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Efficacy of *Trichoderma* Fortified Organic Amendments on *Fusarium* Wilt Suppression, Growth and Yield of Eggplant

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Authors' contributions

This work was carried out in collaboration among all authors. Author VGR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DND and KDN managed the analyses of the study. Author KTA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Trichoderma harzianum is commonly used as effective biological control agent against phytopathogens especially the soil-borne fungi while some isolates are able to ameliorate plant growth. In the present study, *Trichoderma* fortified with different organic amendments were evaluated to reduce the pre-emergence and post-emergence seedling mortality, diseases of stem and root of eggplant caused by *Fusarium oxysporum* f. sp. *melongenae*, a soil-borne fungal pathogen. Two experiments were set up, one at pot culture and second in the field under natural epiphytotic conditions. Among the nine *Trichoderm harzianum* fortified amendments tested, neem seed cake recorded significant and superior effect as pre-sowing soil application against *Fusarium* wilt with respect to seed germination (92.33%), pre-emergence seed rot (7.66%) and post-emergence seedling mortality (15.33%) in pot culture. However, cotton cake recorded least efficacy in all respect. Similar trend observed in wilt incidence under field experiments during

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autumn 2018 (17.47%) and 2019 (18.60%) with *T. harzianum* fortified neem cake soil application against *Fusarium* wilt with mean inhibition of disease incidence (58.43%) and also observed excellent enhancement of mean yield (54.63%). It is observed that organic amendment at higher concentrations further increase the microbial populations and stimulate the microbial activity in soil against *Fusarium oxysporum* resulted to decrease the pathogen populations. Moreover, yield and yield related attributes increased remarkably due to fortified amendments providing adequate nutrient reservoir to the bioagents thereby enhancing its survival in a hostile environment.

Keywords: Trichoderma harzianum; fortified organic amendments; Fusarium wilt; eggplant.

1. INTRODUCTION

Many attempts have been made to control *Fusarium oxysporum* f.sp. *melongenae*, including cultural or chemical methods but neither cultural nor chemical measures alone were found to be effective against these pathogens. Controlling of these soil-borne diseases with fungicides is uneconomical and difficult to achieve because of the soil and seed-borne nature of the pathogen [1]. Moreover, the application of fungicides causes groundwater pollution, killing of non-target beneficial flora and evolving fungicidal resistance variants of the pathogen. The antagonistic *Trichoderma*, a cosmopolitan soil and compost-borne saprotrophic fungus can be used to suppress soil-borne pathogens that cause diseases such as damping-off, root rots, stem rots, and wilting in many vegetables. In addition to its effect as a natural enemy of plant pathogens, *Trichoderma* has also a positive impact on plant growth as it produces different kinds of secondary metabolites which are important for plant growth regulation [2] and improves the soil fertility by acting as decomposer. Composts or compost extracts used as an organic fertilizer have beneficial effects on plant growth and considered as a valuable soil amendment [3]. Recently *Trichoderma* fortified organic amendments have been used in many countries and appeared very effective in controlling different soil-borne pathogen as well as increasing growth and yield of many crops [4,5]. However, scanty published reports on disease suppression and improvement of growth and yield of many crop are available in utilizing *Trichoderma* fortified organic amendments. Therefore, this study was undertaken to select the most effective of *Trichoderma harzianum* against *F. oxysporum* f.sp. *melongenae* under screen house(pot culture) condition and to assess the potential of *Trichoderma* fortified organic amendments in controlling fungal diseases and enhancing growth and yield of eggplant in the field.

2. MATERIALS AND METHODS

2.1 Collection, Isolation and Preservation of *Trichoderma harzianum*

Pure cultures and talc based formulations of biocontrol agent *viz., Trichoderma harzianum* was obtained from the Spawn Production-cum-Biocontrol Laboratory, Department of Plant Pathology, College of Agriculture, VNMKV, Parbhani, MS, India This culture was maintained and multiplied on appropriate culture media and used for present studies.

2.2 Preparation of *Trichoderma* Fortified Organic Amendments

Fortification of organic amendments with *Trichoderma harzianum* was followed as prescribed by Basco et al. [6]. The effective biological control agents were picked from *in vitro* study and forwarded to further study of bio fortification due to their compatibility and the ability to reduce soil-borne diseases in different crops [7]. One liter of five days old *Trichoderma harzianum* culture grown in potato dextrose broth with CFU count approximately $4x10^7$ was used to fortify organic soil amendments containing trays (25 kg each). These trays were placed in the shade and covered with dark polythene sheet for 10 days. Survival of the *Trichoderma harzianum* in fortified soil organic amendments at ten days were determined by serial dilution technique. One gram of fortified amendments were diluted in 10 ml of sterilized water and population densities were measured on potato dextrose agar media. Microbial counts were expressed as CFU per gram dry weight.

2.3 Evaluation of *Trichoderma* Fortified Organic Amendments under Screen House Conditions

Plastic bags of 25×18 cm^2 were used to evaluate antagonistic potentials of fortified organic soil

amendments against *F. oxysporum* f. sp. *melongenae* by following the method suggested by El-Mohamedy [8]. Soil was autoclaved for 30 min at 15 psi for three consecutive days. Poly bags were filled with sterile soil mixed with *Trichoderma harzianum* fortified organic amendments at 10 % (w/w). After 24 hours, sandmaize meal inoculum of test pathogen was added in soil at 40 g. per kg of potting mixture and allowed to stabilize for 48 hours. Ten seeds of test cultivar were sown in each poly bag. For each treatment three replications were maintained. Observations on wilt incidence were recorded up to 90 days after sowing.

Experimental details:

Design	:	Completely Randomized Design (CRD)
Replications	:	Three
Treatments	:	Ten

Treatment details:

Tr. No.	Treatments	Tr. No.	Treatments
T_1	Neem cake + *T. harzianum*	T_6	Cotton cake + *T. harzianum*
T_2	Mustard cake + *T. harzianum*	T_7	Vermicompost + *T. harzianum*
T_3	Safflower cake + *T. harzianum*	T_8	Goat manure + *T. harzianum*
T_4	Ground nut cake + *T. harzianum*	T_9	Poultry manure + *T. harzianum*
T_5	Soya cake + *T. harzianum*	T_{10}	Control (Untreated)

2.4 Evaluation of *Trichoderma* Fortified Organic Amendments in Natural Field Condition

A total of nine *Trichoderma harzianum* fortified organic amendments were applied to the soils of experimental plots, before transplanting of eggplant seedlings. Biofortified organic amendments were incorporated at 4 kg per plot at 15 days prior to eggplant transplantation (susceptible cultivar Arka sirish).The crop was well managed throughout the period of experiment by following recommended agronomic practices. The experiment was conducted for two consecutive years during autumn 2018-19 and autumn 2019-20.

Treatment details: treatments are same as pot culture

Experimental details:

Design	:	Randomized Block Design (RBD)
Replications	:	Three
Treatments	:	Ten
Variety	:	Arka sirish
Spacing	:	60 x 45 cm^2
Block size/ Treatment	:	2.40 x 3.15 m^2

3. RESULTS AND DISCUSSION

3.1 Bio Efficacy of *Trichoderma* Fortified Organic Amendments (Pot Culture)

A total of nine *Trichoderma harzianum* fortified amendments were evaluated as pre-sowing soil application to assess their efficacy against *Fusarium* wlt, employing sick soil technique and sowing susceptible eggplant cv. Arka Shirh in pot culture under screen house conditions. The results obtained on seed germination, pre-emergence seed rot (PREM) and post-emergence seedling mortality (POSM) is presented in the Table 1.

3.2 Effect on Seed Germination

Results (Table 1) revealed that all the test amendments recorded significantly improved seed germination, over untreated control and it ranged from 55.33 to 92.33 %, as against 32.66 % in untreated control. However, significantly highest seed germination was recorded in neem seed cake (92.33 %) with an increase of 64.57 %over control, while, vermicompost, goat manure and poultry manure recorded 84.33, 76.00 and 72.33 %, germination with increase of 61.16 %,57.01 % and 54.80 % over control respectively. These were followed by the amendments *viz*., mustard cake (68.00%), safflower cake (65.00 %), groundnut cake (62.00 %), soybean seed cake (58.00% %) and cotton seed cake (55.3%), with an increase of 51.79 %, 49.34 %, 46.82 %, 43.27 % and 40.40 % over control respectively. Though, all these were on par with each other, comparatively cotton seed cake was found least effective with minimum seed germination of 55.33 %.

3.3 Effect of Pre and Post-Emergence Mortalities

Results (Table 1) revealed that all the test amendments significantly influenced both pre-emergence seed rot (PREM) and post-emergence seedling mortality (POSM), caused by *Fusarium oxysporum* f.sp. *melongenae* in eggplant cv. Arka Shirish.

The pre-emergence seed rot recorded with all the *Trichoderma* fortified test amendments ranged from 7.66 to 44.66 %, as against 67.33 % in untreated control. However, significantly least pre-emergence seed rot was recorded with neem seed cake (7.66 %), while, vermicompost, goat manure and poultry manure recorded 15.66, 24.00 and 27.66 % which were substantially lower pre-emergence seed rot respectively. These were followed by the amendments *viz*., mustard cake (32.00), safflower cake (35.00 %) groundnut cake (38.00 %), soybean seed cake (42.00 %), cotton seed cake (44.66 %).These were on par with each other.

Similar trend with post-emergence seedling mortality was also observed and ranged from 15.33 to 48.67 %, against in untreated control. However, significantly least post-emergence seedling mortality was recorded with neem seed cake (15.33 %), vermicompost (21.33 %), goat manure (23.66 %), and poultry manure (28.66%). These were followed by mustard cake (32.00), safflower cake (33.23 %), groundnut cake (38.33 %), soybean seed cake (45.33 %), cotton seed cake (48.67 %) and these were also on par with each other.

The mean mortality recorded with all the test amendments ranged from 11.50 to 46.67 %, where as in untreated control it was 72.00 %. However, least mean mortality was recorded with neem seed cake (11.50 %) followed by vermicompost (18.50 %), goat manure (23.83 %), poultry manure (28.17 %) which were recorded substantially low mortality. The remaining treatments were also shown significant level of effect on disease incidence with mean of 32.00 (mustard cake), 34.12 (safflower cake), 38.33 (ground nut cake), 43.67 (soya cake) and 46.67 % (cotton seed cake) respectively (Table 1).

3.4 Reduction in Mortality

All the test amendments reduced both pre-emergence seed rot and post-emergence seedling mortality, over untreated control (Table 1). The reductions in both PREM and POSM ranged from 33.66 to 88.61 % and 36.52 to 80.00 %, respectively. However, highest reductions in PREM and POSM were recorded with the neem seed cake 88.61 and 80.00 % respectively with a mean of 84.03 % followed by vermicompost (76.73% and 72.17%), goat manure (64.36 % and 69.13%), poultry manure (58.91 and 62.61 %) with a mean reduction of 74.31 %, 66.90 % and 60.88 % respectively, which were recorded substantially low mortality. These were followed by mustard cake (52.48% and 58.26%), safflower cake (48.02% and 56.65%), ground nut cake (43.56 % and 49.57%), soya cake (37.62% and 40.87%) cotton seed cake (33.66% and 36.52%) with a mean reduction of 55.56, 52.62, 46.76, 39.35 and 35.19 %, respectively.

3.5 Field Evaluation of *Trichoderma* Fortified Organic Amendments on *Fusarium* wilt of Eggplant under Natural Conditions

After ascertaining greenhouse studies on *Trichoderma* fortified organic amendments to inhibit *Fusarium oxysporm* f.sp.*melongenae*, a field experiment conducted on *Fusarium* wilt of eggplant during autumn 2018-19 and autumn 2019-20, to find out its effect.

Table 1. Efficacy of *Trichoderma harzianum* fortified organic amendments on *Fusarium* wilt of eggplant (Pot culture)

Trichoderma harzianum fortified organic amendments (X106 CFU /g) + 0.06									
Tr. No.	**Treatments**	**Germination (%)**	**increase over control (%)**	**% incidence**			**Reduction over control**		
				PREM	**POEM**	**Mean**	**PREM**	**POEM**	**Mean**
T_1	Neem Cake + *T.harzianum*	92.33 (74.04)*	64.57	7.66 (15.92)	15.33 (22.99)	11.50	88.61	80.00	84.03
T_2	Mustard Cake + *T.harzianum*	68.00 (55.54)	51.79	32.00 (34.42)	32.00 (34.42)	32.00	52.48	58.26	55.56
T_3	Safflower Cake + *T.harzianum*	65.00 (53.84)	49.34	35.00 (40.36)	33.23 (34.41)	34.12	48.02	56.65	52.62
T_4	Ground Nut Cake + *T.harzianum*	62.00 (52.00)	46.82	38.00 (37.93)	38.33 (42.30)	38.33	43.56	49.57	46.76
T_5	Soya Cake + *T.harzianum*	58.00 (49.59)	43.27	42.00 (36.11)	45.33 (42.21)	43.67	37.62	40.87	39.35
T_6	Cotton Cake + *T.harzianum*	55.33 (48.08)	40.40	44.66 (41.88)	48.67 (44.92)	46.67	33.66	36.52	35.19
T_7	Vermicompost + *T.harzianum*	84.33 (66.76)	61.16	15.66 (23.19)	21.33 (27.43)	18.50	76.73	72.17	74.31
T_8	Goat Manure + *T.harzianum*	76.00 (60.68)	57.01	24.00 (29.27)	23.66 (29.01)	23.83	64.36	69.13	66.90
T_9	Poultry Manure + *T.harzianum*	72.33 (58.26)	54.80	27.66 (31.70)	28.66 (32.33)	28.17	58.91	62.61	60.88
T_{10}	Control	32.66 (34.83)	0.00	67.33 (55.13)	76.66 (65.31)	72.00	0.00	0.00	0.00
	SE(m)±	**2.15**		**2.15**	**1.88**				
	CD(P=0.01)	**6.41**		**6.41**	**5.59**				

**Figures in the parenthesis are angular transformed values*
PREM: Pre emergence mortality; POEM: Post emergence mortality

3.6 Field Evaluation of *Trichoderma* Fortified Organic Amendments on *Fusarium* willlt of Eggplant (Autumn 2018-19)

3.6.1 Effect on wilt incidence

All the treatments were highly significant in reducing the disease incidence of *Fusarium* wilt of eggplant during autumn2018-19 and the results are presented in Table 2. Soil incorporation of neem cake + *T. harzianum* recorded the significant lowest % disease incidence (17.47%) followed by 23.55 % by Mustard cake + *T. harzianum* at 120 days after transplantation and shown highest disease reduction of 59.88 and 45.91 %, respectively. However, the next best performance were recorded with treatments T7 (Vermicompost+ *T. harzianum*), T8 (Goat manure + *T. harzianum*) and T9(Poultry manure + *T. harzianum*) with decreased disease incidence of 25.31, 29.41 and 30.64%, respectively which were considerably better in disease reduction with 41.87, 32.45 and 29.63 % respectively compared with control (43.54%). Similarly, Soil incorporation of Safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6)were on par with each other in reducing the disease incidence (34.24%,36.05%,36.87% and 36.31 %) at 120 DAT with countable disease reduction i.e 21.36,17.20,15.32and 16.61 %, respectively. However, soil incorporation of cotton cake + *T. harzianum* (T6) showed highest disease incidence by 36.31 % compared with all other treatments.

3.6.2 Effect on root length

There was an increased root length in the treated plots with *Trichoderma* fortified organic amendments. Hence, root length (39.30 cm) significantly increased with the treatment neem cake + *T. harzianum* (T1) at4kg/plot (39.30 cm) followed by Vermicompost + *T.harzianum* (T7) (34.03cm) at 120 days after transplantation (DAT) showing highest % increase in root length (121.03% and 91.39%) respectively (Table 2).

However, third and fourth superior treatments T8 (goat manure + *T. harzianum*) and T9 (poultry manure + *T. harzianum*) have shown considerable increase in root length of 31.75 cm and 28.60 cm respectively, which have at par in % increase root length (78.57% and 60.85%) respectively compared with control (17.78 cm), while, soil incorporation by Mustard cake + *T. harzianum* (T2),safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in improving the root length (27.75,23.49, 24.31,22.11 and 25.53cm) at 120 DAT with countable % increase of root length (56.07,32.11,36.73,24.35 and 43.59 %) respectively. However, soil incorporation by soya cake + *T. harzianum* (T5) recorded least root length at 22.11 cm translating to 19.58 % compared with all other treatments.

3.6.3 Effect on leaf area

Perusals of the data (Table 2) indicated that the leaf area of eggplant increased significantly in all the imposed treatments compared to control. Soil incorporation of neem cake + *T. harzianum* (T1) recorded maximum leaf area (59.41 cm^2) followed on 54.32cm^2 by Vermicompost + *T. harzianum* (T7) at 120 days after transplantation and both treatments showed highest % increased leaf area 74.58 and 59.62 % respectively.

However, third and fourth significant treatments were T8 (goat manure + *T. harzianum*) and T9 (poultry manure + *T. harzianum*) with substantial increase in leaf area 50.38 cm^2 and 46.99 cm^2 respectively, where both were at par in % increased leaf area (48.05 and 38.08 %), compared with control. Minimum leaf area observed with treatment of mustard cake + *T. harzianum* (T2),safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in improving the leaf area (45.48,42.19,40.38,39.56 and 41.55cm^2) at 120 DAT with countable % increased leaf area (33.65,23.98,18.66,16.25 and 22.10%) respectively. However, soil incorporation of cotton cake + *T. harzianum* (T6) recorded least leaf area 41.55 cm2 by 22.10 % compared with all other treatments.

3.6.4 Effect on plant height

The deep examination of the data in Table 2 expressed that the Plant height of eggplant increased significantly in all the imposed treatments compared with control. Soil amendment of neem cake + *T. harzianum* (T1) recorded maximum plant height (132.08 cm) followed by 127.28cm by vermicompost + *T. harzianum* (T7) at 120 days after transplantation

(DAT) which were shown highest % increase of plant height 52.70 and 47.14 %, respectively (Table 2).

However, third and fourth superior treatments were T8 (Goat manure + *T. harzianum*) and T9 (poultry manure + *T. harzianum*) with substantial increase in Plant height 118.21 and 115.00 cm respectively ,but at par in % increased plant height 36.66 and 32.95 %, respectively, compared with control, while, sizable plant height was observed with Soil amendment of Mustard cake + *T. harzianum* (T2),safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in enhancing the plant height 111.96, 105.83, 110.80, 104.46 and 96.83cm respectively at 120 DAT with considerable % increase of plant height (29.43,22.35,28.09,20.76 and 11.94 %) respectively. However, soil incorporation of cotton cake + *T. harzianum* (T6) recorded least plant height 96.83cm by 11.94 % compared with all other treatments.

3.6.5 Effect on yield

The analyzed data in Table 2 revealed that the yield of eggplant increased in all the imposed treatments compared with control. Soil incorporation of neem cake + *T. harzianum* (T1) produced maximum yield (181.20 q/ha) followed by 168.30 q/ha by vermicompost + *T. harzianum* (T7) at 120 days after transplantation and both were shown highest % increase of yield (124.26 and 108.29 %) respectively.

However, third and fourth exceptional yield was recorded in treatments goat manure + *T. harzianum* and poultry manure + *T. harzianum* with substantial increase in yield 166.10 q/ha and 166.00 q/ha respectively ,but at par in % increase of yield (105.57 and 105.45%) respectively compared with control, while, relatively admirable increased yield was observed with soil incorporation of mustard cake + *T. harzianum*, safflower cake + *T. harzianum*, groundnut cake + *T. harzianum*, soya cake + *T. harzianum* and cotton cake + *T. harzianum* were on par with each other in enhancing the yield (156.30,134.10 ,125.50 ,120.50 and 117.40 q/ha) up to 120 DAT with considerable% increase of yield (93.44, 65.97, 55.32, 49.13 and 45.30%) respectively. However, soil incorporation of cotton cake + *T. harzianum* recorded least yield 117.40q/ha by 45.30% compared with all other treatments.

3.7 Field Evaluation of *Trichoderma* Fortified Organic Amendments on *Fusarium* Wilt of Eggplant During Autumn 2019-20

3.7.1 Effect on wilt incidence

All the treatments were highly significant and effective in reducing the disease incidence of *Fusarium* wilt of eggplant during *autumn*2019-20 and the results are presented (Table 3). Soil incorporation of neem cake + *T. harzianum* recorded the significant lowest % disease incidence (18.60%) followed by mustard cake + *T. harzianum* (23.05%) at 120 days after transplantation and they were shown highest disease reduction (54.11 and 43.13%).

However, the next best performance was recorded with treatments vermicompost+ *T. harzianum,* Goat manure + *T.harzianum* and Poultry manure + *T. harzianum* with considerable decrease in disease incidence 25.43 , 26.28 and 27.77 % respectively which were considerably better in disease reduction i.e. 37.26,35.16 and 31.48 %, respectively compared with control (40.53%).Similarly, soil incorporation of safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in reducing the disease incidence (28.89%, 28.01%, 29.81% and 31.37%) at 120 DAT with countable disease reduction (28.72, 30.89, 26.45 and 22.60%) respectively. However, soil incorporation of cotton cake + *T. harzianum* (T6) showed highest disease incidence by 31.37 % compared with all other treatments.

3.7.2 Effect on root length

There was an appreciable increase in root length when applied with *Trichoderma* fortified organic soil amendments. However, root length was significantly increased in treatments with neem cake + *T. harzianum* (39.59 cm) followed by vermicompost + *T. harzianum* (36.36cm) at 120 days after transplantation and both were shown highest % increase of root length(103.65 and 87.04%) respectively (Table 3).

Table 2. Field evaluation of *Trichoderma* fortified organic amendments on *Fusarium* wilt of eggplant during autumn 2018-19

Trichoderma harzianum fortified organic amendments at 10^6 CFU /g ± 0.06										
Tr. No.	**Wilt incidence (%)**	**reduction over control (%)**	**Root length (cm)**	**increase over control (%)**	**Leaf area (cm^2)**	**increase over control (%)**	**Plant height (cm)**	**increase over control (%)**	**Yield (q/ha)**	**increase over control (%)**
T_1	17.47 (24.69)	59.88	39.3	121.03	59.41	74.58	132.08	52.70	181.20	124.26
T_2	23.55 (29.01)	45.91	27.75	56.07	45.48	33.65	111.96	29.43	156.30	93.44
T_3	34.24 (35.79)	21.36	23.49	32.11	42.19	23.98	105.83	22.35	134.10	65.97
T_4	36.05 (36.88)	17.20	24.31	36.73	40.38	18.66	110.8	28.09	125.50	55.32
T_5	36.87 (37.34)	15.32	22.11	24.35	39.56	16.25	104.46	20.76	120.50	49.13
T_6	36.31 (37.04)	16.61	25.53	43.59	41.55	22.10	96.83	11.94	117.40	45.30
T_7	25.31 (30.18)	41.87	34.03	91.39	54.32	59.62	127.28	47.14	168.30	108.29
T_8	29.41 (32.82)	32.45	31.75	78.57	50.38	48.05	118.21	36.66	166.10	105.57
T_9	30.64 (33.59)	29.63	28.6	60.85	46.99	38.08	115	32.95	166.00	105.45
T_{10}	43.54 (41.26)	0.00	17.78	0.00	34.03	0.00	86.5	0.00	80.80	0.00
SE(m)±	0.53		1.96		2.92		3.46		0.62	
CD (P=0.05)	1.61		5.88		8.75		10.36		1.85	

Table 3. Effect of *Trichoderma* fortified organic amendments on *Fusarium* wilt of eggplant during autumn 2019-20.

Trichoderma harzianum fortified organic amendments at 10^6 CFU /g ± 0.06										
Tr. No.	**Wilt incidence (%)**	**reduction over control (%)**	**Root length (cm)**	**increase over control (%)**	**Leaf area (cm^2)**	**increase over control (%)**	**Plant height (cm)**	**increase over control (%)**	**Yield (q/ha)**	**increase over control (%)**
T_1	18.60 (25.53)	54.11	39.59	103.65	60.33	81.50	133.89	76.17	185.00	118.42
T_2	23.05 (28.68)	43.13	29.08	49.59	47.53	42.99	113.95	49.93	164.70	94.45
T_3	28.89 (32.48)	28.72	25.53	31.33	43.08	29.60	112.67	48.25	148.10	74.85
T_4	28.01 (31.92)	30.89	25.49	31.12	41.47	24.76	107.33	41.22	133.60	57.73
T_5	29.81 (33.07)	26.45	24.31	25.05	41.55	25.00	102.33	34.64	126.60	49.47
T_6	31.37 (34.04)	22.60	22.11	13.73	39.64	19.25	91.22	20.03	111.00	31.05
T_7	25.43 (30.27)	37.26	36.36	87.04	54.32	63.42	127.29	67.49	177.40	109.45
T_8	26.28 (30.82)	35.16	35.94	84.88	50.38	51.56	119.00	56.58	168.80	99.29
T_9	27.77 (31.78)	31.48	33.08	70.16	47.84	43.92	117.00	53.95	164.00	93.62
T_{10}	40.53 (39.52)	0.00	19.44	0.00	33.24	0.00	76.00	0.00	84.70	0.00
SE(m)±	**0.62**		**2.03**		**2.80**		**2.82**		**0.79**	
CD(P=0.05)	**1.87**		**6.07**		**8.38**		**8.44**		**2.36**	

However, third and fourth significantly superior treatments were goat manure + *T. harzianum* and poultry manure + *T. harzianum* with considerable increase in root length 35.94cm and 33.08 cm respectively which were at par in % increase of root length (87.04 and 70.16%) respectively as compared with control (19.44 cm). But, comparatively low increaed root length was observed with Soil incorporation of mustard cake + *T. harzianum*, safflower cake + *T. harzianum* , groundnut cake + *T. harzianum*, soya cake + *T. harzianum* and cotton cake + *T. harzianum* were on par with each other in improving the root length (29.08, 25.53, 25.49, 24.31, 22.11 cm) at 120 DAT with countable % increase of root length (49.59, 31.33, 31.12, 25.05 and 13.73%) respectively. However, soil incorporation of cotton cake + *T. harzianum* (T5) recorded least root length 22.11 cm by 13.73% increase over control compared with all other treatments.

3.7.3 Effect on leaf area

Keen study of the data (Table 3) indicated that the leaf area of eggplant increased significantly in all the imposed treatments as compared to control. Soil incorporation of neem cake + *T.harzianum* recorded maximum leaf area (60.33 cm^2) followed by vermicompost + *T.harzianum* (54.32cm^2) at 120 days after transplantation and showed highest % increase of leaf area (81.50 and 65.42%) respectively (Table 3).

However, third and fourth significantly higher leaf area was noted in Goat manure + *T. harzianum*) and Poultry manure + *T. harzianum* with substantial increase in leaf area 50.38 and 47.84 cm^2 respectively, which were at par in % increase of leaf area (51.56 and 43.92%) respectively, as compared with control. But, comparatively less increment in leaf area was observed with soil incorporation of mustard cake + *T. harzianum*, safflower cake + *T. harzianum*, groundnut cake + *T. harzianum*, soya cake + *T. harzianum* and cotton cake + *T. harzianum* were on par with each other in improving the leaf area (47.53,43.08,41.47,41.55 and 39.64cm^2) at 120 DAT with countable % increase of leaf area (42.99,29.60,24.96,25.00 and 19.25 %) respectively. However, soil incorporation of cotton cake + *T. harzianum* recorded least leaf area of 39.64 cm^2 accounting for 19.25 % increase over control, compared with all other treatments.

3.7.4 Effect on plant height

On deep examination of the data (Table 3), it expressed that the plant height of eggplant increased significantly in all the imposed treatments compared to control. Soil incorporation of neem cake + *T.harzianum* recorded maximum Plant height 133.89 cm followed by 127.29 cm by vermicompost + *T.harzianum* at 120 days after transplantation and both were shown highest % increase of plant height (76.17 and 67.49%) respectively.

However, third and fourth next superior treatments were goat manure + *T.harzianum* and Poultry manure + *T.harzianum* with substantial increase in plant height 119.00 and 117.00 cm respectively, but at par in % increase of plant height (56.56% and 53.95%) respectively as compared with control,while, visible encouragement of plant height was observed with Soil incorporation of mustard cake + *T.harzianum* ,safflower cake + *T.harzianum* , groundnut cake + *T.harzianum* , soya cake + *T.harzianum* and cotton cake + *T.harzianum* were on par with each other in enhancing the Plant height (113.95,112.67,107.33,102.33 and 91.22) at 120 DAT with worthful % increase of plant height (49.93,48.25,41.23,34.64 and 20.03 %) respectively. However, soil incorporation of cotton cake + *T.harzianum* recorded least plant height 91.22cm b with 20.03 % increase over control, compared with all other treatments.

3.7.5 Effect on yield

The investigation of the trait,the data in Table 3 revealed that the yield of eggplant increased appreciatably in all the imposed treatments compared with control. Soil incorporation of neem cake + *T.harzianum* produced maximum yield 185.00 q/ha followed by vermicompost + *T.harzianum* (177.40 q/ha) up to 120 days after transplantation and both were shown highest % increase of yield (118.42% and 109.45%) respectively.

However, third and fourth exceptional yield increment was recorded in Goat manure + *T. harzianum* and Poultry manure + *T. harzianum* with substantial increase in yield 168.80 and 164.00 q/ha respectively, but at par in % increase of Yield (99.29 and 93.62 %) respectively as compared with control, while, succeeding yield increment recorded with Soil incorporation of mustard cake + *T. harzianum*, safflower cake + *T. harzianum*, groundnut cake + *T. harzianum*, soya cake + *T. harzianum* and

cotton cake + *T.harzianum* were on par with each other in enhancing the yield (164.70,148.10,133.60 ,126.60 and 111.10 q/ha) up to 120 DAT with considerable % increase in Yield (94.45,74.85,57.73,49.47 and 31.05%) respectively. However, soil incorporation of cotton cake + *T.harzianum* recorded least yield 111.00q/ha with 31.05 % increase over control compared with all other treatments.

3.8 Field Evaluation of *Trichoderma* Fortified Organic Amendments on *Fusarium* Wilt of Eggplant (Pooled)

3.8.1 Effect on wilt incidence

The pooled results presented (Table 4) showed that the treatments were highly effective in reducing the disease incidence of *Fusarium* wilt of eggplant. Soil incorporation of neem cake + *T.harzianum* recorded the significant lowest % disease incidence (17.47%) followed by (23.30% of mustard cake + *T. harzianum* at 120 days after transplantation showing disease reduction (58.43 and 44.57%) respectively. The next best treatments were vermicompost+ *T. harzianum,* goat manure + *T. harzianum* and poultry manure + *T. harzianum* with considerable decrease in disease incidence as 25.37 , 27.85 and 29.21 % respectively which were considerably better in disease reduction (39.64, 33.75 and 30.52%) respectively as compared with control (42.04%). Moreover, Soil incorporation of safflower cake + *T. harzianum* ,groundnut cake + *T. harzianum*, soya cake + *T. harzianum* and cotton cake + *T. harzianum* were on par with each other in reducing the disease incidence (31.57,32.03,33.34 and 33.84 %) at 120 DAT with considerable disease reduction (24.90%, 23.80%, 20.68% and 19.49%) respectively. However, soil incorporation of cotton cake + *T. harzianum* showed highest disease incidence at 33.84 % compared with all other treatments.

3.8.2 Effect on root length

The pooled data on root length (Table 4) revealed an appreciable increase in root length in all the treatments of *Trichoderma* fortified organic amendments as soil incorporation. However, root length was significantly increased in treatments in neem cake + *T. harzianum* (39.44 cm) followed by vermicompost + *T. harzianum* (35.19 cm) at 120 days after transplantation depicting highest % increase of root length 511.93 and 89.09%) respectively.

However, the third and fourth significantly succeeding root length recorded in T8 (Goat manure + *T. harzianum*) and T9 (poultry manure + *T. harzianum*) with considerable increase in root length 33.84cm and 30.84 cm respectively which were at par in % increase of root length (81.84% and 65.72 %) respectively compared with control (18.61 cm), There was relatively low root length was observed with soil incorporation of mustard cake + *T. harzianum* (T2),safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in improving the root length (28.41 cm, 24.51cm, 24.90cm, 23.21cm, 23.82cm) at 120 DAT with considerable % increase in root length 52.66,31.70,33.80,24.72 and 28.08 % respectively. However, soil incorporation of cotton cake + *T. harzianum* (T5) recorded least root length 23.82 cm by 28.08% increase over control compared with all other treatments.

3.8.3 Effect on leaf area

The pooled mean data (Table 4) indicated that the leaf area of eggplant increased significantly in all the imposed treatments compared with control. Soil incorporation with neem Cake + *T. harzianum* (T1) at 4 kg/plot (T1) recorded maximum leaf area (59.87 cm^2) followed by soil incorporation of vermicompost + *T. harzianum* (T7) (54.32 cm^2) at 120 (DAT) and highest % increase in leaf area (77.97 and 61.47%) respectively.

However, third and fourth treatments showed significantly higher leaf area recorded T8 and T9 with substantial increase in leaf area 50.38 and 47.42 cm2 respectively which were at par in % increase of leaf area 49.76 and 40.46 % respectively compared with control. But, there were comparatively inferior increment in leaf area observed with Soil incorporation of mustard cake + *T. harzianum* (T2), safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4),soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in improving the leaf area (46.51 , 42.64 , 40.93, 40.56 and 40.60 cm^2) at 120 DAT with considerable % increase in leaf area (38.26,26.75,21.67,20.57 and 20.69%) respectively, which were at par with each other. However, soil incorporation of cotton cake + *T. harzianum* (T6) recorded least leaf area 40.60 cm^2 at 20.69% compared with all other treatments.

Table 4. Effect of *Trichoderma* fortified organic amendments on *Fusarium* wilt of eggplant during autumn 2018-19 and 2019-20(Pooled means)

Tr. No.	Wilt incidence (%)			reduction over control (%)	Yield (q/ha)			increase over control (%)	Leaf area (cm)	increase over control (%)	Plant height (cm)	increase over control (%)	root length (cm)	increase over control (%)
	2018-19	2019-20	Mean		2018-19	2019-20	Mean		Pooled Mean		Pooled Mean		Pooled Mean	
T_1	17.47 (24.69)	18.6 (25.53)	17.47	58.43	181.20	183.60	182.40	120.29	59.87	77.97	132.99	63.68	39.44	111.93
T_2	23.55 (29.01)	23.05 (28.68)	23.30	44.57	156.30	164.70	160.50	93.84	46.51	38.26	112.96	39.03	28.41	52.66
T_3	34.24 (35.79)	28.89 (32.48)	31.57	24.90	134.10	148.10	141.10	70.41	42.64	26.75	109.25	34.46	24.51	31.70
T_4	36.05 (36.88)	28.01 (31.92)	32.03	23.80	125.50	133.60	129.50	56.40	40.93	21.67	109.07	34.24	24.9	33.80
T_5	36.87 (37.34)	29.81 (33.07)	33.34	20.68	120.50	126.60	123.60	49.28	40.56	20.57	103.40	27.26	23.21	24.72
T_6	36.31 (37.04)	31.37 (34.04)	33.84	19.49	117.40	111.00	114.20	37.92	40.60	20.69	94.03	15.73	23.82	28.00
T7	25.31 (30.18)	25.43 (30.27)	25.37	39.64	168.30	177.40	172.90	108.82	54.32	61.47	127.28	56.65	35.19	89.09
T8	29.41 (32.82)	26.28 (30.82)	27.85	33.75	166.10	168.80	167.50	102.29	50.38	49.76	118.61	45.98	33.84	81.84
T9	30.64 (33.59)	27.77 (31.78)	29.21	30.52	166.00	164.00	165.00	99.28	47.42	40.96	116.00	42.77	30.84	65.72
T10	43.54 (41.26)	40.53 (39.52)	42.04	0.00	80.80	84.70	82.80	0.00	33.64	0.00	81.25	0.00	18.61	0.00
SE(m)±	**0.53**	**0.62**			**6.19**	**7.90**			**2.83**		**2.54**		**1.87**	
CD (P= 0.05)	**1.61**	**1.87**			**18.55**	**23.67**			**8.48**		**7.61**		**5.61**	

3.8.4 Effect on plant height

The attention on pooled mean data (Table 4) implored that the Plant height of eggplant increased significantly in all the imposed treatments compared with control. Soil incorporation of neem cake + *T. harzianum* (T1) at 4kg/plot recorded maximum Plant height(132.99 cm) followed by vermicompost + *T.harzianum* (T7) (127.28cm) at 120 days after transplanting and showed highest % increase of plant height 63.68 and 56.65 % respectively.

However, third and fourth superior treatments wereGoat manure + *T. harzianum* (T8) and poultry manure + *T. harzianum* (T9) with substantial increase in plant height at 118.61 cm and 116.00 cm respectively ,but at par in % increase of plant height (45.98 and 42.77%) respectively compared with control, while, visible encouragement of Plant height was observed with Soil incorporation of mustard cake + *T. harzianum* (T2), safflower cake + *T. harzianum* (T3),groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in enhancing the Plant height (112.96 cm, 109.25 cm, 109.07 cm, 103.40 cm and 94.03 cm) at 120 DAT with considerable % increase of Plant height (39.03,34.46, 34.24,27.26 and 15.73%) respectively. However, soil incorporation of cotton cake + *T. harzianum* (T6) recorded least Plant height 94.03cm by 15.73 % compared with all other treatments.

3.8.5 Effect on yield

The pooled mean data (Table 4) revealed that yield of eggplant increased in all the imposed treatments compared with control. Soil incorporation of neem cake + *T. harzianum* (T1) at 4 kg/plot produced maximum yield (182.40 q/ha) followed by vermicompost + *T. harzianum* (T7) (172.90q/ha) 120 days after transplanting showed highest % increase in yield (120.29% and 108.82%) respectively.

However, third and fourth treatments showed exceptional yield increment recorded in Goat manure + *T. harzianum* (T8) and Poultry manure + *T. harzianum* (T9) with substantial increase in yield 167.50 and 165.00 q/ha respectively ,but at par in % increase of yield (10.29 and 99.28%) respectively compared with control. Relatively less incremental yield was observed in soil incorporation of mustard cake + *T. harzianum* (T2),safflower cake + *T. harzianum* (T3), groundnut cake + *T. harzianum* (T4), soya cake + *T. harzianum* (T5) and cotton cake + *T. harzianum* (T6) were on par with each other in enhancing the Yield (160.50,141.10 ,129.55,123.55 and 114.20 q/ha) up to 120 DAT with significant % increase in yield (93.84,70.41,56.40,49.28 and 37.92%) respectively. However, soil incorporation with cotton cake + *T. harzianum* (T6) recorded least yield 114.20q/ha translating to 37.92% increase over control compared with all other treatments.

The present results were in agreement with the several authors who studied on the management of soil borne fungal disease in combination with compost manure and antagonistic microbial strains resulting in greater efficiency in disease inhibition than using either of them. These combinations were more familiar as bio compost or fortified compost [9,8,10,11].

The fortified treatments neem cake+ *T. harziamum* (T1) to cotton cake + *T.harzianum* (T6)with organic amendments of de-oiled cakes recorded significant efficacy over pathogen as soil drenching application. Probably, as reported by El-Mohamedy et al. [12] as these treatments decreased *Fusarium* population density and increased in rhizosphere *Trichoderma* population achiving control of the pathogen through competition or specific inhibition by releasing degradation compounds such as carbon dioxides, ammonia, nitrites, saponine or enzymes that are generally toxic to the pathogens. Biodegradation of organic amendments by cellulase and glucanase enzymes would greatly enhance availability of cellulose and lignin in soil in high concentration inducing plant defense mechanisms.

Similar observations were obtained by Schneider and Ultrich, [13] who reported that the neem cake attained superior results might be due to induce host plants defense response resulting in a reduction in *Fusarium* wilt development. Growth promoters effect of neem aqueous extract on tomato seedlings could be due to triterpene (azadirachtin) which acts by delaying the transformation of ammonium nitrogen into nitrate as brought about by slow nitrogen conversion leading to continuous availability of nitrogen during plant growth and growth promotion [14]. The high shoot and root lengths in organic amendments treated plants could be explained by the presence of salicylic acid related compounds or plant growth promoter such as IAA and cytokinine [15].

Barakat and Al-Masri [16] reported that manures enriched with *Trichoderma harzianum* significantly reduces *Fusarium* pathogen population by its suppressive activity. Moreover, organic amendment at higher concentrations further increase the microbial populations and stimulate the microbial activity in soil against *Fusarium oxysporum* resulted to decrease the pathogen populations. Successful root and rhizosphere colonization of bioagents through the application of fortified organic amendments could offer the effective protection of the roots against *Fusarium* pathogens [17]. The presence of beneficial microbial species in the rhizospheric soils and their interactions with plant roots makes the plant immune to diseases and even tolerant to abiotic stress [18].

Yield and yield related attributes increased remarkably due to fortified amendments providing adequate nutrient reservoir to the bioagents thereby enhancing its survival in a hostile environment. For instance, it was well known that the widely used *Trichoderma* species as bioagents must not be applied at sporulation phase of conidiospres if not supported by a suitable carrier. This is due to the high sensitivity to soil fungistasis displayed by these asexual reproductive structures. Hence, application of *Trichoderma* based formulations could fail if spores (even at the stage of early germination) were to be applied to the soil without an adequate nutrients supply [19].

Zhao et al. [20] opined that when bioagents in combination with organic amendments as a suitable formulation only could effectively controll *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *melonis* in melon. This is a consequence of the fertilizing properties of organic amendments, which leading to chemical substances release. For instance, Bhadauria et al. [21] reported that application of *T. harzianum* plus soil treatment with neem cake was an effective treatment to reduce *Fusarium* wilt incidence (*Fusarium oxysporum* f. sp. *melongenae*) in eggplant. Likewise, addition of *T. harzianum* to compost improved the biocontrol effectiveness and induced changes in the biotic (e.g., changes in bacterial community composition) and abiotic (pH modification) characteristics of this organic amendments [22].

Hoitink and Boehm [23] observed that with *Trichoderma* colonized poultry manure showed better disease suppressive effect and yield due to increased microbial biomass and release of antifungal compounds on ideal food substrate. Christopher et al., (2010) recorded significantly reduced *F. oxysporum* f. sp. *lycopersici* survival in the rhizosphere region of tomato with soil application of *T. harzianum* together in compost. The average fruit yield and rhizosphere survival of *T. harzianum* were also significantly higher than other treatments. Joshi et al., (2014) observed improved seed germination, stem height, number of leaves, leaf area, dry leaf weight, root size, root number, total yield, and number of fruits / plant with vermicompost. Nandini and Sreenivasa, [24] noticed an increased microbial load after their enrichment in vermicompost followed by FYM and spent slurry biogas.

Talukdar et al. [25] reported that poultry compost contains NH_4-N and NO_3-N (nitrate-nitrogen) readily taken by resident soil microorganisms that tend to exploit NH4+ more quickly than plants. Ammonia liberated with application of high nitrogen amendments kills soil-borne pathogens. Additionally, in several reports, Pugliese et al. [26]; Zhao et al. [27] alluded that application of fortified compost with *Trichoderma harzianum* induces resistance and enhances the plant growth [28].

4. CONCLUSION

Among the nine *Trichoderm harzianum* fortified amendments tested, neem seed cake recorded significant and superior effect as pre-sowing soil application against *Fusarium* wilt with respect to seed germination (92.33%), pre-emergence seed rot (7.66%) and post-emergence seedling mortality (15.33%) in pot culture Similar trend was observed in field experiments during *autumn* 2018 (17.47%) and 2019 (18.60%) with *T. harzianum* fortified neem cake soil application against *Fusarium* wilt with mean inhibition of disease incidence (58.43%) and also observed excellent enhancement of mean yield (54.63%).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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