

Efficacy of Bio-enriched Vermicompost as Organic Amendment in Suppressing Tomato Wilts Incited by *Fusarium oxysporum* f. sp. *lycopersici*

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Abstract *Fusarium* wilt of tomato is a soil-borne disease threatening tomato production in the Savannah ecological zone of Nigeria. Management of the disease using conventional strategies such as the use of resistant cultivars, crop rotation and synthetic fungicides has not always been effective. These necessitate the search for novel alternatives such as the use of vermicompost as organic amendment to control the disease. This work was designed to evaluate the efficacy of vermicompost-amended soil as eco-friendly way of managing *Fusarium* wilts in tomatoes. The field experiment was 2 x 5 factorial, laid out in a split-plot design with Roma-VF (a resistant variety) and UC 82B (a susceptible variety) allocated to the main plots. The sub-plots contained five treatments: Bio-enriched vermicomposted poultry manure (BIVPO), cowdung-based bio-enriched vermicompost (BIVCO) and Bio-enriched vermicomposted rice bran (BIVRI); CAMAZEB[®] as a check and un-amended soil (control). All treatments were replicated three times. The results showed that the incidence and severity of *Fusarium* wilt were significantly lower on Roma VF than on UC 82B. Application of BIVPO significantly reduced the incidence and severity of *Fusarium* wilt comparable to the synthetic fungicide CAMAZEB[®] at the early stage of the disease

development and better than the fungicide at the latter stage. *Fusarium* wilt incidence and severity were higher in 2015 than in 2016 because of the low pathogen inoculum mitigated by the application of bio-enriched vermicomposts in the preceding year. Use of Roma-VF and BIVPO recorded lower disease incidence (38.7%) and severity (20.4%), and had higher disease reduction (30.8%) and lower stem vascular discolouration (2.5) than the other treatments. This is comparable to growing Roma-VF on BIVCO-amended soil which also recorded statistically similar results. The effectiveness of Roma-VF on BIVPO or BIVCO-amended soil is attributable to low phytotoxicity, abundant soil nutrients and the presence of bio-control agents which improved tomato growth and protection against *Fusarium* wilt. Roma VF could be recommended to be grown on soil amended with 25 tonnes ha⁻¹ of BIVPO or BIVCO as an eco-friendly integrated method for the management of tomato wilts caused by *Fusarium oxysporum* f. sp. *lycopersici*.

Keywords *Fusarium oxysporum* f. sp. *lycopersici*, Percentage Disease Reduction, Tomato, Vascular, Discolouration, Vermicomposts

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops grown because of its nutritional and economic values. Nigeria is the largest producer of tomatoes in sub-Saharan Africa having 5.47 tonne ha⁻¹ as an average annual yield which is below the world average yield of 38.1 tonne ha⁻¹ [1]. The total yield of tomatoes in Nigeria does not align with the land area devoted to its production. Despite Nigeria being the 14th world tomato producer, the yield is grossly low compared to Belgium which has 525.00 tonne ha⁻¹ on 500 ha of harvested area. Low yields in Nigeria are attributed to several factors, including diseases and pest attacks [2]. Low yields resulted in huge deficit in the supply of tomato in the country's tomato supply resulting in billions of dollars spent in importing tomato paste. The crop production is affected by inadequate fertilization and pest attacks particularly *Fusarium* wilt. The disease is one of the most common and devastating diseases of tomatoes in Nigeria, endemic in savannah ecological zones often associated with *Meloidogyne incognita* [3].

Attempts by scientists and farmers to control the disease recorded limited success [4]. The difficulties in control were due to new pathogenic races, the indiscriminate use of fungicides and the development of resistance [5]. Management of the disease has always been a major challenge. The use of resistant cultivars and synthetic fungicides is not completely effective due to the development of a new pathogenic race (Race 3) and the resistance of the pathogen to fungicides [6]. Applying fungicides alone to control *Fusarium* wilt can be ineffective [7] and may lead to pathogen resistance [8]. Excessive and indiscriminate use of pesticides on crops has been linked to increased health hazards and soil and water pollution [9,10,11]. In an effort to overcome these challenges many researchers have widely suggested using biological-based approaches to control plant diseases as an alternative to using chemicals [8,12,13,14]. Vermicompost contained rich nutrients and hormones that improve yield of crops as well as increasing the diversity and activity of antagonistic microbes that aid in suppressing soil-borne plant pathogens [12]. This research work is therefore designed to evaluate the efficacy of soil amendment with bio-enriched vermicompost in suppressing *Fusarium* spp. causing wilt of tomatoes.

2. Materials and Methods

2.1. Location and Experimental Set Up

Field experiments were conducted at the Teaching and Research Farm of the Federal College of Horticulture, Dadin Kowa, Gombe State, located in the Sudan savannah ecological zone of Nigeria, on latitude 10° 18'10"N,

longitude 11° 31'09"E, and altitude 218 metres above sea level, alternating with a six-month rainy season [15]. The area has a single peak of the rainy season, which runs from May to October, and a dry season from November to April. Daily mean temperatures range from 32 to 35 °C and relative humidity from 17% to 90%, while evapotranspiration, exceeds the average annual rainfall for the greater part of the year [16].

2.2. Isolation of the Pathogen Causing *Fusarium* Wilts of Tomatoes

Fusarium sp. was isolated from diseased tomato plants with symptoms of wilting and brown discoloration of vascular tissue as described by Mwangi *et al.* [17]. Distilled water was used to remove any foreign materials from the stems of the infected tomato plant. Surface sterilization of the 5 mm pieces cut of the infected stem was done for three minutes with a 0.5% bleach (NaOCl). The samples obtained from the infected plant were rinsed three times using sterile distilled water and blot-dried. To suppress bacterial growth, chloramphenicol at the rate of 0.5 mg per litre of molten potato dextrose agar was added and incubated at room temperature (38 °C) for five days. The fungus was then sub cultured and re-incubated at 38 ± 2 °C for 10 days to ensure the development of macro- and micro-conidia. Repeated sub-culturing was done until pure cultures were obtained.

2.3. Preparation of Conidial Suspension

The conidial suspension of *Fusarium* sp. was prepared using the preserved stock cultures. Two hundred millilitres of solidified autoclaved PDA in a 500mls conical flask were inoculated with a 6mm disc of *Fusarium* isolate using a cork borer and placed in a rotary shaker for 30 minutes to enhance growth. It was left for 72 hours at room temperature (38 ± 2 °C). After 72 hours, 1000mls of distilled water was added to the conical flask to dislodge mycelia and conidia from the agar. The mixture was centrifuged at 2259 rpm for 10 minutes. The concentration of conidia was adjusted to 10⁷ conidia ml⁻¹ using a haemocytometer.

2.4. Production of Vermicompost and Bio-enrichment with *Lactobacillus*

Organic materials in form of poultry manure, rice bran and cow dung were processed separately into bio-enriched vermicomposts as described by Mahimairaja *et al.* [18]. Each type of vermicompost was made using one hundred kilogrammes (100kg) of the following materials:

1. Poultry manure-based organic materials (50% poultry droppings, 35% cow manure, 15% rice bran).
2. Cow dung-based organic materials (50% cow manure, 35% poultry droppings, 15% rice bran).
3. Rice bran-based organic materials (50% rice bran, 25% cow manure, 25% poultry droppings).

These materials were allowed to decompose for 21 days with occasional turning for good air circulation within decomposing organic materials [19,20]. African earthworms were added to each vermicompost bed at the rate of 1 kg earthworms per 100 kg of organic materials after three weeks of primary decomposition. Collection of vermicompost using the photosensitivity technique, started method 40 days after the beginning of vermicomposting then periodically every seven days according to the method used by Haruna *et al.* [21]. To ensure the free flow of air and the retention of the compost quality, vermicast collection was done periodically so that the finished vermicompost would not be compacted due to watering [18]. Vermicomposting lasted for 60 days, maintaining 60% moisture content throughout the vermicomposting period. Trapping was used as a method of harvesting earthworms from the vermicompost bed by inserting fresh balls of cow dung in the middle of each bed. After 24 hours, the earthworms adhered to the cow dung ball which was removed and reserved for the next vermicompost production.

Each of the vermicompost produced was enriched with *Lactobacillus* following the procedures described by Tancho [22]. One kilogramme of un-parboiled rice was soaked in 10 litres (L) of tap water for three days. Five litres of rice wash were poured into a small plastic bucket which was then slightly covered and kept in the laboratory at $38 \pm 2^\circ\text{C}$. The rice wash was allowed to ferment for seven days. The liquid was then transferred to a plastic bucket containing 100ml of fresh cow milk and was fermented for another seven days. After seven days, coagulated particles seen floating on the liquid were removed and disposed of. One kilogramme of brown sugar was added to keep the lactic acid bacteria (*Lactobacillus*) alive. The solution was then stored in a refrigerator for 12 hours before bio-enrichment was done by mixing the solution with tap water at a ratio of 1: 100. One hundred kilogrammes of each vermicompost were sprinkled with 2.5L of the solution and kept for seven days for curing. The storage of the bio-enriched vermicomposts was done separately as Bio-enriched vermicomposted poultry manure (BIVPO), Bio-enriched vermicomposted cow dung (BIVCO) and Bio-enriched vermicomposted rice bran (BIVRI). A periodic sprinkling of water was carried out to maintain a forty percent water moisture level to support biological activities in the vermicomposts before their application. Chemical properties of the three bio-enriched vermicompost are described as follows:

- BIVRI (pH 8.3; EC 4.6 ds m⁻¹; Ca⁺ 16.5 meq l⁻¹; Mg⁺ 12.5 meq l⁻¹; K⁺ 3.6 meq l⁻¹; OC 44.6 g kg⁻¹; 3.2 g kg⁻¹; NH₄ 26.7 mg kg⁻¹; NO₃ 120.3 mg kg⁻¹; C/N 13.9).
- BIVCO (pH 8.5; EC 5.2 ds m⁻¹; Ca⁺ 17.4 meq l⁻¹; Mg⁺ 13.5 meq l⁻¹; K⁺ 3.7 meq l⁻¹; OC 57.6 g kg⁻¹; 3.3 g kg⁻¹; NH₄ 30.4 mg kg⁻¹; NO₃ 140.5 mg kg⁻¹; C/N 17.5).
- BIVPO (pH 8.0; EC 5.5 ds m⁻¹; Ca⁺ 17.9 meq l⁻¹; Mg⁺ 14.4 meq l⁻¹; K⁺ 3.8 meq l⁻¹; OC 59.8 g kg⁻¹;

3.3 g kg⁻¹; NH₄ 34.3 mg kg⁻¹; NO₃ 154.9 mg kg⁻¹; C/N 18.1).

Fungal and bacterial species were obtained from the three bio-enriched vermicompost. *Trichoderma* spp., *Aspergillus* spp., *Fusarium* spp., and *Rhizopus* spp. were found in BIVPO and BIVCO. Rice bran based bio-enriched vermicompost also had all the listed fungal organisms except *Fusarium* spp. Bacterial species like *Bacillus* sp., *Pseudomonas* sp and *Lactobacillus* sp., were also obtained from all the three bio-enriched vermicompost.

2.5. Efficacy of Bio-enriched Vermicomposting Suppressing Fusarium Wilt of Tomato

Field experiments were conducted during the rainy seasons of 2015 and 2016 in a split-plot design consisting of ten treatments replicated three times. The tomato varieties: Roma-VF and UC82B) were assigned to the main plot, while BIVRI, BIVCO, BIVPO, CAMAZEB® (as a check) and un-amended soil (UNASO) as a control were allocated to the sub plots. The field was harrowed, ploughed and marked into 3.6 x 3 m² with a buffer zone of 0.9 m between plots. Three-weeks-old seedlings of tomatoes were transplanted. Each bio-enriched vermicompost was applied at a rate of 10.8 kg on the respective plots one week before transplanting. Fungicide was applied at a rate of 2kg ha⁻¹ as soil drench seven days before transplanting. Manual weeding was done at two-weeks intervals. Sherpa Plus (Dimethoate and Cypermethrin) was applied at two weeks after transplanting and after every two weeks to control insects, particularly whiteflies prevalent in the area. Eight plants were tagged in the two central rows of the subplot.

2.6. Data Collection

Data were collected at two-weeks intervals on plant height, number of leaves and number of branches. For disease incidence and severity, data were taken weekly from 6 weeks after transplanting until harvest. Infected plants were pegged to capture dead plants for subsequent data collection. Severity of Fusarium wilts was measured using a scale of 1–6, Marley and Hillocks [23], where 1 = Absence of any symptoms; 2 = epinasty, yellowing, and wilting of the primary branches; 3 = yellowing and wilting of 2nd and 3rd branches; 4 = yellowing above the 3rd branch; 2nd and 3rd branches may be lost; 5 = yellowing and partial drying; and 6 = complete death of the plant. The severity of the Fusarium wilt of tomatoes was calculated at harvest on a scale used by Haque *et al.* [24] slightly modified as 1 = symptomless, no wilt visible; 2 = slight wilting with 5% wilted leaves; 3 = limited wilting with 6–10% wilted leaves; 4 = moderate wilting, 11–20% wilted leaves; 5 = severe wilting, 21–50% wilted leaves; 6 = severe wilting and plants dead. The data obtained was computed to get severity index (S) with the formula: $S = \{(\sum n) / (N \times 6)\} * 100$ [24]. Where $\sum n$ = summation of individual ratings,

6 = highest score of severity, and N = total number of plants assessed.

At the final harvest disease reduction (DR) and vascular discolouration (VD) were measured. The plots were flooded with water at harvest to maximise root recovery and then three (3) plants were randomly uprooted from the tagged plants from each plot to determine VD. Determine VD was assessed on a scale of 1–9 [23], where 1 = Absence of browning; 2 = browning only around the stem base; 3 = patchy browning below the 1st stem node; 4 = strong browning but limited below the 1st stem node; 5 = browning visible and spreading above the 1st stem node; 6 = browning visible above the 1st stem node and in up to half the total number of nodes; 7 = browning visible in more than half the stem node; 8 = strong vascular browning in all but the uppermost internode; 9 = strong browning of the vascular tissue. The value for VD was obtained by taking the average of scales recorded from the assessed plants. The percent disease reduction was calculated using the formula $DR (\%) = \{(A - B)/A\} \times 100$ [25], where A is the disease severity in the control plots and B is the disease severity in the treatment plots.

2.7. Data Analyses

The statistical software GenStat Release 17.1 (PC/Windows 8), Copyright 2014, VSN International Ltd was used to analyse the data collected. Data on the Fusarium wilt incidence and severity were arcsine transformed $\sqrt{n} + 1$ before they were subjected to analyses of variance. Treatment means separation was done using LSD at a $P \leq 0.005$.

3. Results

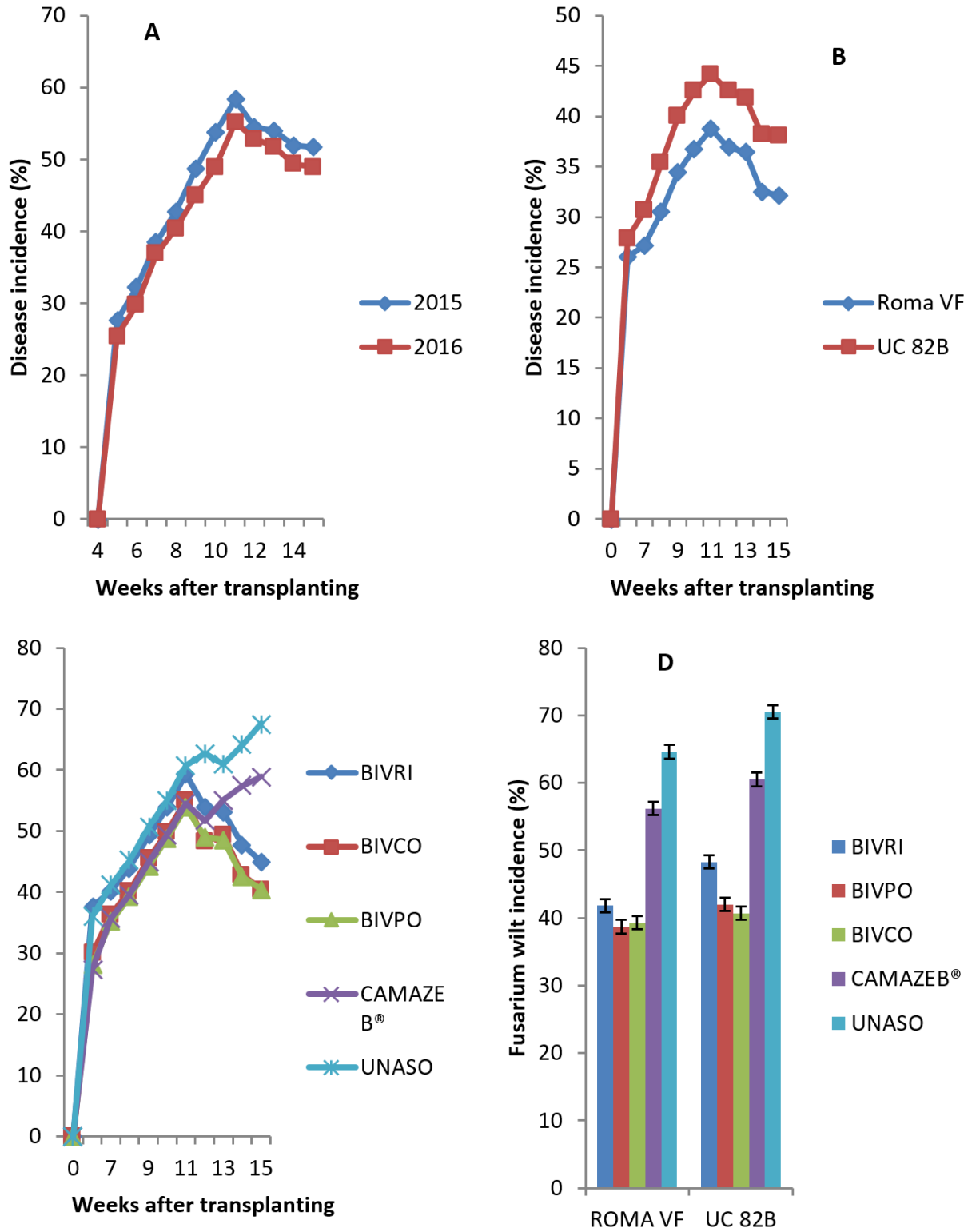
3.1. Efficacy of Bio-enriched Vermicompost in Suppressing Fusarium Wilt of Tomato

Results in Figures 1A–1D show the impact of host resistance and bio-enriched vermicompost on the incidence of tomato Fusarium wilt and their interaction effects at harvest. The incidence of Fusarium wilt in tomatoes in 2015 and 2016 differed significantly at $P \leq 0.01$. Disease incidence was higher in 2015 than in 2016 throughout the growth stages of the crop (Figure 1A). Also, seedlings of

UC82B significantly showed a higher Fusarium wilt incidence than Roma VF throughout the plant growth cycle ($P \leq 0.001$) as shown in Figure 1B. Growing tomatoes on soil amended with vermicompost significantly reduced Fusarium wilt incidence ($P \leq 0.01$) compared to the control (Figure 1C). At early stages, the wilt incidence on tomatoes produced on BIVPO-amended soil was comparable with CAMAZEB®. This was followed by seedlings grown on BIVCO- and BIVRI-treated soils, respectively. However, at final stages of tomato growth (13–15 WAT), the efficacy of BIVCO and BIVPO was at par but significantly higher than that of BIVRI and CAMAZEB®, respectively.

The interaction between different tomato varieties and vermicomposts had a significant effect at various growth stages of the crop. In soil treated with bio-enriched vermicompost and CAMAZEB®, treated soils, the Roma-VF variety showed significantly lower disease incidence compared to the UC82B variety. When comparing the effect of bio-enriched vermicompost types on Roma-VF at 15 WAT, it was revealed that soil amended with BIVPO (39.3%) had a similar effect on disease incidence, as shown in Figure 1D. These treatments exhibited significantly less disease incidence compared to tomatoes grown on BIVRI and CAMAZEB® treated soils which showed disease incidences of 41.7% and 56.9%, respectively. Similarly, transplanting UC82B on soil treated with BIVCO (42%) and BIVPO (40.8%) resulted in lower disease incidence compared to seedlings produced on BIVRI-treated soil (48.3%) and on soil treated with CAMAZEB® (60.8%). High disease incidences were recorded on UC 82B (70.5%) and Roma VF (64.6%) grown in the control treatment.

Table 1 shows the impact of host resistance and the use of vermicomposts on the severity of Fusarium wilt in tomatoes during the years 2015 and 2016. It was observed that Fusarium wilt severity was significantly higher in the rainy season of 2015 than in 2016 with a significance level of $P \leq 0.01$ throughout the sampling periods. Additionally, both tomato varieties showed a similar trend, with Roma-VF displaying lower disease severity compared to UC82B. The application of vermicompost to the soil significantly reduced the severity of Fusarium wilt ($P \leq 0.01$). Furthermore, tomatoes grown in soil amended with bio-enriched vermicompost showed a lower severity of Fusarium wilt compared to those in the control treatment throughout the sampling period.



Figures 1A – D. Effect of a year of cultivation (A), tomato varieties (B), Bio-enriched vermicomposto (C) and interaction between variety and vermicompost (D) on the incidence of Fusarium wilt of tomato

Table 1. Effect of host resistance and application of bio-enriched vermicompost on severity (%) of Fusarium wilt of tomato during the rainy seasons of 2015 and 2016

Treatment	WAT									
	6	7	8	9	10	11	12	13	14	15
Year										
2015	28.3	30.8	35.4	40.3	42.6	43.8	45.7	45.3	39.2	37.9
2016	25.7	27.0	30.4	34.2	36.7	39.2	37.8	33.2	31.3	32.7
LSD (P≤0.01)	0.61	0.09	0.19	1.27	0.25	0.64	0.97	1.23	1.06	4.06
Variety										
Roma VF	26.0	27.2	30.5	34.5	36.8	38.8	36.9	36.5	32.5	32.2
UC 82B	27.9	35.4	40.0	42.5	44.5	44.2	42.5	41.9	38.3	38.1
LSD (P≤0.01)	0.88	2.10	1.50	0.32	0.32	0.57	0.87	0.98	0.76	1.10
Bio-enriched vermicompost (Bio-V)										
BIVRI	27.6	29.8	34.5	36.4	39.2	40.2	36.6	33.2	31.2	30.0
BIVCO	25.8	26.8	31.7	35.1	37.8	38.9	35.2	32.0	28.1	24.5
BIVPO	24.6	26.0	29.1	34.0	36.2	37.4	33.6	30.7	26.0	25.7
CAMAZEB®	24.2	25.8	28.9	35.9	38.3	40.7	41.5	42.5	43.8	39.7
UNASO	32.6	36.1	40.5	44.8	46.8	50.3	51.8	56.3	57.0	59.6
LSD (P≤0.01)	0.33	0.40	1.78	0.70	0.91	1.00	1.11	1.10	1.44	1.50
Interaction										
Var. x Bio-V	**	**	**	**	**	**	**	**	**	**

WAT=Weeks after transplanting; ^aBIVRI = Bio-enriched vermicomposted rice bran; BIVCO = Bio-enriched vermicomposted cow dung; BIVPO = Bio-enriched vermicomposted poultry manure; UNASO = Un-amended soil; CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP), ** significant at 1%

At 6 WAT, it was observed that tomatoes transplanted on soil treated with CAMAZEB® (24.2%) exhibited less severity than those transplanted on soil treated with BIVPO (24.6%), BIVCO (25.8%), and BIVRI (27.6%), respectively. The efficacy of BIVPO as a bio-fungicide on disease severity was found to be comparable to CAMAZEB®, exhibiting a peak at 11 WAT that declined on seedlings transplanted in vermicompost amended soils. However, from 12 to 15 WAT, the effect of bio-enriched vermicompost on disease severity was significantly lower than that of CAMAZEB® (P≤0.01).

Table 2. Interaction of host resistance and bio-enriched vermicompost on the severity of Fusarium wilt of tomato at harvest

Treatment	Roma VF	UC 82B
aBIVRI	23.8	35.6
BIVCO	21.0	30.2
BIVPO	20.4	26.0
CAMAZEB®	38.0	41.4
UNASO	56.1	63.1
LSD (P<0.001)	2.29	

aBIVRI = Bio-enriched vermicomposted rice bran (VC), BIVCO = Bio-enriched vermicomposted cow dung, BIVPO = Bio-enriched vermicomposted poultry manure, UNASO = Un-amended soil, CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP).

There was significant interaction between variety and vermicompost at the various sampling periods. At 15 WAT, it was recorded that Roma-VF transplanted on soil treated with BIVPO and BIVCO did not differ significantly (P≤0.01) but exhibited the least disease severity compared to those seedlings grown on BIVRI and CAMAZEB® treated soil (Table 2). Seedlings of UC 82B transplanted on BIVPO-treated soil significantly produced lower severity than those transplanted on BIVCO-, BIVRI-, and CAMAZEB®, treated soil, respectively. Transplanting Roma VF on soil treated with BIVRI (26.0) showed a similar effect on Fusarium wilt severity as UC82B transplanted on BIVCO-amended soil (27.0). Seedlings of UC 82B had a higher severity of Fusarium wilt compared to Roma-VF.

The impact of host resistance and bio-enriched vermicompost on stem vascular discoloration and the percentage of disease reduction in tomatoes infected with Fusarium wilt are presented in Table 3. Vascular discoloration of the stem was greater in tomatoes cultivated in 2015 than in those grown in 2016. The stem of Roma-VF had significantly lower vascular discoloration compared to UC82B. The application of bio-enriched vermicompost to soils led to significantly lower vascular discoloration in tomatoes than those grown on un-amended soil. Lower vascular discoloration was

observed on tomatoes transplanted on soil treated with BIVPO (3.4) than on those transplanted on soil amended with BIVCO (4.0), BIVRI (4.5), and CAMAZEB® (6.2), respectively. A tomato grown in 2016 had significantly greater disease reduction (18.9%) than those in 2015 (17.2%). Similarly, Fusarium wilt was highly reduced on Roma-VF which recorded an 18.5% reduction compared to UC 82B which had a 17.5% disease reduction. Disease incidence was greatly reduced when tomatoes were produced on soil amended with BIVPO (29.7%), BIVCO (27.4%), BIVRI (17.0%) and CAMAZEB® (11.0%), respectively. No disease reduction was recorded in those grown on the control treatments.

In Table 4, the interaction between host resistance and vermicompost on vascular discolouration is presented. Seedlings of the variety Roma VF produced on soil treated with BIVPO (2.5) and BIVCO (2.8) did not show a statistical difference between themselves but differed significantly with those seedlings transplanted on soil treated with BIVRI (3.8) and CAMAZEB® (5.8) at $P < 0.01$. Seedlings of UC82B also followed the same pattern.

There were significant interactions between the year and variety (Figure 2), the year and vermicompost (Figure 3) and the variety and vermicompost (Figure 4) regarding the percentage of Fusarium wilt reduction. The percentage of disease reduction among the varieties was found to be higher for Roma-VF (19.9%) in 2016 followed by the same variety in 2015 (18.0%). In 2015 Roma-VF recorded the highest percentage of Fusarium wilt reduction (17.2%). However, in 2016, the group of tomatoes on soil treated with BIVPO had the highest percentage of disease reduction (31.2%), then those in BIVCO-amended soil (28.9%), BIVRI, and CAMAZEB®-treated soils which had 18.4% and 16.1%, respectively. Interaction between variety and bio-enriched vermicompost (Figure 4) showed the highest percentage of disease reduction (PDR) on Roma-VF than UC82B and on seedlings grown on BIVPO. The greatest PDR was found on Roma-VF transplanted on BIVPO-amended soil (30.8%) which significantly

recorded the highest PDR compared to BIVCO (29.6%) with $P \leq 0.01$.

Table 3. Effect of tomato variety and bio-enriched vermicompost on stem vascular discolouration and disease reduction of tomato infected with Fusarium wilt

Treatments	Vascular discolouration (Scale 1 – 9)	Disease reduction (%)
Year (Yr.)		
2016	4.5	18.9
2015	5.5	17.5
LDS ($P \leq 0.01$)	0.23	1.74
Variety (Var.)		
Roma VF	4.2	18.5
UC 82B	5.7	17.6
LDS ($P \leq 0.01$)	0.24	0.41
Bio-enriched vermicompost (Bio-v)		
BIVRI ^a	4.5	17.0
BIVCO	4.0	27.4
BIVPO	3.4	29.7
CAMAZEB®	6.2	0
UNASO	6.8	11.0
LSD ($P \leq 0.01$)	0.36	1.06
Interaction		
Yr. x Var.	*	*
Yr. x Bio-v	*	*
Var. x Bio-V	*	*

aBIVRI = Bio-enriched vermicomposted rice bran (VC), BIVCO = Bio-enriched vermicomposted cow dung, BIVPO = Bio-enriched vermicomposted poultry manure, UNASO = Un-amended soil, CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP), * significant at 5%.

Table 4. Interaction of host resistance and bio-enriched vermicompost on the vascular discolouration of tomato infected with Fusarium under field conditions

Variety	Bio-enriched Vermicompost				
	^a BIVRI	BIVCO	BIVPO	CAMAZEB®	UNASO
ROMA VF	3.83	2.83	2.50	5.83	6.17
UC 82B	5.17	5.17	4.33	6.50	7.50
LSD ($P \leq 0.001$)	0.510				

aBIVRI = Bio-enriched vermicomposted rice bran (VC), BIVCO = Bio-enriched vermicomposted cow dung, BIVPO = Bio-enriched vermicomposted poultry manure, UNASO = Un-amended soil, CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP).

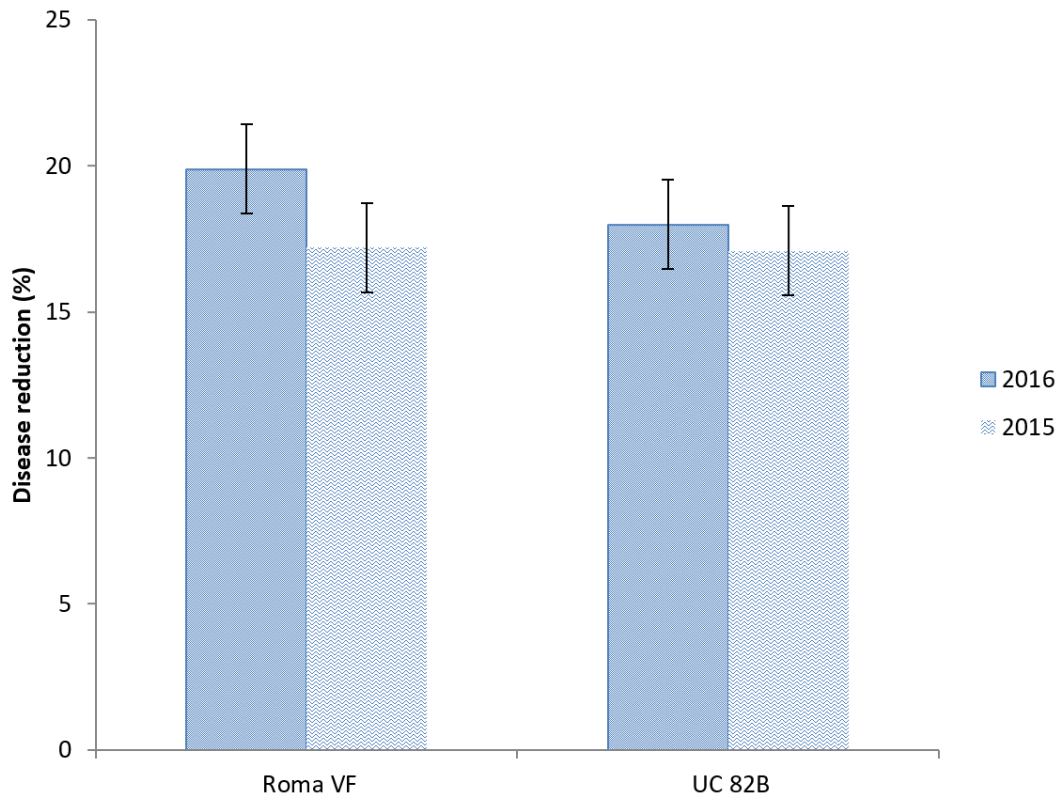


Figure 2. Interaction of year of tomato cultivation and variety on percentage disease reduction of Fusarium wilt

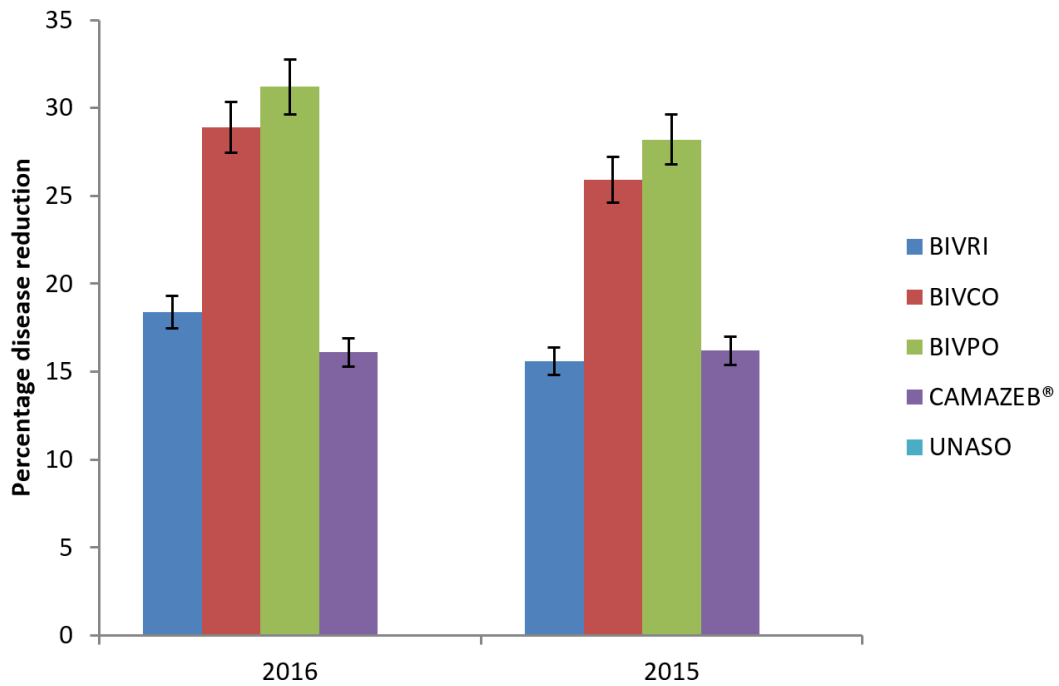


Figure 3. Interaction of year of tomato cultivation and bio-enriched vermicompost on percentage disease reduction of Fusarium wilt

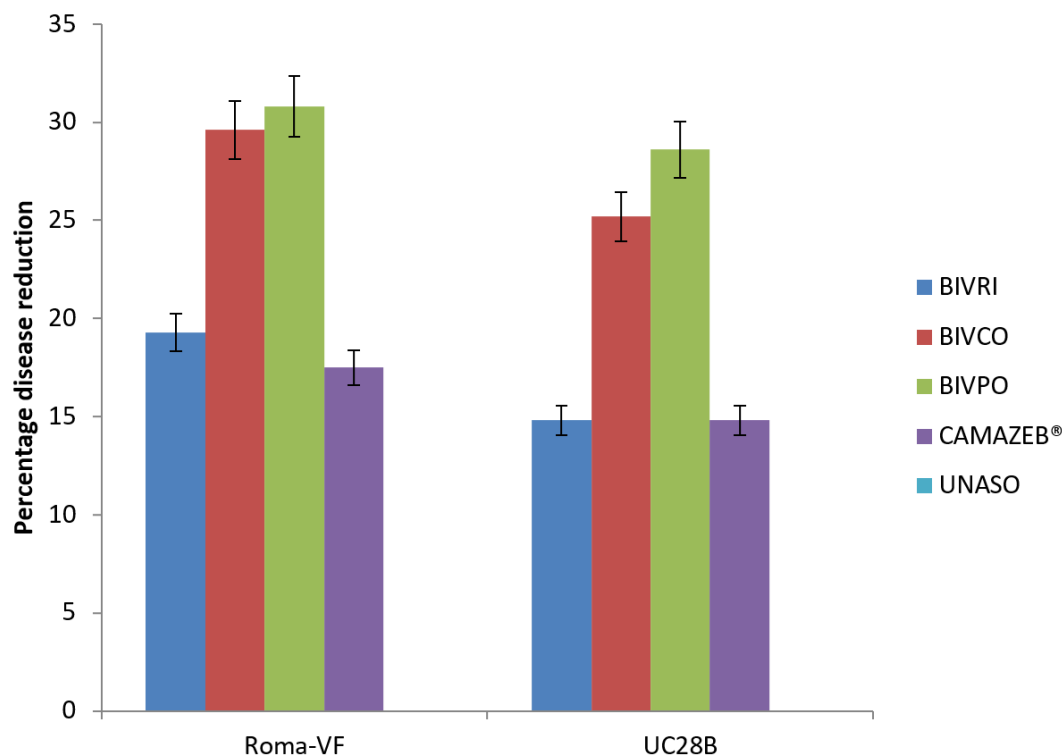


Figure 4. Interaction of variety and bio-enriched vermicompost on percentage disease reduction of Fusarium wilt

4. Discussion

Results from the experiment revealed effective control of Fusarium wilt through the application of vermicompost. A lower incidence and severity of Fusarium wilt in Roma-VF tomatoes grown in soil treated with bio-enriched vermicompost provides evidence that resistance is enhanced by the organic amendment. This is supported by the findings of Haruna [19], who reported the suppression of Fusarium wilt in Roma-VF tomatoes by growing them on soil amended with BIVPO under greenhouse conditions. Soil amendment with bio-enriched vermicompost effectively controlled Fusarium wilt disease, potentially due to high nitrate-nitrogen content in the bio-enriched vermicompost. This high nitrate-nitrogen content, resulting from the rapid conversion of ammonium-nitrogen to nitrate-nitrogen enhanced by cow dung [26] may have created adverse conditions for the development of Fusarium wilt [27,28]. This could be one of the reasons for the suppression of the Fusarium wilt of tomatoes as suggested by Borrero *et al.* [29] in their work on the impact of the ammonium/nitrate ratio in a nutrient solution for managing wilt of tomatoes caused by *Fusarium oxysporum* f. sp. *lycopersici*.

The effectiveness of vermicompost in reducing tomato wilt caused by *Fusarium oxysporum* f. sp. *lycopersici* can be attributed to the presence of bio-control agents and plant nutrients within optimum levels as well as the non-phytotoxicity of the bio-enriched vermicompost [21]. Furthermore, antagonistic microorganisms such as non-pathogenic *Fusarium oxysporum*, *Aspergillus* spp.,

Trichoderma spp., *Bacillus* spp., and *Lactobacillus* found in the bio-enriched vermicompost played an important role in the suppression of soil-borne phytopathogens. This has been supported by the isolation of *Bacillus* spp., *Enterobacter* spp., *Pseudomonas* spp., *Streptomyces* spp., *Penicillium* spp., and *Trichoderma* spp., along with several other antagonistic fungi from vermicompost which have been used to manage soil-borne pathogens [30,31,32]. The mechanisms of disease suppression by these antagonists include competition, antibiosis, hyperparasitism, and systemic plant resistance triggered by the bio-enriched vermicompost [33].

Application BIVPO, BIVCO and BIVRI have demonstrated their ability to suppress the Fusarium wilt in tomatoes. This supports Nakamura's research on the application of vermicompost in managing many fungal pathogens such as *Plasmodiophora brassicae*, *Phytophthora nicotianae* and *Fusarium oxysporum* f. sp. *lycopersici* [34]. Similar work was also reported by Szczec *et al.*, [35] who used vermicompost to control *Fusarium oxysporum* f. sp. *lycopersici* and *Phytophthora nicotianae* in tomatoes. Soil-borne fungi like *Rhizoctonia* spp., *Phytophthora* spp., *Fusarium oxysporum* were also reported to have been controlled by amending the soil with vermicompost [36]. These findings are in conformity with the work of many researchers who reported improvement in soil fertility and structure, and inhibition of soil-borne diseases due to the application of vermicompost, attributing the positive effect to the presence of beneficial microorganisms in the organic amendment [9,37,38,39,40]. Similar findings on the inhibitory effect of vermicompost

against soil-borne diseases were reported [41,42,43,44]. Chaoui *et al.* [45], in their greenhouse experiment reported significant suppression of two soilborne pathogens, *Pythium* and *Rhizoctonia*, with the use of vermicompost as horticultural bedding mixtures, microbial enrichment with *Lactobacillus* enhanced disease suppressive activity against Fusarium wilt of tomato. The work of Postma *et al.* [46] can substantiate this, reporting that the use of microbial enrichment of compost with the fungal antagonists *Verticillium biguttatum* and fungicide-resistant non-pathogenic *Fusarium oxysporum* effectively enhanced the suppressive ability of the compost in controlling *Rhizoctonia* spp., and *Fusarium* spp. of sugar beet and carnation, respectively.

The heterogeneous preparation of bio-enriched vermicompost using three different ingredients: poultry droppings, cow dung, and rice bran and enrichment with *Lactobacillus*, improved the efficacy of BIVPO, BIVCO, and BIVRI against Fusarium wilt in tomatoes. The use of more than one organic material in composting or vermicomposting enhances the disease-suppressive ability of the organic amendments [47]. Poultry manure bio-enriched vermicompost was more effective in controlling Fusarium wilt than BIVCO and BIVRI. However, the effectiveness of BIVPO in being better than other tested vermicompost, may be due to higher nitrogen compound which has the potential to suppress soil-borne pathogens through the toxic effect of ammonia, nitrous acid, or volatile fatty acids on phytopathogen growth, as well as survival and proliferation of antagonists and the better availability of essential nutrients that enhance the health status of tomato plants. This claim aligns with the work of Smiley *et al.*, [48] and Lazarovits [49] who also reported using poultry manure as an organic amendment to suppress soil-borne diseases.

The interaction effects between applications of vermicompost and host resistance were significant, when BIVPO was used on the two tomato varieties, it resulted in the lowest disease incidence and severity compared to a single application of poultry manure based-vermicompost. This indicates that the bio-control agents present in BIVPO and the physicochemical properties of the organic amendment triggered resistance in the UC82B variety, which is susceptible to Fusarium wilt, and improved the ability of the Roma-VF to suppress race 2 or 3 of the Fusarium wilt pathogen of tomatoes. These findings are consistent with the work of several researchers who reported the effectiveness of integrating host resistance through the use of organic materials in producing seedlings with low incidence and severity of soil-borne diseases [50,51,52]. The integrated use of vermicompost with resistant varieties enhanced the level and consistency of Fusarium wilt of tomatoes by improving the suppression mechanism against the pathogen.

Fusarium wilt incidence and severity on tomatoes were lower in 2016 when compared with disease development in 2015. This may be a result of low inoculum of the pathogen

in the field as it was mitigated by the bio-enriched vermicompost applied in the preceding year. This can be substantiated by the fact that bio-enriched vermicompost applied in 2015 augmented those applied in 2016. Since nutrients in the organic amendments were released slowly, thereby preventing nutrient loss, toxicity, and salinity [53,54] subsequently extending the physico-chemical and microbial properties of the bio-enriched vermicompost to 2016. Continuous application of organic amendments promotes long-term management of soil borne-diseases as reported by Steven *et al.* [55].

5. Conclusions and Recommendation

Based on the findings of this work we conclude that Roma-VF grown on BIVPO or BIVCO-amended soil is effective in managing Fusarium wilts of tomatoes. This is attributable to the content of the chemical characteristics of BIVCO and BIVPO, abundant soil nutrients, and presence of bio-control agents (*Lactobacillus* sp., *Bacillus* sp., *Pseudomonas* sp., *Trichoderma* spp., *Aspergillus* spp.) in the organic amendments, which improved tomato growth and conferred protection against Fusarium wilt. Therefore, the application of 25 tonnes ha⁻¹ of BIVPO or BIVCO and transplanting Roma-VF is recommended as an eco-friendly integrated management strategy against the Fusarium wilt of tomato.

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