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EFFECT OF SOIL AMENDMENTS WITH BIO-FUMIGANT CROPS AND ANIMAL MANURE ON GROWTH AND YIELD OF TOMATOES INFECTED WITH FUSARIUM WILT

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ABSTRACT

A screenhouse study was conducted to investigate the effects of bio-fumigation with bio-fumigant crops and animal manure on the growth and yield of tomatoes infected with Fusarium wilt. The evaluation was a 4 x 4 factorial experiment arranged in a split-plot design which consisted of bio-disinfectants as the main plot and bio-fumigant crops as a subplot. The 16 treatment combinations were replicated three times. The main plot contained four treatments: poultry manure, cow dung, synthetic fungicide CAMAZEB® (60% Mancozeb + 40% Carbendazim WP) and untreated soil as control. The subplot constituted three bio-fumigant crops; cabbage, onion, garlic and un-amended soil. Data on growth parameters and yield components were measured and subjected to analysis of variance. Results revealed that tomatoes grown on soil amended with poultry manure and cabbage residues significantly (P≤0.05) produced seedlings with the tallest plant height (83 cm) and the highest number of leaves (154) than the other treatments. Tomatoes with the average highest yield (8.26 t ha^{-1}), fresh shoot (296.5 g) and fresh root (69.2 g) weights were recorded on tomatoes transplanted on poultry manure and cabbage-amended soil. Decomposition of poultry manure and cabbage released gases lethal to Fusarium wilt pathogen and soil nutrients essential for tomato growth. Based on the results obtained, amending soil with 0.85 kg of poultry manure and 200g of cabbage per plant is recommended as the best treatment combination for sustainable organic tomato production under screenhouse conditions.

Keywords: Bio-fumigant crops, cabbage residues, cow dung, fusarium wilt, tomato, poultry manure,

INTRODUCTION

Tomato is widely cultivated in Nigeria where it has been an important component of the daily diets (Gurama and Haruna, 2018). Nigeria is ranked as the 11th world producer and second leading producer of tomatoes in Africa with a total production of 3,693,722 metric tonnes (FAO, 2020). Despite the large area under production, tomato production in Nigeria is beset with many constraints among which are diseases and pest attacks. Pests greatly affect tomato production, leading to low yield, poor quality of fruits and postharvest losses (Bello *et al*., 2016; Abdul *et al*., 2020). The most devastating tomato disease in Nigeria is the Fusarium wilt caused by *Fusarium oxysporum* f. sp. *lycopersici*. The disease occurs wherever tomato is cultivated. Fusarium wilt of tomatoes is globally considered one of the most important diseases of tomatoes both in the field and greenhouse (Sheu and Wang, 2006; Res and Boiteux, 2007; Amini and Sidovich, 2010; Abdel-Monaim, 2012; Hashem *et al*., 2019). Being a soil-borne systemic disease, it severely affects tomatoes at all stages of plant growth thereby reducing yield in both greenhouse and fields (Jabnoun-Khiareddine *et al*., 2019). The use of methyl bromide (MB) can effectively control Fusarium wilt. However, the fumigant MB is no longer used in most countries due to its carcinogenic effects (Ziedan, 2022). Management of fusarium wilt of tomatoes through other conventional strategies is not always effective due to the development of new races of the pathogen and resistance to fungicides (Haruna *et al*., 2019).

The use of organic amendments will serve as an alternative to the outlawed MB to control soil-borne diseases such as fusarium wilt of tomatoes. Applications of amendments significantly alter the soil physicochemical environment and influence the growth and behaviour of antagonistic microbes as reported by many researchers (Litterick, *et al*., 2004; Liu, *et al*., 2007; Jayaraman *et al*., 2021). Incorporation of organic amendment of plant origin into the soil for the purpose of improving plant growth and health upon their decomposition is described as soil disinfection (Katan, 2017). The basis of this biological disinfection has its origin in the biocidal/biostatic effect of the volatile compounds produced during the decomposition of the organic matter as ammonia and additional effects provided by the release of non-volatile molecules (fatty acids) to the soil (Runia *et al*., 2014). Furthermore, it also affects moisture-holding capacity, nutrient availability, and microbial ecology which have a direct impact on plant health and yield (Bailey and Lazarovits, 2003). Lamers *et al*. (2004) classified soil disinfection into bio-disinfection (use of high quantities of organic matter releasing toxic responsible for the destruction of pathogens) and bio-fumigation (use of specific plant species containing identified toxic molecules). The application of animal manure as a soil bio-disinfection strategy to manage soil-borne diseases has been practised by farmers for centuries. However, this method is not effective in managing certain soil fungal pathogens such as *Pythium* sp, *Rhizoctonia* spp. (Manici *et al*., 2004; Bananomi *et al*., 2018).

Bio-fumigation is an intentional use of bioactive plants, mostly *Brassicas*, *Allium* species and other organic materials that aid in reducing populations of plant pests in soil (Arnault *et al*., 2006). Suppression of soil-borne pests by bio-fumigation was achieved due to the presence of biocidal compounds, particularly isothiocyanates released from brassicaceous rotation and green manure crops when the glucosinolates (GSLs) in their tissues were hydrolysed in soil (Smolinska and Kowalczyk, 2014**).** Some hydrolysis products, particularly the isothiocyanates (ITCs) were known to have broad biocidal activity including insecticidal, nematicidal, fungicidal, antibiotic and phytotoxic effects as reported by Gimsing and Kirkegard (2009). Karavina and Mandumbu (2012) opined that bio-fumigation greatly reduced pesticide application making farming cheaper and safer as it added organic matter to the soil, leading to increased soil aeration, water infiltration rates and soil water holding capacity. Bio-fumigation is a sustainable method of soil management that can increase soil organic matter, moderate soil pH, suppress weeds and soil-borne pathogens through glucosinolates, and increases water infiltration (Rudolph *et al*., 2015). Bio-fumigation was also reported to have increased soil porosity if used as a green manure and added more organic carbon to the soil thereby increasing the activity of soil fauna and flora as disclosed by Balesh *et al.* (2005).

Amending soil with bio-fumigant crops to manage the fusarium wilt of tomatoes is a new strategy in Nigeria. The incorporation of bio-fumigant crops has the potential to suppress soil-borne fungal pathogens and improve soil fertility and crop yield. The objective of this study was to evaluate the effect of amending soil with bio-fumigant crops and animal manure on the growth and yield of tomatoes infected with tomato wilt incited by *Fusarium oxysporum* f. sp. *lycopersici*.

MATERIALS AND METHODS

The experiment was carried out in 2014 in the screenhouse of the Federal College of Horticulture, Dadin Kowa, Gombe State. The evaluation was a 4 x 4 factorial experiment arranged in a split-plot design which consisted of bio-disinfectants as the main plot and bio-fumigant crops as the subplot. The 16 treatment combinations were replicated three times. The main plot contained four treatments: poultry manure, cow dung, synthetic fungicide CAMAZEB® (60% Mancozeb + 40% Carbendazim WP) and untreated soil as control. The subplot constituted three bio-fumigant crops; cabbage, onion, garlic and un-amended soil. Eight hundred grammes of poultry manure and cow dung were used while 200g of cabbage, onion and 100 g of garlic were sliced with a knife into 2 – 3 cm separately mixed with 4 kg of soil and incorporated into the soil in plastic containers (128 dsm^3) in the following treatment combinations: poultry manure (PM) + cabbage (CA), PM + onion (ON), PM + garlic (GA), PM + un-amended soil (UA); cow dung (CD) + CA, CD + ON, CD + GA, CD + UA; CAMAZEB® (CA®) + CA, CA® + ON, CA® + GA, CA® + UA; and untreated soil (US) + CA, US + ON, US + GA and US + UA.

The pots containing 4 kg of soil were moistened to field capacity, covered with a polyethylene sheet to reduce evapotranspiration and left for seven days before transplanting. The soil in each pot was inoculated with 5ml conidial suspension of the pathogen before the application of organic amendments (bio-disinfectant and bio-fumigants) following the procedures used by Misrak *et al*. (2004).

Data Collection and Analyses

Data collection started two weeks after transplanting. Plant height, number of leaves and branches were recorded bi-weekly. Data on plant height was measured in centimetres using a tape by placing the zero cm end at the soil level and measurement taken at the tip of the plant. Number of branches per plant was counted including the minor branches from the main stem; number of leaves per plant was obtained by singly counting each leaf on the plant. Fruit weight for each plant was obtained by weighing the fruits harvested per plant using a digital weighing scale. The fruit harvest was done weekly and the accumulative harvests were summed up to get the total yield. The total yield was extrapolated to plot basis and finally to per hectare basis. Fresh root and shoot weights per plant was measured in grammes using a digital scale after recording the last harvest. Data collected were subjected to analysis of variance at $P \leq 0.005$ using GenStat Release 17.1 (PC/Windows 8), Copyright 2014. Treatment means were separated using fishers protected least significant difference (FLSD) at $P \leq 0.005$.

RESULTS

Effect of animal manure as bio-disinfectants and bio-fumigant crops on plant height of tomato infected with Fusarium wilt

Application of animal manure and bio-fumigant crops significantly ($P \leq 0.01$) improved plant height of tomato infected with fusarium wilt pathogen as presented on Table 1. At 2 WAT, amendment with poultry manure, cow dung and CA®, individually produced taller tomato plants than those from un-amended soil. However, at 4 – 10 WAT tomatoes transplanted on soil amended with poultry manure or cow dung showed similar effect which led to taller plants than those on CA® amended soil. Shorter plants were recorded on untreated control. Tomatoes grown on soil amended with bio-fumigant crops differed significantly (P≤0.01) with those tomatoes grown on soil left untreated control. Amendments with bio-fumigant crops at the various sampling periods showed similar effects and led to taller tomato seedlings than CA®. Shortest plants were found on untreated control compared to those on amended soils.

The interaction effect of bio-disinfectants and bio-fumigant crops on plant height is significant in all the sampling periods as presented in Tables 2 and 3. At 2 WAT, significantly taller plants were recorded on tomatoes grown on soils amended with PM and cabbage (20.6 cm) followed by tomatoes grown on soil amended with CD + CA, CD + GA, PM + GA, CA® + CA® and PM + ON, which were all at par. Tomatoes grown on soil not treated with any of the bio-fumigant crops or animal manure/fungicide had the shortest height (16 cm) compared to the other treatment combinations. A similar pattern was observed at 4 WAT, where tomatoes transplanted on soil amended with PM + CA produced the tallest plants (30.1 cm) followed by those on soils amended with CD +CA (29.9 cm) and PM + GA (29 cm), respectively (Table 2).

Similarly, at 6 and 8 WAT, tomatoes grown on soil amended with PM + CA exhibited the highest plant height (47.7cm; 69.9cm) compared to those tomatoes produced on soil amended with other organic amendments (Table 3).

However, at 10 WAT taller tomatoes (81.6cm) were produced on soil amended with poultry manure + cabbage, which is statistically similar to those grown on soil amended with cow dung + cabbage (80 cm). The height of tomatoes grown on soil treated with poultry manure + garlic (75.5 cm) was at par with those grown on cow dung + garlic (76.2 cm), PM + ON (75.1 cm) and CD + ON (74.6 cm). Tomatoes grown on un-amended soil significantly produced shorter plants (44.6 cm) compared to those grown on other treatment combinations.

Table 1: Effect of animal manure as bio-disinfectants and bio-fumigant crops on plant height of tomato infected with Fusarium wilt under screenhouse conditions

Treatments	Weeks after transplanting				
	2	4	6	8	10
Bio-disinfectants (A)					
Poultry manure	19.3a	27.6a	44.2a	62.3a	80.2a
Cow dung	18.7b	27.4a	43.9a	62.4a	79.8a
CAMAZEB®	18.1c	24.4b	41.0b	49.3b	62.2b
Control	16.8d	23.2c	39.8c	40.6c	52.6c
SE±	**0.08**	**0.12**	**0.14**	**0.10**	**0.16**
Bio-fumigant crops (B)					
Cabbage	19.5a	27.2a	43.8a	55.2a	71.0a
Garlic	18.7b	26.3b	42.9b	51.4b	69.0b
Onion	18.0c	25.1c	41.7c	48.9c	67.2 c
Un-amended	16.7d	24.0d	40.5d	46.7d	64.6d
SE±01.8	**0.09**	**0.10**	**0.11**	**0.17**	**0.15**
Interaction					
A x B	**	**	**	**	**

CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP). ** Significant F-test at 1% level of probability. Values in the same column followed by the same letter(s) are not significantly different at *P*< 0.0) based on Fisher's Protected LSD.

Table 2: Interactions of bio-disinfectants and bio-fumigant crops on plant height of tomato infected with Fusarium wilt at 2, 4 and 6 weeks after transplanting

		Bio-fumigant crops			
WAT	Bio-disinfectants	Cabbage	Garlic	Onion	Un-amended
	Poultry manure	21.6a	20.3b	20.0bc	18.1g
	Cow dung	19.9bc	19.6cd	18.7e	17.5fgh
2	CAMAZEB®	19.6cd	18.5ef	18.0efg	17.0gh
	Control	18.4ef	17.1gh	17.2gh	16.0i
	SE±0.18				
	Poultry manure	31.3a	29.0c	27.5e	26.1f
	Cow dung	29.9b	28.4d	26.7d	25.7g
4	CAMAZEB®	25.8g	25.3gh	24.6ghi	23.0jkl
	Control	24.0hi	23.8hij	23.3jk	22.2m
	SE±0.20				
	Poultry manure	47.6a	46.4bc	44.6e	43.5df
	Cow dung	46.8b	45.5d	43.4f	42.5g
6	CAMAZEB®	43.2fg	42.5g	42.1gh	40.4jk
	Control	41.4h	41.1hi	40.5j	39.5k
	SE±0.24				

CAMAZEB®= (60% Mancozeb + 40% Carbendazim WP). WAT = Weeks after transplanting.Values in the same column followed by the same letter(s) are not significantly different at *P*< 0.05) based on Fisher's Protected LSD.

Table 3: Interactions of bio-disinfectants and bio-fumigant crops on plant height of tomato infected with Fusarium wilt at 8 and 10 weeks after transplanting

		Bio-fumigant crops			
WAT	Bio-disinfectants	Cabbage	Garlic	Onion	Un-amended
	Poultry manure	69.9a	64.0b	58.8d	53.9de
	Cow dung	65.1b	60.1c	58.5c	56.5d
8	CAMAZEB®	48.3e	47.8ef	45.5f	42.6gh
	Control	43.5g	42.0gh	41.3h	37.8i
	SE = ±0.31				
	Poultry manure	81.6a	75.5b	75.1b	67.9c
	Cow dung	80.0a	76.2b	74.6b	67.1c
10	CAMAZEB®	61.0d	59.4d	57.4de	52.4f
	Control	55.8e	51.8fg	49.8lg	44.6h
	SE = ±0.33				

CAMAZEB®= (60% Mancozeb + 40% Carbendazim WP). WAT = Weeks after transplanting.
Values in the same column followed by the same letter(s) are not significantly different at *P*< 0.05) based on Fisher's Protected LSD.

Effect of animal manure as bio-disinfectants and bio-fumigation on the number of leaves of tomato infected with Fusarium wilt

Amending soil with bio-disinfectants and bio-fumigant crops significantly (P<0.01) improved leaf production on the crop (Table 4). The incorporation of poultry manure as a bio-disinfectant led to significantly (P≤0.01) higher leaf production than the application of cow dung and CAMAZEB® throughout the growth stages of tomato. The least number of leaves was produced by tomatoes grown on un-amended soil. Similarly, soil amended with cabbage leaf significantly enhanced leaf production, followed by amendments of soil with garlic and onion bulbs, respectively.

The interaction effect between bio-disinfection and bio-fumigant crops on leaf number was not significant at 2 and 4 WAT but was highly significant at 6 – 10 WAT as shown in Table 5. Growing tomatoes on soil amended with poultry manure and bio-fumigated with cabbage or garlic were statistically similar and produced significantly (P≤0.01) higher number of leaves (80.3 cm; 78.7 cm) than tomatoes grown on soil treated with other organic amendments. The least number of leaves was recorded on tomatoes produced on the untreated control (27.6 cm). A similar trend was observed at 8 WAT. However, at 10 WAT, tomatoes grown on soil amended with PM and bio-fumigated with CA (154 cm) had the highest number of leaves which was at par which those produced on soil amended with CD + CA (152 cm).

Table 4: Effect of bio-disinfectants and bio-fumigant crops on leaf production of tomatoinfected with Fusarium wilt under screenhouse conditions

Treatment	Weeks after transplanting				
	2	4	6	8	10
Bio-disinfectants (A)					
Poultry manure	33.2a	52.5a	72.3a	113.7a	146.0a
Cow dung	26.9b	50.2b	63.9b	104.8b	136.8b
CAMAZEB®	19.8c	32.8c	54.8c	96.8c	128.9c
Control	15.6d	28.0d	35.3d	77.8c	109.3d
SE±	**1.71**	**0.23**	**0.98**	**0.73**	**0.76**
Bio-fumigant crops (B)					
Cabbage	27.4a	45.2a	63.9a	105.8a	137.9a
Garlic	24.9b	43.0b	60.2b	101.9b	134.2b
Onion	22.3c	38.9c	54.8c	96.5c	128.9c
Untreated	20.8d	36.3d	47.2d	88.8d	120.2d
SE±	**0.48**	**0.42**	**0.49**	**0.34**	**0.42**
Interaction					
A X B	**ns**	**ns**	**	**	**

CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP), ns = not significant, ** significant F-test at 1% levels of probabilities. Values in the same column followed by the same letter(s) are not significantly different at *P*< 0.05) based on Fisher's Protected LSD.

Table 5: Interaction effect of bio-disinfectants and bio-fumigant crops on number of leaves of tomato infected with Fusarium wilt under screenhouse conditions

		Bio-fumigant crops			
WAT	Bio-disinfectants	Cabbage	Garlic	Onion	Un-amended
	Poultry manure	80.3a	78.7a	70.0b	60.3c
	Cow dung	70.3b	71.0b	62.0c	51.0de
6	CAMAZEB®	62.7c	52.0de	54.7d	49.7e
	Control	44.0f	37.3g	32.3h	27.6i
	SE ± 1.129				
	Poultry manure	121.7a	120.7a	111.7c	102.0e
	Cow dung	119.3b	112.3c	102.3e	92.08gh
8	CAMAZEB®	105.2d	93.7g	97.3f	90.8h
	Control	86.0i	79.7j	74.7k	70.6i
	SE = ±0.94				
	Poultry manure	154.0a	146.0b	144.2b	133.7d
	Cow dung	152.0a	145.0b	134.0cd	123.4fg
10	CAMAZEB®	137.0c	130.0e	126.3f	122.3g
	Control	117.7h	111.3i	107.3j	101.6k
	SE = ± 1.06				

CAMAZEB®= (60% Mancozeb + 40% Carbendazim WP). WAT = Weeks after transplanting. Values in the same column followed by the same letter(s) are not significantly different at *P*< 0.05) based on Fisher's Protected LSD.

Effect of animal manure as bio-disinfectants and bio-fumigation on branching in tomato infected with Fusarium wilt

The effect of bio-disinfection and bio-fumigation on tomato branching at various stages of tomato growth was presented in Table 6. At 2, 4 and 6 WAT, poultry manure and cow dung had statistically similar effects on the branching of tomatoes infected with Fusarium wilt. The two organic manures significantly produced more branches than those grown on soil amended with CAMAZEB®. However, at 8 and 10 WAT poultry manure led to a higher number of branches than cow dung and CAMAZEB®, respectively. The lowest number of branches was recorded on tomatoes grown on the untreated control. Bio-fumigation significantly (P≤0.01) influenced the number of branches. At 2 - 4 WAT, the number of branches recorded on tomatoes grown on soil amended with cabbage (8.9) differed significantly from those on garlic-amended soil (8.2). Tomatoes transplanted on onion-amended soil (7.4) did not differ from those on the untreated control (7.1). The result on the number of branches at 6 – 10 WAT showed a higher number of branches on tomatoes grown on soil amended with cabbage, followed by those on garlic and onion-amended soils, respectively. No significant interaction effect was recorded between animal manure and bio-fumigation on the number of branches on tomatoes.

Effect of animal manure as bio-disinfectants and bio-fumigant crops on fruit weight, fresh shoot and root weight of tomato infected with fusarium wilt

Table 7 presents the interactive effect between animal manure and bio-fumigant crops on yield and yield components of tomatoes. Tomatoes grown on soil amended with poultry manure were at par in producing heavier roots (65.6 g plant^{-1}) and shoot (282.4 g plant^{-1}) than those grown on cow dung

(64.9 g plant^{-1}; 273.2 g plant^{-1}), CAMAZEB® amended soils (61.3 g plant^{-1}; 251.7 g plant^{-1}), and those on untreated control (55.3 g plant^{-1}; 248.2 g plant^{-1}), respectively. Greater tomato yield was obtained when soils were treated with poultry manure (7.63 t ha^{-1}) than those on cow dung (7.48 tha^{-1}), CAMAZEB® (7.27 t ha^{-1}) and untreated control (6.64 t ha^{-1}), respectively. Bio-fumigation significantly influenced tomato yield. Soil bio-fumigated with cabbage had the highest yield (7.73 t ha^{-1}), followed by soil bio-fumigated with garlic (7.53 t ha^{-1}), onion (7.41 t ha^{-1}), respectively, compared to the untreated soil (6.35 t ha^{-1}). The highest weight of roots and shoots were recorded on tomatoes grown on soil amended with cabbage (64.3 g plant^{-1}; 274.0 g plant^{-1}), followed by garlic (62.6 g plant^{-1}; 267.7 g plant^{-1}), onion (61.3g plant^{-1}; 263.5 g plant^{-1}) and untreated control (58.9 g plant^{-1}; 250.0 g plant^{-1}), respectively.

Table 8 showed the interaction between bio-disinfectants and bio-fumigants on roots and shoot weights; and the yield of tomatoes. Heavier shoot weight was found on tomatoes grown on soil amended with poultry manure + cabbage (296.5 g plant^{-1}) than the other treatment combinations. The greatest root weight was obtained on tomatoes grown on soils amended with PM + cabbage (69.2 g plant^{-1}), while the least weight was recorded on those grown on the untreated control (52.3g plant^{-1}). Combined application of PM and CA significantly produced the highest tomato fruit weight (8.26 t ha^{-1}) followed by those grown on soil amended with CD + CA (7.96 t ha^{-1}) that had a similar effect with tomatoes from soil amended with PM + garlic (7.95 t ha^{-1}). Low fruit weight was recorded on tomatoes grown on soil not treated with bio-disinfectant and bio-fumigant crop (5.88 t ha^{-1}).

Table 6: Effect of bio-disinfectants and bio-fumigant crops on branching of tomato infected with Fusarium wilt under screenhouse conditions

Treatment	Weeks after transplanting				
	2	4	6	8	10
Bio-disinfectants (A)					
Poultry manure	9.8a	11.6a	14.4a	17.3a	19.5a
Cow dung	9.7a	11.3a	14.2a	16.6b	18.4b
CAMAZEB®	7.3b	9.2b	12.0b	13.5c	15.5c
Control	5.2c	7.1c	9.5c	11.1d	13.1d
SE±	**0.22**	**0.29**	**0.13**	**0.17**	**0.21**
Bio-fumigant crops (B)					
Cabbage	8.9a	10.8a	13.6a	15.5a	17.8a
Garlic	8.2b	10.1b	12.1b	14.3b	17.0ab
Onion	7.4c	9.4c	12.2c	14.4b	16.2b
Un-amended	7.1c	8.9d	11.3d	13.7c	15.5c
SE±	**0.18**	**0.17**	**0.19**	**0.21**	**0.26**

CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP). Values in the same column followed by the same letter(s) are not significantly different at $P < 0.05$) based on Fisher's Protected LSD.

Table 7: Effect of bio-disinfectants and bio-fumigant crops on yield components and yield of tomato infected with Fusarium wilt

Treatment	Root weight (g plant^{-1})	Shoot weight (g plant^{-1})	Yield (t ha^{-1})
Bio-disinfectants (A)			
Poultry manure	65.6a	282.4a	7.63a
Cow dung	64.9a	273.2b	7.48b
CAMAZEB®	61.3b	251.3c	7.27c
Control	55.3c	248.2d	6.64d
SE±	**0.33**	**0.44**	**0.042**
Bio-fumigant crops (B)			
Cabbage	64.3a	274.0a	7.73a
Garlic	62.6b	267.7b	7.53b
Onion	61.3c	263.5c	7.41c
Un-amended	58.9d	250.0d	6.35d
SE±	**0.21**	**0.48**	**0.021**
Interaction			
A X B	**	**	**

CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP). ** Significant at 1%, ns = not significant. Values in the same column followed by the same letter(s) are not significantly different at $P< 0.05$) based on Fisher's Protected LSD.

Table 8: Interactions of bio-disinfectants and bio-fumigant crops on shoot and root weights and yield of tomato infected with Fusarium wilt

		Bio-fumigant crops			
Parameter	Bio-disinfectants	Cabbage	Garlic	Onion	Un-amended
	Poultry manure	296.5a	285.7c	283.3c	264.2f
	Cow dung	289.9b	279.5d	268.7e	254.9gh
Shoot (g)	CAMAZEB®	257.1g	254.3h	252.6hi	241.3k
	Control	252.7hi	251.4ij	249.4j	239.4k
	SE±0.94				
	Poultry manure	69.2a	66.1c	64.4d	62.6ef
	Cow dung	67.7b	66.0c	64.5d	61.3fg
Root (g)	CAMAZEB®	62.9e	61.7efg	61.0g	59.5h
	Control	57.2i	56.4i	55.1j	52.3k
	SE±0.49				
	Poultry manure	8.26a	7.95bc	7.70de	6.61i
	Cow dung	7.96b	7.79cd	7.66e	6.51ij
Yield (t ha^{-1})	CAMAZEB®	7.66e	7.56ef	7.49f	6.39j
	Control	7.05g	6.82h	6.81h	5.88k
	SE±0.055				

CAMAZEB® = (60% Mancozeb + 40% Carbendazim WP). Values in the same column followed by the same letter(s) are not significantly different at $P< 0.05$) based on Fisher's Protected LSD.

DISCUSSION

Application of animal manure and bio-fumigant crops enhanced vegetative growth and yield of tomatoes. Poultry manure and cabbage applied as soil amendments improved growth parameters and yield of tomato as evident in the results obtained. The incorporation of poultry manure and cabbage has been reported to manage Fusarium wilt and improve tomato yield (Gurama and Haruna, 2018; Haruna et al., 2019; Haruna *et al*., 2020). Smolinska (2000) attributed improved plant growth to the plant materials incorporated into soil which enhanced the activities of soil micro-organisms exerting inhibiting effects on plant pathogens that subsequently led to good effects on yield. The efficacy of PM and CA in improving tomato growth and yield may also be attributed to the availability of essential nutrients and the proliferation of plant growth-promoting organisms in the decomposed organic amendments.

Good yield and yield components obtained on soil amended with poultry manure and cabbage showed their combined effect on tomatoes. This agrees with the findings of Pakeerathan *et al.* (2009) who reported the dual effect of the combined use of animal manure and plant materials for the improvement of disease control and plant growth. Yim *et al*. (2016) reported the effect of bio-fumigation on apples and attributed increased apple plant growth to the suppression of soil-borne pests and pathogens, changes in soil microbial community compositions, and additional nutrients from the incorporated biomass. The result are also in conformity with the findings of Anita (2012) who reported that ethanol extracts of cabbage, cauliflower, radish and Chinese cabbage leaves reduced the population of nematodes and improved celery plant growth resulting in an increase in celery green leaves and stalk yield. A similar trend was reported by El-Sherbiny and Awd-Allah (2014) when air-dried powder of cauliflower reduced nematode infestation and improved the growth and yield of tomato. El-Nagdi and Youssef (2019) reported suppression of root-knot nematode and an increase in cowpea production and yield with the application of Brassica vegetable leaf residues. Soil bio-fumigated with crushed cabbage leaves led to an increase in the plant growth parameters of tomatoes (Youssef and Leshein, 2013).

CONCLUSION

Amending soil infested with Fusarium wilt pathogen with poultry manure or cow dung as bio-disinfectants and use of cabbage residues as bio-fumigant before transplanting effectively improved the growth and yield of tomato infected with Fusarium wilt caused by *Fusarium oxysporum* f. sp. *lycopersici*. Integrated application of poultry manure and cabbage as the organic amendment is therefore recommended as an eco-friendly technology package of bio-fertilizer for sustainable tomato production under screenhouse or greenhouse conditions.

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