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Integrating vermicomposting in animal manure treatment to improve yield parameters of maize (*Zea mays*)

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ABSTRACT

The use of raw animal manure as fertilizer by smallholder farmers to increase agricultural productivity can cause serious environmental issues and an abnormal flavor of the production. These problems make manure treatment necessary before its application. This is possible if producers have the possibility to bear the cost. Vermicomposting is a low-cost and environmentally sustainable technology that transforms organic wastes into vermicompost to improve the productivity, but little is known about its efficacy on maize productivity in Côte d'Ivoire. The experiment consisted of three randomized complete blocks design with three replicates by using vermicompost from pig manure as fertilizer on a ferralitic soil during three season-cycles. The vermicompost was spread at different stages of the plant development. The agronomic parameters as the number of leaves under the ear, the insertion height of ears, plant height and yield attributes were investigated. Results showed that vermicompost improved the agronomic parameters of maize. The tallest plants, the highest number of branches per panicle (19.35±5.70), the highest number of leaves under the ear (7.35±0.93), and the highest insertion height of the ears (108.9±24.87 cm) were observed when the vermicompost was spread at the emergence stage. The highest yield attributes such as the diameter of ears (13.64±1.20 cm), the number of grains per row (38.18±10.30), the length of ear (18.52±2.56 cm), the weight of ear (195,24±49,57 g), the number of row of grains per ear (13.45±1.32) and the weight of 100 grains (17.11±3.79 g) were obtained when the vermicompost was spread at the emergence stage. The highest roots biomass (63.22±50.18 g) and aerial biomass (501.68±229.58 g) of the plant were obtained with the vermicompost spread at the emergence stage. This study recommends vermicompost spreading at maize emergence stage for its optimum productivity.

1. Introduction

Nowadays, achieving food security in Sub-Saharan Africa by raising the productivity of smallholder farmers, the cornerstone of most agricultural economies in that region, is still a challenge (Sasson, 2012). In Côte d’Ivoire, for example, maize is produced all over the country by smallholder farmers with very low productivity. However, maize is one of the most important cereals for human consumption because of its nutritional composition (Nuss and Tanumihardjo, 2010). For 100 grams of corn, the flour contains 10.91 % water, 0.64%

sugars, 6.93% protein, 0.7 % calcium, 3.1 % carbohydrates and 3.86 % lipids. Corn flour also contains vitamin B and energetic value of 76.85 kcal (USDA, 2018). All parts of corn crop can be used for food and non-food products.

The annual human consumption of maize in Côte d'Ivoire is 1,026,000 tons and the annual production is 967,000 tons per year for 278, 679 hectares (ATLAS, 2017). The productivity of maize in Côte d'Ivoire varied between 0.8 to 2 tons per hectare, which is very low compared to the worldwide productivity (5.5 tons/hectare/year). Consequently, Côte d'Ivoire still imports about 42,000 tons of maize per year to meet the needs of the populations (ATLAS, 2017). This has led to an increase of the price of the kg of maize grains (US $ 26.37/kg) (ATLAS, 2017) and therefore to a decrease of maize consumption per capita.

Soil fertility depletion has been described as one of the major biophysical root cause of declining per capita food production (Zake et al., 2015; Panagos et al., 2018). In the Sahel and Savanna of West Africa, soils are old, deep and poor in organic matter, with low capacity to retain nutrients, while this region is also the most densely populated in the continent (Jones et al. 2013). The climatic vulnerability of West Africa, aggravated by high rates of population growth, has prompted major efforts by governments and farmers themselves to intensify agricultural production (Pretty et al., 2011). Fertilization remains the most appropriate way to provide plants with the indispensable complement to the soil supply. The main purpose of mineral or organic fertilization is to satisfy the nutritive requirements of plants and to ensure their optimal growth and development (Elalaoui, 2007). The intensive use of chemical fertilizers at the expense of organic manure certainly increases immediately yield, but gradually destroys the soil (acidification of the environment, loss of mineral elements, release of heavy metals) (Hartmann et al., 2014 ; Kumar et al., 2014). In addition, these fertilizers are now increasingly expensive for small farmers with limited financial resources. In view of the disadvantages of synthetic mineral fertilizers, the need to use organic fertilizers, particularly animal manure produced in large quantity, as an alternative to this type of fertilizer is needed in the countryside. According to Djiakariya (2004), five thousand four hundred tons of pig manure are produced per year in Côte d'Ivoire. In fact, animal wastes can constitute a valuable source for improving soil structure, increasing microorganism's activity and maintaining soil humus (Ipinmoroti et al., 2008). Over 44% of farmers are using manure as fertilizer in Côte d'Ivoire (Lassina et al., 1993). The application of manure has contributed to increase the yield of various plants and was found superior to the yield obtained with mineral fertilization (Bockman et al., 1990; Soltner, 2003; Awodun, 2007). Zougmore et al. (2003) have reported that the application of animal manure on sorghum has increased the yield 20 to 39 times higher than that obtained without amendment. Similarly, N'Dayegamiye and Côté (1996) reported that animal manure intake, at a low dose for long term, achieved same levels of maize productivity as full mineral fertilization. Soro et al. (2015) reported significant improvement in maize productivity with chicken manure.

Despite the undeniable agronomic value of manure, its use in agriculture can cause serious environmental problems such as the emission of odors, the contamination of groundwater by metals, bacteria and nitrates (Elwell et al., 2001; Gay et al., 2003; Kunz et al., 2009; Venglovsky et al., 2009). In addition, while decomposing in the soil, manure is likely to release organic compounds such as skatole, indole and other phenols which, absorbed by plants, can give an abnormal flavor to the production (Maheshbabu et al., 2008). Although manure is an effective organic amendment, the unnatural flavor of the production and the estimation of ecological risks associated with its use make its treatment necessary before application. This may be feasible if smallholders have the opportunity to bear the costs. In recent years, a new method of treating organic wastes with earthworms (vermicomposting) has emerged. This technology is considered more suitable because it is a low-cost, environmentally friendly and sustainable, and allows fairly good stabilization of animal wastes before their use as fertilizer or soil conditioner (Yuvaraj et al., 2018).

The importance of vermicompost at increasing agricultural productivity of many crops, has been well documented (Jeyabal and Kuppuswamy, 2001; Tejada and Gonzalez, 2004a; Tejada and Gonzalez, 2004b; Tejada and Gonzalez, 2006; Guo et al., 2015; Coulibaly et al., 2016; Olle, 2016; Zaremanesh et al., 2017; Coulibaly et al., 2018; Adiloğlu et al., 2018). Despite these monumental research strides in this field, little is known about the effect of vermicompost on maize productivity in Côte d'Ivoire.

This study aimed to investigating the efficacy of vermicompost from pig manure on growth of maize crop in Côte d'Ivoire. Thus, the vermicompost was spread at different growth stages (before sowing, at emergence, and at flowering) of the plant in order to determine which of the stage application permit optimum growth and productivity of maize.

2.Materials and methods

2.1 Study site

The study was carried out at the experimental station of the University Nangui-Abrogoua (Abidjan, Côte d'Ivoire) located in Abidjan (latitudes 5°17 N - 5°31 N and longitudes 3°45W - 4°22W). The climate of the city of Abidjan corresponds to that of southern Côte d'Ivoire. It's a humid tropical climate (Durand and Skubich, 1982) with four seasons including two rainy seasons and two dry seasons. The big rainy season extends from April to July (4 months) and the short rainy season lasts two months (October and November). As for the big dry season, it covers 4 months (December to March), while the short dry season lasts two months (August-September) (Durand and Skubich, 1982). The average monthly temperature varies from 24.54°C in August to 28.45°C in March. The mean maximum precipitation is observed in the month of June (330.25 mm) and the minimum value in January (15.47 mm). The relative humidity is higher in September (91.94%) and lower in April (85.41%).

The soil of the experimental station of the University Nangui Abrogoua is ferralitic (ferralsol) (Yao-Kouamé and Allou, 2008). The pH is more acidic at the surface than at depth, and the organic matter content varies from 2 to 3% (Yao-Kouamé and Allou, 2008).

2.2 Biological materials

Large quantity of pig manure is produced per year in Côte d'Ivoire. The waste was collected in different farms in Abidjan to be used. The excreta were constituted of a mixture of faeces and urine without any bedding material. In order to facilitate the manipulation and reduce smell, the wastes were airdried before their use. The initial physico-chemical characteristics of pig were as followed: pH = 5.28, total carbon = 50.45%, total nitrogen = 0.35%, total phosphorus = 0.50%, total potassium = 0.76%.

The seeds of maize used in this experiment was a local variety called "Boundiali".

Some healthy adults of *Eudrilus eugeniae* weighing 500-1200 mg obtained from the University of Abobo-Adjamé were used in the experiment for the vermicomposting.

2.3 Preparation of the vermicompost

For the vermicompost preparation, 2 pits (1 m × 1 m × 1 m) were dug and their bottom cemented to avoid nutriments loss. The pits received 50 kilos of pig dried manure. The content of the different pits was turned over manually to remove volatile toxic gases, which may be potentially toxic to earthworms. The moisture content of the pits was also regularly adjusted to 70-80%. After pre-composting, each of the four pits received 750 individuals of *E. eugeniae* and covered up with the help of coconut palm leaves to avoid colonization by pests and to maintain humidity for three months.

2.4 Experimental design

The experimental design consisted of three randomized complete blocks. Each block (39.2 m^2) contained 4 plots of 8 m^2 each corresponding to the three different applications time of the vermicompost and the control. The plots were separated each another from a distance of 80 cm. Seedlings of maize were made three crop cycles. The sowing was done on the same day for all treatments with 3 seeds per hole at a depth of 2 to 3 cm at each cropping cycle. The lifting occurred 2 weeks after the sowing and the seedlings were thinned to keep only the two strongest at each sowing point. Sixty plants were retained per plot. A total of 1 kg of vermicompost was spread around the plants at each sowing point in each block at different stages of the plant development. The first consisted of 1 kg of vermicompost spread before the sowing, the second and the third were respectively at emergence stage and flowering stage. After the vermicompost application, it was buried on the same day at 15 cm depth in the soil with a hoe to avoid leaching and facilitate nutrients absorption by plant roots.

Vegetative, yield and biomass parameters were evaluated in this study. The vegetative parameters were the number of leaves under the ear, the insertion height of ears and plant height. Yield attributes investigated were the diameter of ears, the number of row of grains per ear, the number of grains per row, the length of ear, the weight of ear, and the weight of 100 grains. The roots biomass and the aerial biomass of the plant were also evaluated in this study.

Data were analyzed by factorial analysis of variance (ANOVA) using the statistical software R. Least Significant Difference (LSD) multiple range-tests procedure were used to separate the means of the different treatments. Means were given as mean followed by standard deviation (M ± SD). Significant differences were determined at $P \leq 0.05$.

3.Results and discussion

The height of the plant differed significantly in function of the spreading time of the vermicompost (Figure 1). At 45 days, the tallest plant (66.3±20.08 cm) was measured when the vermicompost was spread at the emergence stage of the plant and the shortest plant (22.45±9.05) was obtained with no fertilizer (control). The height of the plant when the vermicompost was applied before sowing and at flowering stage was respectively 34.45±15.94 cm and 38.05±10.73 cm. However, there was no significant difference ($P > 0.05$) between these latter heights.

At 60 and 75 days, the plant height varied respectively from 42.28±30.49 cm to 210.53±40.10 cm and from 76.99±37.18 cm to 210.53±40.10 cm. At both dates, the tallest plants were obtained when the vermicompost was spread at the emergence stage and the shortest were got in the control plots. The tallest plants got with the vermicompost compared to the control could be explained by the efficacy of the vermicompost. In fact, vermicompost is known to contain plant nutrients that can favor plant growth (Suthar, 2008; Lim et al., 2012; Varma et al., 2016). In addition, vermicompost significantly improves the physico-chemical properties of the soil and therefore plant growth (Suthar, 2008). In contrast, the shortest plants in the control might be linked to the lack of nutrients. Nitrogen and phosphorus are the important nutrients which play major role in the cell growth. The growth of maize could be justified by a higher dose of nitrogen and phosphorus in the vermicompost. After germination, plant may need nutrients for its growth and that moment might be the best to apply the fertilizer for taller plants. However, the height of maize obtained in this study were higher than those obtained by Coulibaly et al. (2019) when applying compost from pig and

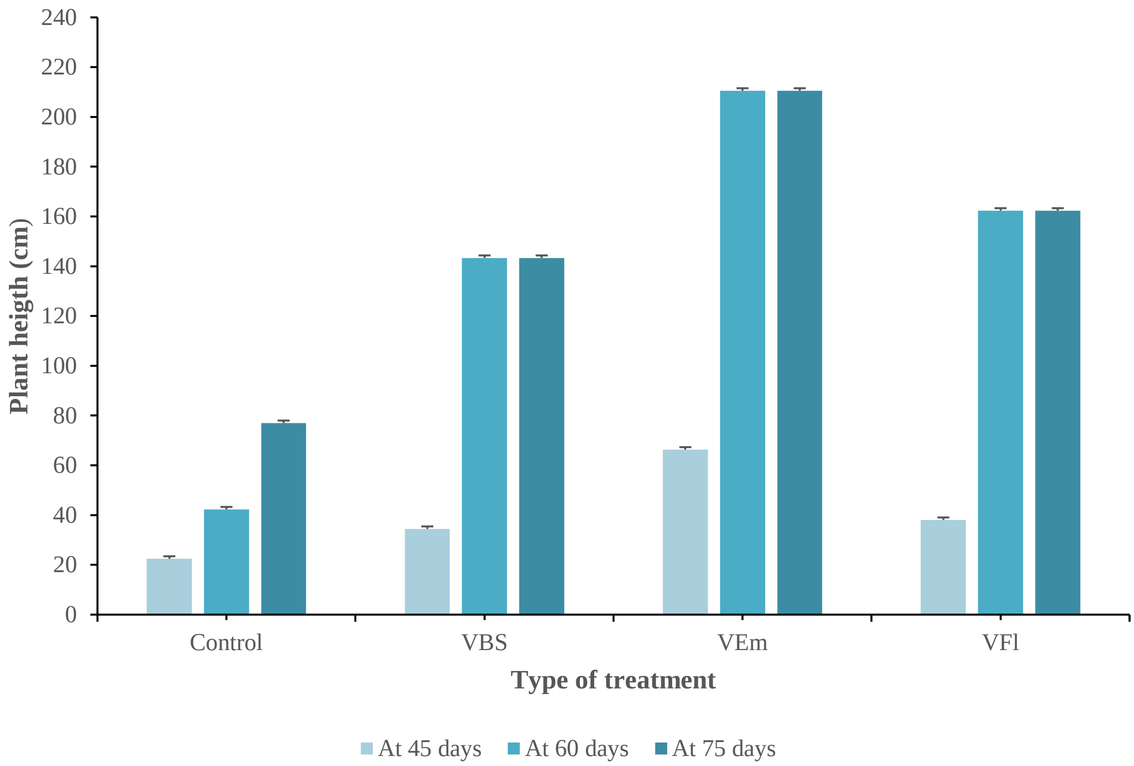

Figure 1. Effect of the application time of the vermicompost on maize height. VBS: Vermicompost before sowing, VEm: Vermicompost at emergence stage, VFl: Vermicompost at flowering stage.

Table 1. Effect of vermicompost application time on maize growth

Parameters	**Vermicompost application**				**Statistical parameters**	
	Before sowing	At emergence stage	At flowering	No vermicompost (Control)	*F*	*P*
IHE (cm)	60.60±19.81[b]	108.9±24.87[a]	77.26±19.91[b]	29.12±21.36[c]	30.41	<0.001
NLUE	7.30±1.03[a]	7.35±0.93[a]	6.50±0.76[b]	5.10±2.75[b]	8.08	<0.001
NBP	11.65±5.49[b]	19.35±5.70[a]	13.95±5.49[b]	8.45±5.72[b]	23.75	<0.001

Mean values of parameters denoted with the same letter in each row were not significantly different.
IHE: insertion height of ears, NLUE: number of leaves under the ear, NBP: number of branches per panicle

chicken manure. The plant heights at the end of the experiment were also higher than the 1.7 m observed by Ridine et al. (2014) when applying bat's manure and NPK as fertilizer. Nutrients in the vermicompost might be more mobile, available and therefore easily absorbable by plant than that in the compost and raw manure and that might be due to earthworms' activity.

The vegetative parameters of maize in function of the spreading time of the vermicompost are registered in Table 1. The insertion height of ears, the number of leaves under the ear, the number of

Table 2. Effect of vermicompost application time on yield attributes

Parameters	Vermicompost application				Statistical parameters	
	Before sowing	**At emergence**	**At flowering**	**No vermicompost (Control)**	***F***	***P***
DiE (mm)	9.59±0.88[bc]	13.64±1.20[a]	12.42±1.67[ab]	8.07±3.67[c]	26.27	<0.001
LE (cm)	9.61±1.85[c]	18.52±2.56[a]	14.20±4.51[b]	8.85±5.62[c]	21.41	<0.001
NGr/R	16.75±7.49[b]	38.18±10.30[a]	25.82±8.96[b]	9.57±11.15[b]	27.24	<0.001
NRGr/E	12.20±1.61[a]	13.45±1.32[a]	12.75±1.33[a]	7.25±5.86[b]	13.44	<0.001
W_{100} (g)	10.26±2.52[c]	17.11±3.79[a]	13.83±3.27[b]	5.11±4.48[d]	24.45	<0.001

Mean values of parameters denoted with the same letter in each row were not significantly different.
DiE: Diameter of ear, NGr/R: Number of grains per ear, LE: length of ear, NRGr/E: Number of row of grains per ear, W_{100}: Weigh of 100 grains.

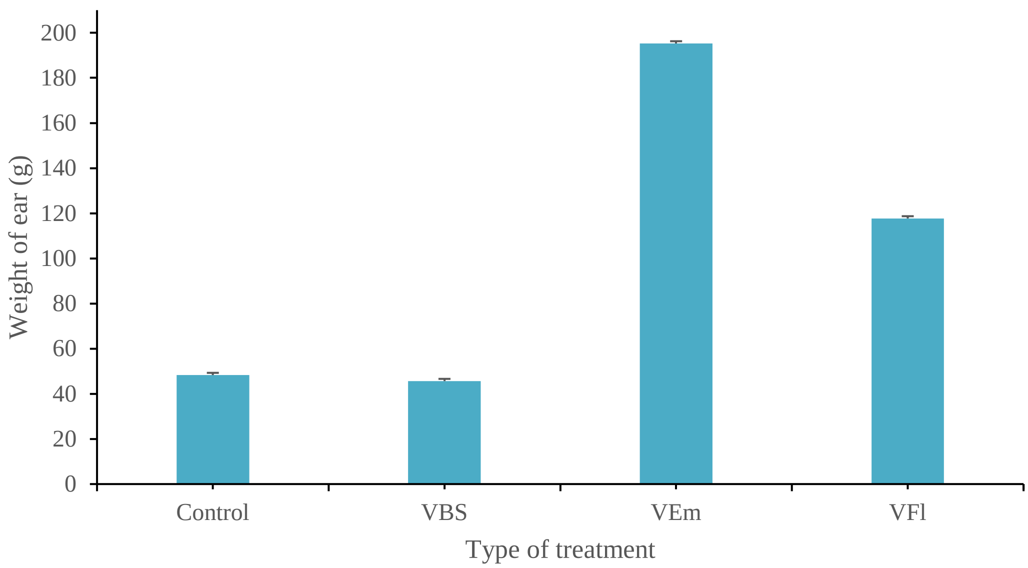

Figure 2. Weight of ear in function of the application time of the vermicompost. VBS: Vermicompost before sowing, VEm: Vermicompost at emergence stage, VFl: Vermicompost at flowering stage.

branches per panicle respectively differed significantly in function of the application time of the vermicompost. The highest insertion height of ears (108.9±24.87 cm), the number of leaves under the ear (7.35±0.93), the number of branches per panicle (19.35±5.70) respectively were obtained when the vermicompost was spread at the emergence stage and the lowest of each previous was obtained in the control plots. The decreasing order of these parameters was obtained with the vermicompost applied at the emergence stage followed respectively by those obtained when the vermicompost was spread at the flowering stage, before sowing and in the control plots. These results could be explained by the fact that, before germination, the plant doesn't have roots to absorb

Table 3. Effect of vermicompost application time on maize biomass.

Parameters	Vermicompost application				Statistical parameters	
	Before sowing	**At emergence stage**	**At flowering**	**No vermicompost (Control)**	***F***	***P***
RBio (g)	22.31±16.37[b]	63.22±50.18[a]	13.60±8.48[c]	11.79±9.12[c]	26.27	<0.001
ABio (g)	216.72±77.21[c]	501.68±229.58[a]	246.72±125.74[b]	108.84±117.48[d]	22.31	<0.001

Mean values of parameters denoted with the same letter in each row were not significantly different. RBio: Roots biomass, ABio: Aerial biomass.

nutrients. Consequently, these nutrients can be leached easily and cannot be profitable to the plant. In contrast, after germination, roots can absorb the nutrients and that can favor the growth of the vegetative parameters. At the stage of flowering, nutrients supply would be too late to boost the growth of the vegetative parameters. The ear insertion level in our study was shorter than the 205 cm got with maize by Soro et al (2015) while spreading poultry manure composted for 6 months in Côte d'Ivoire. This difference might be due to the initial characteristics of the raw material used as fertilizer. However, a very high insertion level of ear can make difficult the harvest.

Yield attributes (the diameter of ear, the number of row of grains per ear, the number of grains per row, the length of ear and the weight of 100 grains) are registered in Table 2. Statistically, yield attributes varied significantly from one to another. The weight of the ear also differed in function of the application time of the vermicompost (Figure 2). The mean diameter of ears ranged from 8.07 mm obtained with the control to 13.64 mm measured with the vermicompost spread at plant emergence. The longest ear (18.52 cm) was observed after spreading the vermicompost at the emergence stage and the shortest (8.85 cm) was got without vermicompost. Similar length of ear (18.83 cm) was measured by Yigermal et al. (2019). In contrast, lower ear length of 16.85 cm was reported by Laekemariam and Gidago (2012) after compost application.

The number of grains per row was 16.75, 38.18, 25.82 and 9.57 respectively with the vermicompost applied before sowing, at emergence, at flowering and without vermicompost (control). Concerning the number of row of grains per ear, it varied from 7.25 to 13.45. The highest row of grains per ear was obtained when the vermicompost was spread at the emergence (13.45) and at flowering (12.75). The weight of 100 grains differed significantly from one treatment to another. The heaviest grains (17.11 g) were obtained when the vermicompost was spread at the emergence followed in decreasing order by those got when the vermicompost was applied at flowering (13.83 g), before sowing (10.26 g) and with no vermicompost (5.11 g).

In general, the different parameters were more important with the vermicompost compared to the control. That can be explained by the higher nutrients content in the vermicompost. Kmetova and Kovacik (2014) obtained an increase in maize yield and its attributes after vermicompost application compared to the control. Vermicompost might contain more essential available nutrients for maize productivity. Among vermicompost treatments, the highest yield attributes were obtained while spreading the vermicompost at the emergence stage. This justify that emergence stage is the best moment to spread the vermicompost for yield increasing. The plant might absorb more nutrients for its growth and for the next coming function as yield and its attributes at the emergence stage. At flowering stage, nutrients might be less useful for the yield as the flowers had already appeared. Also, larger amount of nutrients brought before sowing can be lost by leaching or volatilization before roots appearance. Similarly, Sutharsan and Rajendran (2010) observed a variation in maize yield and its attributes when applying a liquid organic fertilizer at different times on maize plant

Table 3 encapsulates roots biomass and aerial biomass of maize plant in function of the application time of the vermicompost. It appeared that both biomasses differed statistically ($P < 0.001$) in function of the application time of the vermicompost. The highest roots biomass (63.22±50.18 g) was obtained when the vermicompost was spread at the emergence stage followed respectively by those before sowing (22.31±16.37 g), at flowering (13.60±8.48 g) and the control (11.79±9.12 g). Concerning the aerial biomass, the highest was got when the vermicompost was applied at the emergence stage and the lowest was obtained from the control plots. However, the aerial biomass observed when the vermicompost was spread at the flowering stage was statistically higher than that obtained when applying the vermicompost before sowing. Whatever, the time of application of the vermicompost and in the control, the aerial biomass was higher than that of the roots. This can be explained by the fact that roots stock less nutrients than the aerial parts. Roots might absorb the nutrients and lead them to the aerial parts for their development. So, the more aerial parts require nutrients, roots could no longer stock them for their development and this lead more to an increase of the aerial biomass of the plant than the roots biomass.

Conclusion

The obtained results suggest that vermicompost increases yield attributes of maize. Also, the application time of the vermicompost influences maize growth and its yield parameters. The tallest plants, the highest number of branches per panicle, the highest number of leaves under the ear, and the highest insertion height of the ears were observed when the vermicompost was spread at the emergence stage. The highest yield attributes such as the diameter of ears, the length of ear, the weight of ear, the number of row of grains per ear, the number of grains per row, and the weight of 100 grains were measured when the vermicompost was spread at the emergence stage. The highest roots biomass and aerial biomass of the plant were obtained when the vermicompost was spread at the emergence stage.

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Conflict of interest

The authors declare that there is no conflict of interest for the present work.

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