International Journal of Research in Agricultural Sciences
Volume 6, Issue 4, ISSN (Online): 2348 – 3997

Effect of Vermicompost and Biochars from Different Crop Residues in Management of Root Rot of Common Bean (*Phaseolus vulgaris L.*)

Samuel A. Were[1*, 4], Rama D Narla[1], Janice E. Thies[2]., Eunice W. Mutitu[1], James W. Muthomi[1], Luiza M. Munyua[1], Dries Robrooek[3] and Bernard VanLauwe[3].

[1.] Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O. Box. 30197, 00100 Nairobi, Kenya.

[2.] School of Integrative Plant Science, College of Agriculture and Life Sciences, Cornell University 722 Bradfield Hall Ithaca, NY 14853-5905, USA.

[3.] International Institute of Tropical Agriculture (IITA), Nairobi, c/o ICIPE, Kasarani, P.O. Box 30772 00100 Nairobi, Kenya.

[4.] Department of Botany, College of Pure and Applied Sciences, Jomo Kenyatta University of Agriculture and Technology P.O. Box. 62000, 00200 Nairobi, Kenya.

*Corresponding author email id: samaringo@gmail.com

Date of publication (dd/mm/yyyy): 29/07/2019

***Abstract* – Root rot of common beans has continued to increase in importance and in some instances leads to 100% yield loss especially in intensified monocultures. Their broad host range and survival on crop residue as well as in the soil asunder different survival structures posses' a challenge in their management Soil amendments with have been known to influence plant growth and also impact on soil borne pathogens. The effect of vermicompost and biochars from different feed stocks on bean root rot was assessed in a greenhouse study. Soils were amended with vermicompost and biochar at a rate of 1:1 v/v. Inoculation with four different root rot pathogens and their mixture was done using artificially infected sorghum seed at a rate 5g per pot treatment. Five bean seeds were planted and assayed for germination, shoot height; root weight and root rot severity at the end of the study. Treatment combinations of biochar and vermicompost had a positive impact on plant emergence. Rice hulls biochar amendments resulted in the highest shoot height while sugarcane bagasse biochar had the highest root length. Combination of rice hulls and vermicompost had the greatest shoot and root weight. Plants in biochar amended soils had 9% lower severity than plants in vermicompost amended soils and 25% less than the non-amended soils. Rice hulls biochar had greater impact on plant growth whereas sugarcane bagasse biochar greater effect on root rots severity.**

***Keywords* – Root Rot, *Fusarium Solani, Pythium Ultimum, Rhizoctonia Solani*, Soil Amendments, Biochar, Vermicompost.**

I. INTRODUCTION

Root rot diseases greatly affect bean production when plants are grown typically under monoculture with reduced or no fallow periods (Katan, 2002). Soil borne root rot pathogens can survive actively on host, plant residues and organic materials as saprophytes. They can also survive in soil in the form of chlamydospores, oospores, sclerotia and or melanized mycelium until they are triggered into germination by the presence of a suitable host (Waller and Brayford, 1990; Koike *et al.,* 2013).

Losses due to soil borne pathogens have been assessed to be 10-20% of the achievable yield or 100% crop loss for many crops when not managed (Buruchara *et al.,* 2015). There however are limited efficient options for management of soil borne diseases (Abawi and Pastor Coralles 1990, Koike *et al.,* 2013). Most of the options in use rarely result in complete disease control. Furthermore, some of the measures employed can have negative significant impacts that far surpass the impacts of the disease to the producer and consumers. It is therefore important to put in to consideration the effects of the management strategies on both the environment as well as

the population in the area of application.

Disease management strategies such as soil amendments have been known for their influence on plant development and efficacy against soil-borne diseases from the time they were suggested (Noble and Coventry, 2005, Siddiqui *et al.,* 2015). There use has continued to be encouraged following the increased awareness on food safety concerns and environmental pollution as a result of indiscriminate use of agro-chemicals (Muriungi *et al.,* 2014). Studies on application of soil amendments targeting plant development and biological control agents in soil have shown their great potential in root rot disease management (Atiyeh *et al.,* 2000; Graber *et al.,* 2014). Disease suppression due to application of soil amendments such as vermicompost and biochar have been reported for damping-off caused by *Pythium*, *Rhizoctonia* root rot and *Fusarium* wilt (Edwards and Arancon 2004; Matsubara *et al.,* 2002; Jaiswal *et al.,* 2014).

Pythium ultimum, *Rhizoctonia solani, Fusarium solani* and *F. oxysporum* are common soil-borne pathogens causing diseases in common bean. They have numerous hosts, high degree of specificity and enduring resting structures. This in combination with their saprophytic activity makes their management difficult (Agrios 2005). There is therefore a growing requirement for effective approaches for management of soil-borne diseases, more so on small holder farms engaging in intensive farming.

This study aimed at exploring the prospective suppression effect of the vermicompost from vegetable waste and biochar produced from rice hulls and sugarcane bagasse against bean root rot. Soil amendments with vermicompost, rice hulls biochar, sugarcane bagasse biochar and combinations of vermicompost with each biochar were assessed for disease suppression and plant growth development.

II. Materials and Methods

Production of Biochar

Sugarcane bagasse was obtained from Kibos Sugar Co., Kisumu, Kenya whereas rice husks were sourced from Riceland Food Co., Stuttgart, AR, USA. The feed stocks were dried for 24 h at 75°C and ground in a hammer mill with a 4 mm screen. Biochar was produced by pyrolysing the feed stocks at 400°C using a charcolator at Cornell University (Ithaca, NY, USA). The resulting biochars were stored in sterile glass jars before being used in the experiment.

Production of Vermicompost

Vermicompost was produced from vegetable crop residue which were chopped, air dried for 7-10 days then placed in to 30 centimeter deep rectangular troughs which had an initial population of earth worms (*Eisinia andrei*) in pre decomposed crop material and soil mixture. The crop residue was spread evenly on the surface of the trough where it was decomposed by *Eisinia andrei* worms feeding on the plant debris. The vermicompost was packed in gunny bags and stored before being used in the experiment.

Characterization of Biochar and Vermicompost

Biochars were air-dried, ground with mortar and pestle and sieved to achieve 149 to 850 µm particle size before analyses. Chemical Analysis for wood charcoal based on ASTM D1762-84 was used to determine the proximate analysis with modification in order to accommodate biochar reactivity (Enders *et al.,* 2012). Elemental analyses were done after sieved biochars were ground using a ball mill to achieve a fine homogenous powder. Dumas

combustion was used to determine total carbon (C_{tot}) and nitrogen (N_{tot}) of the biochars. The pH was measured after 1 g of each char was weighed directly in to a 60-mL glass vial to which 20mL of 1 M KCl prepared using deionized water was added. The vials were then placed on a mechanical shaker and agitated for one and half hours. The biochar water mixture was continually mixed while the pH was measured (Enders *et al.,* 2012).

Vermicompost on the other hand was rested for one month after production before the determination of it physical and chemical characteristics. A two millimeter strainer was used to sieve the vermicompost followed by air drying for 24 hours at room temperature before analyses were carried out. Determination of organic matter content was done by use of a combustion oven at 550°C following the method of Kacar 1994. Five grams of fresh vermicompost was oven dried at 55°C for a period of 24 hours and the difference in weights used to determine the moisture content. An EC and pH meter was used to determine the electrical conductivity and pH of vermicompost in a 1:5 and 1:2.5 v:v of vermicompost to 1 M KCl mixtures, respectively. Total nitrogen was determined using the Kjeldahl method as described by Kacar (1994). Cation exchange capacity was determined by the ammonium acetate method defined by Kacar (1994). Filtrates from triple repeats of the above described procedure were collected and used in flame photometer reading for Na determination.

III. Disease Suppression Assay

Preparation of the Soil Sand Media and Application of Amendments

Garden soil and sand were sieved using a 2mm mesh before being autoclaved for 30 min at 121°C and 1.5 bars pressure. The autoclaving was repeated three times on consecutive days. The sand and soil mixture were used for potting at the ratio of 1:2 (v:v). Mixing of the soil amendments was done aseptically in buckets which had been surface sterilised with Green shield prior to use. These amendments and the soil sand mixtures were then transferred to the pots and filled up to 1 cm to the brim to prevent overflow at the time of irrigation. The pots were then labeled accordingly. The disease suppression assay of the soil amendments against bean root rot pathogens was conducted under greenhouse conditions with temperatures ranging from 25°C to 30°C with a 12 hour photoperiod.

The experimental design used was a randomized complete block design in a split plot with three replications. The treatment combinations used were biochar, vermicompost, biochar + vermicompost all in soil and sand medium. The rate of biochar and vermicompost used was 1% (v/v) per pot for each amendment. Pots measuring 1650 mL (6″ diameter) were used for the trial. The pots were then placed on non-perforated plates to contain any percolating water from the pots so as to prevent cross contamination.

Inoculum Preparation

Root rot inoculum was prepared following the procedure described by Scandiani *et al.,* 2011 with minor modifications. Sorghum seeds were placed in a 500mL conical flask then soaked in sterile distilled water overnight. Debris and floating seeds were then removed and the remaining seeds washed three times followed by draining of the excess water. The seed were then autoclaved for 60 minutes at 121 ºC on 2 consecutive days. Each flask containing sterilized sorghum seeds was inoculated with an individual isolate of *F. oxysporum, F. solani, P. ultimum* and *R. solani* by transferring five (5) plugs of 5-mm-diameter each cut from the edge of 7 day old cultures on potato dextrose agar using a cork borer. The inoculated sorghum seeds in conical flasks were then incubated at 25ºC and shaken on alternate days to promote uniform growth of fungi. After 14 days of incubation, inocula

was air dried for 24 hours in a laminar flow hood, crushed using a motor and pestle then used for both colony-forming units (CFU) assay and later for inoculation in the greenhouse.

Inoculation of Test Soils and Seedling Establishment

The CFU assay of the root rot infested sorghum grain inoculum was conducted following the procedure by Farias *et al.,* 2008. One gram of sorghum inoculum was soaked in a 250-ml conical flask containing 100 ml of sterile distilled water followed by a 30 min shaking at 150 rpm on mechanical Shaker. Plating of the resultant inoculum was done on PDA after a tenfold serial dilution was done using sterile distilled water to attain dilutions of 10^{-3} and 10^{-4} from each isolate. These were incubated for 7 days at 25 ºC. The inoculum quantity was determined and adjusted to 10^{7} CFUs/gram of sorghum by diluting infested sorghum grain with non-infested sterile sorghum grain (w/w). Five grams of the adjusted infested sorghum grain was then used to inoculate soil in each treatment by mixing it with the 10 cm of the soil in each pot. The soils were then irrigated to water holding capacity and incubated for two weeks in the greenhouse to ensure colonization of the soil by the fungi prior to planting bean seeds.

Prior to planting, Rosecoco bean seeds were surface sterilised in 2.5% Sodium hypochlorite for 3 min followed by washing with 70% ethanol for 3 min. The seeds were then rinsed 3 times with sterile distilled water then blot dried on sterile serviettes before planting. Five seeds were seeded in each pot to a depth of 2.5cm and slightly covered with soil-sand treatment mixture within the pot. Irrigation of the bean plants was done on alternate days to field capacity using sterile distilled water.

Determination of Plant Emergence, Crop Vigour and Disease Rating

Seedling emergence was determined 14 days after planting. This was done by counting and recording the number of seedlings emerging per treatment. Symptoms of root rot were scored visually after four weeks by assessing the plants using a ranking scale of 0-5 as described by Filion *et al.,* (2003) where, 0 = healthy plants, 1 = initial signs of wilting, 2 = up to 25% of the leaves with symptoms, 3 = < 25% up to 50% of the leaves with symptoms, 4 = < 50% up to 75% of the leaves with symptoms, 5 = plants dead. Seven weeks after planting, the whole pot was soaked in water which helped to release the lateral roots from adhering soil. The plants were cut at the soil line to necessitate measurements for the root lengths and shoot heights.

The plants were then dried on paper towels and rated for root rot severity by visual assessment of the roots and hypocotyls. A severity rating scale of 1-9 as described by Abawi and Pastor-Corrales (1990) was used for rating where 1 = no visible symptoms, 3 = light discoloration either without necrotic lesions or with approximately 10% of the hypocotyl and root tissues covered with lesions, 5 = approximately 25% of the hypocotyls and root tissues covered with lesions but tissues remain firm, 7 = 50% of the hypocotyls, and root tissues covered with lesions as well as considerable softening, rotting, and reduction of the root system and 9 = approximately 75% or more of the hypocotyl and root tissues affected with advanced stages of rotting, combined with severe reduction in the root system. Re-isolation of the pathogens from diseased plants was undertaken to confirm the cause of disease and pathogenicity of test samples. Measurement of dry weights was done following 24h of oven drying the plant parts at 55°C until constant weights were achieved. The trial was conducted twice and bean seeds planted in non-inoculated and untreated soil-sand, biochar and vermicompost combinations were controls for the trials.

Data Collection and Analysis

Data on emergence was recorded fourteen days after planting where the total number of plants that had emerged was counted per treatment. Disease incidence was determined by counting the number of diseased plants in each treatment pot. This was then divided by the total number of plants in the pot multiplied by 100. Data on plant height, root length and disease severity was determined at seven weeks after planting. The shoots and roots were measured from the soil level to the tip. Disease scoring on roots was done based on a scale of 1 to 9. Dry shoot and root weights were measured after drying at 50º C for 24 hours.

The data of measured variables were analyzed by ANOVA ($p<0.05$) using Genstat 15 edition. The means were separated by the least significant difference using the Tukeys range test.

IV. RESULTS

Characteristics of Biochar and Vermicompost

All the soil amendments analysed varied in their composition. Vermicompost had the highest moisture content while rice hull biochar (RH biochar) had the least (Table 1). No volatile compounds were found in vermicompost but were highest in Rice hulls biochar as compared to sugarcane bagasse biochar (SB biochar). Ash content was also high in RH biochar and low in SB biochar. The pH in rice hulls biochar was found to be alkaline while that of vermicompost and SB biochar were observed to be near neutral. Electrical conductivity was found to be very high in RH biochar as compared to SB biochar. Vermicompost had the lowest EC of all the amendments used. Dry matter content was recorded highest in RH biochar and lowest in vermicompost. The C:N ratio was also highest in RH biochar and lowest in vermicompost.

Nutrient Composition of Biochar and Vermicompost

Phosphorus was the nutrient with the highest percentage in the biochars as compared to other nutrients in the respective biochars (Table 2). RH biochar had the highest level of phosphorus as compared to SB biochar and vermicompost. Potassium was recorded highest in vermicompost while the lowest percentage was recorded in SB biochar. No calcium was found in the two biochars but vermicompost had 2.5%. Rice hulls biochar was found to have highest level of magnesium which was more than 58% higher than in vermicompost and SB biochar. Conversely Sulphur was highest in vermicompost and RH biochar as compared to SB biochar. Iron was the highest micro nutrient in all the soil amendments with the highest recorded in vermicompost while the lowest micro nutrient was Boron recorded in SB biochar. Other micro nutrients available in the amendments including sodium, zinc, copper and manganese were higher in RH biochar as compared to SB biochar.

Table 1. Characteristics of vermicompost and biochar.

Amendment	MC %	Volatiles (%)	As (%)	pH	EC (mS/cm)	DM %	C %	N %	C:N %
Vermicompost	48.2	-	-	6.92	12.0	50.8	30.1	3.5	8.5
Rice hulls biochar	1.7	18.4	54.8	11.92	1978.5	98.3	53.2	2.8	18.7
S. bagasse biochar	3.1	9.1	9.7	6.83	73.5	96.9	62.9	5.3	11.9

MC- Moisture Content, EC- electrical conductivity, DM- Dry matter, C- Carbon, N- Nitrogen, C:N- Carbon Nitrogen ratio; S. bagasse- Sugarcane bagasse.

Table 2. Chemical composition of biochar and vermicompost.

Amendment	P %	K %	Ca %	Mg %	S %	Mn (ppm)	Fe (ppm)	B (ppm)	Na (ppm)	Zn (ppm)	Cu (ppm)
Vermicompost	0.6	3.3	2.5	0.5	0.40	410.0	6600.0	101.0	1480.0	185.0	17.8
Rice hulls biochar	4.7	1.2	n/a	1.3	0.40	188.1	4191.4	53.0	3865.9	3520.6	263.5
S. bagasse biochar	1.0	0.7	n/a	0.4	0.03	36.9	485.3	14.4	2668.3	570.2	38.2

P-Phosphorus, K- Potassium, Ca- calcium, Mg- Magnesium, S- Sulphur, Mn- Manganese, Fe- Iron, B- Boron, Na- Sodium, Zn- Zinc, Cu- Copper; S. bagasse- Sugarcane bagasse; ppm- parts per million; N/A- not available/present.

The Effect of Soil Amendments on Seedling Emergence

There was no significant difference ($p<0.05$) in seedling emergence among the treatments with the exception of *F. oxysporum* inoculated soils (Table 3). Vermicompost and sugarcane bagasse biochar recorded 35 percent increase in emergence as compared to the non-amended soils. Similar trends were observed in all the other treatments though the difference was not significant. The lowest emergence was however recorded in the non-amended soils inoculated with *R. solani* and a mixture of all the test root rot pathogens.

Effect of Biochar and Vermicompost on Growth and Development in Common Bean Plants Inoculated with Root Rot Pathogens

Significant differences ($p<0.05$) were recorded for plant shoot heights across all treatments with the exception of control (Table 4). Plants in soils amended with a combination of rice hulls biochar and vermicompost inoculated with *F. oxysporum* had the greatest shoot height which was 29% higher than the plants in non-amended soils challenged with a mixture of all test pathogens. The non-amended soils were observed to have 17% to 27% reduced shoot height across all treatments with the differences being significant ($p<0.05$).

Significant difference ($p<0.05$) in root length were also observed across all the treatments (Table 5). Plants inoculated with *R. solani* in with sugarcane bagasse biochar amended soils had the longest roots. These were 53% longer than plants challenged with *R. solani* in soils amended with vermicompost which were observed to have shortest roots. The same trend was observed in other plants challenged by different root rot pathogens with the exception of *F. solani*. Sugarcane bagasse biochar amended soils were however observed to record up to 53% higher root length than other treatments. Plants in vermicompost amended soils were however observed to record a 31% higher root length than plants in non-amended soils challenged with *F. solani* the differences being significant.

Table 3. Plant emergence (%) of bean in soils amended with different biochars and vermicompost and inoculated with root rot pathogens.

	Percentage emergence (%)						
Treatment	Control	*Fo*	*FS*	*Pu*	*Rs*	Mix	Treatment means
Non amended soil	83a	64a	67a	77a	56a	56a	67.1b
Vermicompost	97a	87a	87a	77a	87a	80a	85.8a
R.H biochar	100a	77a	84a	80a	84a	80a	84.2a
R.H Vermicompost	90a	87a	84a	77a	77a	83a	83.0a

S.B biochar	87a	87a	74a	77a	84a	87a	82.7a
S.B biochar Vermicompost	94a	77a	73a	77a	73a	76a	78.3a
LSD treatment x pathogen	25.7						
LSD treatment	10.5						
%CV	15.8						
F. Pr	0.991						

Means with different letter(s) within each column are significantly different at p≤ 0.05. R.H - Rice hulls, S.B-Sugarcane bagasse. *Fo- F. oxysporum, Fs- F. solani, Pu- P. ultimum, Rs- R. solani,* Pat Mix - mixture of the four pathogens. LSD: Least significance difference at 5% level, CV: Coefficient of variation, F.pr -Frequency of probability.

Table 4. Effect of vermicompost and different biochars on bean shoot height (cm) in root rot inoculated soils.

	Shoot height (cm)						
Treatment	Control	*Fo*	*FS*	*Pu*	*Rs*	Pat Mix	Treatment means
Non amended soil	19.7d	18.2d	18.5c	18.3c	18b	17.8c	18.4c
Vermicompost	20.7cd	20.3c	21.6b	20.7b	20.9a	20.6b	20.8c
RH biochar	23.0a	22.1b	21.8ab	20.9ab	21.4a	21.8ab	21.8ab
RH biochar Vermicompost	21.6bc	23.5a	21.8ab	21.6ab	21.5a	22.4a	22.1a
SB biochar	22.6ab	21.3bc	23.0a	20.9ab	21.6a	21.3ab	21.8ab
SB biochar Vermicompost	22.7ab	21.5bc	21.1b	22.1ab	20.4a	20.5b	21.4b
LSD treatment x pathogen	1.23						
LSD treatment	0.5						
%CV	2.9						
F. Pr	0.013						

Means with different letter(s) within each column are significantly different at p ≤ 0.05. RH-rice hulls; SB- sugarcane bagasse; *Fo- F. oxysporum, Fs- F. solani, Pu- P. ultimum, Rs- R. solani,* Pat Mix – mixture of the four pathogens. LSD: Least significance difference at 5% level, CV: Coefficient of variation.

Table 5. Effect of vermicompost and different biochars on bean root length (cm) in soils inoculated with root rot pathogens.

	Root length (cm)						
Treatment	Control	*Fo*	*FS*	*Pu*	*Rs*	Pat Mix	Treatment Means
Non amended soils	24.6c	28.6b	29.1a	25.0bc	22.4c	25.0c	25.8c
Vermicompost	31.6a	19.9d	21.2c	19.2d	18.3d	19.1d	21.5e
R.H biochar	28.1b	22.9c	22.5c	23.6c	26.2b	24.6c	24.6d
RH biochar Vermicompost	24.9c	31.8a	29.6a	26.1b	22.7c	27.0b	27.0b
SB biochar	27.8b	28.4b	30.7a	33.2a	39.7a	33.9a	32.3a
SB biochar Vermicompost	31.2a	25.3c	24.8b	26.6b	25.1b	24.7c	26.3bc
LSD treatment x pathogen	1.63						

	Root length (cm)						
Treatment	Control	*Fo*	*FS*	*Pu*	*Rs*	Pat Mix	Treatment Means
LSD treatment	0.67						
%CV	3.1						
F. Pr	<0.001						

Means with different letter(s) within each column are significantly different at $p \leq 0.05$. R H-rice hulls; S B- sugarcane bagasse; *Fo- F. oxysporum, Fs- F. solani, Pu- P. ultimum, Rs- R. solani,* Pat Mix – mixture of the four pathogens. LSD: Least significance difference at 5% level, CV: Coefficient of variation.

Effect of Biochar and Vermicompost Amendments on Dry Shoot and Root Weights of Common Bean Plants Inoculated with Root Rot Fungi

Significant differences ($p<0.05$) in dry shoot weight were observed across all treatments (Table 6). Plants challenged with the four root rot pathogens in soils amended with rice hulls biochar in combination with vermicompost recorded the highest dry shoot weight while the lowest was recorded from control plants in non-amended soil translating to a 91% difference.

Dry root rot weights were observed to be significantly different ($p<0.05$) across all treatments (Table 7). The highest dry root weight was recorded from *R. solani* challenged plants in soils amended with sugarcane bagasse. The lowest dry root weight was recorded in non-challenged plants in the non-amended soils. Sugarcane bagasse biochar as well as the rice hulls biochar and vermicompost amendments resulted in a 53% to 80% increase in dry root weight of plants challenged with root rot.

Table 6. Effect of biochar and vermicompost on dry shoot and root weights of common bean inoculated with root rot pathogens.

	Dry Shoot weight (g) Experiment 1						
Treatment	Control	*Fo*	*FS*	*Pu*	*Rs*	Pat Mix	Treatment Means
Non amended soil	0.08c	0.17c	0.17c	0.21c	0.30c	0.19d	0.18d
Vermicompost	0.29a	0.40b	0.43b	0.73a	0.79a	0.55b	0.53b
R.H biochar	0.21b	0.44b	0.44b	0.45a	0.30c	0.34c	0.36c
R.H biochar vermicompost	0.36a	0.86a	0.80a	0.52b	0.78a	0.87a	0.69a
S.B biochar	0.35a	0.26c	0.28c	0.42a	0.54b	0.38c	0.37c
S.B biochar Vermicompost	0.33a	0.45b	0.44b	0.40b	0.36c	0.36c	0.39c
LSD treatment x pathogen	0.11						
LSD treatment	0.04						
%CV	12.4						
F. Pr	<0.001						

Means with different letter (s) within each column are significantly different at $p \leq 0.05$. RH-rice hulls; SB- sugarcane bagasse; *Fo- F. oxysporum, Fs- F. solani, Pu- P. ultimum, Rs- R. solani,* Pat mix – mixture of the four pathogens. LSD: Least significance difference at 5% level, CV: Coefficient of variation.

Table 7. Effect of different biochars and vermicompost on dry root weights of common bean inoculated with root rot pathogens.

Treatment	Dry root weights (g)						
	Control	*Fo*	*FS*	*Pu*	*Rs*	Pat Mix	Treatment Means
Non amended soils	0.11d	0.16c	0.16c	0.14d	0.24c	0.17c	0.16e
Vermicompost	0.21c	0.32b	0.34b	0.26c	0.39b	0.26b	0.29c
R.H biochar	0.30b	0.31b	0.33b	0.27c	0.24c	0.28b	0.29c
RH biochar Vermicompost	0.64a	0.57a	0.53a	0.57a	0.43b	0.52a	0.54a
S.B biochar	0.28bc	0.38b	0.41b	0.45b	0.86a	0.58a	0.49b
SB biochar Vermicompost	0.23bc	0.22c	0.24c	0.23c	0.29c	0.24b	0.23d
LSD treatment x pathogen	0.08						
LSD treatment	0.03						
%CV	12.1						
F. Pr	<0.001						

Means with different letter(s) within each column are significantly different at $p \leq 0.05$. RH-rice hulls; SB- sugarcane bagasse; *Fo- F. oxysporum, Fs- F. solani, Pu- P. ultimum, Rs- R. solani,* Pat mix – mixture of the four pathogens. LSD: Least significance difference at 5% level, CV: Coefficient of variation.

Effect of Biochar and Vermicompost on Root Rot Diseases Rating in Common Bean Inoculated Root Rot Pathogens

Significant differences ($p<0.05$) in disease severity were observed across the treatments following inoculation with root rot pathogens (Figure 1). The highest percent severity index was observed in the non-amended soils inoculated with all four root rot pathogens at 81.5%. The lowest severity was recorded from plants in soils amended with sugarcane bagasse biochar in combination with vermicompost and challenged with *R. solani* at 33.3%. Plants in biochar amended soils were observed to record a 9% lower root rot severity than vermicompost amended soils.

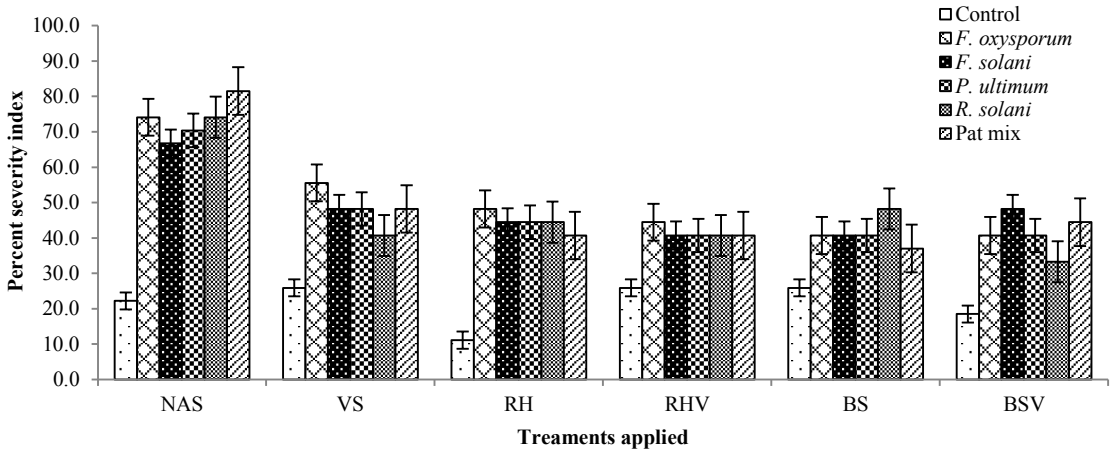

Fig. 1. Effect of biochar and vermicompost on bean root rot severity.

NAS non amended soil; VS-vermicompost amended soil; RH-rice hulls biochar; BS-sugarcane bagasse biochar; BSV-sugarcane bagasse biochar + vermicompost; RHV-rice hulls biochar + vermicompost; Pat mix- mixture of all four pathogens.

V. DISCUSSION

In this study, biochar that was produced from different feed stocks using similar pyrolitic conditions varied in their composition. The highest variability was noted for ash; volatile matter contents; pH and carbon. Sugarcane bagasse had low ash content and the higher fixed carbon content than rice hulls biochar. Consequently, rice hulls which had high ash content were observed to have 53% of carbon content. Similar results were previously reported by Mitchell *et al.,* (2013) who observed strong negative correlation between ash and fixed carbon content. They however slightly depart from the findings by Enders *et al.,* (2012). They concluded that fixed carbon contents for biochar with greater than 35% ash content were limited to below 30%. Vermicompost was produced from crop residue using *Eisinia andrei* worms. It did not greatly vary from the sugarcane bagasse biochar in the pH. It however had lower dry matter, carbon content and C:N ratio than the two biochars.

This study observed that, application of vermicompost and the two biochars in pots resulted to slight differences in common bean germination. Sugarcane bagasse biochar and rice hulls biochar had high germination percentage of above 72% in the first trials while vermicompost had the lowest germination of 56%. The results point to moderate toxicity of biochar to germination in the first trial but this was eliminated in the second trial when it recorded a germination of over 96 %. Vermicompost was observed to have higher toxicity during the first trial with a germination of 56% but the effects were lower in the second trial with a germination of 88%. According to Zucconi *et al.,* (1985) and Emino and Warman (2004), germination index (GI) values <50% suggest a high phytotoxicity; 50–80% suggest moderate phytotoxicity and GI values of 80% suggest no phytotoxicity. When GI exceeds 80%, the material can be considered as a phytonutrient or phyto stimulant.

In this study, plant height was significantly enhanced with the addition of biochar to the soil medium. SB biochar and RH biochar significantly ($p<0.005$) influenced plant height both in control and in challenged plants. In subsequent experiments, plants challenged with *F. solani* and *R. solani* had the highest plant height in comparison to non-challenged plants in controls with the same treatments. The same trend was observed with root length and dry root weight. Similar observations were previously reported by Jaiswal *et al.,* 2014. They observed reduced sensitivity of plant growth parameters to biochar dose in the absence of the disease causing pathogen than when it was present. Other findings by Guerena *et al.,* 2015 reported on increased crop biomass of common bean following application of sugarcane bagasse biochar. Increase in root length in biochar treated plants has also been reported by Atiyeh *et al.,* 2001 and Gutierrez-Miceli *et al.,* 2007 when working with tomato.

Treatment combinations of RH biochar and vermicompost had a fivefold increment in dry weight of roots as compared to the non-amended pots which had the lowest dry root weight. The findings were replicated in all the subsequent trials. The results are in agreement with previous findings by Rondon *et al.,* 2007 who observed a 39% increase in common bean crop biomass following vermicompost amendments. Other studies by Roy *et al.,* 2010 and Valdez-Perez *et al.,* (2011) also reported significant increase of 20% in total shoot; root and pod dry biomass of the three legumes in vermicompost treatment in comparison to control plots.

Bean root rot severity was significantly reduced due to the application of soil amendments in this study. Sugarcane bagasse biochar amendments which had high fixed carbon of 62% recorded the lower disease severity as compared to rice hulls biochar and vermicompost. These findings suggest that biochar's ability to influence soil fungal pathogens is related to recalcitrant forms of Carbon which was earlier suggested by Graber *et al.,* 2010. Similar findings on effect of fixed carbon on disease severity have been observed by Jaiswal *et al.,* 2014. They

observed high incidence of *Rhizoctonia* damping off disease in cucumber following application of comparatively low C content (40.2% and 13.2 % C) glasshouse waste biochars. In the same study the reported low disease incidence following application of biochars with relatively high C content (69.3% and 76.7 % C). Gasco *et al.,* 2016 also found similar results when studying the influence of biochar on sudden syndrome disease caused by *Fusarium virguliforme* on Soy bean.

Percent severity index was significantly different ($p<0.05$) across all the treatments. Greatest suppression was observed in SB biochar treated pots which had been challenged by root rot pathogens. Pots amended with SB biochar and challenged with *F. solani* had the lowest root rot disease severity index as well as those challenged with *R. solani*. The same trends were repeated in the subsequent trials. The superiority of SB biochar over RH biochar and vermicompost may be attributed to its higher fixed carbon and C:N ratio. In earlier studies Mutitu *et al.,* 1988 observed that organic amendments high in C:N ratio resulted in reduction of severity of *Fusarium* yellows severity on beans. Other studies have shown soils poor in organic matter resulted in high severity of root rot. Addition of biochar rich in fixed carbon to soils may alleviate root rot severity. However the recommended rates of application should be observed in-order to avoid the hormesis effect of biochar (Graber *et al.,* 2010) as earlier reported. (Graber *et al.,* 2010; Jaiswal *et al.,* 2014). This is in relation to the organic compounds contained on biochar that at lower doses, they result in beneficial effects, but may result in making plants susceptible to disease and retard growth at higher doses.

VI. Conclusion

Addition of vermicompost and biochar from different feed stocks inhibit root rot pathogens. Their addition as a combination or stand-alone treatments resulted in reduction of root rot disease incidence and severity. This in turn led to increased common bean productivity. A combination of biochar and vermicompost resulted in higher plant growth and yield. However, since biochar does not provide nutrients to the soil, it is important to incorporate a source of nutrient supplement in soils that are deficient. A combination of biochar and vermicompost does improve bean yield with the environmental benefits of improving soil nutrient status.

References

[1] Abawi, G.S., and M.A. Pastor-Corrales. 1990. Root Rots of Beans in Latin America and Africa. Diagnosis, Research Methodologies and Management Strategies. *CIAT Publication* No.35. Cali, Colombia. 114 pp.
[2] Agrios G.N. 2005 - Plant Pathology. 5th edition. Elsevier Academic Press, San Diego, California, 384 pp.
[3] Atiyeh R.M., Arancon N.Q., Edwards C.A., Metzger J.D., 2000 Influence of earthworm-processed pig manure on the growth and yield of green-house tomatoes Bio-resource Technology 75:175–180.
[4] Atiyeh, R.M., Edwards, C.A., Subler, S., Metzger, J.D. 2001. Pig Manure Vermicompost as a Component of a Horticultural Bedding Plant Medium: Effects on Physicochemical Properties and Plant Growth. Bio resource Technology 78:11– 20.
[5] Buruchara, R., Estévez de Jensen, C., Godoy, G., Abawi, G., Pasche, J.and Lobo Junior, M., Mukankusi, C. (2015). A review of the root rot diseases of common bean with emphasis in Latin America and Africa Common Bean Disease on Angular Leaf Spot and Root Rot oral paper presentation in the conference. Protea Hotel Kruger Gate Skukuza, South Africa. July 20-23, 2015. Last accessed 10th December 2018. Available at (http://arsftfbean.uprm.edu/bean/wpcontent/uploads/2015/09/BDW-Day2-Robin-Buruchara.pdf).
[6] Edwards, C.A. and Arancon, N.Q., 2004: Vermicomposts suppress plant pest and disease attacks. Biocycle 45 (3), 51-55.
[7] Emino E, and Warman P. 2004. Biological assay for compost quality. Compost Science Utilization. 12:342–348.
[8] Enders A, Hanley K, Whitman T, Joseph S, Lehmann J. 2012. Characterization of biochars to evaluate recalcitrance and agronomic performance. Bio-resource Technology. 114:644–653.
[9] Farias Neto AL, Schmidt M, Hartman GL, Li S, Diers BW 2008. Inoculation methods under greenhouse conditions for evaluating soybean resistance to sudden death syndrome. Pesq Agropec Bras 43:1475–1482
[10] Fillion, M., St-Arnaud, M., Jabaji-Hare, S. H., 2003 Quantification of Fusarium solani f. sp. phaseoli in mycorrhizal bean plants and surrounding mycorrhizosphere soil using real time polymerase chain reaction and direct isolations on selective media. Phytopathology 93:229-235.
[11] Gascó, G., P. Cely, J. Paz-Ferreiro, C. Plaza & A. Méndez 2016. Relation between biochar properties and effects on seed germination and plant development, Biological Agriculture & Horticulture, DOI: 10.1080/01448765.2016.1166348.
[12] Graber, E. R., Frenkel, O., Jaiswal, A. K., Elad Y. 2014 'How may biochar influence severity of diseases caused by soil borne pathogens?' Carbon Management DOI: 10.1080/17583004.2014.913360.
[13] Graber, E.R., Meller Harel, Y., Kolton, M., Cytryn, E., Silber, A., David, D.R., Tsechansky, L., Borenshtein, M., Elad, Y., 2010. Biochar

impact on development and productivity of pepper and tomato grown in fertigated soilless media. Plant and Soil 337(1-2), 481-496.
[14] Güereña DT, Lehmann J, Thies JE, Enders A, Karanja N, Neufeldt H, 2015. Partitioning the contributions of biochar properties to enhanced biological nitrogen fixation in common bean (Phaseolus vulgaris). Biology and Fertility of Soils. 51:479–91.
[15] Gutiérrez-Miceli, F. A.; Santiago-Borraz, J., Montes-Molina, J. A., Nafate, C. C., Abud-Archila, M., Oliva-Llaven, M. A., Rincón-Rosales, R., Dendooven, L., 2007.Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (Lycopersicum esculentum). Bio resource Technology, 98, (5), 2781-2786.
[16] Jaiswal A. K, Elad Y, Graber E. R, Frenkel O 2014. Rhizoctonia solani suppression and plant growth promotion in cucumber as affected by biochar pyrolysis temperature, feedstock and concentration. Soil Biology & Biochemistry 69:110–118.
[17] Kacar, B. 1994. Plant and Soil Chemical Analyses III. Soil Analyses. Ankara University of Agriculture, Faculty of Education Research and Extension. Publications, No: 3 Ankara, Turkey.
[18] Katan J., 2002. Interactions of soilborne pathogens with roots and above ground plant organs. In: Weizel Y., Eshel A., Kafkafi V. (eds). Plant Roots: the Hidden Half (third edition), pp. 949-959. Marcel Dekker, USA.
[19] Koike, S. T., Gordon, T. R., Daugovish, O., Ajwa, H., Bolda, M., and Subbarao, K. 2013. Recent Developments on Strawberry Plant Collapse Problems in California Caused by *Fusarium* and *Macrophomina*. International Journal of Fruit Science, 13(1-2), 76–83. doi:10.1080/15538362.2012.697000
[20] Matsubara, Y., Hasegawa, N., Fukui, H. 2002. Incidence of Fusarium Root Rot in Asparagus Seedlings Infected with Arbuscular Mycorrhizal Fungus as Affected by Several Soil Amendments. Engei Gakkai Zasshi. 71. 370-374. 10.2503/jjshs.71.370.
[21] Mitchell PJ, Dalley TSL, Helleur RJ 2013. Preliminary laboratory production and characterization of biochars from lingo cellulosic municipal waste. Journal of Analytical and Applied Pyrolysis 99, 71–78. doi:10.1016/j.jaap.2012.10.025.
[22] Muriungi, J.S., Mutitu, E.W. and Siboe, M.G., 2013. Bio control of Fusarium root rot in beans by antagonistic Trichoderma fungi. College of Agriculture and Veterinary Sciences (CAVS) [5111]. University of Nairobi Digital Repository http://hdl.handle.net/11295/81674.
[23] Muriungi S. J, Mutitu E. W. and Muthomi J. W. 2014. Efficacy of cultural methods in the control of *Rhizoctonia solani* strains causing tomato damping off in Kenya. African Journal of Food, Agriculture, Nutrition and Development 14 (2): 8776-8790.
[24] Mutitu, E W., D M. Mukunya, S O Keya, 1988. Biological control of Fusarium yellow on beans by Fusarium oxysporum Schl. p. Sp. Phaseoli kendrick and synuber using organic amendments locally available in Kenya. Act. Horticulture 218: 267-274. En.
[25] Noble, R. and Coventry, E. (2005) Suppression of soil-borne plant diseases with composts: A review. Bio control Science and Technology, 15, 3-20. doi:10.1080/09583150400015904.
[26] Rondon M, Lehmann J, Ramirez J, Hurtado M 2007. Biological nitrogen fixation by common beans (Phaseolus vulgaris L.) increases with bio-char additions. Biology and Fertility of Soils, 43:699-708
[27] Roy, S., K. Arunachalama, B.K. Dutta and A. Arunachalam (2010). Effect of organic amendments of soil on growth and productivity of three common crops viz. Zea mays, Phaseolus vulgaris and Abelmoschus esculentus. Applied Soil Ecology., 45: 78-84.
[28] Scandiani M.M., Ruberti D. S., Giorda L. M., Pioli R. N., Luque A. G., Bottai H., Ivancovich J. J., Aoki T. O'Donnel l. K. 2011. Comparison of inoculation methods for characterizing relative aggressiveness of two soybean sudden-death syndrome pathogens, *Fusarium virguliforme* and *F. tucumaniae*. Trop Plant Pathol 36:133–140, doi:10.1590/S1982-56762011000300001
[29] Siddiqui, S., Alamri, S. A., Alrumman, S. A., Meghvansi, M. K., Chaudhary, K. K., Kilany, M., & Prasad, K. (2015). Role of Soil Amendment with Micronutrients in Suppression of Certain Soilborne Plant Fungal Diseases: A Review. Organic Amendments and Soil Suppressiveness in Plant Disease Management, 363–380. doi:10.1007/978-3-319-23075-7_17
[30] Valdez-Perez, M.A., F. Fernandez-Luqueno, O. Franco-Hernandez (2011). Cultivation of beans (Phaseolus vulgaris) in limed or unlimed wastewater, sludge, vermicompost or inorganic amended soil. Scientia Horticulturae, 128:380-387.
[31] Waller, J., and Brayford, D. (1990) Fusarium diseases in the tropics. Tropical Pest Management, 36, 181- 194.
[32] Zucconi, F.; Monaco, A.; Forte, M.; Bertoldi, M. 1985: Phytotoxins during the stabilization of organic matter. In: Gasser, J.K.R. ed. Composting of agricultural and other wastes. London and New York, Elsevier Applied Science. Pp. 73-88.

AUTHORS PROFILE'

Samuel A. Were
Mr. Were holds a Master of Science Degree in Crop Protection from the University of Nairobi, Kenya. Currently, he is pursuing a Doctor of Philosophy Degree in Crop Protection from the same institution. The aim of this paper was to project the suppression effect of the vermicompost from vegetable waste and biochar produced from rice hulls and sugarcane bagasse against bean root rot. Mr. Were was a recipient of the USDA -FEED THE FUTURE NIFA Bean Productivity Program collaboration between the University of Nairobi; Cornell University and IITA.

Prof. Rama D. Narla
Prof. R.D. Narla is an Associate Professor of Plant Pathology in the Department of Plant Science and Crop Protection, Faculty of Agriculture, University of Nairobi. Prof. Narla has over 25 years of research and teaching experience at the University of Nairobi and has published over 35 papers in international peer reviewed scientific journals. Prof. Narla has supervised many Masters and Ph.D students to completion.

Prof. Eunice W. Mutitu
Prof. E.W. Mutitu is a full professor of the Department of Plant Science and Crop Protection Faculty of Agriculture University of Nairobi. She has over 39 years of research and teaching experience at the University of Nairobi. Prof. Mutitu has published 36 papers in international peer reviewed scientific journals and over 42 papers in conference proceedings. She has supervised 32 Masters and 8 Ph.D students to completion. Prof. Mutitu has been an external examiner for university examinations and postgraduate theses for various public and private universities.

Prof. James W. Muthomi
Prof. J.W. Muthomi is an Associate Professor of Plant Pathology in the Department of Plant Science and Crop Protection, Faculty of Agriculture University of Nairobi. He has 24 years of research and teaching experience at the University of Nairobi. Prof. Muthomi has published 70 papers in international peer reviewed scientific journals and over 75 papers in conference proceedings. He has supervised 62 Masters and 5 Ph.D students to completion. Prof. Muthomi has been an external examiner for university examinations and postgraduate theses for various public and private universities.

Prof. Janice E. Thies
Janice Thies is an Associate Professor of Soil Biology in Soil and Crop Sciences and International Professor of Soil Ecology. She is a 2006 American Society for Microbiology Latin America International Professor and has led five international workshops on Soil Molecular Ecology. She is a current associate editor of the Soil Science Society of America Journal and past member of the Editorial Board of Applied and Environmental Microbiology and the CALS Faculty Senate, where she served on the Executive Committee and as both Secretary and acting Chair. Her research program in soil ecology focuses on developing, testing and implementing methods to assess soil biological quality,
remediate degraded soils, and improve soil management practices to ensure the long-term sustainability of agricultural ecosystems.

Ms. Luiza M. Munya
Ms. L. Munyua holds a Master of Science Degree in Crop Protection from the University of Nairobi, Kenya. Currently, she is pursuing a Doctor of Philosophy Degree in Crop Protection from the same institution. She has previously worked at the Kenya Plant Health Inspectorate Services as a training co-coordinator. She has published two papers in scientific journals. Ms. Munyua was a recipient of the USDA -FEED THE FUTURE NIFA Bean Productivity Program collaboration between the University of Nairobi; Cornell University and IITA.

Dr. Bernard Vanlauwe
Prof B. Vanlauwe is a visiting Professor of the Swedish Agricultural University in Uppsala in the Soils and Environment Department. He is currently Director of RD4 Central Africa and the Natural Resource Management research area (IITA). He has also been the leader of the Integrated Soil Fertility Management (ISFM) program of the Tropical Soil Biology and Fertility research area of CIAT (TSBF). He had also worked at the Catholic University of Leuven, Belgium, focusing on unraveling the mechanisms underlying nutrient and soil organic matter dynamics in tropical agro-ecosystems. He has published over 100 papers in scientific journals and over 120 in other forms and has (co-) supervised over 30 MSc and 10
PhD students.

Dr. Dries Roobroeck
Dries Roobroeck is a Soil Fertility Management Specialist. His field of expertise is soil biogeochemistry and multivariate statistical analysis. He is currently a research scientist at RD4 Central Africa and the Natural Resource Management research area (IITA). At IITA, he investigates the non-responsiveness of soils in Kenya, Tanzania, Nigeria and Congo. He has published over 19 papers and supervised more than 3 PhD students and 5 MSc students to completion.