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Ecofriendly Management of Wilt Complex in Black Pepper (*Piper nigrum* L.)

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ABSTRACT: Black pepper (*Piper nigrum* L.) is prone to attack by burrowing nematode, *Radopholus similis* and fungal wilt pathogen, *Phytophthora capsici* causing wilt complex and considerable yield loss. The field experiment was carried out in the farmer's field, with a view to evaluate bioagents (*Trichoderma harzianum*, *Purpureomyces lilacinum*, *Pseudomonas fluorescens* and *Bacillus subtilis*), organic amendment (Neem cake) and chemicals (Carbofuran and Bordeaux mixture) separately and in combination for the management of *R. similis* and *P. capsici.* The final population of *R. similis* in soil was lowest in Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (302.66/ 200 cc soil), followed by Carbofuran 3G (15 g) (335.33 nematodes/200 cc soil), Bordeaux mixture (1%)+ Carbofuran- 3G (15 g) (349.33 nematodes/200 cc soil) and *P. lilacinum* (50 g) (371.33 nematodes/200 cc sol) as compared to untreated control (922.00 nematodes/ 200 cc soil) respectively. The final root population of *R. similis* was minimum in Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (150.66/ 5 g roots) followed by Carbofuran 3G (15 g) (178.00 /5 g roots nematodes) as compared to untreated control (478.00/5 g roots) respectively. The lowest foliar yellowing, defoliation and lesion indices were observed in the treatment Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (1.33, 1.00 and 1.00) followed by Bordeaux mixture (1 %) + *T. harzianum* (50 g) (1.66, 1.33 and 1.00) and these two treatments were at par with each other. Vines treated with Bordeaux mixture (1 %) spray + *T. harzianum* (50 g) recorded maximum dry berry weight of 2.27 g / vine and it was on par with vines treated with Bordeaux mixture (1 %) + *P. lilacinum* (50 g) with 2.05 g/vine. However, untreated control vines recorded lowest dry berry weight (0.63 g) and it was at par with Carbofuran 3G (15 g) (1.04g).

Keywords: Burrowing nematode, *Phytophthora capsici*, wilt complex, black peper

Black pepper (*Piper nigrum* L.), (Family *Piperaceae*) known as the "King of Spices" has remained most precious and valuable spice in the world. It is also called as "Black gold" due its durability and value. It is playing a vital role in International trade. It is said that the European invaded India primarily for this very spice. Black pepper is native to India and is extensively cultivated in tropical regions. Currently, Vietnam is the world's largest producer and exporter of black pepper, producing 34 per cent of the world's demand (Anon., 2005).

The cultivation of black pepper is mainly confined to India, Brazil, Indonesia, Malaysia, Thailand, Sri Lanka and Vietnam. During 2013-14, 21,250 tonnes of black pepper worth Rs. 94,002 lakhs were exported to various countries (Devasahayam *et al*., 2015). Black pepper is cultivated to a large extent in Kerala, Karnataka and Tamilnadu and to a limited extent in Maharashtra, north eastern states and Andaman & Nicobar Islands and Pondicherry. Kerala and Karnataka account for a major portion of production of black pepper in the country and to a lesser extent, in Maharashtra, Andhra Pradesh, Tamil Nadu and north eastern regions (Anon., 2005).

Slow wilt of black pepper is a debilitating disease where the affected plants survive for several years and death of plant occurs gradually over a period of 3-4 years. This disease has been referred to under different names such as slow wilt or slow decline in India, yellow or yellows disease in Indonesia.

The drastic drop in the black pepper production in India has been attributed mainly for pronounced mortality of vines by the dreaded foot rot caused by *Phytophthora capsici* and nematodes, *Meloidogyne incognita* and *Radopholus similis.* The other major constraints for low production of black pepper are old gardens occupied with traditional cultivars having poor genetic potential, non-adoption of improved package of practices and bad management of gardens.

R. similis and *M. incognita* are the primary incitants of slow decline in black pepper, though *P. capsici* can also induces similar symptoms (Ramana *et al.*, 1992). Slow decline causes up to 32 per cent crop loss in Indonesia (Sitepu & Kasim, 1991) and about 30 per cent vines are damaged annually in Guyana by this disease (Biesser, 1969). Unfortunately, in spices still nematicides have been the primary option for growers in managing nematodes. There is an urgent need for the development of a non chemical and eco friendly control options. Such work is necessary to develop eco friendly management practices and minimize chemical use while maintaining high production standards. By keeping these factors the present study was taken to manage effectively by using biocontrol agents.

MATERIAL AND METHODS

The present experiment was conducted in the garden of farmer field. The field was heavily infested with *R. similis* with population density of more than one nematode per g soil i.e., 864 nematodes per 200cc soil. Farm was situated in Agro climatic zone-9 (Hilly region Zone) of Karnataka state at varied elevations (900-950msl) and rainfall (2500 to 3000mm) with 11^0 56' and 15^0 46' N latitude and 74^0 31' and 76^0 46' E longitude. Further the experiment was conducted in the existing 10-12 years of old orchard, which was grown as mixed crop-black pepper (Panniyur-1) along with arecanut and forest plants. Farm Yard Manure @ 10 kg /vine was commonly applied for all the treatments and normal package of practices like irrigation, fertilizer application and weeding was done uniformly to all the plants.

Treatment Details

T_1: Bordeaux mixture spray (1%), T_2: T_1 + *Trichoderma harzianum* (50g), T_3: T_1 + *Pseudomonas fluorescens* (50g), T_4: T_1 + *Purpureomyces lilacinum* (50g), T_5: T_1 + *Bacillus subtilis* (50g), T_6: T_1 + Carbofuran 3G–15gms, T_7: T_1 + Neem cake 2 kgs, T_8: Neem cake 2 kgs, T_9: *Pseudomonas fluorescens* (50g), T_{10}: *Trichoderma harzianum* (50g), T_{11}: *Purpureomyces lilacinum* (50g), T_{12}: *Bacillus subtilis* (50g), T_{13}: Carbofuran 3G–15g, T_{14}: Untreated Control. Each treatment was replicated thrice.

The talc-based formulations of *T. harzianum*, *P. lilacinum P. fluorescens*, and *B. subtilis* were obtained from Indian Institute of Horticultural Research (IIHR), Bangalore.

The experiment was conducted in two seasons' *viz.*, 2014-15 and 2015-16 and biocontrol agents were applied before and after monsoon along with 10 kgs of farm yard manure. Organic amendments and Bordeaux mixture were sprayed before and after monsoon every year.

Observations recorded

1. **On host:** Number of runner shoots, number of spikes, spike length, spike weight, dry weight (per vine)

2. **On nematode:**

I. Initial nematode population before the treatment imposition
II. Nematode population at 60 days intervals
III. Final nematode population
IV. Number of lesions per plant
V. Root lesion index

3. **On wilt complex incidence:**

1. Number of wilted plants
2. Per cent defoliation index (1-4)
3. Per cent leaf yellowing index (1-4)
4. Per cent root necrosis (0-5)
5. Leaf lesion index (0-4)
6. Root lesion index (1-5)

The total number of plants showing foliar yellowing symptoms and defoliation were recorded by using the following scale (Mohandas and Ramana, 1991).

Foliar Yellowing Index (FYI): 1-4 scale

Scale	Descriptions
1	No leaves showing yellowing
2	Up to 20 per cent of leaves showing yellowing
3	20-60 per cent leaves showing yellowing
4	More than 60 per cent leaves showing yellowing

Defoliation Index (DFI): 1-4 scale

Scale	Descriptions
1	Less than 10 per cent defoliation
2	More than 10 per cent upto 30 per cent defoliation
3	More than 30 per cent upto 60 per cent defoliation
4	More than 60 per cent defoliation

The virulence rating of *P. capsici* in green house condition was done at 10 days interval till the termination of the experiment using the following disease rating scale by Turner (1973) based on per cent root necrosis.

Grade	Root necrosis (%)
0	0
1	1-10
2	11-25
3	26-50
4	51-75
5	76-100

Lesion Index: The root lesion index was calculated using the lesion index rating scale (Ramana *et al.*, 1987).

Lesion number and size	Lesion index
No lesions	1
Few up to 1mm diameter (1-20 lesions)	2
Many up to 1mm diameter (21-50 lesions)	3
Many upto 1cm diameter (51-100 lesions)	4
Very severe 1 cm diameter (>100 lesions)	5

While collecting soil and root samples lesion characters were also recorded. The wilt disease incidence in the fields was calculated by using following formula.

$$\text{Disease incidence (\%)} = \frac{\text{Number of plants infected}}{\text{Total Number of plants observed}} \times 100$$

Soil sample of 200 cc was washed thoroughly and processed using combined Cobb Sieving and Baermann's funnel technique (Ayoub, 1977).

RESULTS AND DISCUSSION

The field experiment was carried out in the farmer's field for two years, with a view to evaluate bioagents (*T. harzianum*, *P. lilacinum*, *P. fluorescens* and *B. subtilis*), organic amendment (Neem cake) and chemicals (Carbofuran and Bordeaux mixture) separately and in combination for the management of *R. similis* and *P. capsici*.

Observations on plant growth parameters like Number of runner shoots, Number of spikes, Spike length, Spike weight, and dry weight (per vine) was calculated and presented in the Table 1.

Number of runner shoots: Among combined treatments of bioagents, organic amendments and chemicals, maximum number of runner shoots was observed in plants with Bordeaux mixture (1 %) spray + soil application of *T. harzianum* (50 g) with 27.33 followed by Bordeaux mixture (1 %) + *P. lilacinum* (50 g) recorded 25.00 and it was at par with 24.33 number of runner shoots in Bordeaux mixture (1 %) + *P. fluorescens* (50 g). lowest number of runner shoots was observed in Bordeaux mixture (1 %) + Carbofuran-3G (15 g) treated vines with 19.66 number of runner shoots and it was at par with Bordeaux mixture (1 %) + Neem cake (2 kg) with 20.33 number of runner shoots.

Among the individual treatments, maximum number of runner shoots (16.33) was observed in *T. harzianum* (50 g) and lowest number of runner shoots (7.33) in untreated control.

Table 1: Influence of various treatments on growth and yield parameters of black pepper under field conditions (Season-I)

Treatments	Number of runner shoots	Number of spikes	Spike length (cm)	Spike weight (g)	Dry berry weight/ vine (Kg)	Yield Kg/ha
$T_{1:}$ Bordeaux mixture (1 %) spray	11.66	183.33	10.33	1316.33	1.27	254.66
$T_{2:}$ T_1 + *T. harzianum* (50 g)	27.33	321.33	17.66	2992.00	2.27	453.33
T_3: T_1+ *P. fluorescens* (50 g)	24.33	285.66	16.66	2516.66	1.91	381.33
$T_{4:}$ T_1+ *P. lilacinum* (50 g)	25.00	294.66	17.66	2760.66	2.05	411.33
$T_{5:}$ T_1+ *B. subtilis* (50 g)	22.33	284.66	15.66	2309.33	1.70	340.66
$T_{6:}$ T_1+ Carbofuran-3G (15 g)	19.66	213.33	11.66	2016.00	1.59	317.33
$T_{7:}$ T_1+ Neem cake (2 kg)	20.33	280.00	14.33	2189.33	1.83	366.66
T_8: Neem cake (2 kg)	11.00	179.33	9.33	1316.33	1.36	271.33
T_9: *P. fluorescens* (50 g)	13.33	191.33	9.00	1511.00	1.48	296.66
$T_{10:}$ *T. harzianum* (50 g)	16.33	214.66	12.33	1968.00	1.59	319.33
$T_{11:}$ *P. lilacinum* (50 g)	14.66	203.33	11.33	1778.66	1.41	282.66
$T_{12:}$ *B. subtilis* (50 g)	12.33	163.33	8.66	1164.66	0.82	164.66
$T_{13:}$ Carbofuran 3G (15 g)	10.66	151.33	8.33	1241.66	1.04	208.00
$T_{14:}$ Untreated	7.33	89.33	7.66	1072.66	0.63	127.33
S. Em ±	0.52	24.18	0.92	135.72	0.27	2.93
CD @ 5 %	1.50	70.29	2.67	394.63	0.77	8.54
CV (%)	5.29	19.18	13.06	12.39	29.35	1.69

Number of spikes: Highest number of spikes was produced in the vines treated with Bordeaux mixture (1 %) +*T. harzianum* (50 g) with 321.33 followed by Bordeaux mixture (1 %) + *P. lilacinum* (50 g) which recorded 294.66 number of spikes and lowest number of spikes was produced in untreated control plots (89.33) followed by 151.33 in Carbofuran-3G (15 g).

Spike length (cm): With respect to spike length, all the treatments were at par with each other**.** Vines treated with Bordeaux mixture (1 %) +*T. harzianum* (50 g) and Bordeaux mixture (1 %) + *P. lilacinum* (50 g) recorded maximum spike length of 17.66 cm respectively and it was at par with vines treated with T_3: Bordeaux mixture (1 %) + *P. fluorescens* (50g) (16.66 cm) and Bordeaux mixture (1 %) + *B. subtilis* (50 g) (15.66 cm). Lowest spike length was observed in vines with untreated control (7.66 cm) and it was at par with Carbofuran 3G (15 g) (8.33 cm) and *B. subtilis* (50 g) (8.66 cm).

Spike weight: Highest spike weight was recorded in Bordeaux mixture (1 %) + *T. harzianum* (50 g) with 2992.00 g followed by Bordeaux mixture (1 %) + *P. lilacinum* (50 g) with 2760.66 g and lowest spike weight was recorded in untreated control (1072.66 g) and it was at par with Carbofuran 3G (15 g) (1241.66 g).

Dry berry weight per vine (kg): Vines treated with Bordeaux mixture (1 %) spray + *T. harzianum* (50 g) recorded maximum dry berry weight of 2.27 g / vine and it was at par with vines treated with Bordeaux mixture (1 %) + *P. lilacinum* (50 g) with 2.05 g/vine. However, untreated control vines recorded lowest dry berry weight (0.63 g) and it was at par with Carbofuran 3G (15 g) (1.04 g).

Effect of various treatments on nematode population in soil and roots of black pepper infected by *R. similis* and *P. capsici* at different intervals (Season-I)

Nematode population in soil and roots

The *R. similis* population in soil and roots was recorded at 60 days interval from treatment imposition to harvest. The population of *R. similis* in soil differed significantly among all the treatments compared to control. The data is presented in Table 2.

Among the individual treatments, lowest multiplication of *R. similis* was observed in Carbofuran 3G treatment followed by *P. lilacinum* and *T. harzianum*, the same trend was followed in all the intervals of sampling till the harvest of the crop. Among combined treatments, the T_2: Bordeaux mixture (1 %) + *T. harzianum* (50 g), T_3: Bordeaux mixture (1 %) + *P. fluorescens* (50 g), T_4: Bordeaux mixture (1 %) + *P. lilacinum* (50 g), T_5: Bordeaux mixture (1 %) + *B. subtilis* (50 g), T_6: Bordeaux mixture (1 %) + Carbofuran-3G (15 g) and T_7: Bordeaux mixture (1 %) + Neem cake (2 kg) the soil was maximum in *Bacillus subtilis* treated vines followed by *P. fluorescens* at all the intervals.

The population of *R. similis* in roots was differed significantly among the treatments compared to control. The same trend was observed in root population as that of soil population.

Table 2: Effect of treatments on population of *R. similis* in soil and roots of black pepper at different intervals under field conditions

Treatments	Nematode population (200 cc soil) Days after treatment				Nematode population (5 g roots) Days after treatment			
	60	120	180	240	60	120	180	240
T_1 : Bordeaux mixture (1 %) spray	632.00	618.00	558.66	543.33	303.33	324.00	338.00	290.66
T_2 : T_1 + *T. harzianum* (50 g)	594.00	516.66	482.00	389.33	237.33	276.00	241.33	179.33
T_3: T_1+ *P. fluorescens* (50 g)	610.66	552.66	510.66	451.33	278.00	300.66	281.33	203.33
T_4 : T_1+ *P. lilacinum* (50 g)	555.33	505.33	418.00	302.66	222.66	267.33	249.33	150.66
T_5 : T_1+ *B. subtilis* (50 g)	626.00	596.00	501.33	417.33	280.00	317.33	304.00	230.66
T_6 : T_1+ Carbofuran-3G (15 g)	489.33	432.00	402.66	335.33	179.33	235.00	214.66	184.66
T_7 : T_1+ Neem cake (2 kg)	608.66	530.00	476.00	412.00	256.00	291.33	265.33	191.33
T_8 : Neem cake (2 kg)	618.00	561.33	434.00	430.00	260.00	297.33	273.33	196.00
T_9 : *P. fluorescens* (50 g)	600.00	570.66	503.33	444.66	276.33	308.66	287.33	210.00
T_{10} : *T. harzianum* (50 g)	583.33	531.33	494.66	401.33	252.00	282.00	259.33	190.00
T_{11} : *P. lilacinum* (50 g)	578.66	493.33	464.66	371.33	230.66	251.33	232.66	163.33
T_{12} : *B. subtilis* (50 g)	619.99	583.33	520.00	463.33	264.00	309.33	296.66	219.33
T_{13} : Carbofuran 3G (15 g)	519.33	477.33	384.66	349.33	215.33	244.00	226.66	178.00
T_{14} : Untreated	699.33	814.00	883.33	922.00	338.66	405.33	435.33	478.00
S. Em ±	3.89	31.45	3.92	2.75	17.91	1.80	1.49	2.96
CD @ 5 %	11.33	91.47	11.39	8.01	52.09	5.25	4.34	8.61
CV (%)	1.13	9.77	1.35	1.07	12.08	1.06	0.93	2.34

INP: 864 J_2/200 cc soil

The final population of *R. similis* in soil was lowest in T_4: Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (302.66/200 cc soil), followed by T_6: Carbofuran 3G (15 g) (335.33 nematodes/200 cc soil), T_{13}: Bordeaux mixture (1%)+ Carbofuran- 3G (15 g) (349.33 nematodes/200 cc soil) and T_{11}: *P. lilacinum* (50 g) (371.33 nematodes/200 cc sol) as compared to untreated control (922.00 nematodes/200 cc soil) respectively.

The final root population of *R. similis* was minimum in T_4: Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (150.66/5 g roots) followed by T_{13}: Carbofuran 3G (15 g) (178.00 /5 g roots nematodes) as compared to untreated control (478.00/5 g roots) respectively.

Effect of various treatments on wilt complex incidence in black pepper infected with *R. similis* and *P. capsici*

Influence of bioagents, organic amendments and chemicals on foliar yellowing, defoliation and leaf lesion indices were recorded before harvest and the data is presented in Table 3. The lowest foliar yellowing, defoliation and lesion indices were observed in the treatment T_4: Bordeaux mixture (1 %) + *P. lilacinum* (50 g) (1.33, 1.00 and 1.00) followed by T_2: Bordeaux mixture (1 %) + *T. harzianum* (50 g) (1.66, 1.33 and 1.00) and these two treatments were at par with each other. Highest foliar yellowing, defoliation and lesion indices were observed in untreated control (4.00, 4.00 and 4.00) followed by T_{13}: Carbofuran 3G (15 g) (4.00, 3.66 and 3.66) respectively.

Effect of various treatments on multiplication of nematodes and per cent root necrosis on black pepper infested with *R. similis* and *P. capsici*

Influence of bioagents, organic amendments and chemicals on number of lesions, lesion index and percent root necrosis on black pepper was analyzed before harvest and the data is presented in Table 4.

Table 3: Effect of treatments on foliar yellowing, defoliation and lesion indices on balck pepper under field conditions

Treatments	Foliar yellowing (1-4)	Defoliation index (1-4)	Leaf Lesion index (0 - 4)
$T_{1:}$ Bordeaux mixture (1 %) spray	2.66	2.33	1.33
$T_{2:}$ T_1 + *T. harzianum* (50 g)	1.66	1.33	0.66
T_3: T_1+ *P. fluorescens* (50 g)	3.00	3.00	1.66
$T_{4:}$ T_1+ *P. lilacinum* (50 g)	1.33	1.00	1.00
$T_{5:}$ T_1+ *B. subtilis* (50 g)	4.00	3.33	2.33
$T_{6:}$ T_1+ Carbofuran-3G (15 g)	4.00	3.66	2.33
$T_{7:}$ T_1+ Neem cake (2 kg)	2.66	2.33	2.00
T_8: Neem cake (2 kg)	3.33	2.66	2.33
T_9: *P. fluorescens* (50 g)	3.33	2.66	2.66
$T_{10:}$ *T. harzianum* (50 g)	2.33	1.66	2.66
$T_{11:}$ *P. lilacinum* (50 g)	2.00	1.66	2.00
$T_{12:}$ *B. subtilis* (50 g)	4.00	3.00	3.00
$T_{13:}$ Carbofuran 3G (15 g)	4.00	3.66	3.66
$T_{14:}$ Untreated	4.00	4.00	4.00
S. Em ±	0.23	0.23	0.31
CD @ 5 %	0.69	0.67	0.91
CV (%)	13.60	15.96	24.00

Table 4: Effect of various treatments on *R. similis* and *P. capsici* under field conditions

Treatments	No. of lesions	Lesion index (1- 5)	Root necrosis (%)	Wilt incidence (%)	% decrease over control	Yield/ Vine (Kg)	Per cent increase over control	B: C Ratio
$T_{1:}$ Bordeaux mixture (1 %) spray	116.00	5.00	32.00	28.33	64.28	1.27	101.58	1.19
$T_{2:}$ T_1 + *T. harzianum* (50 g)	60.00	4.00	26.67	13.33	83.19	2.27	260.03	2.92
T_3: T_1+ *P. fluorescens* (50 g)	73.66	4.00	39.33	38.00	52.09	1.91	203.17	1.61
$T_{4:}$ T_1+ *P. lilacinum* (50 g)	51.33	3.66	23.00	13.66	82.78	2.05	225.39	2.48
$T_{5:}$ T_1+ *B. subtilis* (50 g)	97.00	4.00	64.66	48.66	38.66	1.70	169.84	1.33
$T_{6:}$ T_1+ Carbofuran-3G (15 g)	65.00	4.00	35.67	23.00	71.00	1.59	152.38	1.24
$T_{7:}$ T_1+ Neem cake (2 kg)	89.67	4.00	48.66	33.66	57.56	1.83	190.47	1.60
T_8: Neem cake (2 kg)	106.00	5.00	74.00	55.66	29.83	1.36	115.87	1.46
T_9: *P. fluorescens* (50 g)	106.66	5.00	69.33	61.33	22.69	1.48	134.92	1.30
$T_{10:}$ *T. harzianum* (50 g)	96.66	4.00	53.00	42.00	47.06	1.59	152.38	1.38
$T_{11:}$ *P. lilacinum* (50 g)	80.67	4.00	44.66	42.33	46.66	1.41	123.80	1.24
$T_{12:}$ *B. subtilis* (50 g)	110.33	5.00	75.33	69.33	12.60	0.82	30.15	0.73
$T_{13:}$ Carbofuran 3G (15 g)	82.66	4.00	59.00	74.66	5.89	1.04	65.07	0.91
$T_{14:}$ Untreated	146.67	5.00	83.66	79.33	0.00	0.63	0.00	0.71
S. Em ±	1.16	0.09	0.68	0.82	-	0.27	-	0.02
CD @ 5 %	3.37	0.26	1.98	2.38	-	0.77	-	0.05
CV (%)	2.19	3.50	2.26	3.18	-	29.35	-	2.12

Number of lesions and lesion index

There were significant differences observed between the treatments in number of lesions on roots and the lowest number of lesions and lesion index was observed in the T_4: Bordeaux mixture (1 %) + *P. lilacinum* (51.33 and 3.66), T_2: Bordeaux mixture (1 %) +*T. harzianum* (60.00 and 4.00) and T_6: Bordeaux mixture (1 %) + Carbofuran (65.00 and 4.00) respectively. Highest number of lesions and lesion index were observed in untreated control (146.00 and 5.00) followed by Bordeaux mixture (1 %) (116.00 & 5.00).

Per cent root necrosis

Similar trend was also followed in per cent root necrosis and lowest root necrosis was recorded in T_4: Bordeaux mixture (1%) + *P. lilacinum* (23.00 %), followed by T_2: Bordeaux mixture (1 %) +*T. harzianum* (26.67 %) and these two treatments were at par with each other. Highest per cent root necrosis was observed in untreated control (83.66 %) followed by T_{12}: *B. subtilis* (75.33 %).

Per cent wilt incidence

The results indicated that plants treated with $T_{2:}$ (Bordeaux mixture (1 %) + *T. harzianum* (50 g) recorded very less wilt incidence of 13.33 % compared to the maximum wilt incidence (79.33 %) in untreated control. The next best treatment was plant inoculated with T_4: (Bordeaux mixture (1 %) + *P. lilacinum* (50 g), which recorded the wilt incidence (13.66 %) which was at par with T_2: Bordeaux mixture (1 %) +*T. harzianum* reduced the wilt incidence compared to individual application of bioagents (Table 4).

Influence of various treatments on yield and economic benefit of disease management in black pepper infested with *R. similis* and *P. capsici*

All the treatments recorded increased yield and B: C ratio with decreased wilt incidence and the data is presented in Table 4.

Individual application of *P. lilacinum* (1.41 kg), *T. harzianum* (1.59 kg), *P. fluorescens* (1.48 kg), *B. subtilis* (0.82 kg), neem cake (1.36 kg), Bordeaux mixture (1 %) spray (1.27 kg) and Carbofuran (1.04 kg) and these treatments did not significantly differ in yield per vine and the lowest yield was recorded in untreated control (0.63 kg/vine).

Among the combined treatments, maximum yield (2.27 kg) was recorded in plants treated with Bordeaux mixture (1 %) +*T. harzianum* (50 g) followed by 2.05 kg in Bordeaux mixture (1 %) + *P. lilacinum* (50 g) treated plants.

The economic analysis, for integrated management of *R. similis* and *P. capsici* wilt on black pepper under field conditions was carried out. The results revealed that, the T_2: Bordeaux mixture (1 %) +*T. harzianum* (50 g) recorded maximum B: C ratio (2.92) with wilt lowest incidence of 13.33 per cent followed by T_4: Bordeaux mixture (1 %) + *P. lilacinum* (50 g) recorded B: C ratio (2.48) and per cent disease incidence (13.66 %) and these two treatments were at par with each other and superior over other treatments.

It was apparent that, the integrated application of Bordeaux mixture (1 %) +*T. harzianum* (50 g) or Bordeaux mixture (1 %)+ *P. lilacinum* was most effective in improving plant growth parameters, berry yield and in reducing nematode population, per cent yellowing, defoliation, leaf lesion indices and per cent root necrosis and also maximum B: C ratio.

Integrated disease management would be the ideal strategy to tackle the complex and elusive soil borne problems like foot rot of black pepper, since single approach would be of little consequence to contain the disease. Nursery hygiene, phytosanitation and other cultural practices, chemical control, biocontrol measures coupled with host resistance are important components of integrated disease management that would reduce the pesticide load into the environment. Out of the various components of integrated disease management, biocontrol programmes are of high priority in managing soil borne plant pathogens. An integrated approach with cheap and efficient plant protection technology is of great relevance to check plant parasitic nematodes and *P. capsici.*

The results revealed that combination of Bordeaux mixture (1%)and *T. harzianum* (50 g) application or combined applications of Bordeaux mixture (1%) + *P. lilacinum* (50 g) provided the maximum growth and yield of black pepper infested with *R. similis* and *P. capsici* under filed conditions.

The present findings are in confirmation with findings of Haffeez *et al*. (2001) who reported that the addiction of *Paecilomyces lilacinus* and *T. harzianum* as nematophagous fungi separately along with organic manure to the infested field sufficiently retarded the pathogenic activity of *M. incognita* and increased the plant vigor. Thankamani *et al*. (2005) who reported that number of roots and biomass production were higher with combined application of *P. fluorescens* (thrice) and *T. harzianum* which was at par with application of *P. fluorescens* thrice.

Use of a biocontrol agent (*T. harzianum*) for *Phytophthora* foot rot in black pepper, parameters such as yield increase (*i.e*. quantity saved), change in cost of cultivation and improvements in economic returns were used to assess the impact of the project. Adoption of the technology resulted in maximum proportionate productivity increase of 11.6 % and the net proportionate reduction in cost per ton output was 78.3 % (Madan *et al*., 2005).

Combined treatment of *P. putida* ($2X10^{-6}$/ml) and *P. lilacinus* ($2X10^{-6}$/ml) was more effective when compared with all other treatments. These treatments increased the plant growth and rhizospheric colonization of both bioagents significantly and reduced the disease incidence of *M. incognita* and *F. oxysporium* f. sp. *gladioli* by 66 per cent and 57 per cent respectively. There was also a significant increase in the yield of the crop which was to the tune of 23 per cent (Sowmya and Rao, 2013).

Dipel (*B. thuringiensis*) & Bio-nematon (*Paecilomyces lilacinus*) showed their superiority on the shoot, root length and root weight (Mohamed, 2013). This performance of fungal bioagents in the present study may be attributed to their strong fungicidal and nematicidal property against both the pathogens which provided maximum defense with improved plant growth. The various phytoharmones produced by PGPR play a major role in growth promotion and many bacteria have the ability to produce auxins, gibberlines and cytokinines and ethylenes (Bottini *et al*., 2004). Similarly, *T. harzianum* is potential biocontrol agent which poses growth hormone and all these combinations resulted in improved plant growth parameters. The *T. viridae* has been reported to be a natural source of enzymes and plant hormones provide additional support to plants for its better growth development and immunity.

Nematode population and wilt incidence

With respect to nematode population in soil plants treated with Bordeaux mixture (1 %) + *P. lilacinum* (50 g) recorded lowest nematode population compared to other treatments and it was significantly superior over other treatments.

Ramana (1994) reported the efficacy of *P. lilacinus* in suppressing *M. incognita* and *R. similis* infestations in black pepper (*Piper nigrum*). Though the fungus could not affect absolute control of nematodes, it significantly suppressed nematode infestation and increased total root mass production.

Biocontrol agent *T. harzianum* along with potassium phosphonate has recorded highest disease suppression with least foliar yellowing (Kumar *et al.,* 2000)

It was demonstrated that *P. lilacinum* is an effective biocontrol agent against *R. similis* in banana and can be an important component of integrated pest management strategies (Mendoza *et al*., 2007).

Less foliar yellowing (13.52 %), less defoliation (15.28 %), less death of vines (4.72 %) and highest green berry yield of 2.46 Kg per vine was recorded when vines were treated before onset of monsoon (May), during rainy season (June- July) and during 2nd fortnight of August with potassium phosphonate (0.3 %) as spray (2 l/vine) and drenching of *T. harzianum* 50g per vine with 1kg of neem cake to the root zone. This was followed by chemical check with application of (1.0 %) Bordeaux mixture spray (2 L /vine) and copper oxychloride (0.1 %) as drenching (3l/vine) wherein less foliar yellowing (16.6%), less defoliation (20.25 %), less death of vines (5.40 %) and green berry yield of 2.08 kg per vine were recorded (Raja Kumar *et al*., 2012).

The antagonistic organisms viz., *T. viride*, *T. harzianum*, *Laetiseria arvalis*, and *Bacillus subtilis* were tested against *P. capsici* in pot culture by adding infected material to healthy vine. Among the four bioagents tried, *T. viride* and *T. harzianum* were effective in reducing the incidence of the disease as compared to *L. arvalis* and *B. subtilis*. The disease incidence was maximum in untreated vines (Lokesh *et al.,* 2013).

Devasahayam *et al.* (2015) have given integrated disease management of wilt complex in black pepper and reported that foliar spraying of 1 % Bordeaux mixture during and May and June followed by drenching and spraying with same fungicide during October coupled with soil application of *T. harzianum* around the base of the vine @ 50 g/vine during May - June and October months.

The reasons for the reduced wilt incidence and increased yield may attributed to the *Trichoderma* spp. involved in the reduction of *P. capsici* by mycoparasitism, spatial and nutrient competition, antibiosis by enzymes and secondary metabolites and induction of plant defense system. The developing *P. lilacinum* kills the nematode by feeding on its body content and in effect *P. lilacinum* acts as a parasite on all the stages of nematode.

The combined effects of these two bioagents against *R. similis* and *P.capsici* helped tremendously for the management of wilt complex in black pepper under field conditions. The amount of disease suppression obtained with a biological control agent depends on the density of the agent, the density of the pathogen and how efficiently individual units of the agents render units of the pathogen ineffective.

Finally, it may be concluded that, soil borne pathogens like *P. capsici* and *R. similis* cannot be controlled with just a single management strategy. In the present study, an integrated approach was attempted to manage this disease, with mixtures of biocontrol formulations which showed significant reduction in the disease incidence. The application of *P. lilacinum* and *T. harzianum* in combination with neem cake and farm yard manure is highly useful in managing *R. similis* and *P. capsici* wilt complex.

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