https://doi.org/10.33472/AFJBS.3.1.2021.176-196

ISSN: 2663-2187

AFJBS

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper **Open Access**

Biochar and vermicompost soil amendments reduce root rot disease of common bean (*Phaseolous Vulgaris* L.)

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Article Info

Volume 3, Issue 1, January 2021

Received : 15 August 2020

Accepted : 18 November 2020

Published : 01 January 2021

doi: 10.33472/AFJBS.3.1.2021.176-196

Abstract

Common bean production is constrained by root rot complexes resulting to as much as 70% losses in Kenya. This study sought to establish the effect of soil amendments biochar and vermicompost on root rot fungal pathogens of common bean in Western Kenya. Application of biochar, vermicompost and fertilizer were done in farmer fields in four agro ecological zones of Western Kenya prior to planting during the long rains of 2013 and 2014. No applications were done in the shot rains seasons of 2013 and 2014. Plant emergence and disease incidence was recorded in the field and disease severity determined in the laboratory. Isolation and identification of pathogens was done from treatment plots following a two weeks and six weeks sampling after planting. Pathogens isolated were identified using morphological characteristics. Soil amendments positively influenced plant emergence. Root rot disease incidence and severity was greatly reduced up to 40% and 60% every season respectively. Biochar and vermicompost treatments reduced the population of fungal pathogens and also influenced the populations of beneficial microorganisms such as *Trichoderma* and *Paecilomyces lilacinus.* Application of soil amendments increased yield by 46% and also soil pH and nutrients were increased. In conclusion treatment application of vermicompost and biochar reduce root rot disease and improve bean productivity.

Keywords: *Fusarium solani, Pythium ultimum, Rhizoctonia solani, Soil amendments, biochar, vermicompost*

1. Introduction

Common bean production in Kenya is faced by various constraints such as insect pests, reduced soil fertility, environmental stress and diseases which are major constraints. These constraints have led to low production averaging 220-670 kg/ha (Buruchara *et al.*, 2015). Alongside other diseases, root rot is a major constraint to

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bean production in the tropics. It has been previously reported to cause total crop failure in western Kenya (Nzungize *et al.*, 2012). Root rots are caused by a complex of soil-borne fungal pathogens including *Pythium ultimum*, *Fusarium solani* f.sp. *phaseoli*, *Macrophomina phaseolina*, and *Rhizoctonia* spp (Nzungize *et al.*, 2012; and Mwang'ombe *et al.*, 2008). The root rot fungi persist saprophytically in the soil and on organic matter when there is no host or as resting spores making it difficult to manage the disease complex (Agrios, 2005).

Options available for managing root rot complex of beans are limited and their effectiveness is often low after planting (Abawi and Pastor-corrales, 1990). Broad range and highly specific fumigants are available to effectively manage root rots. Their toxicity to man and environment when not handled well as well as their high cost has however limited their use (United Nations 2008; and Abawi *et al.*, 2006). At the same time, efficacy of the available seed dressing chemicals in the market is not sustainable. This emanates from the development of resistance as a result of multiple pathogen genera found in most areas of production and their degradation following continuous use (Abawi and Pastor Corrales, 1990; and Nolling, 1991). Other limitations to conventional methods of managing root rot pathogens include development of resistance by plant pathogens and lack of tolerant or resistant bean varieties to multiple diseases causing pathogens (Nzungize *et al.*, 2012).

Agronomic practices such as use of organic amendments have shown positive changes in root disease dynamics and yield increase (Bailey and Lazarovits, 2003). Different types of composts and biochar are recognized to increase soil health. They are also known to suppress soil-borne diseases caused by diverse genera such as *Fusarium, Pythium, Rhizoctonia* and *Phytophthora* (Mehta *et al.*, 2014; Sohi *et al.*, 2010; and Elad *et al.*, 2010). Biochar is a product of anaerobic thermal degradation of biomass while vermicompost is a humic substance produced through an accelerated composting process by the feeding of earthworms. These are used as soil amendments in management of root rot pathogens. The suppressiveness of vermicompost and biochar is ascribed to a useful microbial community, an improvement in growth and vigor of plant, improved availability of nutrient, systemic resistance induction or fungistatic capabilities of the vermicompost and biochar modifications (Bonanomi *et al.*, 2017; and Graber *et al.*, 2014). Synergy of biochar and vermicompost has been shown to improve fertility of soil, growth of plants as well as increase the activity of beneficial microbes in the rhizosphere (Agegnehu *et al.*, 2015; and Fischer and Glaser, 2012). Some studies have however reported adverse effects of different types of biochar on crop yield, soil properties and beneficial soil micro biota (Mukherjee and Lal, 2014). It is also not known whether the biochar effect remains protective over a number of seasons in field situations since information on the longevity of these effects for soil borne pathogens has not been documented (Graber *et al.*, 2014). This study therefore aimed at determining the effect of sugarcane bagasse biochar and vermicompost on root rot diseases of common bean.

2. Materials and methods

2.1. Production of soil amendments biochar and vermicompost

Plant residues from sugarcane bagasse were sourced from Kibos Sugar Factory in Kisumu Kenya and sun dried. The bagasse was pyrolised to produce biochar (Laird, 2008; and Lehmann, 2007) using a metallic production kiln with a perforation at the base to allow for air flow and a chimney to expel the burning gases. Biochar was weighed and packed into 6 kgs gunny bags before application. Vermicompost was produced at Dudutech, Naivasha, Kenya from vegetable crop residue. The plant debris were chopped and air dried for 7-10 days then placed into 30 centimeter deep rectangular troughs which had an initial population of 6,000 earth worms (*Eisinia andrei*) in 40 kgs of pre-decomposed crop material and soil mixture. The crop residue was spread evenly on the surface of the trough where it was decomposed by earth worms feeding on the plant debris for a period of six weeks. The resultant worm casting referred to as vermicompost was then analyzed for nutrition and chemical content at Dudutech Naivasha, Kenya while biochar was analyzed for chemical properties at Crop Nutrition Laboratories Nairobi, Kenya.

2.2. Study site and experimental layout

The study was an on farm multi locational trial in 60 farms spread out in three regions of North Teso, Bungoma and Kakamega, Kenya that covered four different agro ecological zones: Lower midland humid (LM1), Lower midland sub humid (LM2), Upper midland humid (UM1) and Upper midland semi humid (UM3) with an altitude range of 800 m to 1,900 m above sea level (ASL) and temperatures of 18° to 24 °C (Jaetzold *et al.*, 2005). All these regions receive a bimodal rainfall consisting of long rains from March to July and short rains from September to November allowing biannual cropping seasons. The regions have varying soil types which include acrisols, gleysols, regosols, cambisols, nitisols, vertisols and ferralsols (Ralph *et al.*, 2005). The 60 farms were selected from a sampling frame of 280 small holder bean growers in the three counties of western Kenya with history of common bean cultivation in the previous season under a technology transfer project. The sample size was calculated following Nassiuma (2000) formula.

Each field measuring 12.5 m by 21.5 m was subdivided into eight treatment plots each of 6 m by 5 m. A susceptible bean variety to root rot (Rosecoco or GLP2) from CIAT Maseno was used in the trial. Treatments applied were biochar, vermicompost and sympal (NPK 0:23:15) fertilizer (MEA); biochar and vermicompost; biochar and sympal; vermicompost and sympal; biochar, vermicompost together with sympal and a control where no amendment was applied. Biochar and vermicompost were each applied at a rate of 2,000 kgs ha^{-1} while Sympal® fertilizer - N.P.K 0: 23:15 was applied at a rate of 300 kg ha^{-1} at planting. Treatments were only applied in the long rain seasons of 2013 and 2014 prior to planting. Planting in the short rain seasons of 2013 and 2014 were undertaken without application of treatments but the same plots were maintained to assess the residual effect of the treatments on bean root rot. The amendments were applied as a micro dose in the planting furrows then mixed with the soil prior to planting the bean seeds which were then covered with about 2 cm of soil. The bean seed was planted at the rate of 40 kg ha^{-1} at a spacing of 60 cm × 15 cm giving a plant population of 330 plants per treatment plot. The experiment was carried out in a completely randomized design.

2.3. Assessment for root rot disease incidence and severity

Root rot disease incidence was recorded as percentage of diseased plants showing root rot symptoms per plot at two after seedling emergence so as to observe both pre-emergence and post emergence damping off. Bean plants infected with root rot were identified based on symptoms such as damping off, yellowing of leaves, stunted growth, wilting, brown discoloration on roots and dark brown to red colored lesions on roots. Five symptomatic and asymptomatic plants were sampled from each plot at the end of the 2nd week after emergence and used to determine the disease severity of root rot in each plot. Scoring of disease severity was by visual assessment of necrotic lesions on roots and hypocotyls based on a rating scale of 1-9 as described by Abawi and Pastor-Corrales (1990). The rating used was 1 = no observable symptoms, 3 = light discoloration without necrotic lesions or 10% of hypocotyl and root tissues covered with lesions, 5 = hypocotyls and root tissues covered with lesions up to 25% but tissues remain firm, 7 = considerable softening, rotting, and reduction of the root system accompanied by lesions covering approximately 50% of the hypocotyls, and root tissues, 9 = advanced stages of rotting approximately with 75% or more of the root tissues and hypocotyl affected, as well as extensive deterioration of the root system. These scores were then converted to percentage severity index (Assefa *et al.*, 2014).

$$Percent\ Severity\ Index = \frac{Sum\ of\ numerical\ rating \times 100}{No.\ of\ plants\ scored \times Maximum\ score\ on\ scale}$$

2.4. Isolation of root rot fungal pathogens from infected bean roots and rhizosphere soil

Five root tissues from each treatment per farmer field were washed under running water. Roots were then cut into pieces measuring 1 cm, and sterilized in 1% sodium hypochlorite then in 10% ethanol for 3 min. The plant pieces were then rinsed in three changes of sterile distilled water then blot drying on sterile serviettes. The roots were then plated on PDA amended with 50 ppm streptomycin and incubated for 7-14 days at room temperature ranging between 25 ºC and 28 ºC.

Rhizosphere soil samples were collected two weeks and six weeks after emergence and at harvest to determine the fungal flora from each treatment plot. Sampling was done at 10 points in each plot in a / \ / \ / shape at a spacing of 1.5 m between the sampling points. A composite soil sample weighing one kilogram was then taken from the 10 samples, placed in well labeled polythene bag and brought to the laboratory at the University of Nairobi and stored at 4 ºC prior to isolation of root rot pathogens. Three sub samples each weighing 1 g were taken from each 1 kg of composite soil samples, dissolved in 10 ml sterile distilled water in three different universal bottles, mixed by shaking for 1 min followed by a 10-fold serial dilution series for each sample to achieve a 10^{-4} dilution. One milliliter of 10^{-4} dilution was plated on potato dextrose agar amended with 0 ppm streptomycin sulphate antibiotic (PDA-HIMEDIA®) medium using pour plate method. Each dilution was replicated three times and incubated at room temperature for seven days. Different fungal colonies were counted and quantified per gram of soil.

The fungi were then sub cultured on fresh PDA medium and upon identification, different genera of fungi were sub-cultured on different media. *Fusarium* spp. was sub-cultured on Spezieller Nährstoffarmer Agar (SNA) (Nirenberg, 1981) and PDA media. Sporulation of cultures on SNA was achieved by incubation under UV light while those on PDA were incubated under normal 12 h photo period. All cultures were incubated at

25 ºC for 14- 21 days to study cultural characteristics of each fungus for their final identification. Based on morphological characteristics, identification of *Fusarium* isolates was done to species level following keys by Nelson *et al.* (1983) and the *Fusarium* laboratory manual (Leslie and Summerell, 2006). Identification of other fungi was based on morphological and cultural features such as color of the colony, growth type, color of mycelia and spore types (Zhou *et al.*, 2010). The colony forming units of each fungal type per gram of soil was also calculated by multiplying the number of colonies with the dilution factor. *Pythium sp.* were sub cultured on corn meal agar to observe the production of sporangia, oogonia and antheridia that were used in identification based on keys by Plaats-Niterink (1981) and Dick (1990).

Relative isolation frequency was calculated for each genus using the formula by Gonzalez *et al.* (1999). All the fungal isolates were preserved on PDA slants at 4ºC at the University of Nairobi for further identification by gene sequencing.

$$Frequency\ (\%) = \frac{Number\ of\ isolates\ of\ a\ genus}{Total\ number\ of\ all\ isolates} \times 100$$

At the end of the fourth season, soil samples were also analyzed using quantitative PCR to establish the pathogen load in comparison with the conventional isolation method.

2.5. Effect of biochar and vermicompost on yield of common bean

Harvesting was done from plants in the net plot measuring 22.56 M^2. The crop stand count for each plot was recorded before harvesting. Total fresh weight of pods and hauls at harvest was recorded in the field. Samples were randomly selected from each net plot and the pods per plant counted, separated and weighed. These were later dried at 65 ºC for 48 h at CIAT Maseno and the weights used to estimate yield parameters such as 100 seed weight per plot and total seed yield per plot and later extrapolated to kg / ha.

3. Data collection and analysis

Data on emergence was recorded 14 days after planting where the total number of plants that had emerged was counted per treatment plot and expressed as percentages. Disease incidence was determined by counting the number of diseased plants in the net plot. This was then divided by the total number of plants in the net plot multiplied by 100. Data on disease severity was determined after scoring of diseased roots on a scale of 1 to 9 for root rot symptoms. Beans were harvested at physiological maturity and dry grains from each net plot were weighed after drying at 65 ºC for 24 h. Data on fungal counts was collected following isolation from the plant and rhizosphere soil samples at 2^{nd}, 6^{th} week and harvest, while other data such as soil particle size percentages, soil pH and soil nutrient content were recorded following laboratory analysis. These data was subjected to analysis of variance (ANOVA) by GENSTAT version 14 and the Tukey test Least Significant Difference (LSD) was used for mean separation at 5% level of significance.

4. Results

4.1. Physical and chemical characteristics of biochar and vermicompost

The two soil amendments analyzed varied in their composition. Vermicompost had higher moisture content than biochar. No volatile compounds or ash were found in vermicompost but were present in biochar from sugarcane bagasse (Table 1). pH of the two amendments was found to be near neutral. Electrical conductivity, dry matter content and C:N ratio were higher in SB biochar as compared to vermicompost. Phosphorus was

Table 1: Characteristics of vermicompost and biochar

Amendment	MC (%)	Volatiles (%)	Ash (%)	pH	EC (mS/cm)	DM (%)	C (%)	N (%)	C:N (%)
Vermicompost	48.2	NIL	NIL	6.92	12	50.8	30.1	3.54	8.51
S. B. biochar	3.10	9.10	9.66	6.83	73.5	96.90	62.87	5.31	11.85

Note: MC – Moisture Content, EC – Electrical Conductivity, DM – Dry Matter, C – Carbon, N – Nitrogen, C:N – Carbon Nitrogen ratio, and S. B. biochar – Sugarcane bagasse biochar.

the highest nutrient in the biochar as compared to other elements. Sugarcane bagasse biochar had higher level of phosphorus than that of vermicompost while Potassium was more in vermicompost than in biochar (Table 2). Vermicompost had 2.5%. Nutrients such as Magnesium, Sulphur, Manganese, Iron and Boron were higher in vermicompost while Sodium, Zinc and Copper were highest in SB biochar.

Table 2: Nutrient analysis of biochar and vermicompost

Amendment	P (%)	K (%)	Ca (%)	Mg (%)	S	Mn (ppm)	Fe (ppm)	B (ppm)	Na (ppm)	Zn (ppm)	Cu (ppm)
Vermicompost	0.64	3.31	2.54	0.54	0.4	410.0	6600.0	101.0	1480.0	185.0	17.8
S. B. biochar	1.01	0.73	n/a	0.37	0.03	36.9	485.3	14.4	2668.3	570.2	38.2

Note: P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, S – Sulphur, Mn – Manganese, Fe – Iron, B – Boron, Na – Sodium, Zn – Zinc, Cu – Copper; S. B. biochar – Sugarcane bagasse biochar; ppm – parts per million; N/A – Not available/present.

4.2. Effect of soil amendments on plant emergence

Significant differences were recorded among treatments in all the four seasons. Interaction between treatments and agro ecological zones resulted in significant differences ($p < 0.05$) in LM1 and UM1. The highest emergence was recorded in treatment combination of biochar, vermicompost and fertilizer in LM1 during the long rain season while the lowest was recorded in vermicompost and fertilizer treatments in UM1 (Table 3). In the short rain season of 2013, significant differences ($p < 0.05$) were recorded for interaction in three AEZ's. In the three

Table 3: Effect of different treatments on plant emergence (%) in different AEZ's of Western Kenya during the long rains and short rains seasons of 2013

Treatments	Long Rains Season 2013					Short Rains Season 2013				
AEZ	LM1	LM2	UM1	UM3	Trt Means	LM1	LM2	UM1	UM3	Trt Means
Control	38.3c	60.3a	24.2c	60.8a	45.9c	84.1a	73.5a	81.5ab	71.1bc	77.5ab
Fertilizer	46.5bc	60.4a	25.8bc	62.8a	48.8b	88.9a	66.4b	71.4d	67.4bc	73.5c
Biochar	47.8bc	59.7a	34.7ab	66.3a	52.1b	85.7a	70.8ab	73.5cd	72.6ab	75.7bc
Biochar + Fertilizer	40.3bc	63.1a	23.4c	64.0a	47.7bc	85.4a	68.8ab	80.1abc	63.9c	74.6bc
Biochar + Vermicompost	49.9b	62.6a	25.0bc	67.1a	51.2ab	83.5a	70.4ab	82.7ab	69.6bc	76.5b
Biochar + Vermicompost + Fertilizer	63.6a	60.5a	44.1a	62.7a	57.7a	81.5a	69.2ab	77.1bcd	61.9c	72.4c
Vermicompost	46.8bc	58.1a	21.7c	63.3a	47.4bc	81.4a	74.6a	87.3a	79.7a	80.8a
Vermicompost + Fertilizer	40.0bc	63.2a	20.9c	61.9a	46.5c	82.0a	65.0b	78.8bcd	62.2c	72.0c
LSD Interaction Treatment × AEZ	10.3				5.2	7.5				3.7
%CV	40.9					19.5				

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. AEZ – Agro-ecological zones, LM1 – lower midland zone 1, LM2 – lower midland zone 2, UM1 – Upper midland zone 1, UM3 – upper midland zone 3, Trt – Treatment. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

AEZ's, the highest emergence was recorded in vermicompost treated plots in UM1 while the lowest was recorded in the vermicompost and fertilizer treated plots in UM3. Significant differences ($p < 0.05$) were also recorded for collective treatments. Treatment combination of biochar, vermicompost and fertilizer had the highest emergence in the long rains of 2013 while the lowest was recorded in non-amended control plots. In the short rains season of 2013, vermicompost treated plots had the highest emergence while the vermicompost and fertilizer treated plots had the lowest emergence, the differences being significant ($p < 0.05$).

Significant differences ($p < 0.05$) in plant emergence were also observed for treatments and their interactions with AEZ's during the long and short rain season of 2014 (Table 4). The highest emergence was recorded in biochar treated plots in LM1 while control and fertilizer treated plots in UM3 had the lowest plant emergence in the long rains of 2014. In the short rains of 2014, highest plant emergence was recorded in biochar and fertilizer treated plots at UM1 while the lowest was recorded in fertilized control plots at LM2. Significant difference ($p < 0.05$) in plant emergence was observed for the treatments across the AEZ's both in the 2014 long and short rains season. The highest plant emergence was recorded in vermicompost treated plots in the two seasons. However, the lowest plant emergence was observed in control plots amended with fertilizer in the long rains of 2014 and in plots with a combination of biochar, vermicompost and fertilizer in the short rains of 2014.

Table 4: Effect of different treatments on plant emergence (%) of common bean in different AEZ's of Western Kenya during the long and short rains seasons of 2014

Treatments	Long Rains Season 2014					Short Rains Season 2014				
AEZ	LM1	LM2	UM1	UM3	Trt Means	LM1	LM2	UM1	UM3	Trt Means
Control	90.1a	77.2a	79.6b	78.4a	81.3ab	79.5c	69.1cd	85.9ab	74.6bc	77.3c
Fertilizer	87.0a	68.2b	81.9b	65.4d	75.6d	84.3abc	67.0d	85.5ab	74.1bc	77.7c
Biochar	92.2a	72.9ab	83.7b	77.6ab	81.6ab	88.3a	74.4bc	83.0b	78.3ab	81.0ab
Biochar + Fertilizer	86.0a	77.1a	84.7ab	69.7cd	79.4bc	87.3ab	74.4bc	89.5a	72.8bcd	81.0ab
Vermicompost	87.3a	77.1a	90.1a	76.9ab	82.7a	84.8abc	83.0a	84.0ab	82.6a	83.6a
Vermicompost + Fertilizer	90.6a	67.3b	84.7ab	69.0cd	77.9cd	81.7bc	75.5b	89.1a	67.5d	78.5bc
Biochar + Vermicompost	89.0a	78.3a	86.1a	72.0bc	81.6ab	83.7abc	73.6bc	81.5b	71.4cd	77.6c
Biochar + Vermicompost + Fertilizer	89.1a	72.6ab	85.5ab	69.3cd	79.1bc	80.7c	70.8bcd	83.9ab	68.9cd	76.1c
LSD Interaction Treatment × AEZ	6.2				3.1	5.7				2.8
%CV	15.2					14.1				

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. AEZ – Agro-ecological zones, LM1 – lower midland zone 1, LM2 – lower midland zone 2, UM1 – Upper midland zone 1, UM3 – upper midland zone 3, Trt – Treatment. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

4.3. Effect of soil amendments on incidence of root rot in Western Kenya

Root rot disease incidence was observed to significantly vary ($p < 0.05$) with treatments and interactions between treatments and AEZ's two weeks after planting (Table 5). During the short rains season of 2013, the highest incidence among the treatments was recorded in vermicompost amended plots while the lowest incidence was recorded in biochar and fertilizer treatment combinations and in vermicompost and fertilizers treatment combinations though the differences were not significant. The same trend was observed in the short rains season of 2014 with the differences also not being significant. During the long rains of 2014, significant

Table 5: Effect of different treatments on incidence (%) of bean root rot at two weeks of plant growth in different AEZ's of Western Kenya

Treatments	Short rains season 2013					Long rains season 2014					Short rains season 2014				
	LM1	LM2	UM1	UM3	Trt Mean	LM1	LM2	UM1	UM3	Trt Mean	LM1	LM2	UM1	UM3	Trt Mean
Control	0.6a	1.0b	1.7ab	3.1a	1.6ab	0.6a	2.7a	1.1ab	2.1a	1.6a	0.7a	1.5b	1.2ab	3.9a	1.8ab
Fertilizer	0.3a	1.3b	1.1ab	2.0a	1.2ab	0.4a	2.3ab	1.3a	2.3a	1.6a	0.6a	1.7b	1.2ab	2.3b	1.4ab
Biochar	1.0a	1.4b	2.0a	2.0a	1.6ab	1.0a	2.0b	0.7ab	1.3b	1.2bc	1.2a	2.0ab	2.5a	2.5ab	2.1a
Biochar + Fertilizer	0.6a	1.1b	0.4b	1.5b	0.9b	0.4a	1.8bc	0.7ab	2.2a	1.3ab	0.8a	1.3b	0.6b	2.1b	1.2b
Vermicompost	1.1a	3.5a	0.8ab	1.5b	1.7a	0.4a	1.5c	0.7ab	1.4b	1.0bc	1.4a	3.3a	1.6ab	2.1b	2.1a
Vermicompost + Fertilizer	0.4a	1.2b	0.6b	1.2b	0.9b	0.7a	2.0b	1.1ab	0.9b	1.2bc	0.5a	1.8b	0.9b	1.9b	1.3b
Biochar + Vermicompost	1.3a	0.5b	1.7ab	2.3ab	1.4ab	0.6a	1.3c	0.5b	1.1b	0.9c	1.9a	1.0b	1.9ab	2.9ab	1.9ab
Biochar + Vermicompost + Fertilizer	1.5a	0.7b	0.7ab	1.8ab	1.2ab	0.4a	1.8bc	1.2a	1.3b	1.2bc	1.9a	1.3b	1.0b	2.5ab	1.7ab
LSD Inter Trt x AEZ	1.3					0.6					1.4				
LSD Treatments					0.7					0.3					0.7
%CV	195.3					98.7					160.3				

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. AEZ – Agro-ecological zones, LM1 – lower midland zone 1, LM2 – lower midland zone 2, UM1 – Upper midland zone 1, UM3 – upper midland zone 3, Trt – Treatment. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

differences ($p < 0.05$) were observed among treatments. Plots with treatment combinations of biochar and vermicompost resulted in a 40% reduction in disease incidence when compared to the disease incidence in the control plots. Interaction between the treatments and AEZ's resulted to significant differences ($p < 0.05$) in LM2, UM1 and UM3 in three seasons. In the short rains season of 2013, the highest incidence was recorded in vermicompost treated plots in LM2 while the lowest was recorded in biochar and fertilizer treated plots in UMI. The same trend was observed in the short rains season of 2014 though control plots in UM3 had the highest incidence of disease. During the long rains of 2014, the highest disease incidence was recorded in control plots of LM2.

4.4. Effect of soil amendments on bean root rot severity in Western Kenya

Addition of soil amendments had an effect on the root rot disease severity at two weeks, six weeks and at harvest. Significant differences ($p < 0.05$) were observed in percent severity index (PSI) among the treatments and their interaction with AEZ's two weeks after planting in three rain seasons (Table 6). In the short rain season of 2013, the highest PSI among treatments was recorded in control plots and the lowest was recorded in vermicompost treated plots. The same was observed among treatments during the long rains season of 2014 and short rains of 2014 with the lowest PSI recorded in plots amended with a combination of biochar and vermicompost. Treatment interaction with AEZ's had the highest PSI recorded in control plots of UM3 while amendments with biochar and vermicompost resulted in 30% reduction in severity in the short rains season of 2014. During the long rains of 2014 and the short rain season of 2014, PSI was significantly reduced ($p < 0.05$) in plots amended with biochar and vermicompost or their combinations. In LR of 2014, disease severity was reduced by 39% to 46% while in the SR of 2014 it was reduced by only 20% to 29%. Control plots had the highest PSI in the second week after planting in all three seasons.

Table 6: Effect of different treatment on bean root rot severity (%) two weeks after planting in the long and short rains seasons of 2013 and 2014 in the four AEZs

Treatments	Short rains season 2013					Long rains season 2014					Short rains season 2014				
	LM1	LM2	UM1	UM3	Trt Mean	LM1	LM2	UM1	UM3	Trt Mean	LM1	LM2	UM1	UM3	Trt Mean
Control	47.6a	45.5a	52.1a	53.5a	49.7a	47.3a	58.9a	51.9b	53.7a	52.9a	53.3a	55.5a	49.3b	54.9a	53.2a
Fertilizer	42.7ab	35.0bcd	39.8bc	44.2b	40.4b	44.8a	42.2b	58.0a	48.3b	48.3b	47.4b	50.0b	58.0a	45.7b	50.3b
Biochar	45.7a	42.8a	36.8cde	39.6bc	41.2b	36.5bc	31.7d	32.5c	33.8c	33.6c	46.8b	41.5c	42.4c	41.4bc	43.0c
Biochar + Fertilizer	32.9c	31.7d	42.7b	40.4bc	36.9c	32.1cd	37.2c	34.3c	35.0c	34.6c	47.8b	42.9c	40.8c	42.8bc	43.6c
Vermicompost	33.4c	39.5b	33.9d	37.2c	36.0c	27.0d	35.6cd	36.0c	33.1c	32.9c	39.3c	50.0b	43.4c	46.0b	44.7c
Vermicompost + Fertilizer	38.3bc	36.1bcd	36.8cde	38.2c	37.4c	37.1b	34.5cd	32.5c	31.0c	33.8c	39.7c	43.2c	43.3c	43.4bc	42.4c
Biochar + Vermicompost	34.8c	32.3cd	39.3bcd	39.5bc	36.5c	32.1cd	35.0cd	31.6c	31.7c	32.6c	40.5c	45.3bc	42.7c	40.4c	42.2c
Biochar + Vermicompost + Fertilizer	37.3bc	37.8bc	31.9e	40.0bc	36.7c	33.3bcd	33.9cd	31.6c	34.7c	33.4c	39.9c	41.7c	44.9bc	43.0bc	42.4c
LSD Inter Trt x AEZ	5.5					4.8					5.2				
LSD Treatments					2.7					2.4					2.6
%CV	27.5					25.2					22.5				

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. AEZ – Agro-ecological zones, LM1 – lower midland zone 1, LM2 – lower midland zone 2, UM1 – Upper midland zone 1, UM3 – upper midland zone 3, Trt – Treatment. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

4.5. Effect of soil amendments on populations of root rot fungal pathogens two weeks after planting common bean in 2013

Soil amendments had a significant effect ($p < 0.05$) on the population of fungi isolated from the soils two weeks after planting of common bean in the short rain season of 2013 (Table 7). *Fusarium* spp was the most abundant fungi isolated across all treatments while the lowest populations isolated were those of *Macrophomina* spp. Significant differences ($p < 0.05$) were observed in the populations of *Fusarium* spp with different treatments. Control plots had the highest populations while plots amended with vermicompost and fertilizer resulted in a 38% reduction.

Table 7: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) two weeks after planting common bean in the short rains season of 2013

Treatments	Fungal colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Trichoderma* spp	*Aspergillus* spp	*Penicillium* spp
Control	134.1a	46.3a	35.3a	33.0a	2.9ab	3.5bc	8.1bcd	6.7bc
Fertilizer	133.8a	40.6b	37.3a	31.0a	3.7a	1.3c	8.8abcd	11.3bc
Biochar + Fertilizer	116.0b	29.3c	29.7b	23.7b	1.2b	8.9a	11.9a	14.2ab
Vermicompost	114.6b	30.3c	27.7b	24.0b	1.9ab	4.4b	9.0abcd	16.4ab
Biochar + Vermicompost + Fertilizer	111.3b	30.6c	26.4b	23.6b	2.2ab	3.1bc	6.1d	18.7a

Table 7 (Cont.)

Treatments	Fungal colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Trichoderma* spp	*Aspergillus* spp	*Penicillium* spp
Biochar	110.1b	31.5c	26.3b	23.1b	2.0ab	4.6b	6.5cd	14.8ab
Vermicompost + Fertilizer	109.9b	28.7c	26.2b	24.7b	2.3ab	4.2b	9.4abc	11.9bc
Biochar + Vermicompost	108.5b	30.7c	25.7b	22.3b	3.3ab	4.4b	11.2ab	11.3bc
LSD	11.3	3.7	4.5	4.2	2.4	2.2	3.2	5.9
%CV	39.1	44.2	59.8	63.0	434.1	204.1	143.3	175.7
Fpr	<0.001	<0.001	<0.001	<0.001	0.329	0.016	0.004	0.004

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

Biochar and vermicompost treatments also resulted in a 30% reduction in the populations of *Pythium* and *Rhizoctonia* spp when compared to control plots. Biochar and fertilizer treatments were observed to result in a 60% and 30% increase in populations of *Trichoderma* and *Aspergillus* spp respectively when compared to control. The highest populations of *Penicillium* spp were found in plots treated with a combination of biochar, vermicompost and fertilizer which was 64% higher than the control which had the lowest populations.

4.6. Effect of soil amendments on population of root rot fungal pathogens six weeks after planting common bean in 2013

Significant differences were observed in the population of fungi isolated from the soil rhizosphere; six weeks after planting during the long rains season of 2013 (Table 8). *Fusarium* spp populations were found highest across all treatments while *Macrophomina* spp was the least isolated. The highest population of *Fusarium* spp was recorded in control plots whereas biochar and vermicompost amendments caused a 50% reduction in the populations of *Fusarium* spp. Biochar treatments resulted in a 54% and 49% reduction in the populations of *Rhizoctonia* and *Pythium* spp respectively. Control plots also had the highest populations of these fungi. Biochar and vermicompost treatments resulted in the highest populations of beneficial fungi including

Table 8: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) six weeks after planting common bean in the long rains season of 2013

Treatments	Fungal colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Trichoderma* spp	*Aspergillus* spp	*Penicillium* spp
Control	154.2a	49.9a	31.8a	38.0a	1.9abc	0.8c	26.1b	5.6de
Control + Fertilizer	152.8a	44.3a	35.6a	35.9a	3.1a	0.5c	26.3b	3.7e
Biochar + Vermicompost + Fertilizer	115.0a	24.4b	17.7c	20.8bc	2.1ab	2.9b	47.8a	6.7cde
Biochar + Fertilizer	114.8a	24.4b	18.3bc	21.4bc	0.5bc	1.7bc	30.0b	8.0bcd
Verm + Fertilizer	114.5a	28.9b	22.8b	24.0b	0.8bc	2.6b	27.4b	10.8b
Biochar	114.2a	24.8b	16.1c	19.1c	0.3c	1.4bc	26.9b	6.3de
Biochar + Vermicompost	108.3a	24.1b	20.3bc	21.1bc	0.9bc	3.1b	24.6b	9.7bc

Table 8 (Cont.)

Treatments	Fungal colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Trichoderma* spp	*Aspergillus* spp	*Penicillium* spp
Vermicompost	105.7a	24.9b	17.8c	20.5bc	0.2c	11.3a	18.1b	15.7a
LSD	NS	9.9	4.5	4.0	1.7	1.8	11.7	3.0
%CV	50.7	63.7	77.2	62.4	421.0	227.4	162.5	143.4
Fpr	0.07	0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001

Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp, NS: No significant difference, LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

Trichoderma spp and *Aspergillus* spp whereas plots treated with vermicompost alone had the highest populations of *Penicillium* spp. The lowest populations of *Trichoderma* spp and *Aspergillus* spp were recorded in fertilizer treated plots, with significant differences ($p < 0.05$) when compared to control.

4.7. Effect of soil amendments on population of root rot fungal pathogens at harvest of common bean during the long rains of 2013

Soil amendments were observed to have an effect on root rot pathogens and other soil inhabiting fungi at the time of bean harvest after the long rains season of 2013 (Table 9). *Fusarium* spp were highly prevalent among

Table 9: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) at harvest of common bean in the long rains season of 2013

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Trichoderma* spp	*Aspergillus* spp	*Penicillium* spp
Control	161.3a	63.6a	15.1b	42.8a	3.6a	10.0ab	19.5a	11.4c
Fertilizer	120.5b	44.3b	19.6a	36.5b	3.0a	11.7ab	15.7abc	5.8d
Biochar	86.9cd	25.5c	8.5c	21.1c	1.0bc	2.5c	13.7bc	13.1bc
Biochar + Fertilizer + Vermicompost	 75.7d 117.1b	 23.5c 27.1c	 5.9d 7.1d	 20.6cd 20.2cd	 0.4bc 0.02c	 9.1abc 13.5a	 18.3ab 18.4ab	 10.4cd 20.8a
Vermicompost + Fertilizer	100.2bc	23.7c	10.7c	21.8c	0.01c	13.9a	13.1c	13.4bc
Biochar + Vermicompost	101.7bc	25.4c	9.1cd	16.8d	1.1b	11.3ab	18.9a	14.6bc
Biochar + Vermicompost + Fertilizer	98.8bcd	20.6c	7.4d	19.6cd	0.2bc	5.6bc	20.5a	17.8ab
LSD	24.3	8.2	3.2	4.2	1	6.9	4.9	5.5
%CV	43.9	54.1	106.1	64.7	319.6	278.6	111.5	161.8
Fpr	<0.001	<0.001	<0.001	<0.001	<0.001	0.016	0.018	<0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

all the fungi across all treatments while *Macrophomina* spp was the least of all fungi. Significant differences ($p \leq 0.05$) were found in population of all fungi across the treatments except for *Aspergillus* spp where no significant differences were recorded. Treatment combinations of biochar, vermicompost and fertilizer resulted in the reduction of *Fusarium* spp population by 67% when compared to control. Vermicompost and fertilizer combination reduced *Fusarium* by 63%. The population of *Pythium* spp was significantly lower in biochar and fertilizer treatment translating to a 60% population reduction. Populations of *Rhizoctonia* were lowest in biochar and vermicompost treatment combination while the highest populations were recorded in the non-amended control plots. Vermicompost and fertilizer treatment combination at the same time resulted in elevated population of *Trichoderma* spp which were lowest in biochar treatment. Vermicompost standalone treatments resulted in significantly ($p < 0.05$) high populations of *Penicillium* spp which were lowest in the control plots.

4.8. Effect of soil amendments on population of root rot fungal pathogens two weeks after planting of common bean in the long rain season of 2014

Soil amendments were observed to have a significant effect ($p < 0.05$) on the population of bean root rot two weeks after planting in 2014 (Table 10). *Fusarium* spp were most abundant across all treatments while the lowest populations were of *Macrophomina* spp. Populations of *Fusarium* spp were significantly different ($p < 0.05$) across the six treatments. The highest populations were found in the control plots while soils amended with vermicompost had a 59% reduction in populations. Vermicompost treatment resulted in a 52% reduction of *Pythium* spp populations. Combination of vermicompost and fertilizer reduced *R. solani* populations by 48%. Biochar treatments were observed to reduce all root rot pathogens by 40% margin. The control plots recorded the highest populations of all root rot pathogens. Consequently, the populations of *Penicillium*, *Aspergillus, Paecilomyces, Athrobotrys* and *Trichoderma* spp were highest in vermicompost treatments in the range of 60% to 90%. Biochar resulted in an increase of between 50% and 80% of these fungi. Similar observations were made in the short rains season of 2014, though the effect of the treatments was observed to have reduced by a margin of 20% (Table 11).

Table 10: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) two weeks after planting common bean in the long rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	140.2a	52.9a	38.4	31.7a	4.5a	0.8d	3.6d	3.8bc	0.3c	4.1e
Fertilizer	132.5a	45.9b	37.9	34.6a	3.3ab	1.6d	2.4d	1.3d	0.3c	5.3de
Biochar	95.3bc	31.1c	18.5	19.4b	0.5d	5.6bc	9.5ab	1.9cd	0.4c	8.4ab
Biochar + Fertilizer	97.7bc	26.7de	22.1	18.9b	1.0cd	7.2ab	7.6bc	4.4ab	2.3b	7.7bc
Vermicompost	104.8b	21.4f	18.3	18.9b	1.7bcd	10.0a	11.9a	6.7a	5.7a	10.3a
Vermicompost + Fert	91.0c	22.5f	19.3	16.4b	2.1bcd	9.5a	5.1cd	4.9ab	5.6a	5.7c
Biochar +Verm	95.2bc	27.2d	18.5	19.7b	3.3ab	3.8cd	7.6bc	5.6ab	3.0b	6.4bcd
Biochar + Verm + Fert	90.2c	23.3ef	19.1	17.7b	2.3bc	6.2bc	6.7bc	5.6ab	4.7a	4.6d
LSD	10.2	3.7	NS	3.8	1.7	3.2	2.8	2.4	1.4	2.0
%CV	37.8	48.6	64.3	67.9	261.6	180.7	145.3	239.3	200.2	146.4
Fpr	<0.001	<0.001	0.074	<0.001	0.05	0.05	<0.001	<0.001	<0.001	<0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp. Fert: Fertilizer, Verm: Vermicompost, NS: No significant difference, LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

Table 11: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) two weeks after planting of common bean during short rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	139.1a	52.0a	36.7a	28.9ab	1.3ab	4.7bc	5.4bc	4.9cde	0.01d	5.1d
Fertilizer	130.5ab	46.7b	39.0a	32.3a	3.3a	1.9c	2.8c	2.1e	0.4cd	1.9e
Biochar	129.9ab	39.2c	31.1b	24.6bc	1.8ab	7.4ab	6.6b	3.0de	1.7bc	14.6a
Biochar + Fertilizer	122.4bc	38.2c	29.3bc	25.4bc	0.8b	4.8bc	5.5bc	6.3bc	2.9b	9.2b
Vermicompost	130.5ab	35.2cd	28.8bc	25.8bc	1.3ab	9.2a	11.8a	5.6cd	4.4a	8.5bc
Vermicompost + Fert	115.7c	32.1d	25.2c	23.9c	1.8ab	8.9ab	6.8b	11.2a	0.01d	5.7d
Biochar + Verm	121.7bc	37.3c	27.3bc	25.8bc	1.0ab	7.7ab	8.0b	6.2bc	2.1b	6.4cd
Biochar + Verm + Fert	122.7bc	34.8cd	29.0bc	24.6bc	0.7b	6.9ab	7.3b	9.2ab	0.4cd	9.8b
LSD	11.7	4.7	4.1	4.6	2.3	4.3	3.5	3.1	1.4	2.6
%CV	37.1	49.0	53.9	67.6	467.4	202.3	185.6	214.3	367.1	153.9
Fpr	<0.001	<0.001	0.002	<0.001	<0.001	≤0.05	<0.001	0.004	0.001	<0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp, Fert: Fertilizer, Verm: Vermicompost, LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

4.9. Effect of soil amendments on populations of root rot fungal pathogens six weeks after planting common bean during the long rain season of 2014

Significant differences were observed in the population of root rot fungi isolated from the soils of treated plots six weeks after planting in the long rains season of 2014 (Table 12). *Fusarium* spp was the most prevalent of all the fungi across all treatments while *Macrophomina* spp was the least. Vermicompost treatment and the combinations of biochar and fertilizer were observed to cause a 40 to 50% reduction in the populations of *Fusarium* spp when compared to control. Biochar and fertilizer amendments also resulted in a 32% reduction of *Pythium* populations and a 42% reduction of *Rhizoctonia* populations. Control plots had the highest populations of all the root rot fungi. Vermicompost treated plots were observed to have the highest population of *Penicillium* spp representing a 55% difference from the control plots which had the lowest populations. *Paecilomyces* spp, *Trichoderma* spp and *Aspergillus* spp were positively affected by biochar treatments. *Athrobotrys* spp population was highest in plots treated with a combination of biochar, vermicompost and fertilizer whereas the control plots had the lowest population.

Similar trends in reduction of root rot populations were observed in the short rains season of 2014 but at lower percentages (Table 13). Significant differences ($p < 0.05$) were observed for all root rot fungi. Vermicompost treatments resulted in a reduction of between 32% and 37% for *Fusarium, Pythium* and *Rhizoctonia* spp while control plots recorded the highest population of the root rot fungi. Treatment combination of biochar, vermicompost and fertilizer resulted in 50% and 89% increase in the populations of *Paeciliomyces* spp and *Athrobotrys* spp. Biochar and fertilizer on the other hand resulted in a 54% increase in the populations of *Aspergillus* spp with the control plots recording the lowest populations of *Aspergillus* and *Athrobotrys* spp.

Table 12: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) six weeks after planting common bean in the long rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	158.2a	50.4a	29.7a	32.0a	6.3abc	6.8c	15.3c	7.8a	1.8c	8.1ab
Fertilizer	152.3a	46.2a	30.3a	27.6a	8.2a	8.4bc	17.1bc	8.0a	2.6c	3.8c
Biochar	133.9b	28.5b	20.4b	19.8b	3.8c	8.6bc	22.5b	10.5a	9.5a	10.2a
Biochar + Fertilizer	132.7bc	27.6b	20.2b	18.4b	6.7abc	10.7bc	29.5a	8.6a	4.1bc	6.8b
Vermicompost	132.9bc	29.4b	21.5b	17.7b	5.2bc	19.7a	19.2bc	10.2a	4.1bc	5.9bc
Vermicompost + Fertilizer	121.9c	25.6b	22.9b	20.3b	4.2c	11.6b	19.2bc	9.0a	2.5c	6.6b
Biochar + Vermicompost	126.4bc	30.4b	20.9b	19.3b	7.4ab	10.9bc	16.9bc	10.9a	5.8b	3.8c
Biochar + Vermicompost + Fertilizer	129.9bc	29.3b	20.3b	21.7b	4.1c	9.5bc	18.1bc	9.1a	11.5a	6.3b
LSD	11.8	5.2	4.3	4.6	2.9	4.2	6.0	4.5	2.8	2.3
%CV	34.7	62.2	71.4	80.9	190.9	163.1	123.8	191.1	238.4	156.5
Fpr	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.07	0.009	<0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. Nonpathogenic fungi – *Aspergillus* spp, *Penicillium* spp, *Trichoderma* spp. LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

Table 13: The residual effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) six weeks after planting common bean in the short rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	160.9a	50.0a	33.9a	36.6a	5.2a	9.7b	15.5b	5.1bc	0.5c	5.6ab
Fertilizer	155.4ab	44.8b	30.7a	33.7a	5.9a	5.6c	19.7b	8.5ab	2.7abc	3.6bc
Biochar	138.7cde	37.7c	26.1b	27.4b	4.7a	7.4bc	19.9b	9.6a	2.1bc	3.8bc
Biochar + Fertilizer	146.8bc	36.1c	26.2b	27.7b	6.2a	7.0bc	32.9a	4.7bc	2.8abc	3.3c
Vermicompost	134.5de	33.3c	25.8b	22.8c	6.9a	13.6a	19.2b	5.0bc	3.7ab	4.1bc
Vermicompost + Fertilizer	127.7e	34.3c	22.9b	27.6b	5.1a	8.1bc	18.5b	3.9c	2.0bc	5.2bc
Biochar + Vermicompost	143.1cd	35.0c	26.5b	28.5b	4.7a	9.1bc	17.8b	9.9a	4.3ab	7.4a
Biochar + Vermicompost + Fertilizer	137.5cde	33.8c	25.0b	29.0b	3.6a	10.3ab	17.0b	10.2a	4.8a	3.9bc

Table 13 (Cont.)

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
LSD	11.3	4.9	3.7	4.2	NS	3.8	6.6	4.2	2.3	2.1
%CV	31	51.1	54.3	58.2	213.8	164.4	126.9	230.2	334.9	161.3
Fpr	<0.001	<0.001	<0.001	<0.001	0.10	<0.001	0.01	0.016	0.003	0.002

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. LSD: Least significant difference at 5% level, CV: Coefficient of variation, and NS- No significant difference.

4.10. Effect of soil amendments on population of root rot fungal pathogens at harvest of common bean during the long rain season of 2014

During the harvest period of long rains season of 2014, soil amendments were observed to have an effect on root rot pathogens and other soil inhabiting fungi (Table 14). *Fusarium* spp*.* was most isolated of all the fungi in all treatments while *Macrophomina* spp was the least isolated. Significant differences ($p \leq 0.05$) were observed in population of all fungi across the treatments. Treatment combination of biochar, vermicompost and fertilizer resulted in the reduction of *Fusarium* spp population by 39% and the highest populations being recorded in control plots. The population of *Pythium* spp was significantly lower ($p < 0.05$) in biochar and fertilizer treatment translating to a 40% reduction in population. *Rhizoctonia* was also observed to be lowest in biochar and fertilizer treatment combinations while the highest populations were recorded in the control plots. Biochar

Table 14: Effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) at harvest of common bean in the long rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	159.5ab	50.6a	25.3a	34.1b	7.5b	8.9b	17.5	9.0ab	1.7e	4.8c
Fertilizer	164.8a	47.8a	27.5a	39.1a	11.0a	8.9b	17.5	6.7b	2.1e	4.3c
Biochar	146.7c	31.0b	16.5b	21.7cd	4.7c	14.2a	25.8	8.8b	13.2a	10.8ab
Biochar + Fertilizer	147.7bc	31.2b	17.7b	19.5d	4.7c	16.0a	30.4	9.5ab	6.7c	12.1a
Vermicompost	132.2d	30.7b	18.5b	21.2cd	4.9bc	13.6ab	21.0	7.7b	5.7cd	9.0b
Vermicompost + Fertilizer	139.9cd	32.5b	17.5b	25.0c	5.3bc	12.3ab	26.5	8.7b	3.4de	8.6b
Biochar + Vermicompost	136.1cd	31.2b	17.4b	20.0d	7.5b	12.5ab	18.3	12.8a	7.0bc	9.4ab
Biochar + Vermicompost + Fertilizer	139.4cd	28.4b	18.4b	22.9cd	4.0c	13.1ab	23.6	8.2b	9.6b	11.2ab
LSD	12.4	5.2	3.2	4.6	2.7	4.7	NS	3.8	2.8	2.7
%CV	34.1	58.3	65.6	71.3	171.6	152.0	107.1	173.6	193.9	124.9
Fpr	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.065	<0.001	<0.001	<0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. NS: No significant difference, LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

and fertilizer treatment combination at the same time resulted in elevated population of *Penicillium* spp, *Aspergillus* spp and *Trichoderma* spp. The population of these three genera was observed to be lowest in the control plots. Similar trends were observed for root rot pathogen as well as other soil inhabiting fungi in the short rains season of 2014 though the percentage reduction in populations was 10% lower than in the long rains season (Table 15).

Table 15: The residual effect of biochar and vermicompost on fungal populations (× 10^3 CFU/g soil) at harvest of common bean in the short rains season of 2014

Treatments	Fungal Colonies	*Fusarium* spp	*Pythium* spp	*Rhizoctonia* spp	*Macrophomina* spp	*Penicillium* spp	*Aspergillus* spp	*Paecilomyces* spp	*Athrobotrys* spp	*Trichoderma* spp
Control	155.5a	49.8a	27.8a	38.0a	4.2a	6.9cd	16.7b	5.1bcd	0.9c	5.5bc
Fertilizer	141.5b	43.9b	25.0abc	29.7b	4.5a	6.0d	18.9b	8.5a	2.8bc	3.6c
Biochar	137.4b	37.8c	19.9c	25.8bcd	6.5a	5.8d	20.3b	8.7a	5.8a	7.5ab
Biochar + Fertilizer	137.5b	37.1c	21.9bc	22.6d	6.6a	9.0bcd	30.4a	3.3cd	1.7bc	4.5c
Vermicompost	134.0b	36.4c	22.2bc	22.7d	5.3a	15.7a	18.8b	5.8abcd	3.1b	3.8c
Vermicompost + Fertilizer	131.9b	36.1c	25.3ab	23.1cd	5.9a	12.1ab	18.1b	2.7d	2.3bc	7.7ab
Biochar + Vermicompost	141.0b	35.1c	23.2bc	24.7cd	6.3a	10.4bc	19.7b	8.0ab	2.5bc	9.0a
Biochar + Vermicompost + Fertilizer	134.8b	34.6c	22.8bc	26.8bc	4.6a	8.0bcd	18.3b	6.6abc	3.6b	9.2a
LSD	11.2	4.9	3.4	4.0	NS	4.1	6.4	3.3	1.9	2.7
%CV	31.9	50.4	57.3	59.1	208.3	178.9	127.2	188,5	272.9	133.8
Fpr	<0.001	<0.001	<0.001	<0.001	0.09	<0.001	0.006	0.018	<0.001	0.001

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. NS: No significant difference, LSD: Least significant difference at 5% level, and CV: Coefficient of variation.

4.11. Effect of biochar and vermicompost on yield and 100 seed weight of common bean

Bean grain yield was significantly affected ($p \leq 0.05$) by the treatments in all the seasons except the short rains season of 2014 where the differences were not significant (Table 16). The long rains season of 2013 recorded the highest average yield across all treatments. The yields were observed to be 17% higher than the long rains season of 2014 which ranked second. There was however a significant drop of 45% in yield from the long rains season of 2013 into the short rains season of the same year. This trend was reversed in the long rains season of 2014 recording a 30% to 50% increase in yield across all treatments.

Vermicompost and fertilizer treatments had the highest grain yield in the long rains and short rains of 2013 as well as in the long rains of 2014. In the long rains of 2013, the yield was observed to be 81% higher in vermicompost and fertilizer treatment and 46% higher in biochar, vermicompost and fertilizer treatment plots. These were in comparison to the non-amended control plots. During the short rains of 2013, plots that were amended with solitary biochar treatments recorded the lowest grain yield as was the case during the long rains of 2013. There was no significant difference in bean yield in the short rains season of 2014 where the yields were greatly reduced. Treatment combinations of vermicompost and fertilizer still recorded the highest grain yield while biochar and vermicompost plots had the lowest yield.

Table 16: Effect of biochar and vermicompost on common bean yields (kg/ha) and seed quality (weight per 100 seeds) across all the four seasons in 2013 and 2014

Treatments	Common bean grain yield (kg/ha)				Common bean seed quality (g/100 seeds)			
	Long rains 2013	Short rains 2013	Long rains 2014	Short rains 2014	Long rains 2013	Short rains 2013	Long rains 2014	Short rains 2014
Vermicompost + Fertilizer	565.2a	306.3a	481.1a	64.7a	33.3a	32.1a	37.3a	17.5b
Biochar + Vermicompost + Fertilizer	489.7ab	282.3ab	445.9ab	46.8a	32.1a	29.2a	36.3a	17.9b
Vermicompost	455.0abc	252.6ab	333.5bc	48.6a	31.9a	29.5a	36.1a	14.5c
Biochar + Fertilizer	433.8bcd	254.0ab	380.9abc	51.0a	32.7a	28.2a	36.5a	21.4a
Biochar + Vermicompost	413.3bcd	220.7b	456.5ab	41.1a	31.9a	29.4a	36.3a	16.4bc
Control + Fertilizer	377.7bcd	239abc	319.5c	57.2a	30.6a	28.5a	36.2a	16.8bc
Biochar	353.9cd	172.8c	259.1c	52.8a	30.4a	26.2a	36.1a	16.9bc
Control	311.7d	271.5ab	350.5bc	44.3a	29.7a	28.2a	34.8a	19.1ab
LSD	126.0	76.9	124.3	NS	NS	NS	NS	2.8
%CV	54.1	62.4	71.7	117	14.2	34.7	12.3	28.4
Fpr	0.004	0.037	0.005	0.88	0.065	0.524	0.532	0.002

Note: Means with same letter(s) within the same column are not significantly different at $p \leq 0.05$. NS: No significant difference, LSD: Least significant difference at 5% level; and CV: Coefficient of variation.

Bean seed weight was affected by the soil amendment treatments in all the seasons with differences being significant ($p \leq 0.05$) in all the seasons (Table 16). Vermicompost and fertilizer amended treatment plots had the highest 100 seed weight in three seasons averaging 8% to 20% change in g / 100 seeds. Biochar vermicompost and fertilizer amended treatment plots had the second highest seed quality which was 10% higher than the control plots in the long rains of 2013. In the subsequent short rain season of 2013, biochar treated plots recorded the lowest seed quality though it was observed to only be significantly different ($p < 0.05$) from the vermicompost and fertilizer treated plots from which the highest seed quality was recorded. In the short rains season of 2014, the highest seed quality was in biochar and fertilizer treatment combinations. This was 48% higher than in vermicompost amended treatment plots which had the lowest seed quality the differences being significant ($p \leq 0.05$).

5. Discussion

5.1. Effect of soil amendments on plant emergence

Plant emergence was affected by the application of individual treatments of biochar and vermicompost as well as their combinations. Soil amendments positively influenced the plant emergence. Treatment combinations of biochar and vermicompost had the highest emergence immediately after application and the subsequent season when amendments were not applied. The results concur with those reported by Ievinsh *et al.* (2017) and Arancon *et al.* (2012) where there was increase in germination of hemp seeds and cucumber seeds treated with vermicompost. Solaiman *et al.* (2011) also reported an increase in mung bean germination with biochar treatment. The results from this study also confirm the presence of positive residual effect of biochar and vermicompost on plant emergence in short rain seasons of 2013 and 2014 which has not been previously reported. Plant emergence was also observed to be influenced by the AEZs. Lower midland humid (LM1) and upper midland humid (UM1) were observed to have higher emergence in the long rains season of 2014 and the two short rain seasons. However in the long rains season of 2013 UM3 and LM2 were observed to have significantly higher emergence. This can be attributed to the distribution of the rainfall at the time of planting. Upper midland zone 3 (Kakamega region) recorded highest precipitation at 712 mm in the three growing months and lowest in LM1 (N. Teso sub county) at 447 mm for the three months of growth. Plant emergence is of great importance since the plant population would eventually affect the final yield.

5.2. Effect of soil amendments on root rot disease incidence

Different treatments of biochar and vermicompost and their interaction with AEZ's reduced bean root rot incidence. The findings also point to the influence of AEZ's on the effectiveness of soil amendments in suppressing root rot disease in common bean. Disease incidence was reduced by 60% in both the long rain seasons when the treatments were applied and 40% in the short rain seasons with no treatment application but with residual effect. Treatment combinations of biochar and vermicompost greatly reduced root rot incidence after application. These plots had the lowest disease incidence showing a synergy at play while those that received one amendment alone had a higher disease incidence which was however significantly ($p < 0.05$) lower than the control plots. This finding corroborate previous findings by Chaoui *et al.* (2002) and Edwards and Arancon (2004b) who reported on suppression of root rots in strawberry using vermicompost. Jaiswal *et al.* (2014) also reported on root rot disease suppression in cucumber using biochar.

During the period of this research, rainfall amounts varied between 143 mm and 712 mm in the four different seasons in the months of March to July; September to November of 2013 and 2014. Disease incidence was lower in the long rains season after application of soil amendments. This was observed both at two weeks and six weeks after planting where the disease incidence was reduced by as much as 60% as compared to that in the control plots. In the long rains season, the highest incidence was in LM1 while UM3 recorded the lowest. This concurs with previous studies by Mwang'ombe *et al.* (2007) and Hall and Philips (1992) who worked on bean root rots in Embu, Kenya and South Western Uganda respectively. They observed that elevated rainfall stimulated root infection. In turn this would lead to accumulation of inoculum in the root tissues. The impact of the inoculum build up is then felt in the short rains season with elevated root rot incidences where no rotation is practiced. However in this study, findings show that amendments with biochar and vermicompost prevented development of inoculum resulting to reduced disease incidence. Similar findings have been reported by Warnock *et al. (*2007) and Ameloot *et al.* (2013) that biochar can be used as a source of energy or mineral nutrients which may induce changes in community composition.

In the subsequent season, disease incidence was observed to be higher in the plots where no inorganic fertilizer sympal® (N.P.K 0:23:15) had been applied. This implies the importance of the phosphorus in root development and in turn disease suppression. Similar findings were reported Yamato *et al.* (2006) who stated that biochars antifungal potential was due to its important properties among them increased nutrient retention, increased soil cation exchange capacity and effects on Phosphorus. Ceroz and Fitzsimmons (2016) and Cichy *et al.* (2007) observed that disease severity may reduce through new growth resulting from improved crop vigor as a result of phosphorus nutrition.

5.3. Effect of soil amendments on root rot disease severity in Western Kenya

Root rot disease severity was greatly reduced by as much as 60% following application of biochar and vermicompost soil amendments across all seasons and growth stages. In the subsequent seasons when no amendments were applied, disease severity was reduced by 30%. Treatment combinations of biochar and vermicompost with addition of sympal® fertilizer had the lowest disease severity than with amendments alone. Similar findings were reported by Matsubara *et al.* (2002) who observed reduced *Fusarium* wilt disease in Asparagus following application of biochar. Jaiswal *et al.* (2014) also reported reduction in damping off disease caused by *Rhizoctonia solani* in cucumber and beans following addition of 0.5% wt / wt of greenhouse waste biochar. Other findings by Jack (2012) also showed disease suppression in cucumber caused by *Pythium aphanidermatum* following application of vermicompost extract.

The control plots recorded the highest severity in all seasons across the AEZ's. This can be attributed to the continuous planting of beans with no rotation period. Disease severity did not however vary greatly across the agro-ecological zones though LM2 appeared to have the highest severity while the lowest severity was recorded in UM1. These levels of severity can also be linked to the rainfall received in different agro-ecological zones. Similar findings have been reported by Mwang'ombe *et al.* (2007) working on bean root rots in Embu. They observed that increased rainfall leads to high soil moisture which favors root rot pathogens such as species of *Pythium* and *Rhizoctonia*.

5.4. Effect of soil amendments on fungal populations isolated from soils planted with common bean

Treatments with biochar, vermicompost and in combination were found to greatly impact soil fungal populations. Vermicompost treatment resulted in significant ($p < 0.05$) reduction of *Pythium* spp populations across the agro-ecological zones. Vermicompost treatments also resulted in the highest reduction of *Fusarium* spp. populations at the second week of plant growth. With the progression of the cropping season, biochar treatments as well as in combination with vermicompost resulted in significant reduction of *Fusarium* spp and *Rhizoctonia* spp. These findings are similar to those of Jack (2012) and Scheuerell *et al.* (2005) who observed significant suppression of *P. aphanidermatum* and *P. ultimum* populations in soils treated with vermicompost in cucumber and beans respectively. Graber *et al.* (2010) attributed the reduction of detrimental fungal populations to chemical compounds in the residual tars found on biochar. They identified several biochar compounds known to have detrimental effects on growth and survival of pathogenic microorganisms. In low levels, these compounds can suppress sensitive components of the soil microorganisms and result in a proliferation of resistant microbial communities that are beneficial to plant growth. This phenomenon was observed in biochar treatments which resulted to an increase in population of beneficial microorganisms such as *Trichoderma* spp, *Paeciliomyces* spp and *Athrobotrys* spp. Similarly vermicompost treatments were also observed to result in an increase of *Penicillium* spp and *Aspergillus* spp after application and also as a residual effect when no amendments were applied.

5.5. Effect of biochar and vermicompost on yield and seed weight of common bean

Yields of common bean were significantly ($p \leq 0.05$) influenced by the treatments in all the seasons other than the short rains season of 2014 where the differences were not significant. Higher grain yield was recorded in plots amended with vermicompost and sympal® fertilizer treatments as well as in the biochar, vermicompost and fertilizer amended plots. The amendments resulted in yield increase of between 46% and 81%. Similar findings have also been reported in previous studies by Guerena *et al.* (2015) and Lin *et al.* (2015). They observed an increase in bean biomass and grain yield following the application of biochar and vermicompost. This study also showed an increase in yield when biochar was combined with fertilizer than in individual application of biochar or Sympal fertilizer. Similar results were reported earlier by Liang *et al.* (2014) and Oram *et al.* (2014) who reported improved yield following application of biochar and organic/inorganic fertilizers together. This was attributed to an increase in nutrient resource to plants. Liard *et al*. (2010) on the other hand demonstrated heightened nutrient preservation in soils amended with biochar. This explains why biochar stand-alone treatments posted low yields which were only higher than the control treatments without inorganic fertilizer in the first season and lowest in the subsequent seasons. Seed weight was highest in vermicompost and fertilizer amended treatment plots ranging between 33.3g and 37.3g 100^{-1} seeds followed by biochar and fertilizer amended treatment plots ranging between 32.65 and 36.49g 100^{-1} seed. Biochar standalone treatment plots recorded low 100 seed weight in subsequent seasons when no amendments were added. The non-amended control treatment plots recorded the lowest seed weight of 29.7g 100^{-1} seeds.

6. Conclusion

Applications of biochar and vermicompost greatly inhibited the growth of root rot fungi hence protecting the plants from pathogenic attack. The soil amendments do have the potential to suppress soil borne pathogenic microorganisms directly and also induce multiplication of resistant microbial communities that are beneficial to plant growth. They also suppress pathogens in the soil environment. The addition of amendments as a combination or standalone treatments resulted in reduction of incidence and severity of root rot. This in turn led to increased common bean productivity.

Conflicts of interest

Authors declare no conflict of interests

Acknowledgment

We are grateful to USDA-NIFA FEED THE FUTURE project which is the US Government's Global Hunger and Food Security Initiative for their support and funding of the study. We also acknowledge Cornell University; International Institute of Tropical Agriculture for their support.

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Cite this article as: Samuel A. Were, Rama Narla, E. W. Mutitu J.W. Muthomi, Liza M. Munyua, Dries Roobroeck, Bernard Vanlauwe and Janice E. (2021). Biochar and vermicompost soil amendments reduce root rot disease of common bean (*Phaseolous Vulgaris* L.). *African Journal of Biological Sciences.* 3(1), 176-196. doi: 10.33472 / AFJBS.3.1.2021.176-196.