The Scientific Temper (2023) Vol. 14 (1): 37-49
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.1.06
https://scientifictemper.com/

RESEARCH ARTICLE

Physicochemical Characterization of Vermicompost and its Effect on Acidic Soils in Ethiopia

Getasew Mesfin[1], Isreal Zewide[2*], Abdeta Jembere[3]

Abstract

Many parts of the Ethiopian highlands have a problem of acidity which causes the gradual reduction of soil fertility and crop productivity. There has been no research done on the effect of vermicompost (VC) individually or combined with lime and inorganic fertilizers in ameliorating the acidic soils of the country. Hence, the objective of the present study was to characterize the physicochemical properties of VC prepared from different feedstock and to evaluate the effect of VC on selected properties of acidic soil of the site. The study was conducted during 2021 at Yeferzeye kebele and cow manure (CM), enset leaf (EL), potato peels (PP), and paper waste (PW) were utilized to prepare the VC from earthworms (*Eisenia fetida)*. A two-month incubation experiment was also conducted in the green house with four different VC rates (0, 2.5, 5 and 7.5 t ha^{-1}). The highest value of organic carbon (21.44%) and total nitrogen (3.04%) were found in the CM whereas the highest total phosphorus (2794.8 mg kg^{-1} VC) was recorded from vermicompost made from PW. VC produced from PP substrates had the greatest available Potassium (7286.67 mg kg^{-1} VC). The highest VC rate (7.5 t ha^{-1}) elevated the pH of the PW from 4.94 to 5.48. Similarly, the highest content of OM (3.2%) was produced in EL, (3.21%) in PP and (3.25%) in PW at the highest rate. The highest increase in total N (0.25%) was also recorded in EL at the highest rate and the lowest was recorded (0.18%) in CM and EL at the control. The available P of the soil varied from 1.78–24.33 mg kg^{-1} after incubation. The highest available K (1360 mg kg^{-1}) was obtained when the rate of 7.5 t ha^{-1} were applied with PP compared to the control. Hence, the findings showed that applying VC to the acidic soil can improve soil fertility and increase crop nutrient availability.

Keywords: Acidity, *Eisenia foetida,* Selected soil properties, Substrates, Vermicompost.

Introduction

Vermicompost (VC) is a stabilized, finely divided organic fertilizer with a low C:N ratio, high porosity, and high water-holding capacity. It is one of the few organic fertilizers in which most nutrients are present in forms that are readily available to plants (Naidoo *et al*., 2017). VC is one of the simplest processes for converting agricultural waste into high-quality compost. The potential use of VC as a soil amendment is gaining popularity (Ayilara *et al*., 2020). Because of the stimulation of soil microbial growth and activity, subsequent mineralization of plant nutrients, and higher soil fertility and quality, the application of VC to the soil is regarded a good management practice in any agricultural production system (Tahat *et al*., 2020). The use of VC resulted in significant improvements in overall physical and biochemical qualities and a reduction in exchangeable acidity, which can aid in releasing plant nutrients in acidic soils (Abafita, 2016, Tigist *et al*., 2019). Agriculture's current trends are centred on replacing inorganic fertilizers by biofertilizers such as VC (Zhang *et al*., 2021). VC stimulates growth from 50–100% above ordinary compost and 30–40% over chemical fertilizers when compared to conventional compost (Sinha *et al*., 2010).

In many places, soil acidity is a major constraint to crop production (Fageria and Nascente, 2014). It is estimated that nearly half of the world's arable soils are acidic and may be affected by aluminum (Al) toxicity, with the tropics and subtropics accounting for 60% of the world's acid soils (Kochian *et al*., 2015). It is also a major constraint to agricultural output in Africa, where high rainfall causes

[1]Department of Natural Resource Management, Wolkite University, Ethiopia.

[2]Department of Horticulture, Mizan-Tepi University, Ethiopia.

[3]Department of Natural Resource Management, Wolkite University, Ethiopia.

***Corresponding Author:** Isreal Zewide, Department of Horticulture, Mizan-Tepi University, Ethiopia, E-Mail: isrealzewdie@mtu.edu.et

How to cite this article: Mesfin, G., Zewide, I., Jembere, A. (2023). Physicochemical Characterization of Vermicompost and its Effect on Acidic Soils in Ethiopia. The Scientific Temper, **14**(1):37-49.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.1.06

Source of support: Nil

Conflict of interest: None.

Received: 12/02/2023 **Accepted:** 03/03/2023 **Published** : 25/03/2023

nitrogen (N) deficiency by leaching, phosphorus (P) deficiency by fixation, and low soil organic matter (OM) deficiency (Mahmud *et al.*, 2021). Acidic soils make up a large portion of Ethiopia's soils. As a result, it poses a substantial danger to agricultural production in most highlands and is a major crop production constraint for the country's small-scale farmers. Many crops in the study district produce very low yields due to the severity of the soil acidity problem (Haile and Boke, 2009, Achalu *et al.*, 2012, Abdenna, 2013, Tigist *et al.*, 2019). As a result of Ethiopia's high soil acidity, multiple coping techniques are needed to handle the problem (Abiyotu, 2019). Organic fertilizers serve as a source of soil organic matter; improve soil buffering capacity; release nutrients gradually over the crop growth period and are excellent suppliers of balanced nutrients to plants; and improve soil chemical, physical, and biological properties (Wassie, 2017).

VC aids in the growth and yield of a wide range of field crops, vegetables, and flower and fruit crops. It contains a lot of plant-available nutrients, disease-fighting microbes, humic acids, and growth-promoting hormones (Lim and Wu, 2015). Furthermore, VC is a mix of worm castings, organic materials such as humus, earthworms, cocoons, and other microorganisms obtained from earthworms feeding on organic sources (Wani *et al.*, 2013). The earthworm *Eisenia foetida* lives in moderate to cold temperatures and can be used as a vermicomposting agent in tropical and subtropical climates. Vermicomposting is a non-thermophilic organic waste decomposition method that utilizes aerobic bio-oxidation. Earthworms break up and mix decaying material, enriching it and encouraging microbial activity (Bhat *et al.*, 2015). The availability of easily decomposable organic matter is required to form VC.

Soil acidity problem has reduced yield in Cheha District, Gurage zone. Farmers in the area have been using urea and DAP fertilizers for a long time, possibly contributing to soil acidity (Brady and Weil, 2016). Many parts of the Ethiopian highlands have a problem of acidity which causes the gradual reduction of soil fertility and crop productivity. Research on the effect of VC individually or combined with lime and inorganic fertilizers in ameliorating the acidic soils of the country has not been done. Actually, there have been few studies conducted in different areas on lime and lime with other organic and inorganic fertilizers other than vermicompost to amend acidic soils (Achalu *et al.*, 2012, Asmare *et al.*, 2015, Abdissa *et al.*, 2018, Alemu and Melese, 2021, Wubayehu, 2021). Therefore, to improve the soil's productivity and fill the knowledge gap in the study area's soil acidity problems, a study is necessary to determine the extent of soil acidity and the level of VC need. Hence, the objective of the present study was to characterize the physicochemical properties of VC prepared from different feedstock and to evaluate the effect of VC on selected properties of acidic soil of Yeferzeye site.

Materials and Methods

Description of the Study Area

The study was conducted during 2021 at Yeferzeye Kebele, Gurage zone, Ethiopia. It is located about 188 kilometers from Addis Ababa, the capital. The specific study site is situated at an altitude of 2046 masl and geographically lies at 8° 10′ 00″ N latitude and 38° 0′ 0″ E longitude. The soil of site is strongly acidic (pH<5). Vertic Alisols are the most common soil type in the study area (Figure 1 and 2)

Experimental Procedure

Waste Collection and VC Preparation

The wooden vermicomposting box was placed in a cool, damp location, and a shade was erected over it. A wooden vermicomposting box with a size of 112 ×56 ×59.5 cm with a broad base and drainage holes was employed for this aim. To give low light inside the wooden box, the top of the wooden box was covered with a piece of gunny bag. The wooden box was left undisturbed for a week once it was filled. Cow manure (CM), enset leaf (EL), potato peels (PP), and paper waste (PW) were utilized to make the VC. Except cow manure, all of these inputs were chopped to a size of at least 3 cm. These organic wastes were chosen for their availability and ease of production. CM was mixed with the EL, PP and PW on a dry weight basis completely in a 1:1 ratio (Suthar *et al.,* 2015, Srivastava *et al.,* 2018).

Materials were air dried for 7–10 days to reduce volatilization and nutrient transformation in the biomass or that had partially decomposed were placed in the wooden box in alternate layers. Earthworms of the species *Eisenia fetida* were gathered from the Woliso Agricultural Office. The substrate was pre-decomposed for three weeks, with thorough rotation after each week. During this time, water was sprayed to keep the moisture level up. To achieve thermal stability and the elimination of volatile hazardous

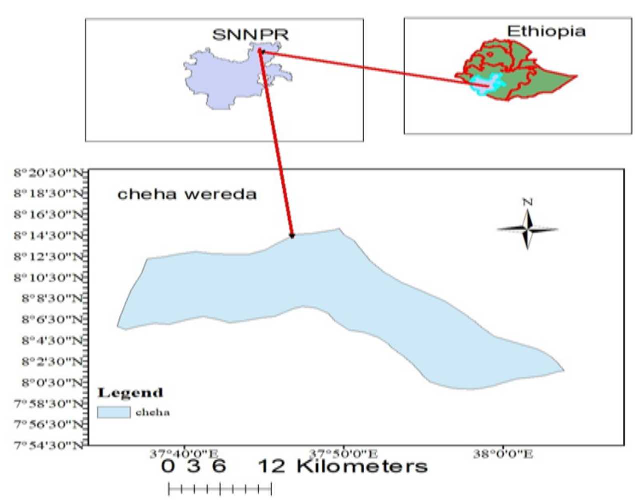

Figure 1: Map of study area.

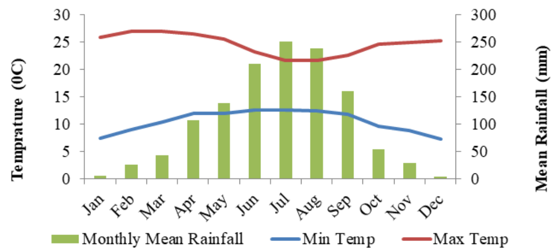

Figure 2: Mean monthly rainfall (mm), minimum, and maximum monthly temperatures (°C) of the study area recorded for the year from 2011-2020.

compounds, pre-decomposition was carried out (Srivastava *et al.*, 2018, Arora and Kaur, 2019, Sharma and Garg, 2019). It also aids in the palatability of the substrate material to earthworms and the breaking down of oily and fatty compounds in the feed material prior to the inoculation of earthworms (Sharma and Garg, 2019).

After pre-decomposition, 20 red earthworms were released in each wooden box after partially decomposing the waste materials according to Wrushali *et al.* (2019). The materials were regularly moistened by frequently spraying water using hand sprinkler. The organic input mixture in the wooden box was covered with gunny bags to avoid sunlight. The optimum amount of water was daily sprinkled to maintain the moisture level of 60–70 % during the complete study period of 90 days from April–June, 2021 as recommended by Mupondi et al. (2018). The castings were manually collected and separated from earthworms. The setup was established in triplicate. The collected casting (compost) were packed in polythene bag and stored in cool and shady place. Experimental VC samples were air-dried, powdered and passed through < 2 mm sieve for determination of physicochemical properties.

Soil Sampling

A bulk soil sample was taken from the surface soil (0–20 cm) at the Yefereze site. Soil samples from eighteen subsamples at the site were auger collected and carefully mixed to create a composite (Wilding, 1985). The soil was air-dried, ground, and passed through a 2 mm for pH, available P, electrical conductivity, total N determination, and organic carbon. They were sieved and tested for the physicochemical qualities of soil. A total of one undisturbed soil sample was taken at the same time at 0–20 cm depth to determine soil bulk density (BD) were collected using the core method.

Soil Analyses

The Bouyoucus hydrometer method was used to examine the size distribution of soil particles (Bouyoucus, 1962). After the soil samples were dispersed with sodium hexametaphosphate [(NaPO3)[6]]. After determining sand, silt and clay separates, the soil was assigned to textural classes using the USDA soil textural triangle (USDA, 1998). According to Jamison *et al.* (1950), soil bulk density (b) was measured from one undisturbed soil sample taken using a core sampler (2.5 cm radius and 5.0 cm height). The following formula was used to compute total porosity (φ) using the values of b and s:

$$\varphi = 1 - \frac{\rho b}{\rho s} \times 100 \qquad (1)$$

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

Total soil porosity was estimated using the average soil particle density (2.65 g cm^{-3}) (Rowell, 1994). A combination glass electrode pH meter was used to measure the pH of the soil in a 1: 2.5 Soils: H_2O solution (Chopra and Kanwar, 1976). The Walkley and Black (1934) wet combustion process was used to measure the soil's organic carbon (OC) level. By multiplying OC by 1.724 factors, organic matter was calculated. Kjeldahl method was used to determine the soil's total nitrogen (N) content (Wilke, 2005). The available phosphorus content of soil samples was determined using the Bray-II method (Bray and Kurtz, 1945) with a 0.03M NH4F and 0.1M HCl solutions, with a reading at 880 nm. An extract of neutral normal ammonium acetate was used to estimate exchangeable Potassium using a flame photometer (Jackson, 1967).

Vermicompost Analyses

Dry samples were ground to pass through a 2 mm sieve to determine selected VC parameters as Pisa and Wuta (2013) described. VC color was measured by using Munsell Soil Color Charts (Munsell, 2000). Electrical conductivity (EC) and pH were determined from a suspension of 1:10 VC: H_2O as Ndegwa and Thompson (2001) described. Wet digestion and rapid titration were used to estimate total OC (Walkley and Black, 1934). The total N content of the VC was determined using the Kjeldahl method's wet-oxidation procedure (Wilke, 2005). The Olsen method determined the total phosphorus with a spectrometer reading at 880 nm (Olsen and Sommers, 1982). A flame photometer was used to estimate exchangeable Potassium in a neutral normal ammonium acetate extract (Jackson, 1967).

Set up of the Incubation Experiment

The two-month incubation period was used in the experiment. The composite soil sample was air-dried, crushed and sieved with a 2 mm sieve, and 1.5 kg of soil was placed in a plastic pot (40 cm long and 25 cm wide) with a height of 15 cm and combined with various treatments in a greenhouse. At the end of each 3 day period, the soil moisture was adjusted to a constant weight of 60% (field capacity) with distilled water. In this experiment, four rates of VC were applied to the soil samples (0, 2.5, 5 and 7.5 t ha^{-1}) and four VC sources (cow manure, Enset leaf with cow manure, potato peels with cow manure, paper waste with cow manure) were applied to the soil (Table 1). The experiment was set up in a completely randomized design (CRD) with each treatment being replicated three times.

The treatments' units were converted to hectare bases by assuming a plough depth of 20 cm and a bulk density of 1.09 g cm^{-3} for the soil. The soils were incubated with treatments in the Wolkite University greenhouses pots for two months (August and September, 2021). Soil samples from each pot were taken at the end of the incubation time, air-dried, ground, and sieved through 2 mm and 0.5 mm sieve to observe the effects of VC on selected soil acidity-related and other soil chemical properties at Wolkite University laboratories.

Statistical Analyses

The study was a factorial experiment in a completely randomized design (CRD) with two factors: rate and sources of VC. Analysis of variance was carried out on the effect of treatments on selected soil chemical properties using SAS software V.9.3 (SAS, 2011). The least significant difference (LSD) test was used to compare mean values between treatments. A simple Pearson correlation analysis was used to evaluate the relationships between various soil acidity parameters and other soil chemical properties.

Results and Discussion

Physico-chemical Properties of Soil before Incubation

Physical Properties of Soil before Incubation

The soil texture of the experimental site had 8% sand, 26% silt and 66% clay (Table 2). The measured bulk density (1.09 g cm^{-3}) at the study site was below the critical value of bulk density (1.4 g cm^{-3}) for plant growth at which root penetration is likely to be severely restricted for clay soil as described by Hazelton and Murphy (2007) (Table 2).

Chemical Properties of Soil before Incubation

The soil pH of the experimental field showed that the field had a pH value of 4.92 which is under strongly acid category (Table 3). The experimental soil was characterized by 1.49% organic carbon and 2.57% organic matter, categorized as low range as described by EthioSIS (2016). Total nitrogen value was 0.15%. According to EthioSIS (2016), N content of soil between 0.15–0.3% is medium. The value of C:N ratio of the soil of study was 7.85 which is low. Available phosphorus of soil was categorized within very low (4.66 mg kg^{-1}) (EthioSIS, 2016). Regarding available K, EthioSIS (2016) described soil is high in K (840 mg kg^{-1}).

Physico-chemical Characterization of VC

Moisture Content

The moisture content of VC prepared from various sources varied. EL (75.41%) had the highest moisture content followed by PW (66.49%). As shown in Table 4, the substrate PP had the lowest moisture content (44.65%). The rate of mineralization and decomposition becomes faster with the optimum moisture content (Bhargava and Bhattacharya, 2004). According to Liang *et al.* (2003), 60–70% moisture content was proved to have maximal microbial activity, while 50% moisture content was the minimal requirement for rapid rise in microbial activity. VC that were prepared from EL during the present study showed higher moisture content than the other substrate, which may be due to their high absorption capacity. It may also be because of the microbial population's assimilation rate indicating the higher waste degradation rate by earthworms.

pH and Electrical Conductivity

The pH value of VC ranged from 7.93–8.35 according to laboratory analysis (Table 4). The highest pH value (8.35) was obtained from VC of PP and PW. On the other hand, VC produced from CM substrates had the lowest pH value (7.93) followed by EL substrate pH value (8.08). A pH greater than 8.5 is harmful to microorganism (Santamaria, 2001). As a result, the pH values of all types of VC are determined to be within a safe range for earthworm survival as well as plant growth. This finding is in agreement with Tekalign's (1991) study which found pH ranged from moderately alkaline to strongly alkaline. Similarly, Rogelio *et al.* (2017) obtained similar results with VC pH levels ranging from 6.8–8.41. Earthworms were shown to be harmed by a pH greater than 8.5. Both earthworms and microorganisms are damaged by alkalinity and salinity (Romero *et al.*, 2001).

The electrical conductivity (EC) of VC was ranged between 2226.67–6520 µS cm^{-1} (Table 4). Electrical conductivity measurements are used to determine the salinity hazard of a VC. The electrical conductivity of a VC suspension in distilled water is used to estimate the salt concentration. CM and PW had the highest (6520 µS cm^{-1}) and lowest (2226.67 µS cm^{-1}) ECs, respectively. Salinity with an EC value greater than 8000 µS cm^{-1} is harmful to microorganisms (Santamaria, 2001). Therefore, the values of EC of VC made from all materials are suitable for earthworm survival and applicable for crop production. This result is similar with Richards's (1954) finding who found that VC made from EL was slightly saline; whereas VC derived from PP was moderately saline. The increased EC during the vermicomposting processes is consistent with that of previous researchers (Kaviraj and Sharma, 2003) and is most likely due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K and P in their available forms, i.e. as cations in the VC (Guoxue, 2001).

Organic Carbon, Total Nitrogen and C:N

The analysed result showed that the highest organic carbon (21.4%) was recorded under CM and the lowest (18.1%) organic carbon was registered from the VC prepared from PW (Table 4). In general, the status of organic carbon in all types VC is high when compared with its availability in garden soil. This finding is in conformity with the study of Nagavallemma (2004), Eyasu and Anteneh (2015), Hiranmai

Table 1: Details of treatment combination

Vermicompost sources	*Rates*
Cow manure	(0, 2.5, 5, 7.5 ton ha^{-1})
Enset Leaf with cow manure	(0, 2.5, 5, 7.5 ton ha^{-1})
Paper waste with cow manure	(0, 2.5, 5, 7.5 ton ha^{-1})
Potato peels with cow manure	(0, 2.5, 5, 7.5 ton ha^{-1})

Table 2: Selected physical properties of experimental soil before incubation

Physical properties	*Result*	*References*
Soil textural class (%)	Clay	USDA (1998)
Sand (%)	8	
Silt (%)	26	
Clay (%)	66	
BD (g cm^{-3})	1.09	
PD (g cm^{-3})	2.65	
TP (%)	58.9	

BD= bulk density; PD= particle density; TP= total porosity

Table 3: Selected chemical properties of experimental soil before incubation

Chemical Properties	*Result*	*Rating*	*References*
pH(H_2O)	4.92	Strongly acidic	EthioSIS Team Analyis (2016)
OC (%)	1.49	Low	EthioSIS Team Analyis (2016)
OM (%)	2.57	Low	EthioSIS Team Analyis (2016)
Total N (%)	0.13	Low	EthioSIS Team Analyis (2016)
C:N	7.85	Low	(Landon, 1991)
Available P (mg kg^{-1})	4.66	Very low	EthioSIS Team Analyis (2016)
Available K (mg kg^{-1})	840	High	EthioSIS Team Analyis (2016)

OC= organic carbon; OM= organic matter; total N= total nitrogen; C:N= carbon to nitrogen ratio

Table 4: Physico-chemical properties of VC from different sources

Treatment	*Physical properties*			*Chemical properties*						
	Colour	*odour*	*MC (%)*	*pH*	*EC(µS/cm)*	*OC (%)*	*TN (%)*	*TP(mg.kg^{-1})*	*TK(mg.kg^{-1})*	*C:N*
CM	Brown	No odour	60.130^{c}	7.93^{b}	6520^{a}	21.44^{a}	3.04^{a}	2430^{c}	7243.3^{a}	7.04a
EL	Black	No odour	75.41^{a}	8.08^{ab}	5400^{c}	20.11^{b}	2.94^{b}	2679.3^{b}	7176.6^{a}	6.85a
PP	Grey	No odour	66.49^{b}	8.35^{a}	2226.67^{d}	18.11^{c}	2.76^{c}	2794.8^{a}	5846.6^{b}	6.56a
PW	Dark brown	No odour	44.65^{d}	8.35^{a}	6250^{b}	13.77^{d}	2.38^{c}	2338^{d}	7286.6^{a}	5.76ab
SE±	-	-	1.25	0.08	33.45	0.38	0.03	15.87	45.39	0.015
LSD(0.05)	-	-	4.07	0.277	109.1	1.27	0.11	51.76	148.06	0.05
P value	-	-	***	*	***	***	***	***	***	Ns
CV (%)	-	-	3.51	1.98	1.14	3.67	3.57	1.07	1.14	0.23

Where, ***= Very Highly Significant at p≤0.001, **= Highly Significant at p≤0.01, *= Significant at p≤0.05, EC= Electrical conductivity, OC= Organic Carbon, TN= Total Nitrogen, TP= Total Phosphorus, TK= Total Potassium, MC= Moisture content. Means followed by the same letter(s) with in row or column are not significantly different at P= 0.05.

and Anteneh (2016) and Derib *et al.* (2017) who found that the worm castings contain higher % of organic carbon as compared to conventional compost and garden soil.

VC prepared from CM and EL substrates had the highest total nitrogen (TN) content 3.04% and 2.94%, respectively and the lowest was obtained from PP (2.38%) and PW (2.76%). The substrates eaten by worms are responsible for the variation in TN among the VCs because different substrate types contained different nitrogen contents. The current result is in agreement with Tekalign (1991) findings who reported that the TN in a VC made from all substrates was high (>0.25%) and much greater than in a soil. As a result, adding VC to the soil could increase total nitrogen levels. It was also in line with the findings of Kifle *et al.* (2017) who found that applying VC to a soil could increase total nitrogen levels. Compost made from CM and EL was higher in TN than compost made from other sources like PP and PW.

In line with the trends perceived in soil organic matter and total nitrogen, the substrates' carbon to nitrogen ratio (C:N) also revealed differences among the four substrate groups (Table 4). The mean carbon to nitrogen (C:N) ratio of 7.04, 6.85, 6.56 and 5.76 was observed in CM, EL, PW and PP substrate, respectively. According to the rate established by Landon (1991), C/N ratios >25 as very high, 16–25 as high, 11–15 as medium and <11 as low. Thus, the C:N ratio of CM, EL, PW and PP substrate falls under low rate of C/N (Landon, 1991).

The C:N ratio is considered a key indicator that directly affects vermicomposting because it shows the degree of decomposition of organic waste; a lower C:N ratio leads to a higher degree of degradation (Lazcano *et al.*, 2008). But the lowest was recorded in PP; this indicates that PP was higher degree of degradation than the other substrates.

As C:N ratio below 20 is a good indicator of VC maturity (Morais and Queda, 2003), therefore, VC produced in the present study could be considered as mature and stable. Low C:N ratio was registered from all types of VC. Low C:N ratio indicates higher mineralization rate; thus, the VC prepared from all substrates contains high % of total nitrogen (Brady and Weil, 2002). Therefore, lower C:N ratio was recorded due to higher mineralization of nitrogen. In line with this result, several studies confirmed that the lowest C:N ratio was recorded from VC (Mirian *et al.*, 2006, Hiranmai and Anteneh, 2016, Derib *et al.*, 2017).

Total Phosphorous and Total Potassium

The results revealed that VC prepared from PW and EL had the maximum available phosphorus (2794.8 mg kg^{-1} VC) and (2679.3 mg kg^{-1} VC), respectively, followed by CM (2430 mg kg^{-1} VC) (Table 4). The lowest value (2338 mg kg^{-1} VC) was found in VC made from PP substrate. Their differences could be related to the substrates' nature. The increased P level in VC indicates that phosphorus mineralization occurred during the process. The worms converted the insoluble P into soluble forms during vermicomposting with the help of P-solubilizing bacteria and phosphatases in the gut, making it more available to plants (Padmavathiamma *et al.*, 2008, Ghosh *et al.*, 1999). Total phosphorous from VC made from all substrates, especially PW, was considerably high when the values were compared to soil. The current investigation supported Nagavallemma *et al.* (2004) findings. The total phosphorus in VC was substantially higher than in soil and regular compost, according to study. Thus, if the soil is lacking in phosphorus, the application of VC could raise the P content of the soil. Our findings are consistent with those of Nagavallemma *et al.* (2004) who discovered that worm casting has the highest total phosphorus content ranging from 1900–10,200 mg kg^{-1}.

VC produced from PP substrates had the greatest total Potassium (7286.6 mg kg^{-1} VC) followed by CM (7243.3 mg kg^{-1} VC) and EL (7176.6 mg kg^{-1} VC) and the lowest total Potassium was obtained from PW (5846.6 mg kg^{-1} VC). According to a recent study, the total Potassium (950.5 mg kg^{-1}) in VC was reported by Kalantari *et al.* (2010); however, Tognettia *et al.* (2005) reported total potassium content 8.2 g kg^{-1} in backyard VC which contradicts Kalantari. Furthermore, the results of this investigation are within the range given by Nagavallemma *et al.* (2004) which is 1500–7300 mg kg^{-1} of VC.

Selected Properties of Acidic Soil After Incubation

Effect of Treatment on pH and Electrical Conductivity of the Soil

The most important chemical soil parameter is soil pH which reflects the overall chemical status of the soil and controls a wide range of chemical and biological processes in the soil (Bloom, 2000). The soil pH was significantly high ($p < 0.001$) affected by the main effects of rate and VC source and their interaction. The result of the analysis revealed that the highest soil pH (5.48 H_2O) was recorded from application of 7.5 ton ha^{-1} with PW but statistically non-significant with CM with the highest rate, while the lowest soil pH (4.82 H_2O) was recorded from sole application of EL at the control. The result shows an improvement in soil pH by 14% (from 4.82 to 5.48) with reference to the control and the highest rate (7.5 ton ha^{-1}) of VC source treatment (Table 5).

It is generally believed that applications of organic materials reduce soil pH (Abdala *et al.*, 2015). However, contrary to the general contemplation, the results of the present study confirmed that the application of vermicompost resulted in a higher and more significant effect on the pH of studied soils compared to control treatment. The high amount of basic cations and pH in VC treatment could lower soil acidity by substituting acidic cations at exchange sites resulting in an increase in soil pH. The relatively increase in pH over the control as rate of VC increase could be attributed to the high pH value of the compost. This could be confirmed by a significantly and positive correlation ($r=0.59^{***}$) of soil pH with organic carbon (Table 8). Similarly, Tesfaye *et al.* (2020) reported the increase of pH as result of filter cake compost application to soil. This result is also in agreement with the findings of Abdissa *et al.* (2018) and Isreal *et al.* (2021) who reported the significant effect of application lime at each respective level either alone and or in combination with vermicompost had a significant effect on soil pH. There is also another finding when VC was applied to the soil, the pH changes from 4.68 to 4.99 (Alemu and Melese, 2021).

EC is a soil parameter that directly measures salinity and indirectly shows the overall concentration of soluble salts. At each application level, the VC and rate interaction effect had significant ($p < 0.001$) effects on soil EC. When compared to the control, the EC of soil samples increased significantly with all treatments. The highest EC (118.93 µ Scm^{-1}) was

Table 5: Effects of the treatments on pH and Electrical conductivity

Treatment	*pH*				*EC (μS cm⁻¹)*			
	Rate (t ha⁻¹)							
	0	*2.5*	*5*	*7.5*	*0*	*2.5*	*5*	*7.5*
CM	4.92^j	5.18^defg	5.23^cde	5.40^ab	68.13^i	66.63^i	93.2^f	96.90^e
EL	4.82^k	5.06^hi	5.17^defg	5.33^bc	77.46^g	108.96^c	115.5^b	118.93^a
PP	4.99^ij	5.12^gh	5.15^efgh	5.22^cdef	54.56^j	73.67^h	104.0^d	115.0^b
PW	4.94^j	5.13^fgh	5.27^cd	5.48^a	52.76^j	71.60^h	110.76^c	115.40^b
SE±	0.03				0.74			
LSD(0.05)	0.09				2.12			
P value	***				***			
CV (%)	1.13				1.42			

Where, ***= Very Highly Significant at $p \leq 0.001$, **= Highly Significant at $p \leq 0.01$ *= Significant at $p \leq 0.05$; CM= cow manure; EL= enset leaf; PP= potato peels; PW= paper waste; EC= Electrical Conductivity; CV= Coefficient of Variation; LSD= Least significance difference; SE= Standard Error; Means followed by the same letter(s) with in row or column are not significantly different at $p = 0.05$.

Table 6: Effects of treatments on organic matter, and total nitrogen of the soil after incubation

Treatment	*OM (%)*				*TN (%)*			
	Rate (t ha⁻¹)							
	0	*2.5*	*5*	*7.5*	*0*	*2.5*	*5*	*7.5*
CM	2.55^de	2.78^c	2.93^bc	3.03^ab	0.18^j	0.20^gh	0.21^cd	0.23^cd
EL	2.93^bc	3.10^ab	3.14^ab	3.20^a	0.18^j	0.21^f	0.23^ab	0.25^a
PP	2.35^e	2.71^cd	2.76^cd	3.21^a	0.19^hi	0.21^f	0.22^de	0.24^bc
PW	2.47^e	2.93^bc	3.20^a	3.25^a	0.19^ij	0.21^fg	0.22^e	0.24^b
SE±	0.078				0.003			
LSD(0.05)	0.22				0.009			
P value	***				***			
CV (%)	4.68				2.67			

Where, ***= Very Highly Significant at $P \leq 0.001$, **= Highly Significant at $P \leq 0.01$ *= Significant at $P \leq 0.05$; OM= organic matter; TN= total nitrogen; SE= standard error; LSD= least significance difference; CV= coefficient of variation; Means followed by the same letter(s) with in row or column are not significantly different at P= 0.05.

Table 7: Effects of treatments on available Phosphorus and Potassium

Treatment	*Av.P (mg kg⁻¹)*				*Av.K (mg kg⁻¹)*			
	Rate (t ha⁻¹)							
	0	*2.5*	*5*	*7.5*	*0*	*2.5*	*5*	*7.5*
CM	1.78^k	2.76^j	6.93^ef	7.72^d	885^hi	921.67^gh	941.6^fgh	1008.3^de
EL	5.55^g	6.49^f	6.67^f	7.55^de	826.67^ij	976.6^efg	923.33^gh	995^def
PP	3.46^i	4.54^h	7.52^de	18.95^b	823.33^j	853.33^ij	1250^b	1360^a
PW	7.86^d	10.24^c	19.15^b	24.33^a	825^j	823.33^j	1043.3^d	1141.6^c
SE±	0.22				21.09			
LSD(0.05)	0.63				60.77			
P value	***				***			
CV (%)	4.31				3.74			

Where, ***= Very Highly Significant at $p \leq 0.001$, **= Highly Significant at $p \leq 0.01$ *= Significant at $p \leq 0.05$; AV.K= available Potassium; Av.P= available phosphorus; SE= standard error; LSD= least significance difference; CV= coefficient of variation; Means followed by the same letter(s) with in row or column are not significantly different at P= 0.05.

obtained from sole application of EL at the rate of 7.5 t ha^{-1}. The lowest EC value of 52.76 μS cm^{-1} in PW and 54.56 μS cm^{-1} in PP was observed over control. When the highest rate applied with EL, the EC raised by more than 100% (from 54.56 to 118.93) compared to the control (Table 5).

The lowest EC was in CM, which may be attributed to the presence of fewer salts in the feed of cow. Similar finding was reported by Sangwan *et al.* (2010). This increase in

Table 8: Pearson correlation coefficients among selected soil chemical properties.

	pH	EC	OC	OM	TN	AVP	AVK
pH	1						
EC	0.63***	1					
OC	0.59***	0.83***	1				
OM	0.59***	0.83***	0.99***	1			
TN	0.59***	0.82***	0.99***	0.99***	1		
AVP	0.58***	0.57***	0.60***	0.59***	0.59***	1	
AVK	0.49***	0.69***	0.49***	0.49***	0.49***	0.62***	1

Where; ***= Very Highly Significant at p≤0.001, **= Highly Significant at p≤0.01 *= Significant at p≤0.05; EC= electrical conductivity; OC= organic carbon; OM= organic matter; TN= total nitrogen; AVP= available phosphorus; AVK= available potassium

EC may be due to increased level of soluble salts, such as phosphates, ammonium salts and nitrates due to the mineralization of the waste by worms and microorganisms (Lazcano *et al.* 2008). This suggests that a high application rate as soil amendment is not recommended because of the salinity stress it might cause, which was similar to the results of Azarmi *et al.* (2008). According to EthioSIS (2016), the EC observed in the pot with maximum level of treatment combinations was within the range of salt free as a result <2000 µS cm^{-1} is considered salt free.

Effects of Treatments on Organic Matter and Total Nitrogen of the Soil

The use of organic materials is an important component for sustainable agricultural production. The interaction effect of VC and rate showed a significant (*P<0.001*) increase in soil organic matter (OM) as compared to the control. When the soil was treated with the highest level (7.5 t ha^{-1}), the highest content of OM (3.25%) was obtained from the application of PW which is statistically similar with pots amended with application of PP and EL with a rate of 7.5 t ha^{-1} but non-significant different with CM at a rate of 7.5 t ha^{-1} with EL at the rate of 2.5 and 5 t ha^{-1}, while the lowest OM (2.35%) was observed in PP and statistically similar with PW and also non-significant with CM at the control treatment (Table 6). The highest rate of PW application raised the OM by 38 percent compared to the control.

The increment of organic matter over the control is due to increasing soil organic matter contents with increasing vermicompost rates. The addition of VC to the soil increased the microbial community by raising the pH and OM content. An increase in pH may reduce stress on soil microorganisms and microbial activity, increasing soil OM. The fact that pH was positively and strongly (r= 0.59***, *P<0.001*) linked with OM which supports this idea (Table 8). The increased organic matter with higher doses of vermicompost and cattle manure improves the soil properties like water-holding capacity, water infiltration, particle-binding capacity (aggregate stability) that determine the microbial biomass and mineral nutrient reserves. Similarly, Narasimha (2013) suggested that using organic sources could increase the organic matter content of soil. According to Amba *et al.* (2011), a rise in soil OC due to applying lime and manure was linked to improved overall soil conditions. Such significant enhancement in soil organic matter after amending with VC clearly shows improvement in soil fertility status. Our result is similar to the findings of Abdissa et al. (2018) who reported that the application of vermicompost on the acidic soil increases the soil's organic matter and total nitrogen contents.

The total soil N was significantly (*p<0.001*) influenced by the application of the main effects of VC source and rate and their interaction. When the highest rate of 7.5 t ha^{-1} was applied, the highest total N (0.25%) was recorded in EL and statistically non-significant with EL at 5 t ha^{-1}, while the lowest was recorded (0.18%) in CM and EL at the control but statistically non-significant with PW at the control (Table 6). In comparison to the control of EL, the TN increased by 39 percent at the maximum rate of 7.5 t ha^{-1}.

The availability of N increase in the soil is due to the VC nutrient retention capacity and might reduce the nitrogen losses according to Prativa and Bhattaria (2011) findings. Similar observations were reported by Liu *et al.* (2012) for the increment of TN; vermicomposting can accelerate the mineralization of OM, thereby transforming insoluble particles into their soluble forms. The application of OM in the form of VC is expected to enhance OM and TN levels in the soil. This is further supported by the positive and significant connection between total N (r = 0.99***, p≤0.001) and OM (Table 8). This is in agreement with Adeleye *et al.* (2010) and Efthimiadou *et al.* (2010) who found that when biofertilisers are simply administered, soil total N increases due to the addition of OM. VC is similarly high in total nitrogen, according to Mary and Sivagami (2014). From earlier studies it is also evident that VC provides N in readily available form and enhances uptake by plants (Atiyeh, 2000). Another finding is similar to the current result (Abdissa *et al.*, 2018). The application of organic fertilizers (vermicompost and farmyard manure) significantly improved soil nitrogen from 0.14% to 0.23% on Nitisols of Central Ethiopian Highlands (Girma *et al.,* 2020).

Effects of Treatments on Available Phosphorus and Potassium

P is the most commonly plant growth-limiting nutrient in tropical soils next to water and N. Their concentration influences the plant's rate of absorbing phosphate ions in the soil solutions. The analysis result also indicated that soil available P was significantly (*P<0.001*) affected by the main factors of VC source and rate and their interaction. The available P of the soil varied from 1.78–24.33 mg kg^{-1} after incubation (Table 7). The highest available P (24.33 mg kg^{-1}) was obtained when PW with a rate of 7.5 t ha^{-1} were applied in combination, while the lowest (1.78 mg kg^{-1}) was observed in CM at the control. As a result, applying the treatments at the highest rate with PW significantly (*p<0.001*) raised available P by more than 100% (from 7.86–24.33) compared to the control.

This could be due to the fact that VC caused a significant increase in soil pH, which lowered P fixation. The findings of a simple correlation study showed that the soil-accessible P was positively and significantly linked with the pH ($r= 0.58^{***}$, *p<0.001*) (Table 8). Opala *et al.* (2015) found a similar rise in soil accessible P in tropical soils. VC application increases the phosphorus contents of the soil, which influences nutrient availability by controlling net mineralization-immobilization patterns and also interacts with soil minerals in complexing P-fixing cations thereby reducing P-sorption capacity. The use of vermicompost improved the soil structure, nutrient exchange and overall soil health. This amendment added to soil is often viewed as a way to improve soil fertility and increase the amounts of soil organic carbon and other major nutrients such as phosphorus. Kisinyo (2016) and Opala *et al.* (2010) reported similar findings. This finding was further supported by Getachew and Tilahun (2017) who discovered that adding organic residues to soil increased phosphate dissociation and therefore improved the available P content. There is also another finding when VC was applied to the soil, the available P changes from 8.77 to 10.30 mg kg^{-1} (Alemu and Melese, 2021). The application of organic fertilizer significantly improved soil phosphorous from 7.84 to 12.59 mg kg^{-1} on Nitisols of Central Ethiopian Highlands (Girma *et al.*, 2020). Abdissa *et al.* (2018) also approves this result.

Because of the absence of a remarkable response to potassium application in the country's central and northern part of the country; there is limited knowledge on the potassium dynamics in Ethiopian soils (Karmakar, 2009). After incubation, the VC and rate interaction effect showed a significant (p<0.001) increase in soil available K compared to the control. The highest available K (1360 mg kg^{-1}) was obtained when the rate of 7.5 t ha^{-1} was applied with PP, while the lowest (823.33 mg kg^{-1}) was observed in PP which is statistically similar with PW at the control. As a result, applying the treatments at 7.5 t ha^{-1} rate raised available K by 65% when compared to the control (Table 7).

A rise in soil pH due to the alkaline nature of applied VC might be responsible for the increase in exchangeable bases above the control. The increment in exchangeable Potassium over the control might be due to Potassium released from VC to soils. Soil exchangeable potassium level increased with VC doses treatments might be due to high potassium content of VC (Table 8). The findings of a simple correlation study showed that the soil's available K was positively and significantly connected with the OC ($r=0.49^{***}$, *p<0.001*). Likewise, Kumar *et al.* (2018) reported enhancement in exchangeable bases like K status in soil with increased doses of VC. This is also similar with the findings of Ibrahim *et al.* (2015) who reported an increase of exchangeable Potassium with increasing doses of VC. Similarly, Azarmi *et al.* (2008) discovered that as VC levels increased, exchangeable bases enhanced. Therefore, application of VC to a low-fertility status of acidic soil can enhance concentrations of basic cations in soil solution. This is also supported by the findings of Ayeni and Adetunji (2010), Adeleye *et al.* (2010), and Adeniyan *et al.* (2011) who found that when the biofertilizer is applied, soil available bases increase. The exchangeable Potassium of experimental site ranged from 823.33–1360 mg kg^{-1}, which ranges to high according to FAO (2006) rating after applying VC.

Conclusion

VC is a nutritionally rich natural organic fertilizer that releases nutrients into the soil and enhances plant quality by restoring the soil's physical and biological properties. However, VC made from locally available materials such as cow manure, enset leaf, potato peels and paper wastes mixed with CM were tested for nutrient contents. The nutrient content of VC prepared from all substrates had the greatest values for all physico-chemical parameters, according to the findings of this study. The pH of VC created from various sources was in the range of 7.9–8.4, which is within the slight alkalinity range and acceptable for plant growth. The electrical conductivity of VC created from various sources of materials ranged from 2226.67–6520 µS cm^{-1}. TN% ranged from 2.38–3.04%. The available phosphorus of VC from various sources of material ranged from 2338 to 2794.8 mg kg^{-1} VC. The total Potassium of VC from various sources of material ranged from 5846.6 to 7286.6 mg kg^{-1} VC. As a result, VC produced from any material might fix plant nutrient imbalances when applied to nutrient-deficient soil and could be used for VC preparation dependent on material availability. The research revealed that the study area's soils have limits due to a lack of major plant nutritional elements and high soil acidity. As a result, the majority of the soil parameters studied responded positively to VC treatments. This incubation experiment showed that applying VC to acidic soils in the research area could reduce soil acidity while also improving soil fertility. Application of different rates of treatments showed statistically significant positive effects on the physico-chemical properties of acidic soil. The result showed that combined application of VC source and rate raises the soil pH, EC, OM and improved the total N, available P and available K of the soil. After considering all of the factors, it was determined that VC was the most effective organic fertilizer for increasing growth, yield, and changing soil properties. Therefore, it can be concluded that the best result was obtained at 7.5 t ha^{-1} VC from all the sources. However, the findings must be confirmed in the field and the economic feasibility of a particular combination's application must be determined.

Data Availability

The data of this study are available with the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Funding Statement

This was a self-funded study, and no funding was received.

References

Abafita, R., 2016. Evaluation of vermicompost on maize productivity and determine optimum rate for maize production. *World Journal of Biology and Medical Sciences*, *3*(1), pp. 9–22.

Abdala, D.B., da Silva, I.R., Vergütz, L. and Sparks, D.L., 2015. Long-term manure application effects on phosphorus speciation, kinetics and distribution in highly weathered agricultural soils. Chemosphere, 119, p. 504–514.https://doi.org/10.1016/j.chemosphere.2014.07.029

Abdenna, D., 2013. Evaluation of soil acidity in agricultural soils of smallholder farmers in South Western Ethiopia. *Sciences, Technology and Arts Research Journal, 2*(2), pp. 01-06.https://doi.org/10.4314/star.v2i2.98859

Abdissa, B., Kibebew, K., Bobe, B., and Marklar, Y., 2018.Effects of lime, vermicompost, and chemical P fertilizer on selected properties of acid soils of Ebantu district, western highlands of Ethiopia. *Applied and Environmental Soil Science,* pp. 1-13. https://doi.org/10.1155/2018/8178305

Abiyotu, G.S., 2019. Soil acidity and its management options in Ethiopia: A review. https://doi.org/10.18535/ijsrm/v7i11.em01

Achalu, C., Heluf, G., Kibebew, K. and Abi, T., 2012. Response of barley to liming of acid soils collected from different land use systems of Western Oromia, Ethiopia. *Journal of Biodiversity and Environmental Sciences*, *2*(7), pp.1-13.

Adeleye, E.O., Ayeni, L.S. and Ojeniyi, S.O., 2010.Effect of poultry manure on soil physicochemical properties, leaf nutrient contents and yield of Yam (*Dioscorea rotundata*) on Alfisol in Southwestern Nigeria, *Journal of American Science*,*6*(10), pp.871–878.http://www.Americanscience.org

Adeniyan, O.N., Ojo, A.O. and Adediran, J.A., 2011. Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils. *Journal of Soil Science and Environmental Management*, 2(1), pp. 9–13. https://doi.org/10.5897/JSSEM.9000022.

Alemu, B. A. and Melese, A., 2021. Inorganic Phosphorous, Lime and Vermicompost Induced Changes on Phosphorus Fractions and Other Properties of Acidic Soil of Cheha District, Ethiopia. https://doi.org/10.21203/rs.3.rs-250222/v1

Alemu D, Nigussie D, Fikreyohannes G, 2014. Effect of vermicompost and inorganic NP fertilizers on growth, yield and quality of garlic (*Allium sativum L.*) in Enebse Sar Midir District, Northwestern Ethiopia, M.Sc. Thesis at Haramaya University, Ethiopia.

Amba, A.A., Agbo, E.B., Voncir, N. and Oyawoye, M.O., 2011.Effect of phosphorus fertilizer on some soil chemical properties and nitrogen fixation of legumes at Bauchi.*Continental Journal of Agricultural Science*, *5*(1), pp. 39–44.http://www.wiloludjournal.com

Angelova, V.R., Akova, V.I., Artinova, N.S. and Ivanov, K.I., 2013. The effect of organic amendments on soil chemical characteristics.*Bulgarian Journal of Agricultural Science*, *19*(5), pp.958-971.

Arora, M., and Kaur, A., 2019. *Azollapinnata, Aspergillus terreus*and *Eisenia fetida* for enhancing agronomic value of paddy straw.*Scientific Reports*, *9*(1), pp.1-11.https://doi.org/10.1038/s41598-018-37880-1.

Asmare, M., Yli-Hall, M.J. and Birru, Y., 2015. Effects of lime, wood ash, manure and mineral P fertilizer rate on acidity related chemical properties and growth and P uptake of wheat (*Triticum aestivum* L.) on acid soil of Farta district, northwestern highlands of Ethiopia.*International Journal of Agriculture and Crop Sciences*, *8*(2), pp. 256-269.

Atiyeh, R.M., Subler, S., Edwards, C.A., Bachman, G., Metzger, J.D. and Shuster, W., 2000. Effects of vermicomposts and composts on plant growth in horticultural container media and soil.*Pedobiologia*, *44*(5), pp.579-590.http://dx.doi.org/10.1078/S0031-4056(04)70073-6.

Ayeni and Adetunji, 2010.Integrated application of poultry manure and mineral fertilizer on soil chemical properties, nutrient uptake, yields and growth components of maize.*Nature and Science*, *8*(1), pp. 60–67.https://doi.org/10.1155/2018/8178305.

Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O. and Odeyemi, O., 2020. Waste management through composting: Challenges and potentials. *Sustainability*, *12*(11), pp. 4456.https://doi.org/10.3390/su12114456.

Azarmi, R., Giglou, M.T. and Taleshmikail, R.D., 2008. Influence of vermicompost on soil chemical and physical properties in tomato (Lycopersicum esculentum) field. *African Journal of Biotechnology*, *7*(14),pp. 2397-240.http://www.academicjournals.org/AJB.

Baez-Rogelio, A., Morales-Garcia, Y.E., Quintero-Hernández, V. and Muñoz-Rojas, J., 2017.Next generation of microbial inoculants for agriculture and bioremediation.*Microbial Biotechnology*, 10(1), pp. 19-21.https://doi.10.1111/1751-7915.12448.

Bhargava, N.S.A.K.D. and Bhattacharya, S., 2004. Optimum moisture requirement during vermicomposting using Perionyx excavatus.*Applied ecology and environmental research*, *2*(1), pp.53-62.

Bhat, S.A., Singh, J. and Vig, A.P., 2015. Potential utilization of bagasse as feed material for earthworm *Eisenia fetida* and production of vermicompost.*Springer Plus*, *4*(11), pp.1-9. https://doi.10.1186/s40064-014-0780-y.

Bloom, P.R., 2000. Soil pH and pH buffering.In Sumner, M.E. (eds). Handbook of Soil Science. Boca Raton, FL: CRC Press.

Bouyoucos, G.J., 1962. Hydrometer method improvement for making particle size analysis of soils. *Agronomy Journal*, *54*(5), pp. 179-186. https://doi.org/10.2134/agronj1962.00021962005400050028x.

Brady, N.C. and Weil, R.R., 2002. The nature and properties of soils 13th ed Prentice Hall. *New Jersey, USA*, *249*.

Brady, N.C. and Weil, R.R., 2016. The nature and properties of soils. Pearson Education, Columbus, EUA.

Bray, R.H. and Kurtz, L.T., 1945. Determination of total, organic, and available forms of phosphorus in soils.*Soil science*, *59*(1), pp.39-46.http://dx.doi.org/10.1097/00010694-194501000-00006.

CASCAPE (capacity building for scaling up of evidence-based practices in agricultural production in Ethiopia), 2015. Characterization of agricultural soils in CASCAPE intervention woreda in southern nation nationalities people regional state (SNNPRS), pp .118-135.

Efthimiadou, A., Bilalis, D., Karkanis, A. and Froud-Williams, B., 2010. Combined organic/inorganic fertilization enhances soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. *Australian Journal of Crop Science*, *4*(9), pp.722-729.

Ethiopian Institute of Agricultural Research) (EIAR), 2011. Coordination of national agricultural research system, Ethiopia, English and Amharic Version, Addis Ababa.

Ethio-SIS (Ethiopia Soil Fertility Status). 2016. Fertilizer Recommendation Atlas of the Southern Nations, Nationalities and Peoples' Regional State, Ethiopia.

Eyasu, M. and Anteneh, A., 2015. Bioconversion of Wastes (Khat Leaf Leftovers and Eucalyptus Twigs) into Vermicompost and Assessing Its Impact on Potato Yield.*Journal of Agronomy*, *14*(1), pp. 37-42.https://dx.doi.org/10.3923/ja.2015.37.42.

Fageria, N.K. and Nascente, A.S., 2014. Management of soil acidity of South American soils for sustainable crop production.In *Advances in agronomy* (Vol. 128, pp. 221-275).Academic Press. https://doi.org/10.1016/B978-0-12-802139-2.00006-8.

FAO (World Reference Base for Soil Resources), 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, P.192. http://www.fao.org.

FAO, 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, fertilizer and plant nutrition Bulletin 16.FAO, Rome.

Getachew, A.and Tilahun, A., 2017. Integrated soil fertility and plant nutrient management in tropical agro-ecosystems: A review. Pedosphere,27(4), pp. 662-680.https://doi:10.1016/S1002-0160 (17)60382-5.

Ghosh, M., Chattopadhyay, G.N. and Baral, K., 1999. Transformation of phosphorus during vermicomposting.*Bioresource Technology*, *69*(2), pp.149-154.https://doi.org/10.1016/S0960-8524(99)80001-7.

Girma, C., Zeleke, O. and Getachew, A., 2020.The Ameliorative Effects of Organic and Inorganic Fertilizers on Yield and Yield Components of Barley and Soil Properties on Nitisols of Central Ethiopian Highlands. Ethiopian Journal of Agricultural Sciences, *30*(4), pp. 169-182.

Guoxue, L., 2001. Vermicomposting of vegetable waste: A bio-physicochemical process based on hydro-operating bioreactor, *7*(20), pp. 3723-3730.

Haile, W. and Boke, S., 2009. Mitigation of Soil Acidity and Fertility Decline Challenges for Sustainable Livelihood Improvement: Research Findings from Southern Region of Ethiopia and Its Policy Implications, Awassa Agricultural Research Institute,Awassa, Ethiopia.

Hazelton, P. and Murphy, B. 2007. *Interpreting soil test results. What do all the numbers mean 2nd* (ed.). CSIRO Publishing. Australia 152p.

Hiranmai, Y. R. and Anteneh, A., 2016. Manurial value of khat waste vermicompost from Awday, Harar town, Ethiopia. *International Journal of Recycling Organic Waste Agriculture*, *5*(2), pp. 105–111.https://doi.10.1007/s40093-016-0121-y.

Ibrahim, M.M., Mahmoud, E.K. and Ibrahim, D.A., 2015. Effects of vermicompost and water treatment residuals on soil physical properties and wheat yield. *International Agrophysics*, *29*(2), p.157.https://doi.org/10.1515/intag-2015-0029.

Isreal, Z., Sanjay, S. and Lemma, W., 2021. Soil physico-chemical properties as affected by integrated use of blended fertilizer, cattle manure, vermicompost and mineral nitrogen and phosphorus in potato (*Solanum tubersoum*) in acidic soil of south-western Ethiopia. *Indian Journal of Agronomy*, *66*(3), pp. 8-16.https://doi.org/10.14719/pst.2021.8.3.1048.

Jackson, M.L. 1967. Soil Chemical Analysis, Prentice Hall of India, Pvt. Ltd., New Delhi.

Jamison, H. H. Weaver, and I. F. Reed, 1950. "A hammer driven soil core sampler," *Soil Science*, *69*, pp. 487–496.

Kalantari, S., Hatami, S., Ardalan, M.M. and Alikhani, A.H., 2010. The effect of compost and vermicompost of yard leaf manure on growth of corn.*African Journal of Agricultural Research*, *5* (11): 1317-1323.http://www.academicjournals.org/AJAR.

Karmakar, S. Gangopadhyay, A., Brahmachari, K. and Bandyopadyay, P. K., 2009. Soil Health Management by applying vermicompost prepared from Organic Wastes. *Journal of Interacademicia*, *13*, pp. 412-417.

Kaviraj and Sharma, S., 2003. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms.*Bioresource Technology, 90*, pp.169-173.http://dx.doi.org/10.1016/S0960-8524 (03)00123-8.

Kifle, D., 2017. Characterization of Vermicompost for Major Plant Nutrient Contents and Manuring Value.https://doi.org/10.17352/ojps.000031.

Kisinyo, 2016. Maize response to organic and inorganic soil amendments grown under tropical acidic soil of Kenya. *Journal of Agricultural Science and Food Technology*, *2*(3), 35–40.

Kochian, L. V., Piñeros, M. A., Liu, J. and Magalhaes, J. V., 2015. Plant adaptation to acid soils: the molecular basis for crop aluminum resistance. Annual Review of Plant Biology, *66*, pp. 571-598.https://doi.org/10.1146/annurev-arplant-043014-114822.

Kp, M., Thomas, T., P, A.H., and Rao, S., 2018. Effects of vermicompost and inorganic fertilizers on physico-chemical properties of soil in Indian mustard.*Journal of pharmacognosy and photochemistry*, *7*(3), pp.1999-2001.

Kumar, A., Prakash, C.B., Brar, N.S. and Kumar, B., 2018.Potential of vermicompost for sustainable crop production and soil health improvement in different cropping systems. *International Journal of Current Microbiology and Applied Sciences*, *7*(10), pp.1042-1055. https://doi.org/10.20546/ijcmas.2018.710.116.

Landon, J.R., 1991. Booker Tropical Soil Manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. (ed.). John Wiley & Sons Inc., New York.

Lazcano, C., Gómez-Brandón, M. and Domínguez, J., 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere*, *72*(7), pp.1013-1019. https://doi.org/10.1016/j.chemosphere.2008.04.016

Liang, C., Das, K.C. and McClendon, R.W., 2003. The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource technology*, *86*(2), pp.131-137.https://doi.org/10.1016/S0960-8524(02)00153-0

Lim, S.L., Lee, L.H. and Wu, T.Y., 2016. Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis. *Journal of Cleaner Production*, *111*, pp.262-278. https://doi.org/10.1016/j.jclepro.2015.08.083.

Lim, S.L. and Wu, T.Y., 2015. Determination of maturity in the vermicompost produced from palm oil mill effluent using spectroscopy, structural characterization and thermogravimetric analysis. *Ecological Engineering*, *84*, pp.515-519.https://doi.org/10.1016/j.ecoleng.2015.09.050.

Liu, J., Lu, Z., Yang, J., Xing, M., Yu, F. and Guo, M., 2012.Effect of earthworms on the performance and microbial communities of excess sludge treatment process in vermifilter.*Bioresource technology*, *117*, pp.214-221.https://doi.org/10.1016/j.biortech.2012.04.096.

Mahmud, K., Panday, D., Mergoum, A. and Missaoui, A., 2021. Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. *Sustainability*, *13*(4), p.2400. https://doi.org/10.3390/su13042400.

Mary, D.D. and Sivagami, S., 2014.Effect of individual and combined application of biofertilisers, vermicomposts and inorganic fertilizers on soil enzymes and minerals during the post harvesting stage of chilli (NS 1701). *Research Journal of agriculture and environmental Management*, *3*, pp.434-441. https://doi.org/10.1155/2018/8178305.

Mirian R. Alves, Maria D. Landgraf and Maria O. O. Rezende, 2006. Sorption and Desorption of the Herbicide Alachlor on Humic Acid Fractions From Two Vermicomposts*, Journal of Environmental Science and Health*, *36*(6), pp.797-808. https://doi.10.1081/PFC-100107413.

Morais, F.M.C. and Queda, C.A.C., 2003, April. Study of storage influence on evolution of stability and maturity properties of MSW composts. In *Proceedings of the fourth International Conference of ORBIT association on Biological Processing of Organics: Advances for a sustainable Society Part II, Perth, Australia*.

Munsell, 2000. *Munsell Soil Color Charts*. Year 2000 revised washable edition. Michigan, USA: Munsell Color 4300 44th Street SE, Grand Rapids, MI 49512, USA.

Mupondi, L.T., Mnkeni, P.N.S., Muchaonyerwa, P. and Mupambwa, H.A., 2018. Vermicomposting manure-paper mixture with igneous rock phosphate enhances biodegradation, phosphorus bioavailability and reduces heavy metal concentrations.

Nagavallemma, K.P., Wani, S.P., Lacroix, S., Padmaja, V.V. and Vineela, C., 2004. Vermicomposting: recycling wastes into valuable organic fertilizer.

Naidoo, K., Swatson, H., Yobo, K.S. and Arthur, G.D., 2017. Boosting Our Soil With Green Technology: Conversion of Organic Waste Into "Black Gold". In *Food Bioconversion* (pp. 491-510). Academic Press.https://doi.org/10.1016/B978-0-12-811413-1.00015-2.

Narasimha, G., 2013. Comparative studies on physico-chemical, biological and enzymatic properties of soil amended with organic manure, vermicompost and indigenous microorganisms (IMOs).

Ndegwa, P.M. and Thompson, S.A., 2001. Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. *Bioresource technology*, *76*(2), pp.107-112.https://doi.org/10.1016/s0960-8524(00)00104-8.

Olsen, S. and Sommers, L., 1982. Phosphorus Pp. *Methods of Soil Analysis, Part*, *2*.

Opala, P.A., Kisinyo, P.O. and Nyambati, R.O., 2015. Effects of Tithoniadiversifolia, farmyard manure and urea, and phosphate fertiliser application methods on maize yields in western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *116*(1), pp.1-9. http://nbn-resolving.de/urn:nbn:de:hebis:34-2015011347180.

Opala, P.A., Okalebo, J.R., Othieno, C.O. and Kisinyo, P., 2010. Effect of organic and inorganic phosphorus sources on maize yields in an acid soil in western Kenya.*Nutrient cycling in agroecosystems*, *86*(3), pp.317-329. https://doi.org/10.1155/2018/8178305.

Padmavathiamma, P.K., Li, L.Y. and Kumari, U.R., 2008. An experimental study of vermi-biowaste composting for agricultural soil improvement.*Bioresource technology*, *99*(6), pp.1672-1681. https://doi.org/10.1016/j.biortech.2007.04.028.

Pisa, C. and Wuta, M., 2013. Evaluation of composting performance of mixtures of chicken blood and maize stover in Harare, Zimbabwe. *International Journal of Recycling of Organic Waste in Agriculture*, *2*(1), pp.1-11. https://dx.doi.org/10.1186/2251-7715-2-5

Prativa, K.C. and Bhattarai, B.P., 2011. Effect of integrated nutrient management on the growth, yield and soil nutrient status in tomato. *Nepal Journal of Science and Technology*, *12,* pp.23-28. https://doi.10.3126/njst.v12i0.6474

Richards, LA., 1954. Diagnosis and Improvement of Saline and Alkali Soils.US Salinity Laboratory Staff, US Department of Agriculture, Washington DC.

Rowell, D.L., 1994. The meaning of pH and its measurement, the determination of organic nitrogen and the dichromate method for the determination of oxidizable carbon and soil organic matter.*Soil science, methods and applications*, pp.48-161.

Sangwan, P., Garg, V.K. and Kaushik, C.P., 2010. Growth and yield response of marigold to potting media containing vermicompost produced from different wastes. *The Environmentalist*, *30*(2), pp.123-130.

Santamaría-Romero, S. and Ferrera, R., 2001. Dynamics and relationship among microorganisms, C-Organic and N-Total during composting and vermicomposting. *Agrociencia*, *35*(4), pp. 337-384.

SAS Institute, 2011. *SAS/IML 9.3 user's guide*. Sas Institute.

Sharma, U.C. and SINGH, K., 1991.Integrated management of phosphate and farmyard manure in potato-radish cropping sequence on an acidic soil.*Journal of the Indian Society of Soil Science*, *39*(3), pp.468-471.

Sharma, K. and Garg, V.K., 2019. Recycling of lignocellulosic waste as vermicompost using earthworm Eisenia fetida.*Environmental Science and Pollution Research*, 26(14), pp.14024-14035. https://doi.org/10.1007/s11356-019-04639-8.

Sinha, R.K., S. Agarwal, K. Chaudhan and D. Valani, 2010. The wonders of earthworms and its vermicomposting in farm production: Charles Darwin's friends of farmers', with potential to replace destructive chemical fertilizers from agriculture. Agricultural Sciences, *1*(2), pp.76-94. https://doi.10.4236/as.2010.12011

Srivastava, V., Gupta, S.K., Singh, P., Sharma, B. and Singh, R.P., 2018. Biochemical, physiological, and yield responses of lady's finger (Abelmoschus esculentus L.) grown on varying ratios of municipal solid waste vermicompost. *International Journal of Recycling of Organic Waste in Agriculture*, *7*(3), pp.241-250. https://doi.org/10.1007/s40093-018-0210-1.

Suthar, S., Kumar, K. and Mutiyar, P.K., 2015. Nutrient recovery from compostable fractions of municipal solid wastes using vermitechnology.*Journal of Material Cycles and Waste Management*, *17*(1), pp.174-184. http://dx.doi.org/10.33552/

WJASS.2019.01.000516.

Tahat, M., Alananbeh, M., Othman, A., and Leskovar, D., 2020. Soil health and sustainable agriculture.*Sustainability*, *12*(12), p.4859. http://dx.doi.org/10.3390/su12124859.

Tekalign, 1991. Describes procedures for the analysis of chemical constituents in soil, plant, water, fertilizer, animal manure and compost samples.

Teshome, Y., Abdeta, J. and Habtamu, K., 2018. Characterization and classification of soils.*Eurasian journal of Soil Science*, 7(4), pp. 292-299.https://doi. 10.18393/ejss.436186.

Tesfaye, W., Kibebew, K., Bobe, B., Melesse, T. and Teklu, E., 2018. Long term effects of cultivation on physicochemical properties of soils at metahara sugar estate. *American-Eurasian Journal of Agricultural Research*, *18*, pp.246-257. https://doi: 10.11648/j.ajpb.20210603.14

Tesfaye, W., Kibebew, K., Bobe, B., Melesse, T. and Teklu, E. 2020. Effects of long term sugarcane production on soils physicochemical properties at Finchaa sugar Estate. *Journal of Soil Science and Environmental Management*, *11*(1), pp. 30-40.http://dx.doi.org/10.5897/JSSEM2018.0710

Tigist, A., Lemma, W. and Tesfaye, F., 2019. Soybean (Glycine max L.) response to lime and vermicompost amelioration of acidic Nitisols of Assosa, North Western Ethiopia. International Journal of Plant & Soil Science *27*(2): 1-18. https://doi.org/10.9734/ijpss/2019/v27i230072.

Tognetti, C., Laos, F., Mazzarino, M.J. and Hernández, M.T., 2005. Composting vs. Vermicomposting: A vermicomposting, In: C.A. Edwards, N.Q. Arancon, R.L. Sherman (Eds.), Vermiculture. https://doi. 10.1186/s40068-017-0079-4.

USDA (United States Department of Agriculture), 1998. Soil Mechanics Level I-Module 3: USDA Textural Classification Study Guide. National Employee Development Staff, Soil Conservation Service, USDA.

Walkley, A. and Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method.*Soil science*, *37*(1), pp.29-38.https://doi.10.1097100010694-193401000-00003.

Wang, J.P., Raman, H., Zhang, G.P., Mendham, N. and Zhou, M.X., 2006. Aluminium tolerance in barley (Hordeum vulgare L.): physiological mechanisms, genetics and screening methods. *Journal of Zhejiang University SCIENCE B*, *7*(10), pp.769-787. https://dx.doi.org/10.1631%2Fjzus.2006.B0769.

Wassie, H., 2017.Integrated Soil Fertility Management Technology for Improving Potato (Solanum tubersosum L.)Production and Soil Productivity at Chencha, Southern Ethiopia.*Journal of the Drlylands*, *7*(2), pp.683-696.

Wilding, L.P., 1985. Spatial variability: its documentation, accomodation and implication to soil surveys. In *Soil spatial variability, Las Vegas NV, 30 November-1 December 1984* (pp. 166-194).

Wilke, B.M., 2005. Determination of chemical and physical soil properties.In *Monitoring and assessing soil bioremediation* (pp. 47-95).Springer, Berlin, Heidelberg.

Wrushali, M., Meshram, N.A., Dalvi, V.V., Shigwan, A.S., Tripathi5,V.D., Rane, A.D., and V.G., 2019.Physicochemical and biological characterization of vermicomost prepared from different residues of agroforestry component, *Applied Biological Research, 21*(3), pp.255-264.https://doi. 10.5958/0974-4517.2019.00034.X.

Wubayehu, K.B., 2021. Response of barely (*hordeum vulgare l.*) yield and yield components to lime and vermicompost application on acidic soil of sanket lideta kebele banja district northwestern Ethiopia (Doctoral dissertation, Bahir Dar University).

Yuvaraj, A., Karmegam, N. and Thangaraj, R., 2018. Vermistabilization of paper mill sludge by an epigeic earthworm Perionyx excavatus: mitigation strategies for sustainable environmental management. *Ecological Engineering*, 120, pp.187-197.www.elsevier.com/locate/ecoleng

Zhang, J., Cook, J., Nearing, J.T., Raudonis, R., Glick, B.R., Langille, M.G. and Cheng, Z., 2021. Harnessing the plant microbiome to promote the growth of agricultural crops.*Microbiological Research*, *245*, p.126690. https://doi.org/10.1016/j.micres.2020.126690