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ORIGINAL RESEARCH

Quality assessment of compost produced from agricultural wastes: Impact on the growth and yield of *Zea Mays* L.

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Abstract

Purpose Maize (*Zea mays* L.) is a major crop grown and consumed in Nigeria but poor soil quality has resulted in low yield. This study assessed the quality of compost produced from agricultural wastes and its impact on the yield of *Zea mays* L.

Method The composting process was carried out on a windrow (2 m × 1 m × 1.5 m) in a portion of land beside the Department of Applied Microbiology and Brewing Laboratory, Nnamdi Azikiwe University, Awka. Microbial plate count and isolation were done and various physicochemical parameters were used to assess the quality of the compost. Different combinations of compost and soil were used to determine the growth parameters of *Zea mays* L. Data was analyzed using SPSS software.

Results Microbiological analysis revealed the presence of several bacterial and fungal genera in the compost piles. Temperature increased at the initial phase of composting and decreased towards the end of the composting period. pH increased from 6.7±0.1 to 8.2±0.1 while C: N ratio decreased from 22.5±0.6 to 14.3±0.9. Similarly, there was a decrease in moisture content, organic carbon and total nitrogen from 57±1.0% to 36±1.0%, 45±1.0% to 24.3±0.6% and 2.0±0.1% to 1.7±0.1% respectively, during the composting period. The plant height, number of grains and weight of cob were significantly higher ($p < 0.05$) in the 100% compost and 75/25% compost/soil treatment when compared to those of the control without compost.

Conclusion Compost produced in this study contained microorganisms, nutrients and minerals, which improved the yield of *Zea mays* L.

Keywords Agricultural waste, Composting, Microorganisms, Nutrients, *Zea mays* L.

Introduction

In the olden days, the disposal of solid wastes was not a challenge due to few populations and the availability of large expanse of land for absorption of such wastes (Jodar et al. 2017). However, with the advent of modern society and with ever-increasing consumption of goods and inadequate refuse disposal, the menace of solid waste is becoming severe. Rapid upsurge in human population has led to an increase in agricultural activities to meet the growing food demand. This has however, contributed to the increase in generation of agricultural solid waste (Adejumo and Adebiyi 2020).

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Agricultural wastes may be composed of crop residues, weeds, leaf litter, sawdust, forest waste, as well as livestock waste (Sharma and Garg 2019). These wastes are generated through agricultural activities and may pose serious threat to human health and the environment if not properly managed. Indiscriminate dumping of agricultural wastes in open ground or burning, is a common practice by farmers in developing countries especially Nigeria. Apart from being unpleasant when dumped by the roadsides, these wastes serve as a breeding ground for insect vectors, pests and rodents as well as pollute the air by releasing foul odor. Burning or incineration of agricultural wastes may reduce the volume of wastes but has an adverse effect on the environment. Combustion releases greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O), which have the capability of depleting the ozone layer, thereby contributing to global warming (Bhat et al. 2018).

Maize (*Zea mays* L.) is one of the most important cereal crops in Sub Saharan Africa (SSA) and it is an important staple food for over 600 million people in SSA (Jjagwe et al. 2020). Cereal such as *Zea mays* L. is among the major food cultivated and consumed in Nigeria. The total maize harvest in Africa was estimated at 40 million hectares, with Nigeria being the top producer (16%) in Africa (FAO 2017). Despite being the top producer in Africa, the total productivity is grossly inadequate, due to poor soil quality and improper soil fertilization process (Detchinli et al. 2017). Composting is a biological means of converting different organic wastes into products that can be safely used and beneficially employed as biofertilizer (Ayilara et al. 2020). Comsposting is a natural process of producing nutrient rich beneficial product, which can be used not only to improve soil quality but also to supply the soil with all the essential minerals required for plant growth (Parihar and Sharma 2021). Compost not only contains minerals for plants growth, but also microorganisms for soil health (De Corato 2020). In addition, compost can improve soil structure by increasing aggregate stability. Galitskaya et al. (2017) reported that there are chemical and biological changes during composting as a result of microbial succession, which is dependent on temperature changes. Hafeez et al. (2018) reported that fungi and bacteria are predominantly present during composting. The pH, carbon/nitrogen (C/N) ratio, organic matter content, as well as cation exchange capacity (CEC) are key parameters used to determine the quality of stable compost (Azim et al. 2018). Other factors that may affect the quality of the compost may include, but not limited to, oxygen, moisture content, particle size as well as raw material texture. Oxygen is very important during composting. When oxygen is in short supply, there is a tendency that oxygen may be used up during microbial decomposition of composting materials. As a result, an anaerobic environment may be created, leading to the generation of foul odor as well as gases such as methane, CO_2, and ammonia (Gonawala and Jardosh 2018). The aim of this study was to access the quality of compost produced from agricultural solid wastes and its effect on the yield of *Zea mays* L.

Materials and methods

Study site

The study was conducted at a portion of land allocated for the study, beside the Department of Applied Microbiology and Brewing Laboratory, Faculty of Biosciences, Nnamdi Azikiwe University (NAU) Awka, Anambra State, Nigeria. NAU is a Federal University established in 1991, located in the Southeastern part of Nigeria and situated on the geographic coordinates of $06^0$14’34.5N and $07^0$07’5.919E. However, the compost study site situates on Latitude $06^0$15.2’N and longitude $07^0$06’5.84’E. Awka has two well-defined climatic seasons; the rainy season which takes place from the month of April and ends in October, and the dry season which occur between the months of November to March. Temperature is generally 27 to 30^{o}C between May and January. However, temperature rises between 32 to 34°C from the months of February to April (Ogbodo et al. 2020)

Sample collection and processing

The agricultural wastes used in this study include cassava peels, corn Stover, chicken droppings, goat droppings and cow dung. The fecal materials of animal origin were obtained from abattoir in Amansea, Awka, Anambra State. Cassava peels and corn stover were obtained from the University farms beside Nnamdi Azikiwe University Nursery and Primary School. The cassava peels and corn stover were chopped manually into small pieces to aid microbial decomposition (Pisa and Wuta 2013). The dry corn stover provided a good supply of carbon to the compost. The wastes of animal origin, in addition to being a good source of nitrogen, it aided the activation of the compost process known as biostimulation (the addition of nutrients to kick-start the process). This is important to maintain a good carbon/nitrogen ratio during the process for rich compost. All composting materials were transported in large plastic bags to the composting site. *Zea mays* L. seeds were obtained from the Ministry of Agriculture, Awka Anambra State.

Composting process

Open windrows of 2 m length, 1 m width and 1.5 m height were constructed and used for the composting process. The compost pile consists of 100 kg of cassava peels, 100 kg of corn stover, 50 kg of chicken droppings, 50 kg of goat droppings and 50 kg of cow dung. Layers of fecal materials and farm wastes were placed alternately. The green waste inputs were expected to provide structure and porosity to the compost. All composting materials were piled on the windrows in triplicate. The composting experiments were carried out under shade conditions for 4 weeks. The piles were manually turned using shovel and rake once a week. Water was added to the piles during the turning process to maintain moisture content of 40 to 60% (Jodar et al. 2017) for enhanced microbial activities.

Microbiological analysis

Preparation of inoculums

Compost samples were collected on a weekly basis from four different points viz: top, center, side and bottom. The samples were mixed to obtain a composite sample. 50 g of the composite samples were added to 950 ml of normal saline and homogenized for 30 minutes (Gebeyehu and Kibret 2013). Tenfold serial dilution (up to 10^{-6}) of the homogenate was made and used for the isolation of heterotrophic bacteria and fungi.

Isolation of heterotrophic bacteria

0.1 milliliter of the10^{-6} dilutions was aseptically plated in triplicate on the surface of solidified nutrient agar plates and incubated at 37°C for 24 hours. After incubation, colonies that developed in the growth media were counted with a colony counter and recorded as cfu/ml. To obtain pure cultures of the isolates, the colonies were subcultured onto freshly prepared nutrient agar plates. The pure cultures were identified and characterized using cultural and biochemical characteristics.

Isolation and characterization of fungi

0.1 milliliter of the 10^{-6} homogenate was transferred in triplicate onto the surface of freshly prepared sabouraud dextrose agar (SDA) plates and incubated at 28°C for 72 hours. After incubation, colonies that developed in the growth media were counted with a colony counter and recorded as cfu/ml. The pure cultures of the isolates were obtained by subculturing onto freshly prepared SDA plates. The pure cultures were identified and characterized using cultural and microscopic characteristics.

Physicochemical characteristics of compost

The physicochemical parameters of the samples were determined on the 1st day of composting and subsequently on a weekly basis for 4 weeks. The temperature of the compost piles was determined using mercury-in-glass bulb thermometer. The pH was determined using pH meter (Hanna H15222). Electrical conductivity was measured for compost-water (1:2.5) suspension and in the supernatant, using conductivity meter (Jenway 4510) (Andrade and Abreu 2006). The moisture content was measured as weight loss upon drying in an oven at 105ºC to a constant weight (Lazcano et al. 2008). The compost organic matter (OM) content was determined by measuring the loss of ignition at 550ºC for 4 hour using muffle furnace (Thermolyne F-6125M).The organic carbon (OC) was calculated using the following equation (Mamo et al. 2021): OC % = % OM/1.724.Where OC; organic carbon, OM; organic matter, 1.724 is Van Bemmelen factor commonly used for organic carbon determination, based on the assumption that humidified organic matter of soil contain about 58% organic carbon (Mamo et al. 2021). Total nitrogen was determined using Kjeldal digestion method followed by distillation (AOAC 2005). Total phosphorus was determined using spectrophotometer (Jenway 6320D) (AOAC 2005). The concentration of the following elements: K, Cu, Cr and Pb, was determined using an Agilent model 7500A Inductively Coupled Mass Spectrophotometer (ICP-MS) instrument equipped with an octapole collision cell and auto sampler (Jodar et al. 2017) after digestion with concentrated nitric acid (HNO_3).

Effect of compost on the growth and yield of *Zea mays*

Various combinations of compost and soil were used for the cultivation of *Zea mays* L. The combinations are as follows: 10 kg/ha compost (100%), 7.5 kg/ha compost (75% compost + 25% soil), 5 kg/ha compost (50% compost + 50% soil) and the control soil without compost, 10 kg soil (100%). These measurements were prepared in triplicate and placed in plastic buckets with height ranging from 30 to 40 cm and diameter of 33 cm. The plastic buckets were perforated at the bottom and sides to prevent clogging of water at the base. Three seeds of *Zea mays* L. per bucket were planted and appropriately watered on daily basis. After 72 hours of planting, seedlings emergence was observed in the buckets. The growth parameters such as plant height, number of leaves, weight of cob and number of grains were employed as the indicator parameter of the performance of different combinations. (Jjagwe et al. 2020). Plant height and number of leaves were determined at 2, 4, 6 and 8 weeks after planting. The plant height was measured from the surface of the compost/soil to the topmost leaf tip using a measuring tape (Liangjin, 5 m/16 ft). The number of leaves was also counted and recorded. Weight of cob was determined by weighing the dry unhusked maize cobs from each bucket after harvesting. The grains from each planting bucket were manually threshed to avoid grain loss after which they were counted to obtain the number of grains

Statistical analysis

All data was analyzed and expressed as standard deviation (± SD) of three replicates. Data generated from the effect of compost on the growth and yield of *Zea mays* L. was subjected to one-way analysis of variance (ANOVA), using SPSS software version 22. Duncan multiple range test and least significant difference (LSD) was used to compare the means at $p < 0.05$ level. Pearson's correlation was used to determine the relationship between the microbial counts and the physicochemical parameters.

Results and discussion

The plate counts of the bacterial and fungal isolates are presented in Fig. 1. The bacterial counts increased from 1.5±0.1 × 10^6 cfu/ml to 2.0±0.1 × 10^6 cfu/ml during the first two weeks of composting, and decreased to 0.9±0.6 × 10^6 cfu/ml at the end of the four weeks of composting. However, fungal count was the highest (1.3±0.1 × 10^6 cfu/ml) at the early stage of composting and decreased to 0.3±0.1 x10^6 cfu/ml on the final week of composting. The increase in bacterial count at the initial stage of composting may be attributed to the bioavailability of nutrients for microbial growth from the composting materials. However, a decrease in bacterial count at the final stage of composting could be due to the exhaustion of nutrients and microbial succession that may have occurred as a result of temperature changes. Increase in pH from acidic to alkaline and nutrients exhaustion may be the principal factors contributing to the decline in fungal counts during the composting period. Gebeyehu and Kibret (2013) reported an increase in bacterial and fungal counts at the initial stage of composting and a decrease at the end of the composting period. Wu et al. (2020) reported that pH, total organic matter and nitrate were the most important factors influencing the populations of bacteria and fungi during the process of composting. Microbiological identification revealed the presence of bacteria genera such as *Bacillus*, *Alcaligenes*, *Pseudomonas*, *Micrococcus*, *Staphylococcus* and fungal genera such as *Aspergillus*, *Penicillium*, *Mucor*, *Rhizopus* and *Gliocladium*, in the compost piles. The bacterial and fungal isolates obtained in this study showed that the compost was stable and could be beneficial in controlling plant diseases. For instance, *Pseudomonas* sp was reported to inhibit the growth of pathogenic fungi through the production of antimicrobial metabolites (Raguchander et al. 2011). It was also reported that *Bacillus* sp found in compost was responsible for the suppression of plant wilt and damping-off disease (Lin et al. 2014). The change in temperature during the composting period was presented in Fig. 2a. Temperature increased from 32±1.0 to 47±1.0ºC during the first three weeks of composting and decreased to 36±1.0ºC on the fourth week of composting. The increase in temperature at the early stage and a decrease at the final phase of composting (Fig. 2a) indicated that the compost was mature. This result was in line with the temperature changes during composting process reported in the literature (Ayilara et al. 2020; Parihar and Sharma 2021; Mbachu et al. 2022). The pH increased from 6.7±0.1 to 8.2±0.1, while the C: N ratio decreased from 22.5±0.6 to 14.3±0.9 during the composting period (Fig. 2b). The pH and C: N ratios are important parameters and often employed in determining mature compost (Tamakloe et al. 2021). The pH in the range of 6.7±0.1 to 8.2±0.1 obtained in this study also indicates that the compost was mature. Tibu et al. (2019) reported that mature compost has a pH in the range of 7 to 9. However, Parihar and Sharma (2021) reported that stable compost has a pH in the range of 6.3 to 7.8. A decrease in C: N ratio from 22.5±0.6 to 14.3±0.9% (Fig. 2b) was also reflective of stable compost and it indicates that the compost when applied to the soil, improved the soil fertility by increasing the mineral nitrogen in the soil. This finding is supported by the report that the application of organic matter with C: N ratios lower than 22:1 generally results in an increase in mineral nitrogen in the soil and vice versa (Hoyle et al. 2011).

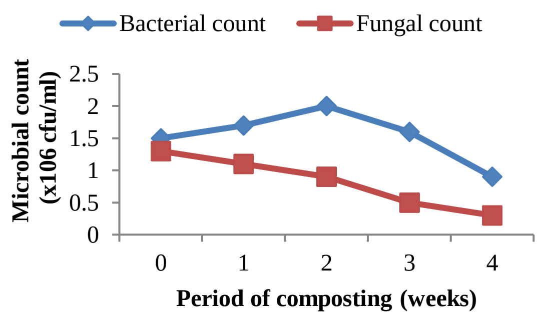

Fig. 1 Total aerobic plate count of bacterial and fungal isolates

A decrease in C: N ratio is generally observed during composting due to microbial breakdown of the carbon sources (composting materials) (Palaniveloo et al. 2020). Mature compost is ascertained by a C: N ratio of 15 to 20, but a C: N ratio in the range of 10 to 15 is still regarded as stable compost (Afraa et al. 2016). However, another report considered C: N ratio of 15 as the threshold below which compost is mature (Tchanaté et al. 2017). Similarly, there was a decrease in moisture content, organic carbon and total nitrogen from 57±1.0 to 36±1.0%, 45±1.0 to 24.3±0.6% and 2.0±0.1 to 1.7±0.1% respectively, during the composting period (Fig. 2c). Moisture content in the range of 57±1.0 to 36±1.0% reported in this study was adequate for microbial activities during the composting period. Gebeyehu and Kibret (2013) also recorded a decrease in moisture content from 58.6 to 47.2% during composting process. This is further supported by the report that moisture content is crucial for metabolic activities of microorganisms and it is expected to decrease as the composting process proceeds (Chennaou et al. 2018). The amount of nitrogen present in compost is important in determining the quality of the product available to plants. The loss of carbon in the form of CO_2 and nitrogen in form of ammonia (NH_3) through microbial decomposition of the composting materials could be associated with the reduction in carbon and nitrogen content with time, as observed in this study. Similar result of a decrease in organic carbon and nitrogen during composting was reported (Gebeyehu and Kibret 2013). Moreover, the nitrogen content (1.7%) of the mature compost obtained in this study was sufficient for plant growth, and in agreement with the compost quality standard (> 0.7%) of some developed countries such as Netherland, Belgium and Italy, but a little higher than the range of 1.05 – 1.13% reported by Switzerland agriculture (Mamo et al. 2021).

Phosphorus, potassium and lead respectively recorded increase in concentration from 0.51±0.01 to 1.1±0.1 mg/kg, 0.43±0.01 to 1.4±0.1 mg/kg and 3.0±0.1 to 7.1±0.1 mg/kg, during the composting period (Fig. 2d). The increase in available phosphorus and potassium with time observed in this study could be attributed to the evolution of the minerals during microbial decomposition of the composting materials. The result was in line with the report of Al-Baraka et al. (2013). The increase in the electrical conductivity (EC) from 2.05±0.01 to 3.0±0.1 µS/cm, reported in this study (Fig. 2e) could be due to microbial activities which may lead to the evolution of exchangeable cations and inorganic salts. This finding was similar to the EC value of 1.9 to 2.7 µS/cm of matured compost reported by Kassa and Workayehu (2014). However, Dadi et al. (2019) reported EC values ranging from 1.5 to 8.8 µS/cm during composting of municipal solid wastes. Moreover, chromium increased from 17.0±1.0 to 18.0±1.0 mg/kg at the initial stages of composting and decreased to 7.0±1.0 mg/kg at the end of the composting period (Fig. 2f). Cobalt decreased from 14.0±1.0 to 4.0±1.0 mg/kg while copper increased from 16.0±1.0 to 23.0±1.0 mg/kg, during the composting period (Fig. 2f). The elemental concentrations of metals Pb, Cu, Co and Cr reported in this study fell below the maximum standard established by the Australian and the European Union for agricultural soils (Maleki et al. 2014). This showed that the compost is free of heavy metal pollutants and suitable for agricultural purposes as evidenced in the growth parameters of *Zea mays* L.

The relationship between the microbial counts and the physicochemical parameters are presented in Table 1. Pearson's correlation revealed that the fungal count was highly significant and negatively correlated with pH ($p = 0.000$; $r = -0.916$), electrical conductivity ($p = 0.000$; $r = -0.928$), phosphorus ($p = 0.000$; $r = -0.919$), potassium ($p = 0.000$; $r = -0.967$), copper ($p = 0.000$; $r = -0.949$) and lead ($p = 0.000$; $r = -0.949$) and positively correlated with moisture content ($p = 0.000$; $r = 0.979$), organic carbon ($p = 0.000$; $r = 0.973$), total nitrogen ($p = 0.001$; $r = 0.775$), C:N ratio ($p = 0.000$; $r = 0.926$), cobalt ($p = 0.000$; $r = 0.925$) and chromium ($p = 0.000$; $r = 0.877$). This suggests that pH, electrical conductivity, phosphorus, potassium, copper and lead influenced the growth of fungi. The significant positive correlation suggests that the macro minerals such as carbon and nitrogen as well as micro minerals including copper and chromium released during microbial decomposition of the composting materials were mainly utilized by fungi for their own growth.

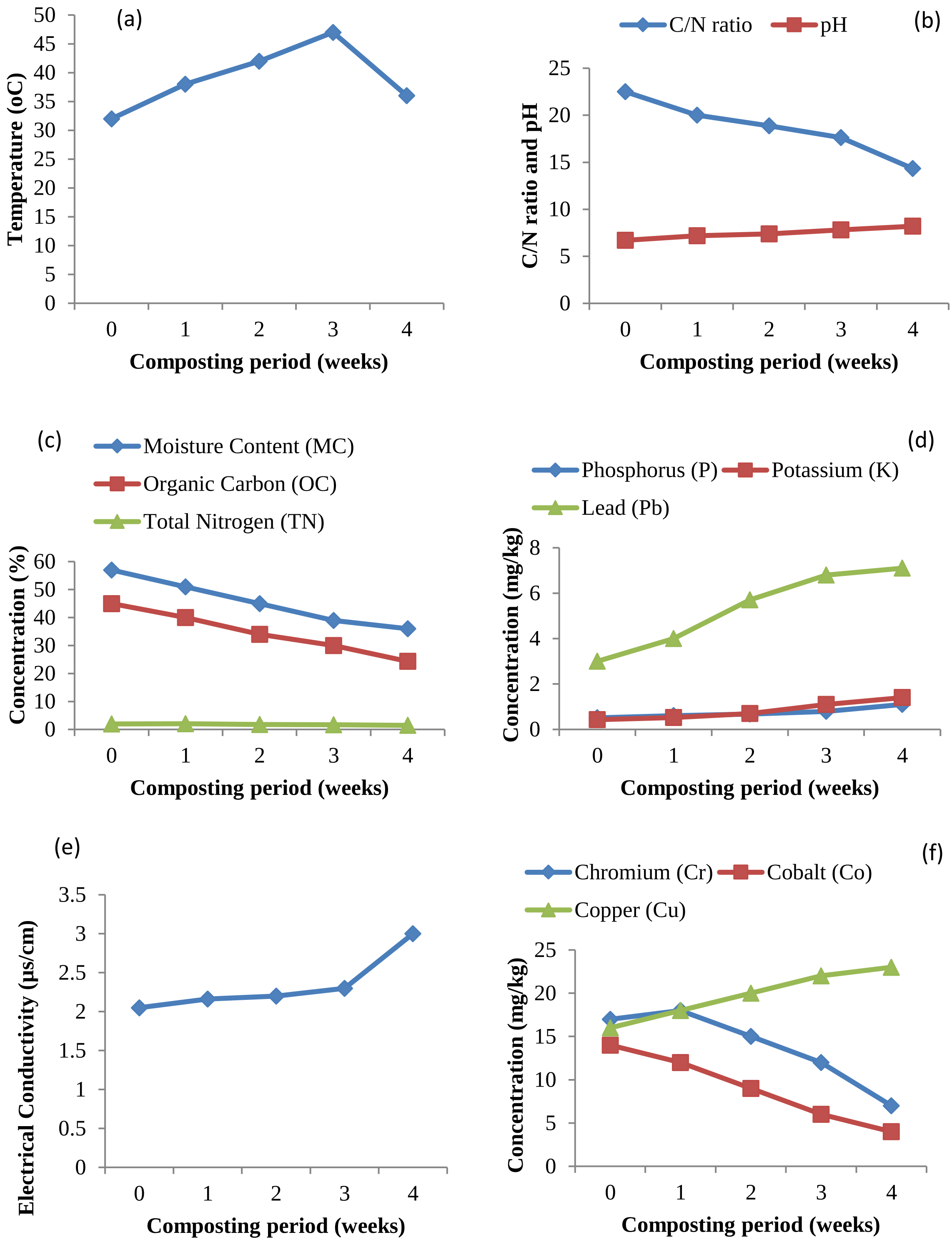

Fig. 2 Variation in physicochemical parameters during the composting period (a) temperature (b) pH and C/N ratio (c) moisture content, organic carbon and total nitrogen (d) phosphorus, potassium and lead (e) electrical conductivity (f) chromium, cobalt and copper. Values are mean of three replicates ±SD

However, excess of these nutrients were released by these microorganisms which was available for the growth and yield of *Zea mays* L. This finding was supported by the report that during microbial decomposition of organic matter, the microorganisms used the carbon and nutrients in the organic matter for their own growth and releasde excess nutrients into the soil where they could be taken up by plants (Hoyle et al. 2011).

However, the bacterial count was significantly and positively correlated with total nitrogen and chromium ($p = 0.047$; $r = 0.519$ and $p = 0.003$; $r = 0.703$ respectively) and negatively correlated with electrical conductivity, phosphorus and potassium ($p = 0.000$; $r = -0.809$, $p = 0.003$; $r = -0.718$ and $p = 0.008$; $r = -0.655$ respectively) (Table 1). This suggests that the bacteria utilized mainly nitrogen and chromium released during microbial decomposition of the organic matter and the excess was made available for the growth of *Zea mays* L. This implied that the compost produced in this study was rich in nutrients and minerals required for plant growth. Similar results of negative correlation between bacterial and fungal count with pH, electrical conductivity and positive correlation with organic matter, C: N ratio as well as temperature, moisture, organic carbon and total nitrogen, during composting experiment were also reported (Gebeyehu and Kibret 2013).

Table 1 Relationship between the microbial count and the physicochemical parameters

Parameters	Bacterial count (×10^6 cfu/ml)	Fungal count (×10^6 cfu/ml)
Temperature	0.429	-0.412
pH	-0.488	-0.916**
Moisture content (MC)	0.427	0.979**
Organic carbon (OC)	0.466	0.973**
Total nitrogen (TN)	0.519*	0.775**
Carbon/Nitrogen ratio (C: N ratio)	0.397	0.926**
Electrical conductivity (EC)	-0.809**	-0.928**
Phosphorus (P)	-0.718**	-0.919**
Potassium (K)	-0.655**	-0.967**
Cobalt (Co)	0.462	0.925**
Copper (Cu)	-0.407	-0.949**
Lead (Pb)	-0.340	-0.949**
Chromium (Cr)	0.703**	0.877**

*Correlation is significant at $p < 0.05$ level, **Correlation is significant at $p < 0.01$ level.

Table 2 shows the effects of different combinations of compost and soil on the growth and yield of *Zea mays* L. The plant height was significantly higher ($p < 0.05$) in the 100% compost, followed by the 75% compost + 25% soil ($p < 0.05$) when compared to the control without compost. However, there was no significant difference ($p > 0.05$) between the number of leaves in 100% compost and 75%:25% compost soil treatment as well as 100% soil and 50:50% compost soil treatment ($p > 0.05$). Nevertheless, the number of grains and the weight of cob were significantly higher ($p < 0.05$) at 100% compost treatment, followed by 75% compost and 25% soil ($p < 0.05$) compared to the control without compost. This shows that the compost improved the growth and yield of *Zea mays* L. Tamakloe et al. (2021) reported that soils amended with compost improved corn height and yield.

Table 2 Effect of compost on the growth and yield of *Zea mays* L.

Compost treatments	Plant height (cm)	Number of leaves	Number of grains (cob)	Weight of cob (g)
100% compost	162.56±1.0[a]	12.0±1.0[a]	350.0±1.0[c]	250.0±1.0[a]
50% compost + 50% soil	147.32±1.0[b]	10.0±1.0[b]	300.0±1.0[d]	150.0±1.0[b]
75% compost + 25% soil	152.4±1.0[c]	12.0±1.0[a]	320.0±1.0[e]	200.0±1.0[c]
100% soil	127.0±1.0[d]	10.0±1.0[b]	220.0±1.0[f]	100.0±1.0[d]

Values are grand mean of three replicates. Means with different superscripts within the column are significantly different at $p < 0.05$ level.

Conclusion

The compost produced in this study was stable and fit to be used as fertilizer by their content of macro and micro minerals. The result obtained on the effect of compost on the growth and yield of *Zea mays* L. further buttressed that the compost contained nutrients and minerals necessary for plant growth and productivity, as reflected in the growth parameters of *Zea mays* L. Moreover, the compost not only contains nutrients and minerals for plant growth but also microorganisms for soil health, thus could be used as soil improver for agricultural purposes.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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