



Effectiveness of Integrated Management on Fusarium-Nematode wilt Complex Disease of Banana cv. Ney Poovan (AB): Insights from a Field Study

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Banana (*Musa* spp.) belongs to the family Musaceae is the most important fruit crop in the world, serving as a staple food and source of income in many developing countries. There are several diseases recorded on Banana causing serious losses. Wilt complex disease caused by

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Fusarium oxysporum f. sp. *ubense* and *Radopholus similis* is considered as a serious threat Banana cultivation. A field experiment was conducted in a randomised complete block design with susceptible Banana variety Nay Poovan (AB) to manage the fungal-nematode wilt complex using treatments of bioagents, organic amendments and chemicals in individual as well as in integrated approach. The experiment results revealed that, Carbendazim (262.73 cm) treated plants had good plant height and it was on par with combined treatments. Among combination treatments, T11 (Neem cake + FYM + *T. viride* + + *P. fluorescens* + *P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) gave maximum plant height (118.00, 195.27 and 262.60 cm). The least plant height was recorded in control 89.60 cm, 140.00 cm and 188.00 cm at 90, 180 days after planting and at harvest respectively. The final population of *R. similis* in soil was lowest in T11 (Neem cake + FYM, *T. viride*+*P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) (6.33 /200 cc soil), followed by T6 (*T. viride* + *P. lilacinus*) (26.33 /200 cc soil), whereas control treatment has maximum (1382.00 /200 cc soil). Regarding wilt incidence, the plants treated with Neem cake + FYM, *T. viride*+*P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months (T11) recorded less incidence (11.12%) as compared to the maximum wilt incidence of 88.89 per cent in control treatment. The next best treatment was T10 (Carbendazim 17.67 %). Individual application the maximum number of hands per bunch, bunch weight and total yield per hectare was recorded in T10(Carbendazim) 13.80, 12.75 kg and 45.75 t/ha), T2(*P. Fluorescens*) (9.67, 9.73 kg and 36.05 t/ha) and least was recorded in T9 (Carbofuron) (8.75, 8.25 kg and 32.50 t/ha) compare to control. Among the combined treatments, the maximum number of hands per bunch (19.75), bunch weight (16.80 kg) and total yield per hectare (26.33 t/ha) was recorded in treatment T11 (Neem cake + FYM, *T. viride*+*P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months). The economic analysis revealed that, the T11 had recorded a maximum benefit cost ratio of 4.26 followed by T10 – Carbendazim (3.96) percent incidence and the least benefit cost ratio was recorded by control (1.23).

Keywords: *Banana*; *Fusarium*; *nematode*; *disease management*; *wilt complex*.

1. INTRODUCTION

"Banana (*Musa* spp.) belongs to family *Musaceae* is the most important fruit crop in the world, serving as a staple food and source of income in many developing countries. Banana is also the world's leading fruit crop and consequently an important export commodity for several agriculture based economies in Asia, America and African continents and represents the fifth most important agricultural crop in world trade" [1]. "The genus *Musa* consists of giant herbs, ranging in height from 0.8 to 15 m. According to the use and genotype, Bananas can be divided into 3 categories: dessert and highland Bananas (AAA), plantains (AAB) and cooking Bananas (ABB)" [2]. Though, it has little fat and protein, it is a rich source of energy and contains all essential nutrients including minerals and vitamin A, B1, B2 and vitamin C and thus it is called as 'Apple of Paradise' and as well as 'Adams Fig' [3]. In India, Banana is the second most important fruit crop next to mango. Since, Banana is being used as food, fiber and for medicinal, cultural and industrial purposes and also gives high returns to small holders it is referred to as "Kalpatharu"- a plant of virtues.

"There are several fungal, bacterial, viral and nematode diseases recorded on Banana causing serious losses. Among these, *Fusarium* wilt complex caused by fungi (*Fusarium oxysporum* f. sp. *ubense*) and nematode (*Radopholus similis*) is serious threat to the Banana cultivation" [4,5].

"The *Fusarium* infects the roots of Banana plants, colonising the vascular system of the plants inducing characteristic symptoms of yellowing, pseudostem spitting, drooping of leaves, wilting of the plant and eventually plant dies. It was first reported from South East Queensland, Australia in 1874" [6,7]. It became serious epidemic in Panama during 1890 and devastated Banana crop in Central American and Caribbean Banana industries [8].

In India occurrence of *R. similis* was first reported by from Kerala by Nair et al. [9], the area of infestation has increased progressively over the years. Following its spread to the neighbouring states viz., Tamil Nadu [10], Karnataka [11], Maharashtra [12], Williams et al. (2004) reported that, "the most abundant root-parasitic nematode

was *R. similis* and was most frequently detected with *Fusarium*. All species of root-inhabiting nematodes and fungi were detected at high and low altitudes". Stover [13] reported this disease in India for the first time. Uppal [14] recorded the serious outbreak of Panama wilt disease in Pune. "In India, the yield loss by this disease was estimated as 30 to 40 per cent and in South India alone from 20 to 90 per cent" [15]. Nanjangud Rasabale, which has been given the Geographical Indication tag in Karnataka, has been almost devastated by wilt diseases, caused by *F. oxysporium* f. sp. *cubense*. The disease was so severe that, it has reduced the area under cultivation of the crop from to about 100 acres in Mysore region [16,17].

Global Banana production is seriously threatened by the re-emergence of wilt complex caused by fungus and nematode. Since, both the pathogens are soil borne in nature, once they enter into the soil, they can survive many years in the soil [18]. As we all know that, the soil borne diseases are very difficult manage with single management component. Hence, in this experiment an effort was done with integrated approach for the management of wilt complex using plant extracts, bioagents and chemicals.

2. MATERIALS AND METHODS

An effort was made under field conditions to effectively manage the fungal-nematode wilt complex by soil application with commercially available plant products like farm yard manure, neem cake, bioagents like *Trichoderma viride*, *Pseudomonas fluorescens*, *Paecilomyces lilacinus* and chemicals like Carbofuran and Carbendazim both individually and in integration.

2.1 Location of the Experimental Site

Experiments was conducted in the garden of farmer Sri. Ramesh, Bikonahalli village, Shivamogga (Tq. & District) of Karnataka. The field was heavily infested with *Fusarium* and *R. similis* population density of more than one nematode per g soil i.e., 864 nematode per 200 cc soil. Elakkibale, the susceptible cultivar for *Fusarium* wilt was used for this study. Farm was situated in agro climatic zone-VII (Southern Transition Zone) of Karnataka state at 5804.245' North latitude and 75034' 35.15" East longitude at an altitude of 930 meters above the mean sea level.

2.2 Soil Characteristics and Climatic Conditions

Soil characteristics of the experimental location were sandy loam soil. Soils have medium to high water holding capacity in the profile. Zone –VII has a semi-arid type of climate. Mean annual rainfall ranges from 800 mm to 1000 mm with a normal rainfall of 830.00 mm and mean monthly maximum and minimum temperature are 32.75 °C and 19.25 °C respectively.

2.3 Field Preparation

Experimental site was thoroughly ploughed to a fine tilth, harrowed and levelled. Pits of 45 cm³ size were dug at a spacing of 1.8+1.2 x 1.8 m as a paired row planting. Uniform sized suckers of 1.2 kg each were planted after imposing different treatments to their respective pits. Normal package of practices like irrigation, fertilizer application and weeding was done uniformly to all the plants by the farmer of the field.

2.4 Pre-treatment Sampling

In order to assess the initial population of nematodes in soil, pre-treatment sampling was taken up separately for each plot, rhizosphere soil samples collected from plants at the corner and from the centre of plot were pooled. Out of this thoroughly mixed soil, an aliquot of 200cc was used for population assessment. These soil samples were processed and nematodes were extracted as explained earlier.

2.5 Experimental Details

Crop :	Banana
Cultivar :	Ney Poovan (AB)
Design :	RCBD
Size of the plot:	1.2 x 1.8m
Treatments :	12
Replications :	3
Number of plants per replication:	18

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

The treatments are applied in two splits, one at the time of planting and another at six months after planting. In the first split application, full dose of bioagents, plant extracts and 50 per cent

List 1. List of treatments and their details

Treatments	Treatment Details
T ₁	<i>Trichoderma viride</i> @ 50 g/plant
T ₂	<i>Pseudomonas fluorescens</i> @ 50 g/plant
T ₃	<i>Paecilomyces lilacinus</i> @ 50 g/plant
T ₄	Neem cake @ 250 g/plant
T ₅	<i>T.viride</i> @ 25 g/plant + <i>P. fluorescens</i> 25g/plant
T ₆	<i>T. viride</i> @ 25 g/plant + <i>P.lilacinus</i> @ 25g/plant
T ₇	<i>P. fluorescens</i> @ 25 g/plant + <i>P.lilacinus</i> @ 25 g/plant
T ₈	Carbofuran (20 g/plant) + Carbendazim (0.2 %)
T ₉	Carbofuran 3G @ 20 g/plant
T ₁₀	Carbendazim 50 % WP @ 0.2% as drenching
T ₁₁	Neem cake + <i>T. viride</i> (50gm)+ <i>P. fluorescens</i> (50gm)+ <i>P. lilacinus</i> (50gm) + FYM (5kg) + Carbofuran (0.2%) + Stem injection of Carbendazim (at 5, 7, 9 months)/plant
T ₁₂	Stem injection of Carbendazim 50 % WP
T ₁₃	Untreated Control

List 2. Vascular discoloration index

Vascular discoloration	Scale
Corm completely clean, no vascular discoloration	1
Isolated points of discoloration in vascular tissue	2
Discoloration upto 1/3 rd of vascular tissue	3
Discolouration between 1/3 rd and 2/3 rd vascular tissue	4
Discolouration more than 2/3 rd of vascular tissue	5
Total discolouration of vascular tissue	6

of carbofuran were applied at the time of planting and remaining 50 per cent of Carbofuran was applied at six months after planting. The treatment T₁₂, stem injection of Carbendazim @ 2 per cent was done at 5, 7, 9 months. Injection of 2 per cent Carbendazim was done at an angle of 45° to the stem of Banana with the help of stem injector at two feet above the soil surface. One injection it releases 5 ml of solution approximately, if stem is smaller one injection was done, for bigger stems two injections were done at opposite directions.

2.6 Observations Recorded

The observations like plant height, girth of pseudostem, number of functional leaves, number of hands/bunch, weight of bunch (kg) nematode population before the treatment imposition, nematode population at monthly intervals, final nematode population, number of lesions per plant, root lesion index Number of wilted plants, per cent disease incidence, length of Psuedostem splitting and vascular discoloration index were recorded. vascular discoloration index was

calculated by using 1-6 scale given by Orjeda [19].

2.7 Analysis of Data

“The data obtained in present investigation for various parameters were subjected to ANOVA for a completely randomized design for *in vitro* studies and Randomized complete block design for *in vivo* studies” [20].

3. RESULTS AND DISCUSSION

The bio-agents (*Trichoderma viride*, *Pseudomonas fluorescens* and *Paecilomyces lilacinus*), organic amendment (Neem cake) and chemicals (Carbofuran and Carbendazim) were evaluated separately and in combination for the management of fungal-nematode wilt complex in Banana. Pairing and prolinage and rhizome dipping @ 0.1 per cent Carbendazim was the common for all treatments except control. The observations were recorded on plant height, number of leaves and pseudostem girth at 90, 180 days after planting and at harvest were given in the Table 1.

3.1 Effect of Integrated Approaches on Plant Growth Parameters

3.1.1 Plant height

The individual treatments of bioagents, organic amendment and chemicals were not significantly different over control at 90, 180 days after planting. At harvest, Carbendazim (262.73 cm) treated plants had good plant height and it was on par with combined treatments.

Among combination treatments, T11 (Neem cake + FYM, *T. viride*+*P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) gave maximum plant height (118.00, 195.27 and 262.60 cm) and it was on par with T8 (Carbofuran + Carbendazim) (113.27, 182.40 and 252.07 cm), T7 (*P. fluorescens* + *P. lilacinus*) (104.67, 172.40 and 238.87 cm), T5 (*T. viride* + *P. fluorescens*) (104.53, 167.87 and 235.40 cm) and T6 (*T. viride* + *P. lilacinus*) (101.87, 163.20 and 224.40 cm) at 90, 180 days after planting and at harvest respectively. The least plant height was recorded in control 89.60 cm, 140.00 cm and 188.00 cm at 90, 180 days after planting and at harvest respectively. The present findings are in confirmation with Dinesh et al. [21] who conducted experiment on Fusarium wilt complex of Banana and revealed that, combined application of Carbofuran + Carbendazim gave maximum plant height, number of functional leaves and pseudostem girth. The alternative to above treatment with the similar efficacy was *T. viride* + *P. fluorescens* + *P. lilacinus* with a higher plant height, number of functional leaves and pseudostem girth at 90, 180 days after planting and at harvest respectively.

3.1.2 Number of leaves

Among the individual treatments, the number of functional leaves was maximum in plants treated with Carbendazim (9.02, 12.47 and 11.36). Among individual bioagents and organic amendment, the plant treated with *P. fluorescens* (7.21, 9.32 and 8.56) followed by *P. lilacinus* (6.55, 7.87 and 7.03), *T. viride* (6.33, 8.40 and 7.65) and neem cake (7.61, 9.30 and 7.96) and which were on par with each other at 90, 180 days after planting and at harvest respectively. Among combination treatments, the plant treated with T11 (Neem cake + FYM, *T. viride*+*P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) had maximum number of functional leaves at 90

(9.96), 180 days after planting (13.80) and at harvest (14.09) and it was on par with T8 (Carbofuran + Carbendazim) 9.24, 11.87 and 12.76 at 90, 180 DAP and harvest respectively. The lowest number of leaves was observed in control 90 (4.96), 180 days after planting (6.75) and at harvest (4.66). Senthil Kumar et al. [22,23] reported “maximum plant growth in treatment with *P. fluorescens* B13 isolate. The soil application of *P. fluorescens* @ 10 g/plant recorded increased plant growth and yield. Further, Jonathan et al. [24] observed significantly enhanced the growth and fruit yield with combined application of *P. fluorescens* (*P. fluorescens* bv22) and *B. subtilis* (Bbv57)”.

3.1.3 Pseudostem girth

The individual treatments of bioagents, organic amendments and chemicals were not found to be significantly different in Pseudostem girth over control at 90, 180 days after planting and at harvest. But among individual treatments, the plants treated with Carbendazim (24.22, 51.06 and 84.06 cm) had maximum pseudostem girth at 90, 180 days after planting and at harvest respectively and it was on par with combined treatments. Among combination treatments, T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) had maximum girth of 28.10, 54.09 and 86.12 cm at 90, 180 days after planting and at harvest respectively and it was on par with T8 (Carbofuran + Carbendazim) (26.17, 52.03 and 82.04 cm), T5 (*T. viride* + *P. fluorescens*) (24.09, 43.11 and 70.04 cm), T6 (*P. fluorescens* + *P. lilacinus*) (23.23, 42.55 and 69.21 cm), and T7 (*T. viride* + *P. lilacinus*) (23.17, 42.49 and 71.39 cm) at 90, 180 days after planting and at harvest respectively. The minimum pseudostem girth was noticed in control plants at 90 (15.27 cm), 180 days after planting (30.33 cm) and at harvest (51.03 cm). *T. viride* was also found effective against wilt. The improved plant growth by this bioagent is in confirmation with findings of Thangavelu and Mustaffa (2010) they found that “soil application of *T. viride* significantly reduced the external (up to 78%) and internal symptoms (up to 80%) of *Fusarium* wilt of Banana and increased the plant growth significantly under field conditions”. “The effect of *P. lilacinus* in managing the *R. similis* and improving the growth of Banana” is in confirmation with findings of Kilama et al. [25]; Mendoza et al. [26]; Marimuthu and Murugesan [27].

3.2 Effect of Integrated Approaches on Nematodes Population in Root and Soil of Banana Infected with Fusarium and *R. similis* under Field Conditions

The population of *R. similis* in soil differed significantly among the treatments compared to control. Among individual treatments, the lowest multiplication of *R. similis* was observed in Carbofuran and it was on par with *P. lilacinus* and *P. fluorescens*. It was followed by *T. Viride* and neem cake. The population of *R. similis* in roots differed significantly among the treatments compared to control. Observation on *R. similis* population in soil (200 cc) and root (5g) was recorded at harvest and are presented in Table 2.

3.2.1 Final population *R. Similis* in root and soil

The final population of *R. similis* in soil was lowest in T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) (6.33 /200 cc soil), it was on par with T6 (*T. viride* + *P. lilacinus*) (26.33 /200 cc soil), T7 (*P. fluorescens* + *P. lilacinus*) (28.00 /200 cc soil), T8(carbofuran + Carbendazim) (52.67/200 cc soil), *P. lilacinus* (63.67 /200 cc soil), carbofuran (63.33 /200 cc soil), *P. fluorescens* (72.67 /200 cc soil) and T5 (*T. viride* + *P. fluorescens*) (71.67 /200 cc soil) compared to control (1382.00 /200 cc soil). The final population of *R. similis* in roots was minimum in T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months) (5.33 /5 g root) and was on par with T7 (*P. fluorescens* + *P. lilacinus*) (14.67 /5 g root), T5 (*T. viride* + *P. fluorescens*) (17.33 /5 g root), T3 (*P. lilacinus* (28.33 /5 g root)) and T6 (*T. viride* + *P. lilacinus*) (32.00 /5 g root) as compared to control (348.33 /5 g root). The results obtained in current investigation were upheld by the results observed by Shreenivasa et al. [28], Shanthi and Rajendran [29], Senthil Kumar et al. [23]; Jonathan et al. [24]; and Shanthi and Sivakumar [30].

3.2.2 Number of lesions per plant and lesion index

The lowest number of lesion and lesion index (4.07 and 0.67) was observed in T9 carbofuran followed by T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5,7,9 months)(9.47

and 0.87) and T8 (carbofuran + Carbendazim) (12.50 and 1.07) and these were on par with each other. The next best treatment in reducing the lesions and lesion index was T6 (*T. viride* + *P. lilacinus*) (24.33 and 1.60) which was on par with, T7 (*P. fluorescens* + *P. lilacinus*) (25.33 and 1.73), T5 (*T. viride* + *P. fluorescens*) (31.93 and 1.87) and *P. lilacinus* (30.87 and 1.87) respectively.

3.2.3 Effect of integrated approaches on wilt incidence

The results indicated that, the plants treated with Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months (T11) recorded very less wilt incidence (11.12%) as compared to the maximum wilt incidence of 88.89 per cent in control treatment. The next best treatment was T10 (Carbendazim 17.67 %) followed by the T8(carbofuran + Carbendazim), which recorded the wilt incidence of 22.22 per cent. It was on par with T5(*T. viride* + *P. fluorescens*) (27.78%) and T7 (*P. fluorescens* + *P. lilacinus*) (33.33%). Even though, individual application of bioagents and organic amendments were significantly reduced the wilt incidence over control, but the efficacy was less compared to their combined application.

3.3 Rhizome Discolouration Index (RDI) and Vascular Discolouration Index (VDI)

Based on the rhizome discolouration index (RDI) and Vascular discolouration index (VDI), the plant treated with T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months) showed very lowest rhizome discolouration and vascular discolouration (1.27 RDI and 0.53 VDI respectively). It was followed by T8(carbofuran + Carbendazim) (2.67 and 1.07) and T10 (Carbendazim) (3.07, 1.67) compared to almost complete discolouration of rhizome and vascular region with a RDI of 6.33 and VDI of 5.80 respectively in control. Individual application of *P. fluorescens* (5.47), *T. viride* (6.13), and *P. lilacinus* (6.20), carbofuran (6.13) and neem cake (6.27) showed higher rhizome discolouration and it was on par with control (6.33). But based on VDI, significant difference was observed in plants applied with *P. fluorescens* (3.60), *T. viride* (3.67), and *P. lilacinus* (4.40) individually with lower vascular discolouration compared to complete vascular discolouration in control treatment (5.80).

3.4 Effects Integrated Approaches on Yield Parameters and Economic Benefit of Disease Management

All the treatments recorded increased yield parameters viz., number of hands per bunch, bunch weight, total yield per hectare and higher net income and benefit: cost ratio compared to control. The data is presented in Table 3. Individual application the maximum number of hands per bunch, bunch weight and total yield per hectare was recorded in T10(Carbendazim) 13.80, 12.75 kg and 45.75 t/ha), T2(*P. Fluorescens*) (9.67, 9.73 kg and 36.05 t/ha) and least was recorded in T9(carbofuran) (8.75, 8.25 kg and 32.50 t/ha) compare to control. Among the combined treatments, the maximum number of hands per bunch (19.75), bunch weight (16.80 kg) and total yield per hectare (26.33 t/ha) was recorded in treatment T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens* +*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months). The next best treatment was T8(carbofuran + Carbendazim)with higher number of hands per bunch (17.50), bunch weight (15.20 kg) and total yield per hectare (24.73 t/ha). Present findings were in confirmation earlier results reported by Roy et al. [31], Raguchander et al. [32], Raguchander et al. [33], Shamarao et al. [34], Thangavelu [35] and Saravanan et al. [36]. Roy et al. [31] reported that dipping disease-free Banana suckers in 0.2 per cent solution of carbendazim for 45 min was effective in reducing disease intensity of wilt complex disease.

The efficacy of *P. fluorescens* and *T. viride* in reducing the wilt disease complex was also reported by Raguchander et al. [32], who reported that, *T. viride* and *P. fluorescens* were equally effective in reducing growth of *Fusarium* under *in vitro*. Dipping of Banana suckers in the suspension of *P. fluorescens* or *T. viride* effectively reduced the *Fusarium* wilt incidence and produced the highest yield under field conditions. Further, Raguchander et al. [33] observed, capsule application of *P. fluorescens* at 3 and 5 months after planting recorded the lowest wilt incidence. Further, Shamarao et al. [34] showed that, the *T. viride*, *P. fluorescens* and *B. thuringiensis*, MPG-3 and carbendazim were all effective against *Fusarium*. Saravanan et al. [36] recommended the basal application of neem cake + sucker dipping *P. fluorescens* + soil

application of *P. fluorescens* at 3, 5 and 7 months after planting showed the greatest suppression of Panama wilt disease under field condition.

The reasons for the reduced wilt incidence and severity and increased yield may attributed to the *Trichoderma* spp. involved in the reduction of *Fusarium* wilt severity by mycoparasitism, spatial and nutrient competition, antibiosis by enzymes and secondary metabolites, and induction of plant defence system. The fluorescent *pseudomonads* produced secondary metabolites like phenazine, 2,4- diacetylphloroglucinol, pyocyanine, pyoluteorin and pyrrolnitrin which were involved in suppression of root diseases causing pathogens [37] and the developing *P. lilacinus* kills the nematode by feeding on its body contents. In effect, the *P. lilacinus* acts as a parasite on all the stages of nematode. The pre-colonization with *P. fluorescens* reduced *Fusarium* colonization. Massive depositions of unusual structures at sites of fungal entry clearly indicated that bacterized root cells were signalled to mobilize a number of defense structures for preventing the spread of pathogen in the tissue [38].

The economic analysis for integrated management revealed that, the T11 had lowest wilt incidence (11.11 %) and recorded benefit cost ratio of 4.26. The next best treatment was T8 (Carbofuran + Carbendazim) with a wilt incidence of 22.22 per centB: C ratio of 3.82 and the least benefit cost ratio was recorded by control (1.23). It was apparent that, the application of T11 (Neem cake + FYM, *T. viride*+ *P. fluorescens*+*P. lilacinus* + Carbofuran + stem injection of Carbendazim at 5, 7, 9 months) was most effective in improving plant growth, fruit yield and in reducing nematode population, root lesion index, wilt incidence and wilt severity and also maximum net and additional returns. The combined action of these three bioagents against *Fusarium* and *R. similis* helped tremendously for the management of wilt complex in Banana under *in vitro* and *in vivo*. 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. In our study, an inoculum dose of 10 g of talc formulation per plant was optimum [39].

Table 1. Effect of integrated approaches on plant growth parameters of Banana infected with Fusarium and *R. similis* wilt complex under field conditions

Sl. No.	Treatments	Plant height (cm)			Number of leaves			Pseudostem girth (cm)		
		90 DAP	180 DAP	At harvest	90 DAP	180 DAP	At harvest	90 DAP	180 DAP	At harvest
1	T ₁ - <i>T. viride</i>	101.47*	161.27	220.67	6.33	8.40	7.65	18.44	36.17	58.29
2	T ₂ - <i>P. fluorescens</i>	99.53	162.07	223.60	7.21	9.32	8.56	19.33	37.09	60.07
3	T ₃ - <i>P. lilacinus</i>	98.13	156.13	213.53	6.55	7.87	7.03	17.42	38.32	57.43
4	T ₄ - Neem cake	95.53	151.27	206.07	7.61	9.30	7.96	16.46	35.09	58.35
5	T ₅ - <i>T. viride</i> + <i>P. fluorescens</i>	104.53	167.87	235.40	8.44	10.09	11.58	24.09	43.11	70.04
6	T ₆ - <i>T. viride</i> + <i>P. lilacinus</i>	101.87	163.20	224.40	8.65	9.96	9.24	23.23	42.55	69.21
7	T ₇ - <i>P. fluorescens</i> + <i>P. lilacinus</i>	104.67	172.40	238.87	9.11	10.45	10.03	23.17	42.49	71.39
8	T ₈ - Carbofuran + Carbendazim	113.27	182.40	252.07	9.24	11.87	12.76	26.17	52.03	82.04
9	T ₉ - Carbofuran	91.07	157.47	211.33	6.03	9.33	7.54	19.22	37.13	59.02
10	T ₁₀ - Carbendazim	97.80	170.40	242.73	9.02	12.47	11.36	24.22	51.06	84.06
11	T ₁₁ - Neem cake + <i>T. viride</i> + <i>P. fluorescens</i> + <i>P. lilacinus</i> Carbofuran + Stem injection of Carbendazim (at 5, 7, 9 months)	118.80	195.27	262.60	9.96	13.80	14.09	28.10	54.09	86.12
12	T ₁₂ Stem Injection of Carbendazim	101.73	146.20	212.20	8.05	10.26	9.55	22.12	48.16	80.22
13	T ₁₃ - Control	89.60	141.00	188.00	4.96	6.75	4.66	16.76	31.24	48.26
S. Em ±		5.38	10.48	14.26	0.31	0.37	0.36	1.54	1.66	2.24
CD @ 5%		15.71	30.58	41.61	0.95	1.23	1.21	4.51	4.85	6.54

Note: * Indicate the mean values of replications of respective treatments, DAP- Days after planting

Note : *T. viride*- *Trichoderma viride*, *Pf*- *Pseudomonas fluorescens* and *Paecilomyces lilacinus*

* Pairing and prolinage and rhizome dipping @ 0.1 % Carbendazim is common for all treatments except control

Table 2. Effect of integrated approaches on Nematode population, lesion index and wilt parameters of Banana

Sl. No.	Treatments	Final nematode population		Number of lesions	Lesion index	Wilt incidence (%)	% decrease over control	RDI	VDI
		Soil (200 cc)	Roots (5 g)						
1	T ₁ - <i>T. viride</i>	298.43	131.00	70.47	3.00	56.33 (48.62)	36.63	6.11	3.67
2	T ₂ - <i>P. fluorescens</i>	72.67	41.33	59.80	2.80	53.56 (47.02)	39.74	5.37	3.60
3	T ₃ - <i>P. lilacinus</i>	63.67	28.33	30.87	1.87	67.44 (55.18)	24.13	6.10	4.40
4	T ₄ - Neem cake	414.67	188.00	76.27	3.20	65.67 (54.11)	26.12	6.27	5.67
5	T ₅ - <i>T. viride</i> + <i>P. fluorescens</i>	71.67	17.33	31.93	1.87	26.78 (31.15)	69.87	5.03	2.20
6	T ₆ - <i>T. viride</i> + <i>P. lilacinus</i>	26.33	32.00	24.33	1.60	37.89 (37.98)	57.34	5.83	3.13
7	T ₇ - <i>P. fluorescens</i> + <i>P. lilacinus</i>	28.00	14.67	25.33	1.73	32.33 (34.62)	63.63	5.10	3.27
8	T ₈ - Carbofuran + Carbendazim	52.67	112.33	12.50	1.07	21.22 (27.42)	76.13	2.67	1.07
9	T ₉ - Carbofuran	63.33	81.33	4.07	0.67	76.78 (61.17)	13.62	6.13	5.53
10	T ₁₀ - Carbendazim	502.00	334.67	94.93	3.27	17.67 (24.85)	80.12	3.01	1.67
11	T ₁₁ - Neem cake + <i>T. viride</i> + <i>P. fluorescens</i> + <i>P. lilacinus</i> + FYM Carbofuran + Stem injection of Carbendazim (at 5, 7, 9 months)	6.33	5.33	9.47	0.87	11.12 (19.47)	87.49	1.27	0.53
12	T ₁₂ Stem injection of Carbendazim	528.67	202.67	80.40	3.13	36.11 (36.92)	59.38	3.07	1.71
13	T ₁₃ - Control	1382.00	348.33	97.40	3.40	88.89 (70.50)	0.00	6.33	5.80
S. Em ±		31.45	12.14	4.42	0.16	2.02	-	0.25	0.22
CD @ 5%		90.86	35.56	12.90	0.47	5.89	-	0.74	0.65

Note: *T. viride*- *Trichoderma viride*, *Pf*- *Pseudomonas fluorescens* and *Paecilomyces lilacinus*, DAP- Days after planting

* Pairing and prolinage and rhizome dipping @ 0.1 % Carbendazim is common for all treatments except control

Table 3. Effect of integrated approaches on yield parameters of Banana infected with Fusarium and *R. similis* wilt complex under field conditions and their economic analysis

Sl. No.	Treatments	Wilt incidence (%)	Number of hands /bunch	Bunch weight (kg)	Yield (t/ha)	B:C ratio
1	T ₁ - <i>T. viride</i>	56.33 (48.62)	9.50	9.28	16.52	2.44
2	T ₂ - <i>P. fluorescens</i>	53.56 (47.02)	10.75	9.36	15.48	2.01
3	T ₃ - <i>P. lilacinus</i>	67.44 (55.18)	9.76	9.30	15.07	1.96
4	T ₄ - Neem cake	65.67 (54.11)	8.75	9.25	14.20	1.73
5	T ₅ - <i>T. viride</i> + <i>P. fluorescens</i>	26.78 (31.15)	12.72	12.80	19.39	3.67
6	T ₆ - <i>T. viride</i> + <i>P. lilacinus</i>	37.89 (37.98)	12.27	11.50	18.84	3.49
7	T ₇ - <i>P. fluorescens</i> + <i>P. lilacinus</i>	32.33 (34.62)	11.90	11.25	18.27	3.37
8	T ₈ - Carbofuran + carbendazim	21.22 (27.42)	17.50	15.20	22.73	3.82
9	T ₉ - Carbofuran	76.78 (61.17)	18.75	8.25	13.61	1.41
10	T ₁₀ - Carbendazim	17.67 (24.85)	13.80	12.75	20.11	3.96
11	T ₁₁ - Neem cake + <i>T. viride</i> + <i>P. fluorescens</i> + <i>P. lilacinus</i> carbofuran + Stem injection of carbendazim (at 5, 7, 9 months)	11.12 (19.47)	19.75	16.80	26.33	4.26
12	T ₁₂ Stem injection of carbendazim	36.11 (36.92)	10.25	9.26	18.93	3.68
13	T ₁₃ - Control	88.89 (70.50)	6.24	4.96	12.06	1.23
S. Em ±		2.02	0.43	0.35	1.31	
CD @ 5%		5.89	1.25	1.03	3.83	

Note: *T. viride*- *Trichoderma viride*, *Pf- Psuedomonas fluorescens* and *P. lilacinus*- *Paecilomyces lilacinus*

* Pairing and prolinage and rhizome dipping @ 0.1 % Carbendazim is common for all treatments except control

4. CONCLUSION

Finally, it may be concluded that, soil borne pathogens like *Fusarium oxysporum* f. sp. *cubense* and *Radopholus similis* cannot be kept under control 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 *T. viride*, *P. fluorescens* and *P. lilacinus* in combination is highly useful in managing the *Fusarium* - *R. similis* wilt complex in Banana. Integration of biocontrol with agronomic practices may also improve the efficacy of the biocontrol organisms and the health of the host plants, which may be sensitive to environmental changes. More research is needed to integrate previous advancements with consideration of disease management, host genetics, identification of resistant sources and the biology of *F. oxysporum* f. sp. *cubense* and *R. similis* and rhizosphere microbe interactions which influence the wilt complex.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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