

Article

Differential Effects of Organic Amendments on Maize Biomass and Nutrient Availability in Upland Calcareous Soil

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Abstract: The current study is focuses on a sustainable agricultural ecosystem for soil fertility and human health improvement. To estimate the effects of applying organic amendments (compost, vermicompost, biochar, organic manure and rapeseed cake) on crop growth of maize and nutrient uptake in calcareous soil, eleven treatments were studied, which included compost (CM), cow manure vermicompost (CMV), pig manure vermicompost (PMV), biochar vermicompost (BCV), biochar (BC), conventional synthetic fertilizers (NPK), CMV in addition to NPK (CMV + NPK), and PMV in addition to NPK (PMV + NPK), organic manure (OM), rapeseed cake (RC) and control without any fertilization (CK). Maize above and belowground biomass were analyzed in glass greenhouse experiments. The results showed that nitrogen and carbon contents showed significant differences among treatments. Vermicompost significantly showed higher biomass as compared to inorganic fertilizers except for RC. All vermicompost treatments also showed better nutrient availability as compared to NPK and CK. In conclusion, vermicompost with all substrates are recommended for application as organic fertilizers. Our study will help promote the application of organic fertilizers alone or in combination with inorganic fertilizers rather than only inorganic fertilizers for environmental health and sustainability.

Keywords: nitrogen; carbon; vermicompost; biochar; maize; rapeseed cake



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1. Introduction

Nitrogen (N) is crucial for living organisms, while it is a limiting element for the larger crop production to feed the growing population. The overuse of inorganic fertilizers to meet the food supply demand often causes major environmental problems due to N losses through several pathways [1]. Recycling of agricultural waste materials containing macro-and micro-nutrients for crop growth is an alternative to synthetic fertilizers and for improving soil fertility.

As concern about environment-related issues have grown, the large human population produces an excess amount of organic waste. Globally, 1.3 billion tonnes of food are wasted every year [2], and if global wastes were considered to be a country then it would represent the 3rd biggest producer of greenhouse gas emissions in the world [3]. The population of the world has experienced tremendous growth from 3.1 billion to 7 billion (2010). Scientists estimate that it might rise to 9.7 billion by 2050 [4]. The large amount of organic waste produced exceeds to billion tons, causing emissions of gases from the soil. These

emissions could be reduced by amendments added in fertilizers [5]. Sustainable agriculture techniques need to be used for the maintenance of an eco-friendly cropping system.

Currently, the use of excess manure from different animals (pig and cow), biochar, and crop residues directly or in the form of mixtures is becoming an important issue. Reference [6] reported that a large number of organic wastes result from different pathways, i.e., farmyard wastes, food, and the agricultural industry accounted for around 46% of solid wastes worldwide. Organic materials also affect the N transformation pathways of agricultural sites under different climatic conditions. Organic amendments in the amount of a billion tons are added to calcareous soils into the agricultural ecosystem [7] have been reported to increase N soil organic carbon (SOC) to maintain soil fertility and carbon stocks [8]. Compost, vermicompost and biochar incorporation in calcareous soil has positive effects on the biological activity, as reported earlier [9]. Organic amendments, including farmyard manure, green manure [10], humic acid fertilizer and vermicompost improve the physicochemical properties of soil [11]. The plant nutrient response is dependent on the biochar type as it could be obtained from several materials and has different soil properties as discussed in previous studies of its application. Biochar application may show negative or neutral responses towards plant biomass and growth [12,13]. Composting (degradation of organic materials by microbial organisms without using earthworms), and vermicomposting with earthworms for nutrient cycling has been studied with crop residues, biochar and manures [14]. The application of compost and vermicompost products needs to be studied for maize growth. Utilization of bio-wastes by vermicomposting is a better way, with high nutrient contents [15]. The vermicomposting technology is more favourable and considered to be an eco-friendly way to produce organic fertilizers [16]. It is an emerging technique for recycling and reusing techniques as organic fertilizers for the agricultural ecosystem [17,18]. Vermicomposting is eco-friendly, a biotechnological technique of organic farming like composting, but with the addition of earthworms (*Eisenia fetida*). Vermicomposting is a less degrading process than the composting process because earthworms engulf the waste materials which passes through their gut, resulting in casts, known as worm manure under 10–32 °C temperature utilizing microorganisms as well [19].

Maize has a vital role globally and can be grown in different types of soil under a wide range of climatic conditions. In Australia, around 6 t ha^{−1} yield of maize were recorded [20] while 2.35 t ha^{−1} have been reported in Uganda in 2015 [21]. Maize is moderately sensitive in saline soil [22]. There is still a need for improvement of our understanding of the nutrient uptake with several types of organic amendments as compared to inorganic fertilizers. Rapeseed is another important crop [23] considered rich in protein. Its leftovers after processing can be used as a vermicompost substrate [24]. Rapeseed is the largest cultivated crop in China and constitutes 20% of the world's production [25]. The leftover rapeseed cake can be used as organic fertilizer but reports on this are rare in literature and further studies need to be done.

Biochar is a highly carbon-rich substance used for alternative fertilization obtained from several types of biomass by pyrolysis (under oxygen-limited conditions) [26]. The application of biochar in soil and different agricultural systems is an emerging trend that can play a significant role in improving the nutrient contents of soil, particularly soil organic matter [27]. The suitability of biochar also depends on the soil type [28]. It contains enough nutrients and can act as a conditioner for the soil [29], while its rich porosity character helps sequester carbon [30,31]. Several studies on biochar-based soil amendment have been done, particularly with compost or a mixture of other materials, to lessen the risk of using fresh biochar in soil directly [32]. Therefore, there is still a gap to study biochar-based vermicompost to compare the effects of biochar and biochar vermicompost- an amendment that is recommended as a lower emitter of gases during its preparation [33], and can be used as organic fertilizer.

There is still a need to understand the recycling and utilization of organic fertilizers and vermicomposting with an excess amount of crop residues and manures combined as nutrient-rich sources in upland calcareous soil areas. The better alternative management of

cropping systems helps to sustain multiple organic forms. Our main hypotheses of this study are: (1) Compost and vermicompost can be utilized as better organic fertilizers by conversion of organic wastes in sustainable ways as a recycling and reuse method. (2) The total nitrogen (TN) and total organic carbon (TOC) nutrients available for crop growth from organic wastes might enhance root and shoot biomass as compared to inorganic fertilizers. (3) Biochar-based vermicompost can be as a better organic amendment compared with biochar alone for nutrient and biomass development.

2. Materials and Methods

2.1. Experimental Design

A pot experiment was carried out to investigate the short-term effects of vermicompost and biochar on the growth of maize under greenhouse conditions at an a typical upland (31°16' N, 105°28' E) agroecological-research station, located at 420 m altitude in southwest China. The climate is classified as 'moderate subtropical monsoon', with annual mean precipitation of 826 mm and an average annual air temperature of 17.3 °C. Daily precipitation and air pressure, and temperature were monitored by a meteorological station at the research station approximately 800 m from the experimental site during the experimental period. From 2017 to 2018 the maximum daily air temperature was 37.9 °C, while the minimum daily air temperature was −5.4 °C.

The calcareous soil was a composite of samples taken at a depth of 0–20 cm from five places around the research site. The soils were mixed and passed through a 5-mm sieve to remove stones. At a depth of 5 cm a mixture of stones and gravel was added for drainage of excess water through small holes and each of the green plastic pots of 35-cm diameter and 28-cm height was filled with 15 kg of soil. The crop of maize (*Zea mays* L.) was planted from September to December (four months) and the N fertilization was carried out according to the traditional local method. The soil temperature ranged between 25–30 °C during the sampling period. The pots were watered at appropriate intervals to maintain constant moisture level around 60–70%, maximum water holding capacity, considered to be optimal for biological activities. There were eleven treatments laid out in a completely randomized design with three replicates. Organic amendments, which included compost (CM), cow manure vermicompost (CMV), pig manure vermicompost (PMV), biochar vermicompost (BCV) and biochar (BC), were applied at a rate of 10 t/ha, commonly used for vermicompost, while conventional synthetic fertilizers (150 kg N, P with 90 kg P₂O₅ 36 kg K₂O ha^{−1} fertilizer applied as urea, superphosphate and potassium chloride respectively, NPK) were applied on the basis of local farming practice to observe the effects. CMV in addition to NPK (CMV + NPK), and PMV in addition to NPK (PMV + NPK), organic manure (OM), rapeseed cake (RC) and control without any fertilization (CK).

The experimental scheme of utilizing organic wastes after different processing ways into useful organic fertilizers is shown in Figure 1.

2.2. Composting and Vermicomposting Preparation

Compost and vermicompost were produced from the crop residues, and the experiment lasted for five months of maturation. The experimental details are reported in [33]. The earthworm species used to produce vermicompost was *Eisenia fetida*. The biochar treatments were amended with a commercial biochar purchased from Sanli New Energy Company in Shangqiu (Henan Province, China). The feedstock for biochar production was a ton of crop straw and 0.3 t of biochar was produced by slow pyrolysis at 500 °C in a fluidized bed furnace on a scale of 1000 t day^{−1}, along with co-products including 0.25 t of pyrolygneous acid, 0.03 t of wood tar, and 780 m³ of gases. The particle size distribution of the biochar used in the experiments is not uniform, as it consists of a <0.25 mm fraction (38%), a 0.25–1 mm fraction (38%) and a 1–3 mm fraction (24%), respectively, as described earlier in details [34]. The main contents of the raw biochar are TN (10.4 ± 0.8, TOC 446.8 ± 15.1, total phosphorous (TP) 1.95 ± 26, total potassium (TK) 32.6 ± 7.2 (gkg^{−1})), and C: N 42.95 ± 3.7. The rapeseed cake was bought from the Yaojia Oil Mill company

(Nanyang, Henan Province, China). Its properties included 7.2% TN, 42.7% TOC, and a C: N ratio of 5.9. The initial physical and chemical properties of the soil are listed in Table 1.

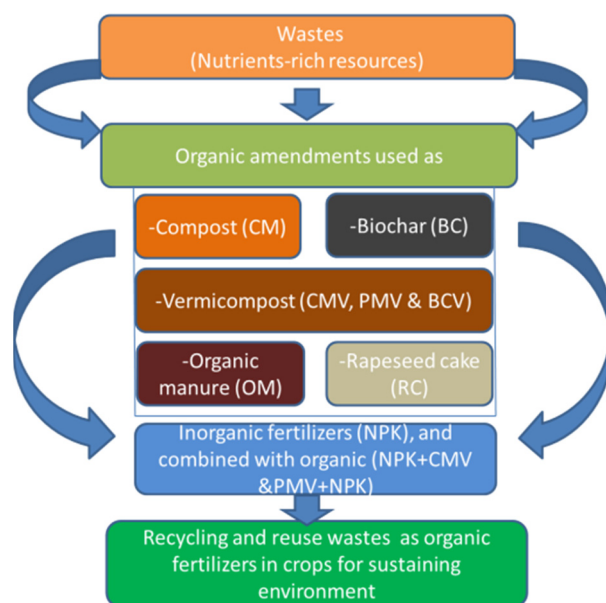


Figure 1. The conceptual diagram of organic wastes and their amendments after processing.

Table 1. Main physic-chemical properties of the soil utilized in the experiment. Values are means ($n = 3$) \pm standard errors.

Properties	Values
N (g kg^{-1})	0.75 ± 1.0
SOM (g kg^{-1})	8.7 ± 0.6
C:N ratio	7.4 ± 2.3
pH	8.1 ± 0.0
EC ($\mu\text{s cm}^{-1}$)	65 ± 0.4
Silt (%)	42 ± 0.5
Clay (%)	19 ± 0.4
Sand (%)	38 ± 0.3

2.3. Determination of Nutrient Contents

Biomass samples were dried at 60°C to a constant weight for approximately 72 h. The maize biomass was calculated on a dry weight basis. Each of the dry deposits was homogenized by grinding to a powder and passing it through a 0.5 mm sieve for analysis of TN and TOC using an elemental analyzer (Vario M Cube, Elemental Analysensysteme GmbH, Langenselbold, Germany). The pH and electrical conductivity (EC) of the compost and vermicompost were measured in a 1:10 solid-to-water solution using suitable pH and EC meters [35].

2.4. Statistical Analysis

Data were analysed for normal distribution using the Kolmorov-Smirnov test and for homogeneity of variance using the Levene test. We tested for significant differences in nutrient contents and biomass by use of One-way ANOVA and Fisher's Least Significant Differences (LSD) test. Microsoft Excel and Origin 9.0 software (Origin Lab Inc., Northampton, MA, USA) was used for data processing and graph plotting. Statistical analyses were conducted using SPSS 21.0 (SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. The Carbon, Nitrogen and C: N Ratios in the Aboveground and Belowground Biomass

The nutrient contents in the aboveground maize biomass with the application of organic amendments, originally combined with inorganic amendments as compared to synthetic fertilizers and control without fertilizers are shown in Table 2. The carbon and nitrogen contents as well as C: N ratios in the aboveground biomass of maize showed significant differences within the treatments after the experiment conclusion, as shown in Table 2.

Table 2. Maize aboveground biomass (AGB-C), nitrogen (AGB-N), and C: N ratio (mean \pm SD, $n = 3$).

Treatments	Aboveground Maize Nutrients		C: N ratio
	AGB-C (gkg ⁻¹)	AGB-N (gkg ⁻¹)	
CM	376.9 \pm 3.5 b	17.8 \pm 0.3 cd	20.9 \pm 1.1 abc
CMV	396.4 \pm 15.5 ab	18.7 \pm 0.6 bcd	20.8 \pm 0.6 abc
PMV	401.1 \pm 1.4 a	20.0 \pm 1.0 abcd	20.0 \pm 1.1 bc
BCV	397.2 \pm 2.2 ab	21.1 \pm 1.4 abc	18.8 \pm 1.4 bc
BC	405.5 \pm 3.4 a	15.7 \pm 1.6 d	25.9 \pm 2.8 a
NPK	407.5 \pm 2.8 a	21.2 \pm 0.7 abc	19.2 \pm 0.6 bc
CMV + NPK	401.5 \pm 3.9 a	20.8 \pm 1.3 abc	19.3 \pm 1.2 bc
PMV + NPK	410.2 \pm 18 a	21.4 \pm 1.8 abc	19.2 \pm 0.8 bc
OM	396.6 \pm 7.6 ab	22.6 \pm 1.4 ab	17.8 \pm 1.4 bc
RC	386.9 \pm 3.0 ab	23.4 \pm 2.3 a	16.6 \pm 1.7 c
CK	393.3 \pm 6.4 ab	18.4 \pm 1.7 bcd	22.4 \pm 5.6 ab

The sign \pm represent standard deviation ($n = 3$). The different letters above the columns indicate significant differences among treatments ($p < 0.05$). The details of treatments are as compost (CM), cow manure vermicompost (CMV), pig manure vermicompost (PMV), biochar vermicompost (BCV), biochar (BC), conventional synthetic fertilizers (NPK), CMV in addition to NPK (CMV + NPK), and PMV in addition to NPK (PMV + NPK), organic manure (OM), rapeseed cake (RC) and control without any fertilization (CK).

In general, the organic amendments showed stronger effects on the AGB-N content and C: N ratio compared with the effects on the AGB-C (Table 2). The TN contents showed significant differences within the treatments. The highest AGB-N was found for dried rapeseed cake (RC), $23.4 \pm 2.3 \text{ gkg}^{-1}$, which is significantly higher than BC. BC showed minimum TN contents ($15.7 \pm 1.6 \text{ gkg}^{-1}$). Our results are similar to earlier studies indicating reduced efficiency with a lower amount of biochar application [36], as its exudates have direct toxic effects and reduce reproduction of *M. graminicola* [37]. It may be due to an effect on nutrient availability that serves as a plant growth parameter. The significant differences in AGB-N rather than in AGB-C resulted in the opposite trend in C: N ratio, i.e., with the highest ratio in BC and lowest in RC treatment. The applied biochar (BC) alone has lower nitrogen contents as compared to biochar vermicompost-amendment (BCV).

The highest AGB-C content was found in PMV + NPK ($410.2 \pm 18 \text{ gkg}^{-1}$) and was significantly higher than CM but non-significant when compared with PMV. For detailed AGB-C comparisons among treatments, CM is significantly lower PMV. In the study [38], the biochar vermicompost increased the maize nutrients compared to control treatments and biochar used alone. All the treatments have a lower C: N ratio of less than 25 except for BC (25.9 ± 2.8) which is slightly higher PMV and BCV ($p < 0.05$). In our study region, the price of inorganic fertilizers is comparatively low which increases the application of direct use of inorganic fertilizers without balancing organic fertilization for soil health and improving crop growth [1].

The effects of organic amendments on the below-ground biomass carbon and nitrogen contents depend on the types of amendments. Vermicompost treatments (CMV, PMV, BC and BCV) showed positive effects on the BGB-C compares with only compost (CM), inorganic amendments (NPK) and CK.

As for the BGB-N, positive effects of organic amendments (CMV, PMV and PMV + NPK), were significantly higher than with CK. In contrast, the C: N ratios were stable regardless of organic amendments and other treatments. Biochar (BC) and vermicompost biochar-amendment (BCV) showed a sufficient amount of TN and slightly significant differences

compared with each other, due to available N contents in plant-derived biochar as contained in the heterocyclic structure [39]. BC was significantly different from RC which might be due to differences in substrate types as reported [40]. The TOC also increased due to particulate organic carbon incorporated in plants in the combined organic with inorganic treatment as compared to control which is consistent with our results as reported earlier [41]. The organic amendments that increased the N contents showed consistent results with the addition of biochar in upland soil. The N use efficiency might be an explanation for biochar addition to tropical soil [42]. The higher TN in plants might be due to the higher C: N ratios of particular treatments because they determine the rate of N release and uptake by the plants [43].

The belowground biomass (BGB) nutrient contents of maize have significant differences ($p < 0.05$) but the C:N ratios showed non-significant differences within the treatments as shown in Table 3. CMV has the greatest ($367.0 \pm 12.0 \text{ gkg}^{-1}$) and highly significant ($p < 0.01$) BGB-C contents as compared to CM and CK. TOC of aboveground biomass (AGB-C), TOC of belowground biomass (BGB-C) is also lower in CM and significantly different as compared to vermicompost treatments might be due to a greater stability and resistance to degradation as reported before [44].

Table 3. Maize belowground biomass with total organic carbon (TOC), total nitrogen (TN), and C: N ratio (mean \pm SD, $n = 3$).

Treatments	Belowground Maize Nutrients		
	BGB-C (gkg^{-1})	BGB-N (gkg^{-1})	C: N ratio
CM	$185.4 \pm 15.4 \text{ e}$	$7.8 \pm 0.9 \text{ d}$	$20.2 \pm 3.0 \text{ a}$
CMV	$367.0 \pm 12.0 \text{ a}$	$17.0 \pm 0.4 \text{ a}$	$21.5 \pm 0.2 \text{ a}$
PMV	$320.1 \pm 18.0 \text{ abc}$	$17.1 \pm 1.9 \text{ a}$	$18.8 \pm 1.6 \text{ a}$
BCV	$323.7 \pm 12.2 \text{ abc}$	$15.0 \pm 2.0 \text{ abc}$	$22.0 \pm 3.0 \text{ a}$
BC	$272.0 \pm 4.8 \text{ bcd}$	$10.0 \pm 2.7 \text{ cd}$	$24.3 \pm 3.7 \text{ a}$
NPK	$242.1 \pm 37.1 \text{ de}$	$14.0 \pm 1.6 \text{ abc}$	$17.2 \pm 0.7 \text{ a}$
CMV + NPK	$300.0 \pm 22.0 \text{ abcd}$	$15.7 \pm 1.5 \text{ ab}$	$19.1 \pm 0.6 \text{ a}$
PMV + NPK	$247.4 \pm 3.6 \text{ de}$	$16.8 \pm 1.0 \text{ a}$	$18.4 \pm 0.8 \text{ a}$
OM	$335.5 \pm 25.8 \text{ ab}$	$14.2 \pm 1.0 \text{ abc}$	$23.7 \pm 3.5 \text{ a}$
RC	$260.0 \pm 9.7 \text{ cd}$	$15.3 \pm 2.4 \text{ ab}$	$19.7 \pm 5.8 \text{ a}$
CK	$247.8 \pm 13.1 \text{ de}$	$10.7 \pm 0.0 \text{ bcd}$	$21.8 \pm 1.6 \text{ a}$

The sign \pm represent standard deviation ($n = 3$). The different letters above the columns indicate significant differences among treatments ($p < 0.05$). The details of treatments are as compost (CM), cow manure vermicompost (CMV), pig manure vermicompost (PMV), biochar vermicompost (BCV), biochar (BC), conventional synthetic fertilizers (NPK), CMV in addition to NPK (CMV + NPK), and PMV in addition to NPK (PMV + NPK), organic manure (OM), rapeseed cake (RC) and control without any fertilization (CK).

In our study, the increased amount of TOC with organic amendments might be due to formation of particulate carbon fractions in plants which enhances organic matter as studied before [45]. The vermicompost and biochar-amendment vermicompost-induced plant nutrients increase might be due to available nutrients in organic fertilizers and pathogens suppression processes [46,47].

3.2. Aboveground Biomass with Organic Amendments

The aboveground biomass of maize had significant differences ($p < 0.05$) within the treatments after the experimental duration as shown in Figure 2. The CM, CMV, PMV showed significantly higher values as compared to NPK and CK. The combined organic and inorganic treatments (PMV + NPK) showed significantly higher biomass while (CMV + NPK) was also found to give slightly higher values than NPK.

Our results showed that the application of organic amendments such as compost, vermicompost (with cow manure, pig manure) promoted the crop biomass as compared to NPK. Biochar and biochar vermicompost-amendments were also slightly comparable within each other, which is consistent with previous studies [48–50]. Total aboveground biomass in organic treatments was higher, except for RC, which is similar to previous findings regarding maize relative to without fertilizer [20]. Biochar application as organic

amendment slightly increased maize biomass compared with NPK and CK as shown in Figure 2, which is consistent with earlier results [51]. Biochar is a favourable medium for earthworms. The effects of biochar on maize growth have been studied in different agricultural systems related to temperate and tropical climates, respectively. The range of results depending on biochar type and climatic conditions while soil type also impacts negative changes on growth [52].

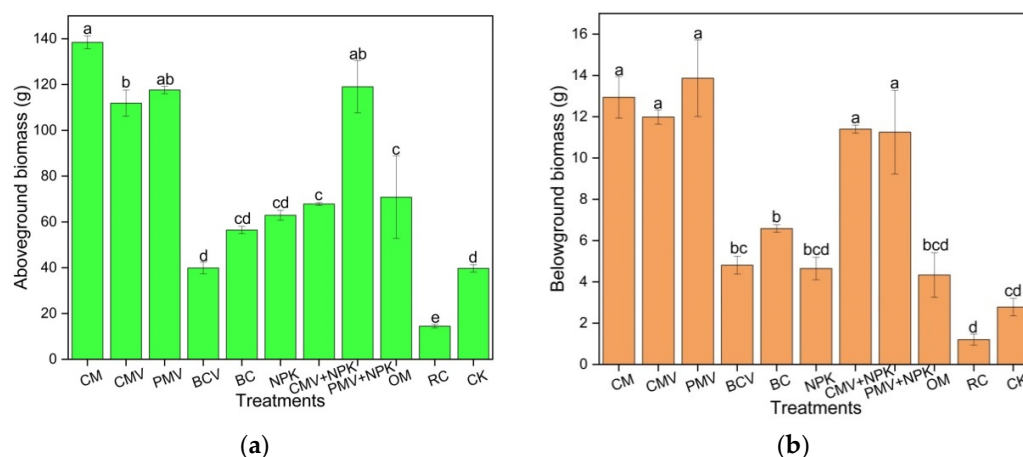


Figure 2. (a) Aboveground biomass, (b) Belowground biomass. Error bars represent standard errors ($n = 3$). The different letters above the columns indicate significant differences among treatments ($p < 0.05$).

3.3. Belowground Biomass with Organic Amendments

The belowground biomass of maize had significant differences ($p < 0.05$) within the treatments, as shown in Figure 2. PMV showed the largest belowground-biomass 13.8 ± 1 , showed significant differences as compared to NPK and CK. NPK showed significant differences with compost and vermicompost (CM, CMV, PMV) treatments. The combined (CMV + NPK and PMV + NPK), effects also showed significant differences as compared to NPK and CK.

The lowest below-ground biomass (1.2 ± 0.2) was found in RC and was significantly lower from other organic treatments. Although the lower values of above and below-ground biomass in RC showed lower significant differences, its higher nutrient values may be the reason it can be used as fertilizer if combined with inorganic fertilizers for plant growth as reported in an earlier study [8]. Biochar vermicompost-amendment (BCV) as soil amendment also enhanced the total biomass, which is consistent with other studies [11,53]. Better plant productivity was seen with applied compost and vermicompost, while the slight increase with biochar amendment is similar to our results and has been discussed in previous studies [11,54].

Vermicomposting was used as an eco-friendly technique to recycle organic waste materials and used as a natural fertilizer. Our results were similar to those described in an earlier study [37], explaining the impact of compost, vermicompost, and biochar on maize growth. The variations in maize biomass between the treatments may be attributed to the differential capability of rates of organic and inorganic amendments causing different available uptake of nutrient supply in plants, as seen in previous studies [42]. Besides reducing the increasing effect of synthetic fertilizers, current management needs to recycle the agricultural wastes as organic fertilizers applied into the soil for better crop biomass with rich nutrients in an eco-friendly way.

The study highlighted the importance of organic waste in bio-fertilizer that would help with economic sustainability. Vermicompost significantly enhanced TN and TOC contents. An increase in nitrogen content of soil and reduction in the C: N ratio makes vermicompost as efficient fertilizer source. The impacts of earthworm activities on vermicomposting for agricultural and ecological waste materials were studied for a more sustainable way and to

recover nitrogen and carbon contents, which is considered to be a significant plant nutrient. Biochar amendment for plant growth and soil fertility is increasing rapidly, but another way of applying an organic amendment such as biochar-vermicompost also recommendable for the agricultural ecosystem.

4. Conclusions

The adoption of organic amendments produced from organic waste materials by vermicomposting is a win-win approach to fulfil the four important criteria of reduce, recycle, reuse and recovery, to reduce environmental pollution and provide a sustainable agricultural system. Based on the results of this study we can make the following conclusions:

- (1) Different forms of organic amendments such as compost and vermicompost applications can be recommended for sustainable agricultural development.
- (2) Biochar-vermicompost (BCV) was found to be another form of organic fertilization for promoting organic amendments in agricultural systems to protect the environment.
- (3) RC showed higher N content but lower growth as an organic amendment, and the combination of RC with inorganic fertilizers might increase biomass. As some researchers put emphasis on a combined organic and inorganic fertilizer approach of in the future study this will be done for higher plant growth. Treatments with vermicompost alone have lower effects as compared to the combined application of vermicompost and NPK for better growth of maize biomass.
- (4) The results of this study will be helpful to promote the use of different types of organic amendments including compost, vermicompost, biochar, biochar-amendment vermicompost, organic manure and rapeseed cake, thus, the trade-offs should not be neglected.

Future economic analysis of different organic amendments based on this study of plant and soil nutrient balance will help to solve the problem of excessive use of inorganic fertilizers which causes environmental problems and provide important evidence for policy development for sustainability.

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