Influence of Farmer-Driven Composting Technology on Below and Above Ground Biology of Common Bean in Western Kenya

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Authors' contributions

Original Research Article

ABSTRACT

Composts are rich in nutrients especially carbon, nitrogen, phosphorus and potassium. These nutrients enhance the colonization of plants by beneficial endophytic and rhizosphere microbes. Therefore, a field experiment was conducted on MMUST farm to determine the effect of farmer-produced composts soil biota and above ground pests on bean plant within Western Kenya. five farmer-produced composts with varying plant and animal waste ingredients (FPC1, FPC2, FPC3, FPC4, FPC5), DAP fertilizer and controls. Each of the resulting 14 treatment combinations comprised of twin plots (3 m × 2 m) for the two bean varieties, each having n = 40 plants per variety, spaced at 50 cm × 15 cm, replicated in 3 blocks (24 m × 14 m) in a randomized block design. Rhizobium root nodules, rhizosphere fungal and bacterial populations (CFU 10⁻g of soil) where

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higher in the compost-treatments than in DAP, while soil nematode populations were low. Therefore, the present study concluded that farmer-produced composts in Western Kenya improve below and above ground of common bean.

1. INTRODUCTION

Compost application to soil affects both diversity and population of microbial communities [1] Composts exert changes in physical, chemical, and biological properties of soil, which may influence relationships between plants, herbivorous invertebrates and microbial pathogens [2,3]. Compost amendments modify physico-chemical properties of soil including nutrients and biological properties especially populations of beneficial soil microbes [4]. Studies have reported increased microbial activities and biomass in soils amended with organic matter in the form of composts [5], which can partly be attributed to increased availability of nutrients to the rhizosphere microbes [6]. This increase in soil microbial activities due to organic amendments results in the suppression of plant diseases [7]. However, the presence of toxic factors such as heavy metals, high salinity and instability of the organic matter in compost can be detrimental to soil microbes [4]. Plots treated with composts have been reported to contain high populations of nematodes and collembola [8]

In organic agriculture, it has at instances been asserted that plants supplied exclusively with nutrients from biological materials are more tolerant to insect pests than those grown using chemical fertilizers [3]. A study conducted by Eigenbrode & Pimentel [9] observed that flea beetle densities were lower on collards receiving macronutrients through manure compared to those receiving similar amounts of the macronutrients from chemical fertilizers. Naluyange, et al. [3] found that *Rhizobium* inoculant was compatible with water hyacinth composts containing effective microbes and cattle manure culture, enhancing tolerance of bean plants to aboveground infestations by the aphid *A. fabae* and the anthracnose pathogen *C. lindemuthianum*.

Composts are rich in nutrients especially carbon, nitrogen, phosphorus and potassium [3]. These nutrients enhance the colonization of plants by beneficial endophytic and rhizosphere microbes [10]. Therefore, the present study sought to determine the effect of farmer-produced composts soil biota and above ground pests on bean plant within Western Kenya.

2. MATERIALS AND METHODS

2.1 Study Site

A field experiment was conducted at the Masinde Muliro University of Science and Technology (MMUST) farm (00°17.104 N', 034°45.874 E'; altitude 1561 m a.s.l.), adjacent to the Kenya Agricultural and Livestock Research Organization (KALRO), in Kakamega County, Western Kenya. The region receives rainfall in two seasons, long rains ~1012 mm between March and July, and short rains ~622 mm between July and November [11].

2.2 Experimental Design

The study was a 2 × 7 factorial experiment with bean cultivar factor having two levels and soil fertility amendment factor with seven levels. Each of the resulting 14 treatment combinations comprised twin plots (3 m × 2 m) each having n = 40 plants spaced at 50 cm × 15 cm replicated in 3 blocks (24 m × 14 m). The interblock spacing was 1 m, with 0.5 m interplot spacing between the twin plots, while a 1 m wide perimeter buffer surrounded the three blocks resulting in a field measuring 26 m × 16 m. This experiment was done in the year 2014 between 1st April and 30th June, and then repeated between 17th July and 5th October.

2.3 Compost Preparation and Composting

The experiment utilized five farmer group-produced composts with organic matter sources summarized in Table 1.

The farmers' groups comprised of a model farmer and 15 general farmers. These were trained by MMUST staff in backyard composting

Table 1. Nutrient composition of each farmer produced compost

Sample description	CF1 [CF]	CF2	CF3	CF4	CF 5
Nitrogen %*	1.75	0.70	1.05	0.35	1.05
Phosphorus %*	0.46	0.40	0.45	0.19	0.45
Potassium %*	0.10	0.05	0.06	0.06	0.13
Calcium %*	0.90	0.50	0.40	0.10	0.90
Magnesium %*	0.20	0.01	0.01	0.01	0.15
Iron %*	0.21	0.08	0.09	0.09	0.12
Copper %*	0.0031	0.0002	0.000517	0.0001	0.00168
Manganese %*	0.12	0.01	0.04	0.03	0.07
Zinc %*	0.02	0.0010	0.0005	0.00017	0.0073
Density (g/250mL)**	105	89	93	50	151

Original data from soil analysis laboratory expressed data in mg/Kg
**Farmer-based application rate of composts is 250 mL cup per plant*
[CF] *Farmer produced compost*

of various available organic materials on their farms (van Haute, 2014). The composting technique in the farmer training involved setting up repeated layers (8 cm thick) of plant material (dry or fresh), animal wastes, wood ashes to accelerate the composting process and soil to provide saprophytic inoculum. Water (20 L) was sprinkled over the layers of organic materials to facilitate enzymatic biodegradation. Each 8 cm thick layer was added three times, resulting in a heap approximately 4 m ×1.5 m × 1.5 m (L × W × H). The compost heaps were then protected from the sun under a shade made of plastic sheet to prevent overheating and drying. Each heap was mixed by turning over three times after every two weeks. Biodegradation and temperature were monitored using a stick pushed into the middle of the heap. The stick was pulled out each time the compost heap was turned and felt by hand for heat generation associated with composting. Regular turning ensured proper mixing, wetting, aeration and hence sufficient decomposition. Compost was ready for use after two months.

2.4 Root Colonization by Rhizobium and Density of Rhizosphere Microbes

During flowering, five bean plants were randomly selected from each treatment per block for estimation of the number of root nodules associated with *Rhizobium* colonization. From each plant, three nodules were selected and crushed; the resulting suspension was streaked onto yeast extract mannitol agar (YMA) containing Congo red stain (Sisco Research Lab pvt ltd, Mumbai, India) [12]. The inoculated dishes were incubated at 28ºC for 4 days to allow the growth of microbes and sub-cultured to obtain pure cultures for morphological identification.

The density of rhizosphere microbes in terms of colony forming units (CFU) was estimated based on methods described by Nonaka et al. [13]. Soil samples (10 g) were collected at four points of each plot at a depth of 15 cm and a depth of 20 cm mixed together thoroughly and a volume of 10 g obtained and put in Ziplock bags and transported to the Laboratory of Microbiology (MMUST). A soil sample (1 g) was subjected to serial dilutions ($\times 10^{-2}$, $\times 10^{-4}$, and $\times 10^{-6}$) in sterile water. Aliquots of 0.5 mL from each dilution was plated on petri dish containing nutrient agar (NA) for bacteria and potato dextrose agar (PDA) for fungi and replicated thrice. The petri dishes were incubated while inverted for 24 hours at 37°C for bacteria and 48 hours at 37°C for fungi. The number of microbial colony forming units was estimated using a Colony Counter and microbial populations calculated using the formula applied by Herigstad & Heersink [14] as follows;

$$\text{Microbe number} = \frac{\text{Colony count}}{\text{Total dilution of tube} \times \text{Amount plated}}$$

2.5 Rhizosphere Populations of Nematodes

Two soil samples (250 g) were collected around the plants from each plot; one sample was used for estimation of nematode populations, and the other for estimation of macro-invertebrate populations. Extraction and estimation of soil nematode population was based on the Baermann's method [15] The nematode populations were expressed as counts per 100 mL of soil using the formula;

$$\text{Number of nematodes per 100 mL volume of soil} = yx$$

Where y = Number of nematodes counted in 2 mL aliquots.

x = a constant (i.e. 2.4) given by

$$x = \left(\frac{a}{b} \times \frac{\beta}{\alpha} \right)$$

Where a = Standardized volume of nematode suspension, i.e. 10 mL
b = Pipetted volume of nematode suspension, i.e. 2 mL
β = Standard volume of soil for nematode counts, i.e. 100 mL
α = Sampled volume of soil, i.e. 250 mL

2.6 Data Analysis

Differences in insect populations and nodule number were determined using Analysis of Variance (ANOVA). In addition, insect population and nodule number were separated using Ls-means when treatment effects were significant (p < 0.05). Nematode populations and microbial CFU were analyzed by Proc Genmod (χ^2 test; Poisson).

3. RESULTS AND DISCUSSION

3.1 Root Nodules and Rhizosphere Microbes

Root nodules produced bacterial cells with some of them appearing to be *Rhizobium* species, since they exhibited the characteristic cultural features on yeast extract mannitol agar (YMA) containing Congo red (Fig. 1).

Number of root nodules was higher on bean plants grown with the farmer-produced composts (CF1-5) than in those that received DAP and without soil fertility amendment (p<0.05; Fig. 2). Number of bacterial colony forming units from the rhizosphere soil was high in the farmer-produced

composts CF3, CF4 and CF5; but the bacterial population was low in the other four treatments, especially in soil that received DAP and CF2 compost (p<0.05; Fig. 3). Number of fungal colony forming units from the rhizosphere soil was lower in the untreated soil (control) compared to the six soil fertility amendments, especially in the farmer-produced composts CF1, CF3, CF4 and CF5 composts (p<0.05; Fig. 4).

Extracted from these bean root nodules were some endophytic bacterial cells, with some of them appearing to be *Rhizobium* species [16], since they exhibited the characteristic cultural features on yeast extract mannitol agar (YMA) containing Congo red [17]. This increase in bean root nodules is a desirable effect of composts [18], as a high number of root nodules is associated with improved nitrogen fixation by the symbiotic diazotrophic *Rhizobium* species. The farmer-produced composts may have promoted root nodulation by addition of nutrients, especially phosphorus and potassium [19]. High number of root nodules may also have been due to increase in soil pH that favours *Rhizobium* survivorship and nitrogenase activity [20].

In the rhizosphere, non-specific bacterial and fungal colonies were detected, with their populations in terms of colony forming units (CFU) being generally high in plots that received any of the five farmer-produced composts. This may partly be attributed to the increased nutrient availability and elevated soil pH, which have been associated with enhancing microbial colonization in the rhizosphere [21]. These enhancements in rhizosphere bacterial and fungal populations tended to be more pronounced in plots that received CF1, CF3, CF4 and CF5 composts. The common factor between the previous four composts is that all of them contained cattle manure as an ingredient.
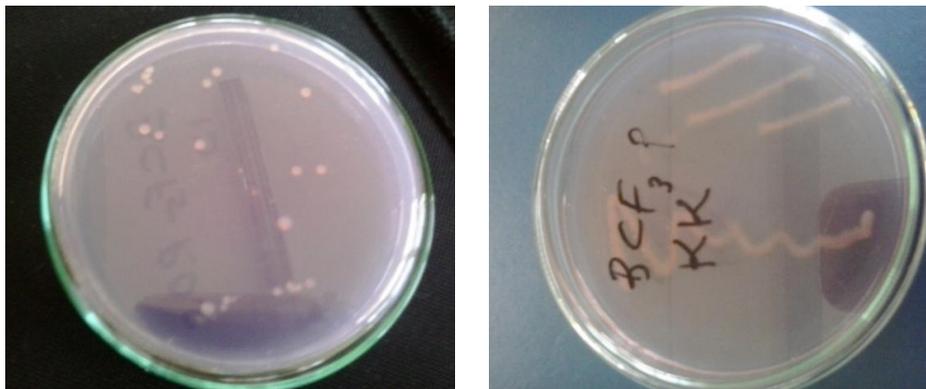

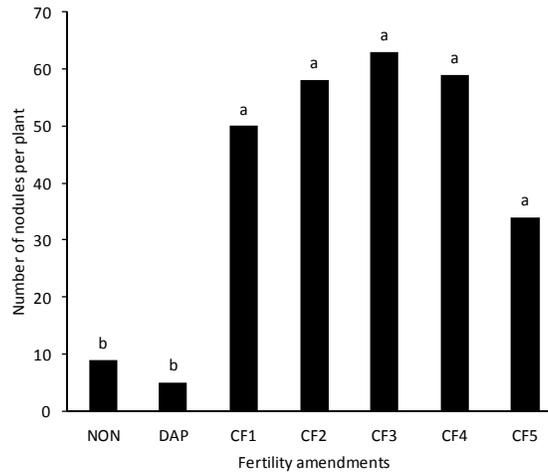**Fig. 1. Plates showing cultural characteristics of *Rhizobium***

Fig. 2. Number of root nodules on bean roots. Grown with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (F test; p > 0.05)
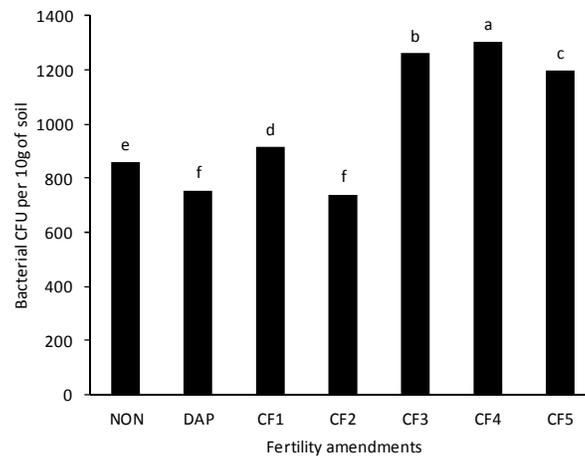

Fig. 3. Bacterial populations (CFU) in the rhizosphere of bean plots. Treated with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; p > 0.05)

Compost made out of cattle manure increases bacterial and fungal diversity by enhancing carbon content in soil [21]. Also, microbes derived from the animal gut add up to the ones that already exist in the soil [22].

3.2 Rhizosphere Nematodes, Macro-invertebrates, Foliar Pests and Anthracnose Disease Incidence

Rhizosphere nematode populations were low in plots that received the five farmer-produced composts especially in the CF2 compost; but

their numbers were highest in DAP-treated plots (p<0.05; Fig. 5).

The overall population of macro-invertebrates (arthropods) was very low (1110 individuals per 100g of soil), and not statistically different between the treatments (p>0.05). These soil arthropods comprised of collembola, crane fly, leaf beetles, plant bugs red ant, rove beetle and sandfly. Population aphid *A. fabae* and the black bean thrip *F. occidentalis* did not vary between the treatments (p>0.05), with the aphids averaging 28 insects per plant and the thrips being 179 insects per sticky trap. Anthracnose

disease severity averaged 4.4, while the trends varied indiscernibly across the fourteen treatment combinations (p<0.05).

The population of rhizosphere nematodes was low in plots that received any of the five farmer-produced composts, especially on plot CF2. This can partly be attributed to the action of soil

microorganisms on organic material during composting that releases a wide range of nematicidal chemical compounds and enzymes [23]. Also, composts that have undergone advanced mineralization may not be suitable for colonization by saprophytic and plant-parasitic nematodes [24], as such species feed on
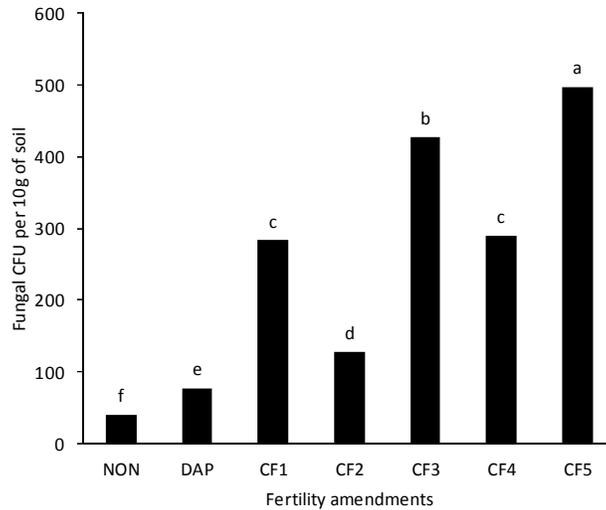

Fig. 4. Fungal populations (CFU) in the rhizosphere of bean. Plots treated with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; p > 0.05)
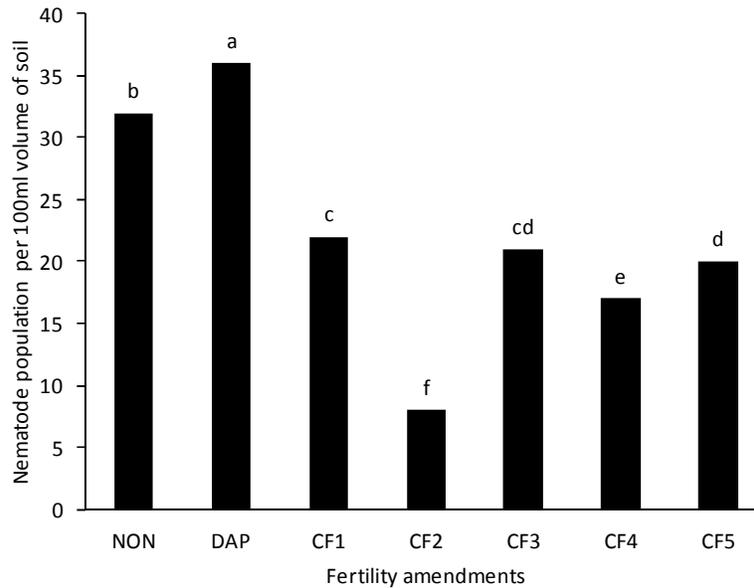

Fig. 5. Nematode populations in the rhizosphere of bean. Plots treated with diammonium phosphate fertilizer (DAP), farmer-produced composts (CF1-5) or without soil fertility amendment (NON). Bars with the same letter(s) are not significantly different (χ^2 test; p > 0.05)

relatively intact organic matter as necrotrophs or biotrophs [23]. On the contrary, increase in microbial density in plots that received farmer-produced composts may have favoured microbivore nematode species that feed on bacteria and fungi [24]. The increase in bacterial and fungal populations may also have included some antagonistic microbes that suppress nematodes [25]. In addition, the low nematode density may have been due high organic matter (total organic carbon) that was relatively enhanced in some plots, which may have slowed nematode migration during extraction using the Baermann's method [26].

Aboveground, infestation levels of the black bean aphid *A. fabae*, the bean flower thrip *F. occidentalis* and anthracnose disease caused by *C. lindemuthianum* was low in all the plots, and did not vary between treatments. It would be expected that a higher level of root nodulation by *Rhizobium* species in compost treatments would be associated with increase in *A. fabae* populations and *C. lindemuthianum* [11]. This was not the case in the present study, as there was no inoculation of the seeds with additional commercial or non-native *Rhizobium*, as was the case for Dean, et al. [27]

4. CONCLUSION

The trained farmers produced composts utilized by bean plants enhanced endophytic colonization by beneficial *Rhizobium* species and promoting rhizosphere colonization by bacteria and fungi, but suppressing soil nematode populations. However, the composts did not affect the foliar pest aphids *A. fabae*, thrips *F. occidentalis* and the microbial pathogen *C. lindemuthianum*.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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