Treatment | Soil pH (1:2.5 H ₂ O) | Ex. Acidity (cmol _c kg ⁻¹) | OC (%) | TN (%) | Av. P (mg kg ⁻¹) |
|-------------------------------------|----------------------------------|---|--------|--------|------------------------------|
| Control | 5.1 | 2.44 | 1.57 | 0.18 | 3.67 |
| 2.5 t ha ⁻¹ VC | 5.4 | 0.98 | 1.65 | 0.20 | 4.42 |
| 5 t ha ⁻¹ VC | 5.5 | 0.95 | 1.76 | 0.20 | 4.96 |
| 25% LR | 5.4 | 0.97 | 1.61 | 0.21 | 5.61 |
| 25% LR + 2.5 t ha ⁻¹ VC | 5.3 | 1.08 | 1.66 | 0.22 | 5.93 |
| 25% LR + 5 t ha ⁻¹ VC | 5.4 | 0.79 | 1.71 | 0.21 | 7.32 |
| 50% LR | 5.4 | 0.72 | 1.60 | 0.19 | 9.09 |
| 50% LR + 2.5 t ha ⁻¹ VC | 5.3 | 1.12 | 1.58 | 0.22 | 8.13 |
| 50% LR + 5 t ha ⁻¹ VC | 5.5 | 0.68 | 1.76 | 0.22 | 9.63 |
| 75% LR | 5.5 | 0.51 | 1.62 | 0.21 | 10.67 |
| 75% LR + 2.5 t ha ⁻¹ VC | 5.8 | 0.31 | 1.78 | 0.23 | 13.27 |
| 75% LR + 5 t ha ⁻¹ VC | 5.7 | 0.37 | 1.80 | 0.23 | 13.23 |
| 100% LR | 5.7 | 0.41 | 1.69 | 0.21 | 12.17 |
| 100% LR + 2.5 t ha ⁻¹ VC | 5.8 | 0.35 | 1.80 | 0.23 | 13.19 |
| 100% LR + 5 t ha ⁻¹ VC | 5.8 | 0.33 | 1.94 | 0.22 | 13.23 |

Ex. Acidity = Exchangeable acidity; OC = Organic carbon; TN = Total nitrogen; Av. P = Available phosphorous.

3.3.4. Exchangeable Bases, Cation Exchangeable Capacity and Base Saturation

Exchangeable calcium (Ca) content of the soil was increased from low to medium in response to the application of lime and VC in combination and for solo application of each. Application of lime rates alone increased soil exchangeable Ca²⁺ by 52.63 to 63.67% over the control; similarly application of vermicompost increased soil exchangeable Ca²⁺ by 29.76 to 51% over the control (Table 6). Highest exchangeable Ca²⁺ (6.81 cmol_c kg⁻¹) was obtained from combined application of lime and VC of 75% LR + 2.5 t VC ha⁻¹ followed by 100% LR + 2.5 t VC ha⁻¹ (6.78 cmol_c kg⁻¹) which were about 64.31 and 64.15%, respectively, while the lowest was obtained from control plot (2.43 cmol_c

kg⁻¹) (Table 6). The increased exchangeable Ca²⁺ concentration could be attributed to the release of Ca²⁺ ions from lime through its dissolution and mineralization of VC, which are expected to be adsorbed on exchange sites. [48] reported increased exchangeable Ca²⁺ for soils of western Ethiopia after application of lime alone and combined with vermicompost. [55] also found significant increase in soil exchangeable Ca²⁺ when lime applied to acidic soils with manure.

The increment in soil exchangeable magnesium (Mg²⁺) due to lime application was from 16.1 to 61.41% over the control (Table 6). Similarly, application of vermicompost alone increased exchangeable Mg from 32.79 to 55.03% over the control. However, the highest increment in exchangeable Mg²⁺ (3.83 cmol_c kg⁻¹) was recorded for soil from plots

treated with combined application of lime with vermicompost at the rates of 100% LR with 5 t VC ha⁻¹ almost similar with application of 75% LR with 2.5 t VC ha⁻¹ (3.82 cmol_c kg⁻¹) (Table 6). The increased exchangeable Mg²⁺ content of the soil might be due to Mg²⁺ content of applied vermicompost and increased soil pH as a result of lime application. The results were also in agreement with the finding of [56] who reported that soil exchangeable bases increased when acidic soils amended by lime and manure.

In general, increases in concentration of soil exchangeable Ca²⁺ was the direct outcome of lime application, since Ca was the main constituents of the lime. The increase of exchangeable Mg²⁺ by the application of VC was due to Mg²⁺ from VC. Increased Ca²⁺ and Mg²⁺ saturation percentage of the exchange sites of the soil colloid and the elevated pH of soil solution could be due to carbonate reactions in acid soils [57]. [58] noted that elevated ionic strength in the soil solution and the domination of Ca²⁺ and Mg²⁺ on the exchange sites at the expense of H⁺ as a result of lime application.

Similarly, exchangeable K⁺ content of the soil was improved (0.26 to 0.37 (cmol_c kg⁻¹) with amendment of both lime and VC (Table 6). This value of exchangeable K⁺ content of the soil is increased from low to medium as per the rating established by [37]. The results were in line with the finding of [50] who reported that the increase of exchangeable K⁺ by the application of VC with lime was due to potassium from VC. Liming could increase K⁺ retention in soils by replacing Al³⁺ on the exchange sites with Ca²⁺, allowing K⁺ to compete better for exchange sites and increasing cation exchange capacity [42].

Exchangeable sodium (Na⁺) content of the soil was low in response to the application of lime and VC in combination and for solo application of each. As might be expected on such acidic soil, the exchangeable Na⁺, which was generally low (Table 6). This might be due to the replacement of sodium with calcium, and then leached the sodium out.

The cation exchange capacity (CEC) of the experimental soil increased from low to medium with the application of lime and VC independently and in combined forms (Table 6). It was increased from 12.84 to 17.04 cmol_c kg⁻¹ due to solo application of lime, which was about 24.65% increase over the control. Similar to this result, [59] reported an increase in soil CEC from 19.18 to 33.34 cmol_c kg⁻¹ after application of lime on haricot bean at Southern Ethiopia. Vermicompost application alone also increased soil CEC from 12.84 to 13.35 cmol_c kg⁻¹, with about 3.82% increment over the control. Furthermore, application of VC with lime increased soil CEC by 28.54% compared to the control. This might be due to combined application of lime with vermicompost, which resulted in improved soil conditions, such as soil pH, increased soil OM and reduction of exchangeable acidity. This result was supported by the finding of [48] who reported increment of soil CEC when lime and vermicompost amendments applied to acid soil. Cation exchange capacity of the soil was not significantly increased by the combined application of lime and VC. This might be due to high clay content of the experimental site soil and clay mineralogy which affects CEC of soil. Therefore, any management options that could improve soil pH could also contribute to increase in soil CEC and subsequently soil fertility.

Table 6. Effects of combined application of lime and vermicompost on soil exchangeable bases, cation exchange capacity and percent base saturation.

| Treatment | Exchangeable bases (cmol _c kg ⁻¹) | | | | CEC (cmol _c kg ⁻¹) | PBS (%) |
|-------------------------------------|--|------|------|------|---|---------|
| | Ca | Mg | Na | K | | |
| Control | 2.43 | 1.25 | 0.15 | 0.26 | 12.84 | 31.85 |
| 2.5 t ha ⁻¹ VC | 3.46 | 1.86 | 0.17 | 0.37 | 12.96 | 45.21 |
| 5 t ha ⁻¹ VC | 4.96 | 2.78 | 0.20 | 0.31 | 13.35 | 61.79 |
| 25% LR | 5.13 | 1.49 | 0.17 | 0.28 | 13.08 | 54.05 |
| 25% LR + 2.5 t ha ⁻¹ VC | 5.50 | 2.34 | 0.21 | 0.33 | 13.96 | 59.95 |
| 25% LR + 5 t ha ⁻¹ VC | 5.27 | 2.36 | 0.15 | 0.31 | 13.65 | 59.26 |
| 50% LR | 5.89 | 1.62 | 0.17 | 0.27 | 13.87 | 57.31 |
| 50% LR + 2.5 t ha ⁻¹ VC | 6.01 | 2.24 | 0.21 | 0.31 | 14.23 | 61.63 |
| 50% LR + 5 t ha ⁻¹ VC | 5.88 | 2.48 | 0.15 | 0.33 | 14.29 | 61.86 |
| 75% LR | 6.61 | 2.60 | 0.15 | 0.27 | 15.58 | 61.74 |
| 75% LR + 2.5 t ha ⁻¹ VC | 6.81 | 3.82 | 0.26 | 0.37 | 17.79 | 63.29 |
| 75% LR + 5 t ha ⁻¹ VC | 6.54 | 3.79 | 0.21 | 0.36 | 17.57 | 62.03 |
| 100% LR | 6.69 | 3.24 | 0.23 | 0.37 | 17.04 | 61.79 |
| 100% LR + 2.5 t ha ⁻¹ VC | 6.78 | 3.76 | 0.24 | 0.36 | 17.82 | 62.51 |
| 100% LR + 5 t ha ⁻¹ VC | 6.71 | 3.83 | 0.26 | 0.42 | 17.97 | 62.44 |

Ca= Calcium; Mg = Magnesium; Na = Sodium; K = Potassium; CEC = Cation exchange capacity; PBS = Percent base saturation.

Percent bases saturation (PBS) for soil of control plot was 31.85% (low), while PBS after amendment ranged from 45.21 to 63.29% (Table 6). Percent bases saturation (PBS) of the experimental soil increased from low to medium after amendments as per the rating established by [32] for soil PBS. The highest percent bases saturation of

63.29% was recorded for soil from plots treated with combined application of 75% LR with 2.5 t VC ha⁻¹ and 62.51% was for that treated with 100% LR combined with 2.5 t VC ha⁻¹, while the lowest PBS was recorded for soil of the control plots. The higher status of PBS might be due to application of VC and lime amendments that increased

organic matter, surface area for exchange site and could create favorable environment for plant growth. Similarly, [60] reported that treatments with high organic matter had high PBS.

4. Summary and Conclusion

Soil acidity is a major yield-limiting factor for crop production worldwide. The problem of soil acidity in Ethiopia is apparently increasing both in area coverage and severity, particularly, in the western region of the country, which receive high rainfall to leach down basic cations appreciably from the surface layers of the soils. Even though soil acidity and low nutrient availability are major problems in the study area, no adequate previous studies that conducted on combined use of lime and VC as amendments for ameliorating soil acidity in the area. Therefore, this study was conducted to evaluate the responses of soil and maize to the combined application of lime and vermicompost (VC) in terms of selected soil physicochemical properties, maize yield and yield components. The experimental 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}) applied on maize field in factorial combinations of randomized complete block design with three replications.

The highest bulk density (1.45 g cm^{-3}) was recorded for soil of the control plot, but the lowest bulk density (1.04 and 1.12 g cm^{-3}) were recorded for soil from plots treated with combined application of 100% LR + 5 t VC ha^{-1} and 75% LR + 2.5 t VC ha^{-1} , respectively. The lowest soil pH (5.1) was recorded for soil of the control plot, but highest soil pH (5.8) was recorded for soil from plots treated with combined application of lime at 75% LR + 2.5 t VC ha^{-1} and 100% LR + 2.5 and 5 t VC ha^{-1} . The highest exchangeable acidity ($2.44 \text{ cmol}_e \text{ kg}^{-1}$) was recorded for control plot while the lowest exchangeable acidity values were recorded for combined application of lime at 75% LR + 2.5 t VC ha^{-1} ($0.31 \text{ cmol}_e \text{ kg}^{-1}$) followed by 100% LR + 5 t VC ha^{-1} ($0.33 \text{ cmol}_e \text{ kg}^{-1}$) and 100% LR + 2.5 t VC ha^{-1} ($0.35 \text{ cmol}_e \text{ kg}^{-1}$). The highest available P (13.27 mg kg^{-1}) was recorded for the soil from plot treated with combined application of lime at 75% LR + 2.5 t VC ha^{-1} followed 100% LR + 5 t VC ha^{-1} (13.23 mg kg^{-1}), but the lowest (3.67 mg kg^{-1}) was recorded from control plot. In general, soil properties such as soil bulk density, soil pH, available phosphorous, exchangeable bases, organic carbon, total nitrogen, and cation exchange capacity were considerably improved and exchangeable acidity was reduced compared to control plot as a result of combined application of lime and vermicompost.

Results of this study clearly indicate that combined application of lime and VC could ameliorate the adverse effects of soil acidity in Lalo Asabi district. However, to draw conclusive recommendation, the study has to be repeated over seasons as lime and vermicompost have long term effects on improving soil properties.

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Appendix

Table 7. ANOVA results of soil bulk density as affected by lime and vermicompost rates and their interaction.

| Mean squares | | |
|----------------------|------|---------|
| Sources of variation | DF | BD |
| Replication | 2 | 0.0072* |
| Lime (L) | 4 | 0.052** |
| Vermicompost (VC) | 2 | 0.102** |
| L*VC | 8 | 0.0063* |
| Error | 28 | 0.00216 |
| CV (%) | 3.74 | |

** and * Significant at (1 and 5%) probability level respectively. DF = Degree of freedom; BD = Bulk density.

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