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RESEARCH ARTICLE

A comparative analysis of composts and vermicomposts derived from municipal solid waste for the growth and yield of green bean (*Phaseolus vulgaris*)

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Abstract This work was conducted to evaluate and compare the responses of *Phaseolus vulgaris* to three types of composts and vermicomposts derived from municipal solid waste (MSW). Different amendment rates were used and evaluated for their effect on germination, growth, and marketable yield. MSW-derived vermicomposts and composts were substituted into mineral brown-earth soil, applied at rates of 0 (control), 10, 20, 30, 40, 50, and 100% (*v*/*v*) in plastic pots of 7.2-L capacity. Green beans which are grown in 40% vermicompost/soil mixtures and compost/soil mixtures yielded 78.3–89.5% higher fruit weights as compared to control. Results showed that MSW vermicomposts consistently outperformed equivalent quantities of composts in terms of fruit yield, shoot, and root dry weights, which can be attributed to the contributions of physicochemical properties and nutrients content (N, P, and K) in the potting experiments. Consequently, it seemed likely that MSW vermicompost provided other biological inputs such as plant growth regulators (PGRs) and plant growth hormones (PGHs), which could have a considerably positive effect on the growth and yields of *P. vulgaris* as compared to composts. More in-depth scientific investigation is required in order to identify the distinctive effects and the exact mechanisms of these PGRs in MSW vermicomposts which influenced plant growth responses.

Keywords MSW-derived compost · Vermicompost · *Phaseolus vulgaris* · Plant growth · Yield · Plant uptake

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Introduction

As a result of urban development, progressive growth of the world's population, and thus the production of intensive solid waste, great quantities of municipal solid waste (MSW) are being generated around the world and causing a serious disposal issue and key concern for the environment. These wastes require large areas for disposal, and the release of odor, noxious gas, and contamination of groundwater with pollutants may cause threat to a variety of human health problems. The direct addition of MSW to soil is not typically done since it can render the soil uncultivable through degraded soil structure, production of phytotoxic substances, and nitrogen inactivation (Warman and AngLopez 2010). Instead, these wastes can be treated in order to render them appropriate for direct land application and for harmless discarding into the environment. The application of organic amendments produced from traditional thermophilic composting into soil has been recognized as an efficient way of enhancing soil fertility and structure (Fornes et al. 2012), increasing microbial activity, improving the moisture-holding capacity of soils (Arancon et al. 2004), improving soil organic matter (Paradelo and Barral 2012; Ounia et al. 2014), and increasing crop yields. There has been an ever increasing interest to decrease the rate of inorganic fertilizer additions to soil as a result of employing the soil nutrients more effectively and by the augmented utilization of organic matter. Vermicomposts which are the products obtained from the aerobic biodegradation and stabilization of organic materials, involving interactions among earthworms and microorganisms, have been shown to significantly improve soil quality, relative to other organic matter sources (Arancon et al. 2005). Vermicomposts are a fine substance similar to peat and typically with an elevated porosity, aeration, drainage, and water-retention characteristics. They typically have a high level of mineral elements relative to commercially available soilless plant growth media Metro-Mix 360 (MM360) (Arancon et al. 2005) and mineral soil. Some of these important mineral elements are converted into more convenient soluble forms which are used for plant uptake (Nair et al. 2006), such as nitrates, phosphates, soluble potassium, calcium, and magnesium (Orozco et al. 1996). Previous experiments which have been carried out in the greenhouse of The Ohio State University have established that vermicomposts consistently promote biological activity, which can increase germination, enhanced rates of seedling growth, and yields of various greenhouse crops than in commercial container media (Buckerfield et al. 1999; Atiyeh et al. 2000a, b, 2001, 2002a). Antecedent reports from small-scale field experiments have shown that mixing soils with vermicomposts can promote the growth and yield of certain crops such as cress (Masciandaro et al. 1997), tomatoes (Arancon et al. 2003), strawberries (Arancon et al. 2004), and cluster beans (Karthikeyan et al. 2014). Plant growth regulators (PGRs) and other plant growth effecting materials involving humates (Atiyeh et al. 2002b) produced by microorganisms are present in vermicomposts (Tomati et al. 1990). Also, large amounts of humic substances are present in vermicomposts (Masciandaro et al. 1997) and the responses of soil-applied PGRs or plant growth hormones (PGHs) have been proven to be very alike to those of humic substances on plant growth (Arancon et al. 2003). Vermicompost is best used as a potting media, organic amendment, and soil conditioner for agricultural purpose since it contains plant-available nutrients and organic matter (Mainoo et al. 2009). In comparison, composting and vermicomposting are distinctive technologies, mostly concerning the natures of microbial communities that prevail during active phase and the optimal temperature for each biological system. Thus, the two processes generated different end-products, whereby vermicomposts are much finer than composts in composition (Edwards and Burrows 1988) and with a higher level of nutrients than composts (Soobhany et al. 2015a) that are readily taken up by plants in suitable forms. Thus, it is surmised that significant differences will be obtained in the performances and effects of composts and vermicomposts on plant growth when used as soil additives or components for horticulture purpose. However, the majority of research on the use of vermicompost has been in the greenhouse or field into a soilless growth medium (MM360), and very few researchers have accounted on the utilization of composts and vermicomposts into mineral soil in a controlled environment. MM360 is a commercial greenhouse container medium and is prepared from vermiculite, Canadian sphagnum peat moss, bark ash, and sand and contains a starter nutrient fertilizer in its formulation as reported by Atiyeh et al. (2001). Although few studies researched on the effects of plants to the substitution of vermicomposts only, either to soil or MM360 (Edwards and Burrows 1988; Wilson and Carlile 1989), reports on composts or vermicomposts derived from MSW as plant growth media on green beans have received very little attention. The advantageous effects that vermicomposts have on plant growth have been affirmed from these few studies, but differences on plant growth effects between composts and vermicomposts were not reported. Hence, the focal theme of this study evaluated and compared the responses of green beans (*Phaseolus vulgaris*) as test crop upon different substitution rates of three types of composts and vermicomposts (food, paper, and yard) produced from MSW into mineral brown-earth soil.

Materials and methods

General

The MSW-based composts and vermicomposts (food, yard, and paper) were provided by the Agricultural University Farm, Reduit. MSW was composted and vermicomposted by the same method as adapted by Soobhany et al. (2015b) and used for the effect on plant growth in this current study. The measured variables included germination rate, shoot length, marketable yield, shoot, and root dry weights. Plant growth was affected by the physicochemical properties of the medium and the mechanisms of MSW vermicomposts. It has been observed that the applications of immature composts resulted in nutrient toxicity or deficiency symptoms in plants (Warman and AngLopez 2010). Therefore, composts and vermicomposts were given time to mature, and their impact was evaluated in terms of growth of green beans in a greenhouse pot trial. Green beans are typically grown by conventional methods with inorganic fertilizers and pesticides. These species were chosen for the study because they are well established in Reduit. Moreover, these plants were chosen on the basis of their growth characteristics and lack of studies on how green beans respond to organic fertilizer.

Location of experiment and physicochemical analysis

The experiments were carried out in the greenhouse of the Agricultural University Farm at the University of Mauritius, Reduit, Mauritius. The basic plant growth medium was mineral brown-earth soil and substitutions of soil with compost or vermicompost derived from MSW (food waste, paper waste, or yard waste). The application of each different type of composts or vermicomposts into mineral soil comprised a separate experiment. By mixing soil with vermicompost from MSW, the percentage porosity and the air space of the resulting mixture are enhanced since vermicompost are known to have high water-retention characteristics (Atiyeh et al. 2001). The preliminary essential chemical properties of soil and the MSW-derived compost and vermicompost in this study are characterized in Table 1. Basically, CS1 and VS4 designated the food waste compost and vermicompost, respectively; CS2 and VS5 represented the paper waste compost and vermicompost, respectively; and CS3 and VS6 denoted the yard waste compost and vermicompost, respectively, which were derived from the MSW. The percentage of total C and N for soil was analyzed using a EURO EA Elemental Analyzer (CHNS). The pH and electrical conductivity (EC) were determined by a pH and conductivity meter in water extracts (1:20, *w*/*v*), respectively. The total phosphorus was determined by PhosVer® 3 Method using Hach DR2500 and Method 8048 with program 535 P React PV TNT, and total K was analyzed using the Flame Photometer 410.

Plant growth experiment

To grow seedlings of green beans (*P. vulgaris*), the method was to sow the seeds in vermicompost growth media and compost growth media in the greenhouse. MSW-derived vermicomposts and composts were substituted into mineral soil, applied at rates of 0 (control), 10, 20, 30, 40, 50, and 100% (*v*/*v*) (with all nutrient levels balanced) in plastic pots of 7.2-L capacity. It has been researched that plants could be supplied with the necessary nutrients through vermicompost added to the container medium consequently diminishing the use for additional inorganic fertilizer (Atiyeh et al. 2001). Moreover, vermicomposts typically have high N contents (Ruz-Jerez et al. 1992). The total N content was 1.86 ± 0.20% for the food waste vermicompost, 1.60 ± 0.02% for the paper waste vermicompost, and 1.59 ± 0.05% for the yard waste vermicompost. In addition, the total N content in the compost samples were 1.52 ± 0.06, 1.56 ± 0.08, and 1.61 ± 0.00% for the food waste compost, paper waste compost, and yard waste compost, respectively. Thus, no supplemental fertilizer was added to the potting mixtures. Regarding the addition of additives or synthetic fertilizers, it was found that the growth of unwanted microorganisms, particularly human pathogens could be promoted which could eventually be conveyed to food crops, thereby causing health threats to consumers (Edwards et al. 2011). Therefore, substitution above 50% was not assessed since for the most part, substituting more than 50% of the soil (by volume) with vermicompost has resulted in stunted plants due to the presence of plant growth hormones in the casts (Atiyeh et al. 2002a; Arancon et al. 2004). Each potting treatment using the three types of compost and vermicompost was replicated three times (18 soil/compost mixtures, 18 soil/vermicompost mixtures, and 1 soil control), comprising a total of 57 potting treatments for each set of mixtures. One-hundred-seventy-one seeds (3 seeds in each pots; total of 57 pots) of green beans, which were obtained from Barkly Experiment Station, Ministry of Agro Industry and Food Security, Beau Bassin, Mauritius, were sown into 100, 90, 80, 70, 60, or 50% soil substituted with 0, 10, 20, 30, 40, or 50% food waste, paper waste, or yard waste composts and vermicompost, respectively, in plastic pots. The plant growth parameters of this study were measured for a period of 55 days after sowing. The N, P, and K requirements for green beans are 39, 39, and 60 kg/ha, respectively (Agricultural Research and Extension Unit 2010). According to the surface area of one pot which was 490.87 cm^2, the N, P, and K requirements were calculated to be 0.191, 0.191, and 0.295 g, respectively. The N, P, and K contents in the greenhouse potting experiments at different rates for green beans were tabulated in the Supporting information Table A.1.

Table 1 Chemical properties of soil, MSW compost, and MSW vermicompost

Medium	pH	EC (dS/m)	Total N (%)	Total C (%)	Total P (%)	Total K (%)
Soil	5.65 ± 0.05 a	0.113 ± 12.5 a	0.96 ± 0.05 a	9.01 ± 0.12 b	0.03 ± 0.00 a	3.57 ± 0.30 a
CS1	7.40 ± 0.05 e	4.53 ± 0.61 d	1.52 ± 0.06 b	26.89 ± 1.80 b	0.47 ± 0.07 de	3.79 ± 0.20 a
CS2	6.88 ± 0.03 d	2.55 ± 0.35 b	1.56 ± 0.08 b	28.57 ± 0.31 bc	0.14 ± 0.00 ab	2.10 ± 0.73 a
CS3	6.84 ± 0.02 cd	4.19 ± 0.24 cd	1.61 ± 0.00 b	35.58 ± 0.83 c	0.35 ± 0.05 cd	2.25 ± 0.23 a
VS4	6.53 ± 0.21 bcd	2.68 ± 0.13 b	1.86 ± 0.20 b	29.47 ± 0.70 bc	0.52 ± 0.04 e	2.98 ± 0.86 a
VS5	6.41 ± 0.02 bc	2.96 ± 0.10 bc	1.60 ± 0.02 b	24.97 ± 0.29 b	0.26 ± 0.02 bc	2.45 ± 0.23 a
VS6	6.31 ± 0.05 b	1.29 ± 0.16 a	1.59 ± 0.05 b	26.73 ± 4.03 b	0.40 ± 0.00 de	2.65 ± 0.06 a

Values (means ± standard deviations) followed by different letters in the same columns for each mixtures are statistically different (ANOVA; Tukey's HSD test, $p < 0.05$)

Plant growth measurement and analyses

The pots were put in the greenhouse under identical ambient conditions (temperature 25 ± 3 °C), where they were watered as required with tap water. For the green beans, the formation of intact seedlings was deemed as normal, whereas damaged seedlings were regarded as abnormal ones. For the calculation of germination rate, only normal seedlings were counted since they could promote entire growth as shown in previous research (Joshi and Vig 2010). The germination rate of green beans was recorded for each treatment. Various growth and yield parameters like the mean shoot length (distance from the potting medium level to the peak node), marketable yield/plant in the composts, and vermicomposts were observed daily and recorded for each treatment and compared across different substitution rates. Fifty-five days after sowing and after harvest, two plants from each mix (soil/compost mixtures or soil/vermicompost mixtures or control) were set apart into shoot and root sections for the determination of dry weight measurements. The shoots were then dried at 60 °C in an oven (OF-750G JEIO TECH) for 3 days (Arancon et al. 2008) for the determination of the shoot dry weight.

Statistical analysis

All results were represented as the average of three replicates. The data recorded for the plant growth parameters were subjected to an analysis of variance (ANOVA) in a general linear model. Tukey's HSD test was used as a post hoc analysis to compare the means (IBM SPSS Package, version 20) for all plant growth and physicochemical parameters. The means were grouped for orthogonal contrasts: (a) composts versus soil, (b) vermicomposts versus soil, and (c) composts versus vermicomposts. Significance was defined as $p < 0.05$.

Results and discussion

Effects of compost and vermicompost on growth parameters

Effects of compost and vermicompost on germination and shoot length

The data demonstrated notably increased rates of germination of green beans in the greenhouse experiments, in response to the three types of vermicomposts produced from MSW. The green bean seeds demonstrated consistent faster growth, most noteworthy when vermicomposts were present in the potting mixtures with frequent emergence of the green bean seedlings as early as 5 days after sowing in all the three types of vermicompost/soil mixtures. As shown from Fig. 1a, b, the germination rates upon substitution of 20, 30, 40, 50, and 100% vermicompost and substitution of 40 and 50% compost into soil were greater than the control (soil). On the whole, it was observed that germination percentage in terms of normal seedlings was maximum (100%) in compost and vermicompost treatment when compared to the control (67%). Thus, it could be noted that vermicomposts improved seedling emergence over that in a commercial plant growth medium, which is similar to results by other researchers (Edwards and Burrows 1988; Subler et al. 1998). Similar improvement in germination trends for radishes in 0–100% mixtures of vermicompost and sand were obtained by Buckerfield et al. (1999). Moreover, Roberts et al. (2007) found that cattle manure vermicompost processed by the earthworm *Dendrobaena veneta* (Rosa) significantly raised the germination rates of tomato by 176%. Treatments VS4, VS5, and VS6 showed germination percentage of 100% at the substitution rate of 20%, whereas its respective compost treatments CS1 showed a lower germination rate of 33%, and CS2 and CS3 showed a germination rate of 67%. Moreover, at the substitution rate of 30%, treatments VS4, VS5, and VS6 showed germination rate of 100%, whereas its respective compost treatments CS1, CS2, and CS3 showed a lower germination rate of 67%. Gradual decrease in germination indices in treatments CS1, CS2, and CS3 at 20 and 30% substitution rates compared to vermicompost treatment could be attributed to presence of nitrogen in excess (Buckerfield et al. 1999), which might consequently leads to germination inhibition. However, the germination rates of the green beans grown in the different vermicompost/soil mixtures were not significantly different (ANOVA; $F = 0.500$, $p = 0.616$) from those grown in the control. Likewise, the germination rates of the green beans grown in the compost/soil mixtures were insignificant (ANOVA; $F = 0.086$, $p = 0.918$). Surface crusts were observed at a substitution rate of 100%, which contained the greatest amounts of composts from CS1, CS2, and CS3, and this might further explain the significantly lower germination of green beans in this substitution. An anaerobic condition in the potting mixtures might have been caused from crusting, which could therefore contribute to phytotoxicity as elaborated by Warman and AngLopez (2010). Therefore, it could be hypothesized that organic materials in the composts might have contributed to the production of phytotoxic substances and this is what reduced germination, rather than soluble salts.

In comparison, between Fig. 1c, d, VS5 showed that the maximum shoot length (62.5 ± 6.7 cm) reached for green beans upon substitution of 30% paper waste vermicompost and the minimum shoot length (13.0 ± 4.9 cm) was recorded upon substitution of 100% of vermicompost from VS5. Green beans grown in 100% vermicompost potting mixtures (VS4, VS5, and VS6) were shorter than those grown in the 100% soil (control), and the result corresponded with the investigation made by Atiyeh et al. (2000b), who reported that tomato seedlings grown in 100% pig manure vermicompost were

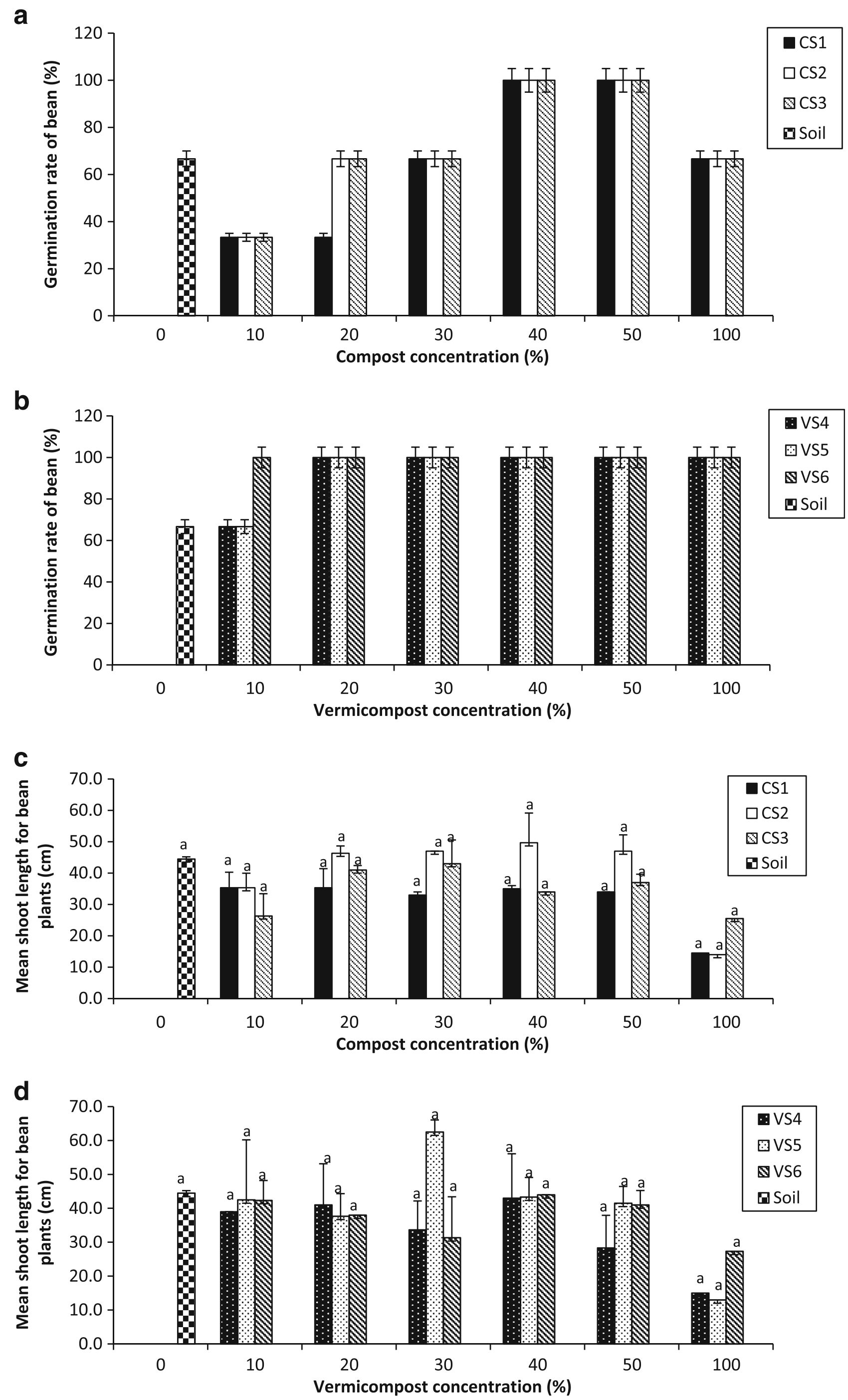

Fig. 1 **a** Germination rate (%) for green bean under compost concentration. **b** Germination rate (%) for green bean under vermicompost concentration. **c** Mean shoot length for green bean plants under compost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$). **d** Mean shoot length for green bean plants under vermicompost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$)

shorter than those grown in the 100% MM360 controls. From this study, it could be noted that substituting soil with 30% paper waste vermicompost (VS5) increased shoot length of green beans at a percentage of 28.8% over those grown in the control mixture, which was somewhat similar with the research made by Atiyeh et al. (2001) on tomato plants at a substitution rate of 50% vermicompost with MM360 (percentage increase of 27.4%). The results of this study confirmed earlier findings by Atiyeh et al. (1998), who reported that the growth of crops do not always increase by the addition of vermicomposts more in response to larger substitution of MM360 with vermicompost at an application rate (100%) than to smaller ones (30–50%). Also, the PGH content of the earthworm casts could explain the difference in the shoot length reached for the different treatments (Arancon et al. 2006). Stimulating effects of MSW vermicomposts and composts could be seen when comparing the shoot length of the seedlings, which have been substituted with compost and vermicompost to that of the control (soil), which is similar to results reported by Chan and Griffiths (1988), on the effect of vermicomposts generated from pig wastes on the growth of soybeans. An insignificant increase in mean shoot length of green bean plant was observed upon addition of different concentrations of vermicomposts from MSW (ANOVA; $F = 1.129$, $p = 0.349$), and this increase corresponds to the findings made by Gutierrez-Miceli et al. (2007), during the application of vermicompost derived from sheep wastes to soil grown tomato. Also, the difference in shoot length of green beans grown in the different compost/soil mixtures was insignificant (ANOVA; $F = 0.512$, $p = 0.609$).

Marketable yields

Yang et al. (2015) reported that tomato yields in plots amended with compost were significantly greater than those in the un-amended plots (control). Similar result was obtained in this study, in which the compost treatments increased green bean yield when compared with 100% soil (control). Under the substitution of 10%, vermicompost/soil mixtures from VS4, VS5, and VS6 produced greater yield than their respective compost/soil mixtures from CS1, CS2, and CS3, which might be explained by the fact that vermicomposting is a distinctively different process from conventional composting since vermicomposting involves earthworms digesting the organic substances (Chaoui et al. 2003). The largest marketable yield in terms of green bean quality was in response to the substitution of 40% yard waste vermicompost (VS6) into soil with a value of 105.0 g per plant. The mean marketable yield of the control was 11 g per plant, which was less than the 10% vermicompost and compost into soil. Thus, plant growth was enhanced even in response to a 10% substitution of both composts and vermicomposts from food waste, paper waste, and yard waste into mineral soil. Similarly, in a research made by Arancon et al. (2004), a mixture of only 10% vermicompost in 90% MM360 was enough to augment pepper yield compared to those grown in 100% MM360. In another study, addition of vermicompost in different concentrations enhanced the yields of strawberry fruits significantly (Arancon et al. 2004). It could be found that higher substitution rates of 100% vermicompost (VS4, VS5, and VS6) did not produce the maximum yield, and this confirmed earlier conclusions by Atiyeh et al. (1998), who suggested that vermicomposts do not always enhance plant growth and yields more in response to replacements of larger concentrations of vermicompost (30–50%) than to smaller concentrations (0–20%). Figure 2a, b depicts that green beans which are grown in 40% vermicompost/soil mixtures and compost/soil mixtures yielded 78.3–89.5% higher fruit weights as compared to control (soil), which somewhat agree with the reports by Arancon et al. (2004), who found an increase of 45% greater fruit weights of peppers grown in a potting mixture ratio of 4:6 of food waste vermicompost to MM360 than those grown in

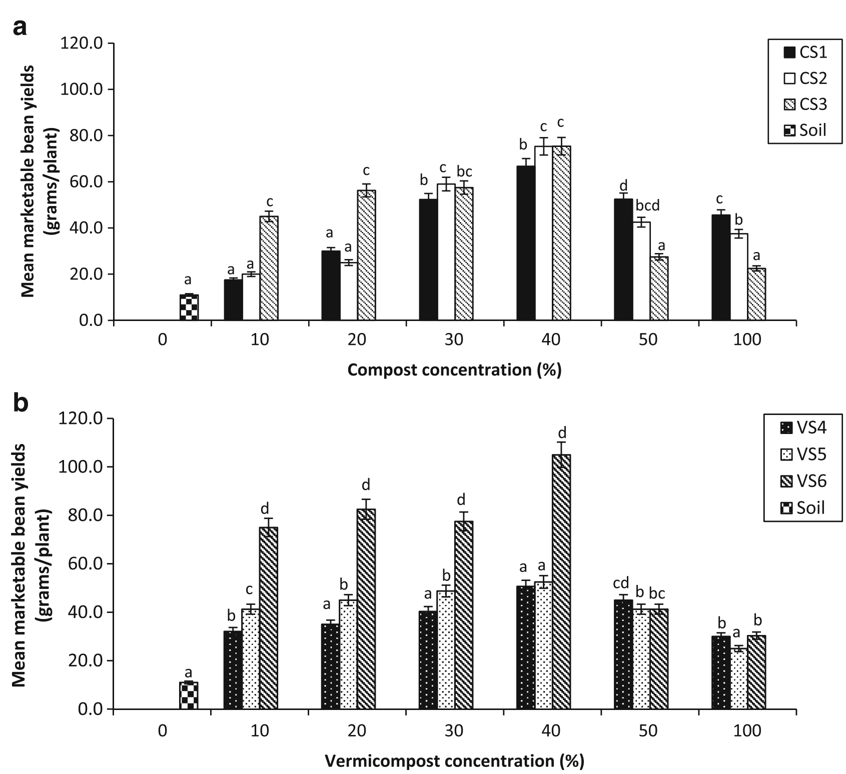

Fig. 2 **a** Mean marketable green bean yields under compost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$). **b** Mean marketable green bean yields under vermicompost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$)

100% MM360. Atiyeh et al. (2002a) reported that the greatest vegetative growth on marigolds as test crop in the greenhouse was from the substitution of MM360 by 30 and 40% pig manure vermicompost. The green beans grown in 40% vermicompost (food, paper, and yard wastes) and 60% soil yielded higher fruit weights also agree with the reports made by Roberts et al. (2007), who found that vermicompost from cattle wastes and processed by the earthworm *D. veneta* (Rosa) significantly increased the marketability of fruits at substitution rates of 40% due to a lower incidence of physiological disorders (blossom end rot and fruit cracking). Commonly, plant growth of green beans increased as substitution rates of vermicomposts to soil augmented till 40% and decreased when substitution rates were greater than 50% as similarly reported by other researchers (Atiyeh et al. 2001; Arancon et al. 2008) with MM360. Statistically, there was a significant difference in the variations of the marketable yield among the three vermicompost/soil mixtures (ANOVA; $F = 5.154$, $p = 0.019$) and a nonsignificant difference among the three compost/soil mixtures (ANOVA; $F = 0.074$, $p = 0.929$). To some point, it could be said that the increase in harvest weights is related to the fraction of the application rates of vermicomposts, which correspond to the findings from a greenhouse experiment made by Buckerfield et al. (1999), using 0–100% mixtures of vermicompost and sand. The enhancement in the physical structure of the potting medium, augmentation of microbial populations, and the possible production of plant growth-influencing materials by microorganisms in vermicomposts (Arancon et al. 2004) are the major elements which could have caused the increase in green bean yields. Nonetheless, it has been found that in the presence of vermicompost, plant growth is effectively promoted from the enhanced plant's protein-synthesizing capacity that has been caused by the metabolites, which have been produced by earthworms as outlined by Edwards et al. (2011). The enhancement in plant growth and augmentation in green bean yields might be due to significant increases in soil microbial biomass after the addition of vermicompost, resulting in the production of hormones and humates in the vermicompost acting as PGHs as similarly reported by Arancon et al. (2003). A few of the high rates of vermicompost substitution resulted in slower growth rates of green beans, which might be in response to higher PGR and PGH concentrations, such as auxins, generated by microorganisms in vermicomposts which can have either positive or negative effects on plant growth (Arancon et al. 2006).

Shoot dry weight

The variation in the mean shoot dry weight at different substitution rates is presented in Fig. 3a, b. The greatest mean shoot dry weight was recorded from the potting mixtures containing 40% VS4 (10.1 ± 0.2 g). The incorporation of vermicompost into plant growth media at substitution rates up to 40% increased shoot weights of tomatoes, strawberry, and raspberries as reported by other researchers (Subler et al. 1998; Arancon et al. 2004; Bachman and Metzger 2008). Plant dry biomass was observed to be 2.7 ± 0.1 g in control (soil), which was the lowest mean shoot dry weight, while it was observed to be significantly higher in vermicompost/soil mixtures even at a substitution rate of 10%. Similar increase in shoot dry weight was observed by Subler et al. (1998). Also, Atiyeh et al. (2000b) reported a significant increase in shoot dry weights of tomato seedlings when 10–50% vermicompost was incorporated in MM360 compared to the 100% MM360 controls. Combinations of 10% compost (CS1, CS2, and CS3) and 90% soil also demonstrated a slight significant increase compared with those in the control. Green beans produced 61.0–73.6% higher shoot dry weight at a substitution rate of 40% compost/soil and vermicompost/soil mixtures over those grown in the control as quite comparably reported by Atiyeh et al. (2001), who noted that substituting MM360 with 50% vermicompost increased shoot dry weights up to 71.0% over those grown in the control. The results showed that green beans grown in vermicomposts from VS4, VS5, and VS6 produced much higher shoot dry weights, which were insignificantly greater (ANOVA; $F = 0.710$, $p = 0.508$) than the shoot dry weights of green beans grown in control soil as similarly noted by Arancon et al. (2008) for the growth of petunias. Statistically, the dry shoot weight of green beans grown in compost/soil mixtures with a substitution rates of 10–50% (CS4, CS5, and CS6) did not differ significantly from those grown in the control (ANOVA; $F = 0.258$, $p = 0.776$). The production of humic substances and other plant growth-influencing materials (PGHs) by microorganisms during vermicomposting and after microbial biomass augmentation and soil activity might have caused an increase in shoot dry weight. This reasoning is justified by Arancon et al. (2005), who reported that the amounts and rate of production of humic substances increased dramatically by vermicomposting process. Several lower shoot dry weight in response to large rates of substitution of composts (100%), notably food waste compost, could be due to the presence of higher salt content (electrical conductivity) or nutrient in extreme levels in the more clustered mixtures, and this reasoning was supported by Arancon et al. (2008).

Root dry weight

The variation in the mean root dry weight at different substitution rates is presented in Fig. 4a, b. The roots of the green bean plants obtained from potting mixtures substituted with 10, 20, 30, 40, and 50% vermicompost weighed more than those in the control (0.6 ± 0.1 g) as similarly reported by Atiyeh et al. (2001) during the substitution of 10, 25, and 50% vermicomposts from pig wastes into MM360. The

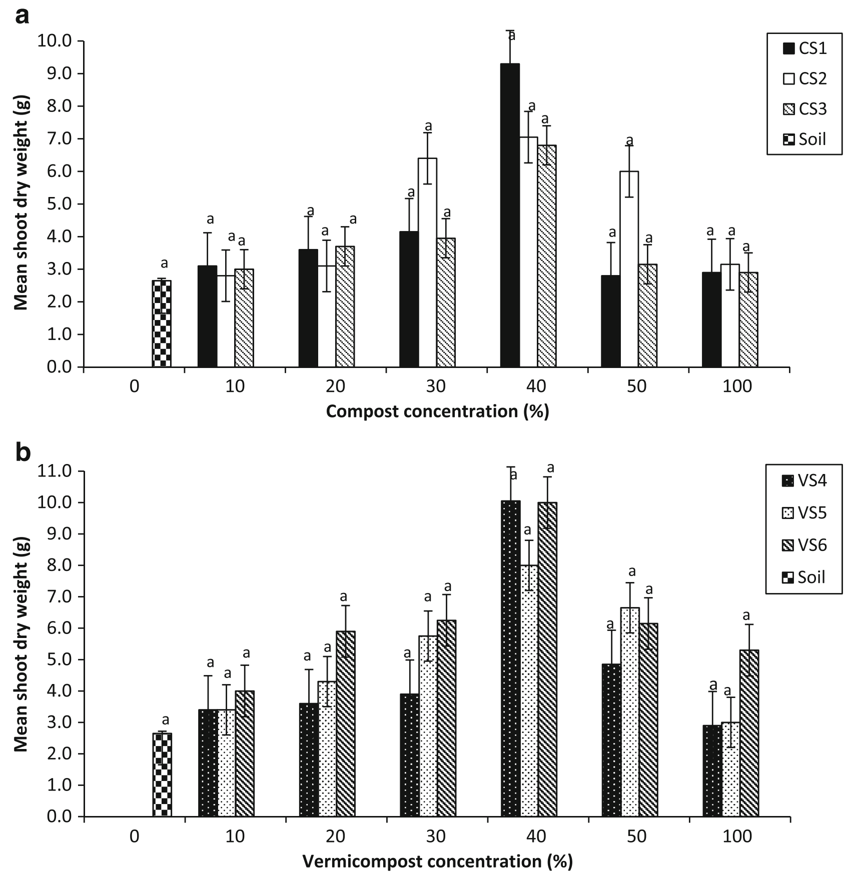

Fig. 3 **a** Mean shoot dry weight for green bean plants under compost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$). **b** Mean shoot dry weight for green bean plants under compost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$)

greatest mean root dry weight was recorded from the potting mixtures containing 40% VS4 (2.0 ± 1.2 g), and the lowest mean shoot dry weight was noted for the control (0.6 ± 0.1 g). From the results obtained for the root dry weight, it could be deduced that the maximum and minimum values of VS4 and the control, respectively, correlated with the maximum and minimum values for shoot dry weight. On the whole, green beans demonstrated a high root dry weight value for a substitution rate of 40% for the compost/soil or vermicompost/soil mixtures. Statistically, there were no significant differences in root dry weight among the compost/soil mixtures (ANOVA; $F = 2.638$, $p = 0.104$) and among the vermicompost/soil mixtures (ANOVA; $F = 1.408$, $p = 0.275$).

Orthogonal contrasts of growth parameters and yield of green beans

Table 2 shows the orthogonal contrasts of growth parameters (shoot length, shoot, and root dry weights) and marketable yield of green beans, which were grouped for composts versus soil, vermicomposts versus soil, and composts versus vermicomposts. There were no significant differences in any of the plant growth parameters for the green beans grown in soils mixed with MSW composts (CS1, CS2, and CS3) compared with those in mineral soils receiving MSW vermicomposts (VS4, VS5, and VS6). There was no significant growth differences between plants in potting mixtures that received vermicomposts compared with those in potting mixtures that received composts (except for shoot dry weights of CS3 versus VS6). The soil/vermicomposts mixtures of VS4 and VS5 had a significantly greater marketable yield ($p < 0.05$) than soils treated with composts.

Connecting plant growth to the physicochemical properties of the potting mix

The substitution of 10, 20, 30, 40, and 50% MSW vermicompost into soil increased the growth of green beans (marketable yield, shoot dry weight, and root dry weight) significantly over that of plants grown in control soil alone. This suggested that these vermicompost/soil potting mixtures were able to provide the plants with sufficient amounts of readily existing nutrients compared to the control (Atiyeh et al. 2001). Several probable factors that promoted the germination, growth, and marketable yield of green beans in the vermicomposts potting mix could include enhancements in the composition of the growth medium such as the combined effects of improved porosity, aeration, water retention, high nitrate content (Atiyeh et al. 2001), and drainage. However, green beans are a legume and an N-fixing plant, and this N-

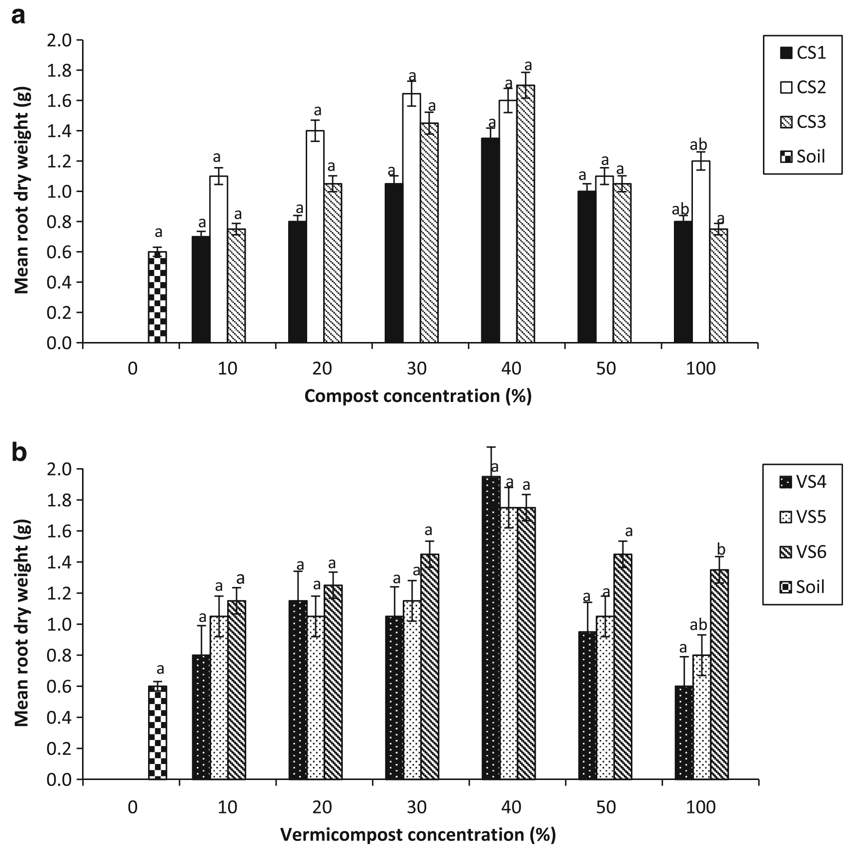

Fig. 4 **a** Mean root dry weight for green bean plants under compost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$). **b** Mean root dry weight for green bean plants under vermicompost concentration. *Columns annotated by the same letter* do not differ significantly (ANOVA; Tukey's HSD test, $p < 0.05$)

fixing effect might have contributed to the enhanced plant growth. The compost/soil mixtures had a more or less neutral pH (between 6.2 and 7.4) as shown in Table 3, and it might be probable that this physicochemical property, pH value of the pot medium, has been raised by the high pH value of these mixtures with an effect in diminished plant growth, which is thereby equivalent to the quantity of compost integrated as compared to the vermicomposts/soil mixtures. However, between compost/soil mixtures, the difference was statistically insignificant in respect to pH (ANOVA; $F = 2.161$, $p = 0.150$). The variation of pH showed a statistically significant difference among vermicompost/soil mixtures (ANOVA; $F = 2.183$, $p = 0.147$). Also, the enhancement in plant growth might be due to the nutritive compounds present in dissimilar quantity in mineral soil, composts, and vermicomposts (Atiyeh et al. 2000b). The low marketable yield (22.5–

Table 2 Orthogonal contrasts of growth parameters and yield of green beans

	Shoot length	Marketable yield	Shoot dry weight	Root dry weight
Composts versus soil				
CS1 versus soil	ns	ns	ns	ns
CS2 versus soil	ns	ns	ns	ns
CS3 versus soil	ns	ns	ns	ns
Vermicomposts versus soil				
S4 versus soil	ns	*	ns	ns
VS5 versus soil	ns	*	ns	ns
VS6 versus soil	ns	ns	ns	*
Composts versus vermicomposts				
CS1 versus VS4	ns	ns	ns	ns
CS2 versus VS5	ns	ns	ns	ns
CS3 versus VS6	ns	ns	*	ns

ns not significant

*$p < 0.05$

Table 3 pH of compost/soil and vermicompost/soil mixtures at different substitution rate

Substitution rate (%)	CS1	CS2	CS3	VS4	VS5	VS6
10	6.19 ± 0.11 cd	6.68 ± 0.05 e	6.34 ± 0.01 d	5.81 ± 0.02 ab	5.65 ± 0.03 a	6.05 ± 0.05 bc
20	6.40 ± 0.05 c	6.73 ± 0.07 d	6.39 ± 0.08 c	5.95 ± 0.06 b	5.71 ± 0.01 a	6.08 ± 0.01 b
30	6.72 ± 0.06 d	6.80 ± 0.02 d	6.41 ± 0.03 c	6.24 ± 0.01 bc	5.87 ± 0.08 a	6.10 ± 0.06 ab
40	6.85 ± 0.04 c	6.84 ± 0.01 c	6.42 ± 0.01 b	6.37 ± 0.02 b	5.99 ± 0.10 a	6.11 ± 0.04 a
50	7.02 ± 0.07 d	6.87 ± 0.06 cd	6.58 ± 0.10 bc	6.50 ± 0.05 b	6.07 ± 0.02 a	6.18 ± 0.03 a
100	7.40 ± 0.05 c	6.88 ± 0.03 b	6.84 ± 0.02 b	6.53 ± 0.21 ab	6.41 ± 0.02 ab	6.31 ± 0.05 a

Values (means ± standard deviations) followed by different letters in the same columns for each mixtures are statistically different (ANOVA; Tukey's HSD test, $p < 0.05$)

45.6 g/plant) of *P. vulgaris* at the substitution rate of 100% MSW composts and vermicomposts in the potting experiments might be due to the presence of quite high concentrations of soluble salts (another physicochemical property) in the mixtures (Table 4). Initially, there were no significant differences in electrical conductivity among any of the potting mixtures (ANOVA; $F = 2.174$, $p = 0.148$ for compost/soil mixtures; $F = 1.146$, $p = 0.344$ for vermicompost/soil mixtures), pointing out that there could have been a possible leakage in the concentrations of the high soluble salts through the holes in the bottom of the pots. Besides these physicochemical properties, it was most probable that other biologically active plant growth-influencing substances, such as PGRs, were released from the vermicomposts (Subler et al. 1998; Atiyeh et al. 2001) into the potting mixtures.

Mechanisms of beneficial effects of MSW vermicomposts

In this experiment, compost and vermicompost derived from MSW stimulated better growth of green bean plants in contrast with soil. However, there appeared to be focal disparities among the effects of the vermicomposts and composts, whereby the addition of vermicomposts derived from MSW constantly outperformed the incorporation of all the three types of composts as a plant growth media. Prior from the vermicomposting process, data analysis clearly suggested that the maturity of the organic MSW was fully enhanced by the earthworms. Thus, substituting soil with 10, 20, 30, 40, and 50% MSW vermicompost, excluding the addition of supplemental fertile elements increased shoot length and shoot dry weight of green beans plants in contrast to those grown in soil. Likewise, Wilson and Carlile (1989) stated a better growth of peppers, lettuce, and tomatoes grown in vermicompost generated from duck wastes than in the control, which were the unprocessed wastes. It was earlier detailed out by these authors that the basic differences between composting and vermicomposting processes which employ relatively different microbial communities and the further beneficial physicochemical characteristics of the processed waste might contribute to the improvement in plant growth. Edwards and Burrows (1988) detailed out that ammonium is being liberated from mineral nitrogen in the composting process, whereas nitrate is being released from nitrogen during vermicomposting, and it is most suitable for plant consumption.

From this study, it could be found that even a small substitution of 10% MSW-derived vermicompost into soil could effectively raised the growth of bean seedlings in regards with those grown in the control. However, this improvement in growth of green beans could not be only justified by the physicochemical and nutritional factors. It was probable that other biologically active plant growth-influencing substances, such as PGRs, were released from the vermicomposts (Edwards

Table 4 Electrical conductivity of compost/soil and vermicompost/soil mixtures at different substitution rate

Substitution rate (%)	CS1 (dS/m)	CS2 (dS/m)	CS3 (dS/m)	VS4 (dS/m)	VS5 (dS/m)	VS6 (dS/m)
10	0.93 ± 0.05 e	0.64 ± 0.00 d	0.84 ± 0.07 e	0.35 ± 0.07 b	0.48 ± 0.02 c	0.22 ± 0.03a
20	1.42 ± 0.10 d	0.92 ± 0.04 c	0.91 ± 0.03 c	0.71 ± 0.02 b	0.71 ± 0.02 b	0.35 ± 0.01 a
30	2.41 ± 0.06 d	1.01 ± 0.01 b	2.15 ± 0.17 c	0.92 ± 0.03 b	1.03 ± 0.06 b	0.63 ± 0.08 a
40	3.04 ± 0.08 e	1.31 ± 0.07 bc	2.69 ± 0.40 d	1.04 ± 0.08 ab	1.38 ± 0.08 c	0.90 ± 0.07 a
50	3.70 ± 0.17 d	1.54 ± 0.16 b	2.97 ± 0.11 c	1.28 ± 0.06 a	1.62 ± 0.03 b	1.04 ± 0.07 a
100	4.53 ± 0.43 d	2.55 ± 0.35 b	4.19 ± 0.24 a	2.68 ± 0.13 b	2.96 ± 0.13 b	1.29 ± 0.23 a

Values (means ± standard deviations) followed by different letters in the same columns for each mixtures are statistically different (ANOVA; Tukey's HSD test, $p < 0.05$)

and Burrows 1988; Tomati et al. 1990; Subler et al. 1998; Atiyeh et al. 2001) into the potting mixtures. These PGRs might be more efficient at lower substitution rates and might probably contain readily available nutrients. It seemed probable that the presence of other biological inputs such as a boost in enzymatic activities, augmentation in microorganism communities, or the development of beneficial plant hormones in vermicomposts contributed to the improved growth and yields of green beans. It might also have been possible that the presence of humic acids in the vermicomposts could contribute to direct positive effects on the growth and yields of the green beans as justified by Arancon et al. (2005). Previous studies reported that auxins or cytokinins could be produced significantly from the activity of earthworms in organic waste (Arancon et al. 2006; Zhang et al. 2014), and these plant hormones are dose specific and very important for plant metabolism. It has been found that PGHs could have a considerably direct positive effect on the growth and development of crops (Roy et al. 2010) and as well as crop quality when present at low quantity (Hopkins 1995). Yet, the complex structure of acids that are generated as a result of the augmentation in microbial communities in earthworm cast (Canellas et al. 2002; Arancon et al. 2004) might have reacted in combination for the improvement in plant growth. The presumed PGHs might persevere and could be released slowly in mineral soil to gradually contribute to plant growth.

Conclusions

The experiments demonstrated that both MSW composts and vermicomposts have substantial capacity for promoting plant growth significantly and affecting germination rate, shoot length, marketable yield, shoot, and root dry weights when compared to the control (soil). Green beans which are grown in 40% vermicompost/soil mixtures and compost/soil mixtures yielded 78.3–89.5% higher fruit weights as compared to control. The addition of vermicomposts into soil consistently outperformed the addition of composts equivalent in terms of fruit yields (for VS6), shoot, and root dry weight. The involvements of physicochemical properties and nutrients content in vermicompost/soil mixtures contributed to an increase in yield of green beans as compared to compost/soil mixtures. Still, distinct differences between specific composts/soil mixtures and vermicomposts/soil mixtures were noted in terms of their effects on bean growth. It seemed probable that in the presence of other biological inputs such as a boost in enzymatic activities and augmentation in microbial communities, vermicomposts contributed to the improved growth and yields of green beans. The increase responses could have been due to the availability of PGRs or the development of beneficial PGHs during vermicomposting (Zhang et al. 2014). If the use of vermicompost into soil is widely adopted, the faster germination, growth, and marketable yield of green beans of the variety reported here would result in a much shorter retention time of plants in the greenhouse.

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