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Integration of soil solarization with bio-fumigation and *Trichoderma* spp for management of damping-off in tomato (*Lycopersicon esculentum*) in the mid altitude region of north-western Himalayas*

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Tomato (*Lycopersicon esculentum* L. Mill.nom.cons.) is a major cash crop of the north-western Himalayan region of India where it is cultivated during 2 cropping seasons, viz March-May and June-September. Amongst the biotic stresses, damping-off caused by a complex of several soil-borne plant pathogens, like *Pythium* spp *Rhizoctonia solani*, *Phytophthora* spp, *Fusarium* spp. etc., is the major problem during the nursery stage of the crop, especially in the main season, ie June–September. Current management practices for this disease involve use of chemical fumigants or fungicides which result in eradication of target along with beneficial microbes and pose health hazards and environmental pollution. Recent studies have reported that efficacy of solarization can be greatly improved by its integration with biocontrol agents or composts, animal manures etc. Therefore, the present study was formulated with an objective to evaluate the efficacy of solarization alone and in combination with farmyard manure, poultry manure and/or *Trichoderma viride* as a technology for managing damping-off of tomato and to assess its impact on the soil microbial population.

The experiment was conducted at the experimental farm of the institute located at Hawalbagh (29° 36' N, 79° 40' E and 1250 m above msl) during 2 crop seasons (2005 and 2006). Raised nursery beds (1×1 m^2) of 10 cm height were arranged in a split-plot design with 3 main plots [30 days, 40 days of solarization and non-solarized beds (NS), 6 sub-plots [(i) incorporation of farmyard manure prior to solarization, (ii) incorporation of farmyard manure prior to solarization + seed treatment with *T. viride* (Strain BIL 198) at sowing, (iii) incorporation of poultry manure prior to solarization, (iv) incorporation of poultry manure prior to solarization + seed treatment of *T. viride* at sowing, (v) seed treatment with *T. viride* at sowing, and (vi) control (no organic manure and no bioagent treatment)] with 3 replications. The nursery beds were deep ploughed and irrigated to field capacity and the manures were amended in the top 5 cm layer of soil @ 10 tonnes/ha over the plots, followed by mulching with transparent polyethylene plastic sheets (0.030 mm thick) for 30 and 40 days period from 1 May of each year. Daily temperature of both solarized and non-solarized plots was recorded at depths of 5 and 10 cm in the centre of each plot. Five hundred tomato seeds (var. 'Manisha') were sown in each bed following the standard package of practices after removal of polyethylene sheets. In bioagent treatment, the seeds were treated with *T. viride* @4 g/kg seeds prior to sowing. Damping-off incidence was recorded at emergence and 30 days later. At the end of the experiment, 3 composite soil samples were randomly collected from the upper 10 cm layer of each nursery bed and bulked, air dried, sieved and then stored at 4°C prior to microbial analysis. The total culturable microbial population (CFU/g of dry soil) of bacteria (5% trypticase soy broth agar), fungi (martins rose bengal agar) and actinomyetes (actinomycete isolation agar) in the different treatments was estimated by dilution plate method. The data on damping-off incidence and microbial population was subjected to angular transformation and log transformation, respectively, prior to analysis.

In general, over the whole solarization period daily differences in soil temperature between S and NS soil ranged from 9 to 12° C. Maximum temperatures of 51.2–53.3° C and 45.1–47.2° C were recorded in solarized soil as compared to 39.7–43.2° C and 37.1–39.1° C in NS soil at 5 and 10 cm depth respectively (Table 1). The addition of organic manures to the soil prior to solarization did not exhibit any significant effect on the soil temperature.

Population densities of fungi, bacteria and actinomycetes were significantly lower in solarized soils as compared to non-solarized beds soil (Table 2). Increasing the duration of

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Table 1 Average daily maximum temperature in solarized (S) and non-solarized (NS) treatments at 5 cm and 10 cm during 2005 and 2006

Time (days)	Soil temperature							
	2005				2006			
	5 cm	5 cm	10 cm	10 cm	5 cm	5 cm	10 cm	10 cm
	NS	S	NS	S	NS	S	NS	S
1	27.3	38.3	25.1	32.1	30.2	37.2	27.3	31.8
6	31.3	40.8	27.1	36.8	34.2	40.2	32.1	37.1
11	36.6	45.4	33.8	41.4	32.2	42.6	31.1	40
16	35.7	45.6	32.8	42.2	34.3	44.4	33.6	40.2
21	33.7	40.6	31.1	37.2	35.1	40.1	33.5	36.5
26	39.8	51.3	36.8	45.4	37.6	45.4	33.2	37.8
31	43.2	53.4	37.8	47.2	39.1	52.1	35.1	41.6
36	37.3	49.8	37.4	44	34.3	41.8	30.1	37.8
41	41.8	51.3	38.9	45.2	39.7	50.1	35.6	40.6

Table 2 Effect of different durations of soil solarization, organic manures and *T. viride* treatment on soil microflora during 2005 and 2006

Treatment	Population (log_{10} cfu/g soil)							
	2005				2006			
Fungi	NS[a]	S-30[b]	S-40[c]	Mean	NS	S 30	S 40	Mean
FYM[d]	4.39	3.77	3.27	3.81	4.90	3.79	3.54	4.08
FYM + Tv	4.49	3.62	3.31	3.80	4.88	3.88	3.48	4.08
PM[e]	4.33	3.79	3.51	3.88	4.73	3.88	3.50	4.04
PM + Tv	4.49	3.70	3.31	3.83	4.83	3.83	3.53	4.06
Tv[f]	4.61	4.01	3.64	4.09	5.01	4.28	4.16	4.48
Control	4.53	4.19	3.68	4.13	5.00	4.33	4.20	4.51
Mean	4.47	3.84	3.45		4.89	4.00	3.74	
CD (*P*=0.05) Main plot (M): 0.25, Sub-plot (S): 0.19, MxS: ns[g] Main plot (M): 0.23, Sub-plot (S): 0.19, MxS: ns								
Bacteria								
FYM[d]	7.78	7.38	7.21	7.46	7.53	7.34	7.27	7.38
FYM + Tv	7.51	7.39	7.18	7.36	7.55	7.33	7.33	7.40
PM[e]	7.74	7.29	7.25	7.43	7.48	7.30	7.34	7.37
PM + Tv	7.51	7.41	7.32	7.41	7.57	7.41	7.39	7.45
Tv[f]	7.65	7.48	7.45	7.53	7.50	7.39	7.42	7.44
Control	7.59	7.46	7.47	7.51	7.62	7.54	7.50	7.55
Mean	7.63	7.40	7.31		7.54	7.39	7.37	
CD (*P*=0.05) Main plot (M): 0.07, Sub-plot (S): 0.14, MxS: ns Main plot (M): 0.15, Sub-plot (S): 0.11, MxS: ns								
Actinomycetes								
FYM[d]	4.32	3.92	3.75	4.00	4.08	3.78	3.68	3.85
FYM + Tv	4.16	4.00	3.94	4.04	4.20	4.01	3.74	3.98
PM[e]	4.30	3.94	3.87	4.03	4.05	3.98	3.89	3.97
PM + Tv	4.13	4.05	3.93	4.04	4.12	3.88	3.78	3.92
Tv[f]	4.19	4.11	4.03	4.12	4.07	4.14	3.88	4.03
Control	4.43	4.12	4.05	4.20	4.21	4.05	3.86	4.04
Mean	4.26	4.02	3.93		4.12	3.97	3.80	
CD (*P*=0.05) Main plot (M): 0.13, Sub-plot (S): 0.15, MxS: ns Main plot (M): 0.08, Sub-plot (S): 0.14, MxS: ns								

A, Non-solarized; b, solarization for 30 days; c, solarization for 40 days; d, farmyard manure; e, poultry Manure; f, *T. viride* seed treatment; g, non-significant difference

solarization from 30 days to 40 days also had a negative impact on the microbial population, especially against fungi which showed significantly lower populations in S 40 treatment in both years as compared to S 30 treatment. The fungal and bacterial populations in solarized soils were further influenced by the incorporation of organic manures prior to solarization. Significantly lower populations of these 2 microbial groups were recorded in farmyard manure or poultry manure amended solarized soils as compared to non-amended solarized soils. A significant reduction in

Table 3 Effect of different durations of soil solarization, organic manures and *T. viride* treatment on damping-off in tomato nursery during 2005 and 2006

Treatment	Pre-emergence damping-off (%)								Post-emergence Damping-off (%)			
	2005				2006				2005			
	NS[a]	S 30[b]	S 40[c]	Mean	NS[a]	S 30	S 40	Mean	NS[a]	S 30	S 40	Mean
FYM[d]	56.0	41.5	35.8	44.4 (41.66)*	62.6	51.6	36.8	50.3 (45.20)*	25.8	12.7	11.1	16.5 (23.61)*
FYM + Tv	54.5	36.4	28.5	39.8 (38.97)	53.4	44.8	35.5	44.5 (41.82)	21.1	9.3	10.2	13.5 (22.21)
PM[e]	51.1	45.0	37.5	44.5 (41.83)	63.8	46.8	37.1	49.2 (44.50)	24.9	11.4	9.9	15.4 (22.62)
PM + Tv	55.5	36.6	31.5	41.2 (39.79)	53.4	45.0	35.3	44.5 (41.84)	19.7	10.3	9.2	13.1 (20.93)
Tv[f]	61.3	41.1	38.1	46.8 (43.17)	54.2	52.2	36.7	47.4 (43.66)	19.7	12.4	12.0	14.7 (22.38)
Control	67.0	53.5	44.3	54.9 (47.92)	68.6	63.6	56.8	63.0 (52.60)	27.8	17.9	16.3	20.6 (26.88)
Mean	57.5 (49.44)	42.3 (40.52)	35.9 (36.71)		59.3 (50.45)	50.6 (45.42)	39.7 (38.95)		23.1 (28.70)	12.3 (19.71)	11.4 (20.91)	

CD (P=0.05) Main plot (M): 2.25, Sub-plot (S): 4.56, MxS: ns[g] Main plot (M): 3.79, Sub-plot (S): 1.96, MxS: ns Main plot (M): 2.27, Sub-plot (S): 4.19, MxS: ns

A, Non-solarized; b, solarization for 30 days; c, solarization for 40 days; d, farmyard manure; e, poultry manure; f, *T. viride* seed treatment; g, non-significant difference; *, Figures in parentheses are angular transformed values

actinomycetes population was also observed after solarization but the organic manure amendment and increased solarization duration did not significantly affect its population. Decrease in fungal, bacterial and actinomycete population by increasing solarization duration and manure amendments has been previously reported by Baradia and Rai (2007) also.

Soil solarization resulted in a significant reduction in the incidence of pre- and post-emergence damping-off incidence in tomato nursery in both 2005 and 2006 (Table 3). Furthermore, an increase in the solarization period from 30 days to 40 days resulted in a corresponding significant decrease in pre-emergence damping-off incidence during both years. Lowest incidence of pre-emergence damping-off was observed in S 40 treatment, followed by S 30 in both the years. In case of post-emergence damping-off also, a reduction of >45% was observed in solarized nursery beds over non-solarized ones; however, the difference between the two solarization durations (S 30 and S 40) was non-significant. The data on post-emergence damping-off could not be recorded for 2006 due to the very low incidence of disease in all the treatments including non-solarized beds. A comparison of the disease incidence values of the various sub-plot treatments (Table 3) revealed that in both the years, the amendment of poultry manure or farmyard manure to the soil prior to solarization and/or seed treatment with *T. viride* resulted in a significant reduction in the disease incidence over control (non-amended and non-*T. viride* treated solarized soils). In 2005, pre-emergence damping-off incidence of 44.3% was recorded in beds with only S 40 treatment which was reduced to <39% in 40 day solarized beds integrated with manure amendment or *T. virde* treatment. Even in 2006, when solarization alone had not provided disease reduction comparable to that of 2005; the integrated treatments reduced the disease incidence from 56.8% in control (S 40) to <38%. In case of post-emergence damping-off also, all integrated treatments, except farmyard manure incorporation, resulted in significant reduction of disease over control (Table 3). The treatment of tomato seeds with *T. viride*, following solarization, exerted a significant effect on disease control. In case of pre-emergence damping off in 2005 and 2006 and post-emergence damping-off in 2005, there was an improvement of 14.7, 24.7 and 28.6% in disease reduction, respectively when *T. viride* was applied following solarization versus beds with solarization alone. The integration of biocontrol agents, like *T. harzianum*, *T. virens* etc. with soil solarization has been reported to significantly improve disease control (Gupta and Khosla 2007; Stevens *et al*. 2003). Combining solarization with farmyard manure or poultry manure amendment also provided an advantage of >18% and >20% in the disease reduction in 2005 and 2006, respectively as compared to beds with solarization alone. Several studies documenting a significant improvement in the effectiveness of solarization when integrated with organic amendments, animal manures, crop residues etc. have been previously published (Stevens *et al*. 2003, Harender 2004, Kurt and Emir 2004). It has been

suggested that the combined effect of the high temperatures existing in solarized soils along with the toxic effects of the released volatiles results in much higher pesticidal activity thus improving disease control. The data on the total culturable microbial population recorded in various treatments in solarized and non-solarized soils further supports this hypothesis. The results show that while solarization alone had a significant and negative impact on the population of all three major groups of microbes (fungi, bacteria and actinomycetes), this effect was significantly increased when soils were amended with farmyard manure or poultry manure prior to solarization. Combining all the three practices together, viz increased duration of soil solarization + organic manure amendment (farmyard manure/ poultry manure) + *T. viride* seed treatment was observed to be the most effective method for reducing damping-off disease and the lowest incidence of pre-emergence and post-emergence damping off was recorded in these treatments. These results support several previous findings for managing damping off under temperate and sub-temperate conditions (Sofi *et al.* 2007).

SUMMARY

The effect of soil solarization (30 and 40 days) alone as well as in combination with organic amendments (farmyard manure or poultry manure) and a biocontrol agent (*Trichoderma viride*) was studied for the management of damping-off disease in tomato (*Lycopersicon essculentum* L. Mill.non.cons.) nurseries under the mid hill conditions of north-western Himalayas. Soil solarization alone was found significantly effective in reducing the incidence of pre- and post-emergence damping-off in both years. Also, increasing the solarization period from 30 to 40 days significantly improved disease control. However, the results revealed that this problem could be offset by integrating solarization with organic manure amendment and biocontrol agents, like *T. viride*. Solarized nursery beds with farmyard manure or poultry manure amendment and/or *T. viride* treatment showed significantly lower pre- and post-emergence damping off compared to beds with solarization alone. Solarization also resulted in a significant reduction in the population of fungi, bacteria and actinomycetes in soil. This reduction was considerably higher in solarized soils amended with organic manures as compared to non-amended solarized soils. A combination of all the three techniques, viz physical control (soil solarization), cultural method (organic amendments) and biological control (*T. viride* seed treatment) was found to be the most effective approach for reducing pre- and post-emergence damping-off. Fungi were observed to be the most thermal-sensitive microbial group.

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