INTEGRATED MANAGEMENT OF *Phytophthora* ROT IN BLACK PEPPER NURSERY

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"Integrated management of *Phytophthora* rot in black pepper nursery"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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BINIMOL, K.S.

In memory of
My beloved Father

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LIST OF ABBREVIATIONS

°C	-	Celsius
h	-	Hour
cfu	-	Colony forming units
g	-	Gram
kg	-	Kilogram
mm	-	Millimeter
cm	-	Centimeter
m	-	Meter
ppm	-	Parts per million
MSL	-	*Mean Sea Level*
N	-	North
E	-	East
VAM	-	Vesicular Arbuscular Mycorrhiza
AM	-	Arbuscular Mycorrhiza
ha	-	Hectare
ml	-	Millilitre

INTRODUCTION

INTRODUCTION

Present day agriculture, which relies more on monoculture is highly energy intensive and has a narrow genetic base. This has disturbed the normal ecosystem and sometimes results in disease epidemics. The problem becomes more serious in case of soil-borne pathogens. Repeated planting of a crop in the same piece of land which is usual with valuable and successful crops, sooner or later results in a high inoculum build up, forcing the farmer to change either the crop or the land. Thus effective control of soil-borne pathogens increases not only yield and quality, but available lands too, by prolonging their use for crop production.

The search for new, effective, simple, inexpensive and non-hazardous methods for controlling diseases caused by soil-borne pathogens is a continuous task as none of the existing methods can be used in all instances. Fumigation, though effective, is expensive and have economically restricted to certain crops and seasons. Heat treatment of soil by steam or other means for the control of such diseases has never been widely used owing to economic considerations.

Nowadays, soil solarization, a new method developed by Katan *et al.* (1976), is widely used in the control of soil-borne plant pathogens. Solar heating is achieved by covering the soil during the hot season with transparent polyethylene sheets, thereby increasing temperature and killing the pathogens.

Solarization offers several advantages compared with other methods of soil disinfestation. It is an eco-friendly method, effective on a wide variety of pests. Besides effective pest control, soil solarization results in increased growth response (IGR), which is attributed to enhanced availability of nutrients in soil and a general shift in soil microflora in favour of antagonists of plant pathogens and pests. In certain cases long term effect of solarization on disease control and/or yield increase

extending for a second or even third crop was observed in various regions in a variety of pathogens and crops.

The exact mechanism of solarization has not been completely worked out. In addition to direct physical effect of heat through killing of pathogens, biological control also is involved in disease control (Katan, 1981a).

Solarization is an integrated method of increasing plant health, growth and yield. It appears to be adapted to a wide range of agricultural applications alone and in conjunction with agricultural chemicals and biological control agents.

India is considered as the 'Home of spices' from ancient times and it produces a variety of spices. Among them, black pepper (*Piper nigrum* L.) known as the 'King of spices' has a unique position with demand all over the world. India is the largest producer of black pepper, growing about 1.98 lakhs ha with a production staggering around 60-65 thousand tonnes $year^{-1}$ (Sadanandan, 1998). However, the productivity in India is the lowest (308 kg ha^{-1}). Kerala is the main pepper producing state in India contributing about 97 per cent of the total production in the country.

The cultivation of black pepper (*Piper nigrum* L.) is threatened by the onslaught of diseases and pests. Among several diseases which affect black pepper, *Phytophthora* foot rot caused by *Phytophthora capsici* Leonian, emend. Alizadeh and Tsao remains as the main threat to this crop not only in India but also in other countries where this crop is grown. It has been estimated to cause an annual loss of 4.5-7.5 million dollars on a global scale (Sarma *et al.*, 1994).

In nurseries, *Phytophthora* rot causes high mortality of cuttings. At times the fungus is inadvertently carried from diseased areas through planting material. For managing the disease, an integrated approach is to be followed from the

nursery. Since healthy planting material is a pre-requisite to raise a healthy plantation, production of healthy planting material is imperative.

With this background, the present study has been undertaken to study the effectiveness of soil solarization and efficacy of selected antagonists viz., *Trichoderma viride* Pers. ex Fr. and *T. harzianum* Rifai on the control of the *Phytophthora* rot in the nursery of black pepper.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Soil-borne pathogens constitute a real menace to world agriculture due to their ability to form long lived, dormant resting structures able to resist adverse environmental conditions even for several years but capable of resuming activity rapidly when favourable conditions return to normalcy. Soil disinfestation when applicable is almost the sole solution in controlling a wide range of them. Fumigation and steaming of soil has never been tried at a wider scale owing to economic constraints. Similarly fungicide application has also got many limitations.

Therefore, the vast potential of solar energy can be harnessed to control the soil pathogenic fungi, which will not only reduce our dependence on costly chemicals and fungicides but can also save the environment from pollution hazards (Shukla *et al.*, 1990). Soil solarization is the most advanced field technology for the control of soil-borne pathogens.

Soil solarization is a method of hydrothermal disinfestation accomplished by covering moist soil with polyethylene sheets during the summer months (Katan, 1981b). In addition to reducing soil fungi, bacteria, nematodes and weeds, soil solarization often results in increased plant growth response (Chen and Katan, 1980; DeVay, 1991).

Soil solarization has been used to manage important diseases in different parts of the world viz. Israel (Katan *et al.*, 1976), Greece (Ursad, 1977), Jordan (Al-Raddad, 1979), Japan (Kodama and Fukui, 1979), England (White and Buczacki, 1979), U.S.A. (Pullman *et al.*, 1981a), Korea (Kye and Kim, 1985), Italy (Garibaldi and Tamietti, 1989), Iraq (Hasan, 1989), India (Lodha *et al.*, 1991; Arya and Mathew, 1993; Vilasini, 1996) and Spain (Melero-Vara *et al.*, 1995).

Principles of solarization

Solarization involves the use of heat as lethal agent for pest control by capturing solar energy and increasing the soil temperature.

According to Katan (1980) and Ogbugi (1989), the following factors should be taken into consideration for getting better results of solarization.

1. Transparent, not black, polyethylene should be used since it transmits most of the solar radiation that heats the soil.
2. Soil mulching should be carried out during the period of high temperature and intense solar radiation.
3. Soil should be kept wet during mulching to increase the thermal sensitivity of resting structures and improve heat conduction.
4. The thinnest polyethylene tarp possible should be used, since it is both cheaper and more effective in heating, due to better radiation transmittance, than the thicker one.
5. Mulching period should be sufficiently extended, usually for four weeks or longer, in order to achieve pathogen control at all desired depths.
6. The soil should be in good tilth allowing close contact between plastic sheets and the soil and to prevent the formation of air pockets which reduce heat conduction.

Pathogen control

Several field experiments were conducted to evaluate the effectiveness of solarization in disease control. Soil solarization was effective against several soil-borne pathogens.

Phytophthora

Mulching with polyethylene sheets was found to be very effective in controlling *Phytophthora* infection. Solarization for the control of *P. cambivora* in

almond was effective only in irrigated plots (Wicks, 1988). Hasan (1989) found solar heating by polyethylene mulching as an effective and in-expensive method for controlling *Phytophthora* in tomato.

Solarization of potting mixture infested with three fungi, pathogenic to gerbera (*P. cryptogea, F. oxysporum* and *R. solani*) for three to four weeks within transparent polyethylene bags controlled root rot of gerbera (Kaewruang *et al.*, 1989a). Kaewruang *et al.* (1989b) also conducted experiments to evaluate the effect of soil solarization on the control of root rot of gerbera in Western Australia and found that solarization reduced root rot of gerbera by 28.6 per cent in comparison to the untreated control (52%).

Effectiveness of solarization in controlling *Phytophthora* diseases in tomatoes and capsicum was reported by Cartia (1989), Moens and Ben-aicha (1990) and Satour *et al.* (1991).

Soil mulching with double layer of polyethylene was effective in checking *P. nicotianae* var. *parasitica* infection of carnation plants (Garibaldi and Tamietti, 1989). Chellemi *et al.* (1994) recorded significant reduction in the population density of *P. nicotianae* var. *parasitica* in soil.

Solarization of potting mixture with a double layer of clear polyethylene mulch, killed *P. nicotianae* var. *nicotianae* (Duff and Barnaart, 1992; Duff and Connelly, 1993).

According to Juarez-Palacios *et al.* (1991), *P. cinnamomi* activity was not detected at 30 cm depth in infested soil tarped for two weeks. Soil solarization increased average maximum soil temperature by 6.9°C and 2°C in unshaded and shaded areas respectively and controlled *P. cinnamomi* root rot in established avocado orchards (Lopez-Herrera *et al.*, 1997). They also observed that *P. cinnamomi* could not be detected at 30, 45 and 60 cm depths after 4-8 weeks of

solarization in unshaded area but could be recovered at all depths except 15 cm in shaded areas.

Hartz *et al.* (1993) observed significant reduction in the population of *P. cactorum* and *P. citricola* using solarization. Soil solarization for three weeks of soil amended with neem cake at 400 g m^{-2} combined with foliar spray of 0.2 per cent metalaxyl recorded 81.3-95.5 per cent control of black shank disease of tobacco incited by *P. parasitica* var. *nicotianae* (Wajid *et al.*, 1995).

Yücel (1995) observed that solarization alone or combined with methyl bromide (40 g m^{-2}) was effective in controlling crown blight of capsicum by *P. capsici.* Sarma *et al.* (1996) reported that solarization of potting mixture was effective in controlling the *P.capsici* infection in black pepper nursery.

Mansoori and Jaliani (1996) reported successful control of *P. dechsleri* in watermelon by solarization.

Pythium

The first report of successful control of a disease by solarization was the control of rot syndrome of sugarcane caused by *Pythium arrhaenomanes* and *Pythium graminicola* (Chen and Katan, 1980). Pullman *et al.* (1981b) reported that propagules of *Pythium* could be reduced or completely eliminated at 0-46 cm depth in soil tarped for 14-66 days. According to Stapleton and DeVay (1984), soil and root population densities of *Pythium* spp. could be reduced by 38.0 per cent after post plant soil solarization of a two year old almond orchard.

Successful control of diseases caused by *Pythium* by solarization has been reported by different workers in different crops - root rot in wheat (Cook *et al.*, 1987), damping off in cucumber (Al-Khafuji *et al.*, 1988), root rot of snap beans (Meron *et al.*, 1989), damping off in tomatoes (Satour *et al.*, 1991; Raj *et al.*, 1997),

die back and collar rot of periwinkle (Kulkarni *et al.*, 1992) and damping off of chillies (Kurian, 1992).

Wajid *et al.* (1995) reported that soil solarization of the seed beds efficiently controlled the damping off in tobacco caused by *P. aphanidermatum*.

Patel *et al.* (1996) observed that soil solarization in combination with Bordeaux mixture or metalaxyl-MZ was effective in controlling damping off in bidi tobacco nursery. Significant effect of solarization in controlling the pre and post emergence rotting of ginger caused by *P. aphanidermatum* was observed by Vilasini (1996).

According to Bihan *et al.* (1997), soil solarization provides a suitable method for controlling the damping off fungus *Pythium* in forest nursery.

Fusarium

Propagules of *Fusarium oxysporum* f. sp. *fragariae* were not detected in solarized soil and were significantly reduced (up to 60%) at 10-15 cm depth (Kodama and Fukui, 1982; Kodama *et al.*, 1980). Control of *F. oxysporum* f. sp. *lycopersici* has been reported by Katan *et al.* (1980). Solarization was highly effective in controlling diseases of crop plants caused by *Fusarium* viz. *F. o.* f. sp. *vasinfectum* on coffee (Katan *et al.*, 1983), *F. o.* f. sp. *lini* on conifer seedlings (Mc-Cain *et al.*, 1986), *F. o.* f. sp. *conglutinans* on cabbage (Villapudua and Munnecke, 1986), *F. o.* f. sp. *lupini* on lupin (Osman *et al.*, 1986), *F. oxysporum* on tomato (Greenberger *et al.*, 1987), *F. o.* f. sp. *ciceri* on chickpea (Arora and Pandey, 1989), *F. solani* on capsicum (Moens and Ben-aicha, 1990) and *F. o.* f. sp. *niveum* on watermelon (Ioannou and Poullis, 1990).

Experiments conducted at ICRISAT with transparent 110 µm polyethylene sheets for 6-8 weeks revealed that solarization could reduce population of *F. udum* on pigeonpea and *F. o.* f. sp. *ciceris* on chickpea (Chauhan *et al.*, 1988).

According to Arya and Mathew (1993), combined use of *Trichoderma harzianum* and soil solarization or a reduced dose of methyl bromide resulted in significant control of *Fusarium* crown and root rot of tomato induced by *F. oxysporum* f. sp. *radicis-lycopersici*. However, *T. harzianum* and soil solarization alone was ineffective in controlling the disease. Similar results were observed by Sivan and Chet (1993).

Soil solarization resulted significant reduction in the incidence of *Fusarium* wilt in tomato (Chellemi *et al.*, 1997; Raj *et al.*, 1997).

Sclerotium

Control of southern blight of tomato caused by *Sclerotium rolfsii* with solarization was reported by Jones *et al.* (1966). Solarization effectively reduced *S. rolfsii* on peanut (Grinstein *et al.*, 1979; Katan, 1981b), on beans (Greenberger *et al.*, 1987), on betelvine (Deshpande and Tiwari, 1991), on tomato (Tu *et al.*, 1991) and *S. sclerotivorum* and *Sclerotinia minor* in lettuce (Porter and Merriman, 1985).

According to Basallote-Ureba and Melero-Vara (1993), soil solarization for 8-11 weeks resulted in the reduction of *S. cepivorum*, white rot pathogen of garlic to undetectable levels in the upper 20 cm layer of infested soil.

Chellemi *et al.* (1997) observed significant reduction in the incidence of southern blight of tomato caused by *S. rolfsii* by soil solarization. According to Tiwari *et al.* (1997), mortality due to collar rot of tomato was significantly low in all the solarized plots compared to unsolarized control.

Verticillium

Mulching with polyethylene sheets increased soil temperature and resulted in a reduction of *Verticillium* wilt by 25-95.0 per cent in egg plant and tomato (Katan *et al.*, 1976; Besri, 1991; Tjamos, 1991). Pullman *et al.* (1981b) reported that solarization reduced propagules of *Verticillium dahliae* in soil and enhanced yield.

Efficient control of *V. dahliae* in potato (Grinstein *et al.*, 1979; Davis, 1991; Lazarovitz *et al.*, 1991), tomato (Cartia, 1989) and capsicum (Gil-Ortega *et al.*, 1990) was obtained through solarization.

Solarization was also effective in the control of *Verticillium* disease of tree crops. Ashworth and Gaona (1982) reported that mulching with polyethylene sheets eliminated *V. dahliae* in a six year old pistachio nut grove. Tjamos and Paplomatas (1987) also got similar results while working with olive trees. Incidence of foliar symptoms due to *V. dahliae* was reduced by 86-100 per cent in apricot and almond trees by covering the soil with black as well as transparent polyethylene (Stapleton *et al.*, 1993).

Melero-Vara *et al.* (1995) observed marked reduction in the population of *V. dahliae* in solarized soil and reduced the wilt incidence in cotton. However, Horiuchi (1984) failed to get effective control of *Verticillium* diseases through solarization.

Rhizoctonia

Effective control of *Rhizoctonia solani* in soil and an yield increase was reported by Katan *et al.* (1980). Solarization reduced diseases caused by *R. solani* in potato (Elad *et al.*, 1980; Davis, 1991; Satour *et al.*, 1991), in onion (Katan, 1981b), in cucumber (Al-Sammaria *et al.*, 1988), in cowpea (Chandran, 1989), in beans

(Garibaldi and Tamietti, 1989), in gerbera (Kaewruang *et al.*, 1989a&b), in radish (Triolo *et al.*, 1989) and in guava (Dwivedi, 1993).

Macrophomina

Dwivedi and Dubey (1987) observed a marked reduction in the survival of *Macrophomina phaseolina* in solarized soil. Stapleton and Garza-Lopez (1988) found that preplanting mulching of moist soil with black and transparent polyethylene for six weeks reduced population of *M. phaseolina*. The efficiency of solarization in reducing *M. phaseolina* propagules in soil was also reported by Hasan (1989) and Lodha *et al.* (1991). This was contradicted by Stapleton *et al.* (1991). According to them, solarization did not reduce the inoculum of *M. phaseolina* in muskmelon and sesame.

Other pathogens

Soil solarization was found to be effective against pathogens like *Pyrenochaeta lycopersici* in tomato (Katan, 1981b), *Theilaviopsis basicola* in cotton (Pullman *et al.*, 1981b), *Plasmodiophora brassicae* (Myers *et al.*, 1983), *Rosellinia necatrix* in apple (Sztejnberg *et al.*, 1987), *Neovossia indica* in wheat (Singh *et al.*, 1991), *Clavibacter michiganensis* sub sp. *michiganensis* in tomato (Antoniou *et al.*, 1995) and *Agrobacterium tumefaciens* in fruit trees (Raio *et al.*, 1997).

Mechanisms of solarization involved in disease control

Soil solarization in its present form involves hydrothermal processes (Stapleton and DeVay, 1985), simultaneously causing many changes in the biotic and abiotic components of the soil, during and after solarization which may finally lead to a change in disease, plant growth and yield or both.

Mode of action of solarization is complex involving direct thermal destruction of propagules, shift in microbial populations and activity and changes in the soil's physical and chemical properties (Katan *et al.*, 1976). Various studies have been conducted to find out the mechanisms involved in the control of soil-borne diseases and identified the following three major mechanisms of disease control.

I. Thermal inactivation of pathogen - the physical effect

Many workers found that this method of control was not only based on a physical mechanism because sublethal temperature levels also gave some disease control (Pullman *et al.*, 1981b; Horiuchi, 1984).

Heat, at temperature exceeding the maximal for growth, has inhibitory or lethal effect on micro-organisms. Baker (1962) suggested that exposing fungi to high temperature leads to denaturation of protein (including enzymes), lipid liberation, destruction of hormones and asphyxiation of fungal tissues.

The effect of temperature on micro-organismshas been well documented. However, only few are dealt with exposure of organisms to low temperature for long periods of time. The thermal death rate of one organism depends on both the temperature level and exposure time which are inversely related (Katan, 1981b).

According to Katan *et al.* (1976), the effectiveness of sublethal temperatures on death of pathogens might be due, either to a direct cumulative effect of temperature or to a combination of thermal and biological factors. They worked out a linear relationship between logarithms of exposure time required to kill 90 per cent of the pathogens when plotted against the temperature levels in the range of 37.0-50.0°C.

Complete inactivation of *Phytophthora cinnamomi* was achieved at a temperature of 44°C for 45 minutes (Benson, 1978).

Katan (1980) found that, the fungal resting structures exposed to sublethal temperatures were weakened and therefore attacked even by micro-organisms that ordinarily could not attack them. Exposure of organisms at relatively low temperatures resulted in enzyme inactivation, phase change in fatty acids and membrane components, a slow turn over of heat sensitive proteins and a delayed germination of propagules (Pullman *et al.*, 1981a).

Horiuchi *et al.* (1983) observed that resting spores of *Plasmodiophora brassicae* lost infectivity when heated at 45.0°C for one day and that artificially infested soil in a slurry state failed to retain infectivity after five days at 45.0°C. They also found that periodical heating as well as continuous heating caused a disease suppressing effect. Sztejnberg *et al.* (1987) observed 56-100 per cent mortality of *R. necatrix* at an exposure of four hours at 38.0°C.

Kumar and Lakra (1990) reported that the sclerotia of *S. rolfsii* were killed after 52 h when exposed to 45.0°C. According to Tiwari *et al.* (1997), soil temperature exceeded 50.0°C at 5 cm depth under plastic mulch and the sclerotia of *S. rolfsii* inoculated at this depth were unable to cause collar rot in tomato.

While analysing the physical effect of solarization on inoculum density and inoculum potential of the pathogen and on disease control, Katan (1987) is of the opinion that the following points should be taken into consideration.

1. The thermal death rate of a population of an organism depends on both the temperature level and exposure time, which are inversely related.
2. Propagules which survive sublethal heating, may be partially damaged or weakened.
3. The course and pattern of heating during soil solarization vastly differ from those usually established for heat mortality curves under controlled conditions,

since with soil solarization, propagules are subjected to varying temperatures in daily cycles in a split-alternate heating mode, which contrasts with constant heating at one temperature, the standard procedure under controlled conditions.

4. The extent of the damage inflicted on the propagules depends on its inherent heat sensitivity, environmental conditions like, moisture level, the protective effect of the soil, inoculum density, quality and age, nutritional conditions and the presence of toxic substances.
5. When a pathogen infested soil is solarized or heated three processes may simultaneously occur; reduction in propagule viability, increase in propagule vulnerability to potential antagonists (Henis and Papavizas, 1983; Lifshitz *et al.*, 1983) and the activity of the antagonist on the pathogen.

II. Biological control

In addition to thermal killing (Physical effect of heat) of pathogen propagules, microbial processes, induced by solarization may also contribute to disease control, since the impacts of any lethal agent in the soil extent beyond the target organisms (Katan, 1981b). Biological control is involved, as a side effect in cases of chemical or physical disinfestation (Garrett, 1970; Baker and Cook, 1974; Munnecke *et al.*, 1976). According to Papavizas and Lumsden (1980), biological control may operate at any stage of pathogen survival or disease development during or after solarization through antibiosis, lysis, parasitism or competition.

Katan (1981b) summarised the mechanisms of biological control which may be created or induced by solarization as

(I) The effect on the inoculum existing in the soil

A. Reduction in inoculum density (in the dormant stage or during penetration to the host) through

(i) microbial killing of pathogen, already weakened by sublethal heat;

(ii) partial or complete annulment of fungistasis and subsequent lysis of the germinating propagule;

(iii) parasitism or lysis by antagonists stimulated by solarization.

B. Reduced inoculum potential due to antibiosis or competition enhanced by solarization.

C. Diminished competitive, saprophytic ability of the pathogen, in the absence of the host, due to antibiosis or competition.

(II) Suppressing inoculum introduced to soil after solarization, from deeper soil layer or adjacent non-treated plots, i.e., preventing reinfestation through activity of micro-organisms possessing mechanisms A2, A3, B and C.

(III) The effect on the host due to cross protection

Soil solarization favours the survival and increase of several heat tolerant micro-organisms able to act as antagonist against soil-borne pathogens. Prolonged high soil temperatures to lethal or sublethal levels produced by solarization may result in the survival and even increase of several known or potential antagonistic fungi.

Elad *et al.* (1980) observed an increase in the population of *Trichoderma harzianum* in solarized soil and the incidence of disease caused by *R. solani* remained low throughout the season. Katan (1981b) also observed *T. harzianum* aggressively colonizing the solarized soil and significantly reduced the *Fusarium* wilt of tomato seedlings. According to Stapleton and DeVay (1982), *Aspergillus, Penicillium* spp. and *Bacillus* spp. were the predominant thermotolerant organisms in the solarized soil.

Populations of *Acrophialophora fusispora, Aspergillus niger, Aspergillus terreus, T. viride* and sterile mycelia increased after 45 days of solarization (Dwivedi and Dubey, 1987).

Tjamos and Paplomatas (1987, 1988) reported that population of *Talaromyces flavus*, an antagonist of *V. dahliae* increased in the rhizosphere of solarized artichoke and olive trees compared to untreated control. They also found that population of *A. terreus*, another potential antagonist, occasionally increased with soil solarization. Triolo *et al.* (1988) reported that *Aspergillus, Fusarium, Penicillium* and *Trichoderma* were the pre-dominant saprophytic organisms in the solarized soil. Solar heating activated growth of saprophytic fungi such as *Trichoderma* (Hasan, 1989; DeVay, 1991).

Lifshitz *et al.* (1983) found that sublethal heating increased the leakage of water soluble organic compounds from sclerotia of *S. rolfsii* which increased their colonization by bacteria and streptomycetes and thus reducing their pathogenic activity.

According to Stapleton and DeVay (1984), the per cent of Gram-positive bacteria exhibiting *in vitro* antibiosis against *Geotrichum candidum* increased nearly 20 fold in solarized soil, but not at all in shaded soil. They also found that six strains of fluorescent pseudomonads, plant growth promoting rhizobacteria colonized sugar beet or radish roots two to six times more in solarized soil.

Increased population of *Pseudomonas* in solarized soil were also observed by Gamliel and Katan (1991). Gamliel and Katan (1992a & b) opined that addition of antimicrobial agents to non-solarized soil supplemented with seed and root exudates reduced population of soil micro-organisms and increased population of fluorescent pseudomonads. They also found that rapid establishment of

fluorescent pseudomonas in the rhizosphere of plants in solarized soil was due to improved capacity of bacteria to compete for exudates.

Raio *et al.* (1997) also observed that soil solarization did not considerably affect the population of fluorescent pseudomonas and actinomycetes in soil. Contrary to the above findings, Ristaino *et al.* (1991) reported a decrease in the population of fluorescent pseudomonas.

Preventing reinfestation is vital for proper disease control. Drastic soil disinfestation measures may result in islands of reduced biological activity which may enhance rapid colonization (Harper, 1974). Severe reinfestation occurred with *R. solani* when soils were disinfested by artificial heating at 80-100°C (Olsen and Baker, 1968). Treating the soil at lower temperatures (50-60.0°C) reduced reinfestation. Katan (1981b) reported that solarization is usually carried out at temperatures lower than aerated steam and thus reduces the chances for a biological vacuum.

Freeman *et al.* (1990) observed no reinfestation of *R. necatrix* in solarized soil and no death of replanted apple trees occurred in the solarized plots.

III. Volatiles and other mechanisms

Apart from increased temperature and biological control, volatiles in the soil are also involved in pest control by solarization. The mulch cover seals the soil and causes an accumulation of volatiles such as carbon dioxide, ethylene and other substances (Horowitz *et al.*, 1983; Greenberger *et al.*, 1984; Rubin and Benjamin, 1984). Volatiles play a key role in the fungistasis and biological control (Papavizas and Lumsden, 1980). Polyethylene is not permeable to many gases (Byrdson, 1970). Lewis and Papavizas (1974) reported that gases such as sulphur containing volatile compounds and ammonia are toxic to *R. solani* and *Aphanomyces eutiches.*

Carbondioxide accumulation under mulch is upto 35 fold over non mulched soil (Rubin and Benjamin, 1981; Horowitz *et al.*, 1983).

Rubin and Benjamin (1984) found that carbon dioxide in solarized soil increased rapidly during the first week and reached maximum, which was 20 fold higher than control. Reduction in soil conditions may cause oxygen starvation, which will affect the survival of pathogen propagules (Horiuchi, 1984). He also found that the weakened structures are easily attacked by antagonists.

Villapudua and Munnecke (1987) conducted laboratory experiments and found nearly cent per cent reduction in the population of *F.* o. f.sp. *conglutinans* by gases arising from the decomposed cabbage residues in soil.

According to Gamliel and Stapleton (1993b), heated cabbage amended soil generated a wide range of volatile compounds like alcohols, aldehydes, sulphides and isothionates. The levels of isothionates and aldehydes generated in heated soil were significantly correlated with reduced propagule numbers of *Pythium ultimum* and *S. rolfsii* by more than 95.0 per cent when they were exposed for 14 days.

Factors influencing the effectiveness of solarization

Factors like soil moisture, soil type, duration of solar heating, type of materials used for covering, season, sunlight/shade, organic matter content of the soil, ridging etc. are known to influence the effectiveness of solarization.

Soil moisture

High soil moisture is necessary for heat conduction, for increasing the heat sensitivity of resting structures and for producing better conditions for the activity of the natural antagonists in the soil (Katan, 1981b). Katan *et al.* (1976)

obtained better control of *V. dahliae* and *F. oxysporum* on tomato and egg plant by irrigating the soil before mulching by drip irrigation. Later they found that only a single irrigation just before (1-4 days) covering the soil with polyethylene sheet is necessary for controlling soil-borne pathogens. Successful control of *S. rolfsii, V. dahliae* and *Fusarium* by pre-tarping irrigation was achieved by Grinstein *et al.* (1979) and Katan (1980).

Ashworth and Gaona (1982) observed that mulching the surface of six year old drip irrigated pistachio nut trees with clear polyethylene for two months eliminated *V. dahliae*. Horiuchi *et al.* (1983) reported that *P. brassicae* infested soil with a moisture content of less than five per cent particularly in air dried state was less affected by heating than soil in a slurry state. Fahim *et al.* (1987) observed an extra increase in the soil temperature under tarp by extra irrigation, which however, did not correspondingly reduced the pre-emergence damping off in common bean plants.

Arora and Pandey (1989) observed no significant difference in mean maximum temperatures in solarized irrigated and non-irrigated treatments at 5, 15 and 30 cm depth. However, mean soil temperatures at 5-15 cm depth were achieved after 5-7 days in solarized irrigated soil compared to 15-20 days in solarized non-irrigated soil. According to Lodha *et al.* (1991), reduction in viable propagules on *F. oxysporum* f. sp *cumini* was 53.4 per cent in dry and 60.8 per cent in wet plots at a depth of 15 cm. Matrod *et al.* (1991) observed a reduction in the number of viable sclerotia of *S. cepivorum*, the causal agent of white rot in garlic by 75.2-83.2 per cent in moist plots with clear plastic compared to 1.6-10.4 per cent in dry covered soil. Tiwari *et al.* (1997) reported that soil temperature at surface and at 5 cm depth was higher in dry soil compared to moist solarized soil. While at deeper depths, decrease in temperature was comparatively slow in moist soil indicating higher transmittance of solar heat.

Soil type

Soil type plays an important role in the temperature fluctuation in the solarized soil. Colour, texture and moisture content of the soil influences the absorption of light and heat energy.

Stapleton and DeVay (1982) conducted experiments with solarization in fine sandy loam with some clay strata (heavy soil), sandy loam (light soil) and in sandy soil. They recorded a soil temperature of 49.0°C in light soil at 15 cm depth (10.0°C higher than non-solarized soil), 46.0°C in heavy soil (7.0°C higher than control) and 45.0°C in sandy soil (8.0°C higher than non-solarized soil). Similar results were also obtained by Stapleton and DeVay (1984), Stapleton *et al.* (1985) and Tjamos *et al.* (1991).

Raio *et al.* (1997) reported that *Agrobacterium tumefaciens* was eliminated in sandy loam soil after four weeks of solarization, while in silty clay soil, the populations were markedly reduced after two months of solarization.

Duration

For achieving effective control of pathogens at all desired depths, the mulching period should be sufficiently extended, usually four weeks or longer (Katan, 1981b).

Katan *et al.* (1976) observed five days of solar heating was sufficient to eliminate 100 per cent *V. dahliae* sclerotia at 5 cm depth, while at 25 cm depth only a slight killing of the pathogen was observed. An additional exposure of eight days enabled complete killing of the sclerotia at 25 cm depth.

Mortality rates of *S. rolfsii* at 5 and 20 cm depths were 100 and 25 per cent after 19 days of solarization and 100 and 80 per cent after 21 additional days of

exposure (Elad *et al.*, 1980). Kaewruang *et al.* (1989a) found that solarization of potting mixture infested with three soil-borne fungi (*Phytophthora cryptogea, Fusarium oxysporum* and *Rhizoctonia solani*) pathogenic to gerbera for three to four weeks within polyethylene bags controlled root rot of gerbera, while solarization for two weeks was less effective.

According to Duff and Barnaart (1992), solarization of a 25 cm mound potting mixture with a double layer of clear polyethylene mulch killed *Pythium myriotylum* and *Phytophthora nicotianae* var. *nicotianae* and *Sclerotium rolfsii* within 7, 3 and 7 days at 10 cm, and 7, 7 and 10 days respectively at 25 cm depth. However, Vilasini (1996) reported that increasing the period of solarization from 30 to 45 days did not result in a corresponding reduction in the pre-emergence rotting in ginger caused by *P. aphanidermatum*.

Mulching material

Type of polyethylene used for solarization influences its effectiveness. Katan *et al.* (1976) used transparent, not black polyethylene for solarization, since it transmits most of the solar radiation that heats the soil.

Tarps of 25 μm thick are more effective in heating soils than 100 μm tarps (Pullman *et al.*, 1981b). McLean *et al.* (1982) reported that watermelon and rockmelon plants mulched with reflective (aluminium coated) polyethylene, was less infected with watermelon mosaic virus than those without mulch. Black polyethylene also produced the same effect, but to a lesser degree.

Solarization with two layers of 25 μm polyethylene film increased soil temperature by 12.7°C and 3.6°C over those in non-covered soil or soil covered with single film (Ben-Yephet *et al.*, 1987). Garibaldi and Tamietti (1989) found a temperature of 36.9-44.5°C under single polyethylene (0.05 mm thick) at 24 cm depth compared to 42.5°C under double film containing small bubbles, which was

2-2.5°C higher than single film. They also reported that double layered film reduced the percentage of infection with *P. nicotianae* var. *parasitica* on carnation plants.

Duff and Barnaart (1992) reported that solarization of potting medium raised the temperature by upto 14.6°C and 17°C respectively under single and double layer at 5 cm depth. Solarization of potting mixture raised temperature to 51.0° and 44.0°C respectively under a double and single layer of clear plastic at 25 cm depth (Duff and Connelly, 1993). *P. myriotylum* and *P. nicotianae* var. *nicotianae* and *S. rolfsii* were eliminated within 2-8 days under double layer of plastic while, 4-20 days were required for elimination of the same pathogens using single layer of plastic.

Garibaldi (1987) found that PVC was more effective than PE (polyethylene) in maintaining high soil temperature. Double layer bubble plastic raised soil temperatures 1-2°C higher than those with PVC.

Horowitz *et al.* (1983) and Abu-Gharbieh *et al.* (1991) opined that black plastic was less effective than transparent. Stapleton *et al.* (1989) noticed that the soil temperature raised upto 10-18.0°C under transparent polyethylene sheet at 15-23 cm depth. While, it was only 8-12.0°C for black film mulching. Reduction in the number of viable sclerotia by 75.2-83.2 per cent in plots covered with clear plastic compared with a decrease of 49.6 to 59.2 per cent with black plastic (Matrod *et al.*, 1991). These findings were contradicted by Stapleton *et al.* (1991). They reported that mulching of soil with black polyethylene was as effective as transparent in controlling diseases and weeds.

Chellemi *et al.* (1997) observed a maximum temperature of 41.8, 45.7 and 49.2°C under white, photo selective and clear plastics respectively at 10 cm depth. Tiwari *et al.* (1997) reported that different coloured polyethylene sheets (black, blue, green, red and transparent) had a significant effect on the increase in

temperature over control at different soil depths. The increase in soil temperature was in order of < black < green < blue < transparent < red. However, transparent and red plastic mulches had similar effects on increase in the soil temperature.

Season

Soil solarization should be carried out during the period of high temperatures for getting better results.

Katan *et al.* (1976) suggested July as the best season for solarization in Israel. Horiuchi and Hori (1983) observed unsuccessful effects of solar heating during the cool season. Horowitz *et al.* (1983) reported that solarization was effective during summer months compared to winter.

Malathrakis and Kambourakis-Tzagaroulakis (1989) observed that solarization increased soil temperatures to 45.0°C at 10 cm depth during July while, when the experiment was repeated in August the maximum temperature observed was only 40.0°C. According to Deshpande and Tiwari (1991), solarization for 3-4 days in the month of May was effective in controlling collar rot of betel vine.

Duff and Connelly (1993) reported that solarization of potting mixture raised temperatures of 51.0°C and 44.6°C under a double and single layer of clear plastic respectively at 25 cm during November. While, the maximum temperatures observed were 41.3°C and 35.1°C in July under the double and single layer of mulch respectively.

Shade

Shade reduced the effectiveness of solarization. Ashworth and Gaona (1982) obtained successful control of *Verticillium* wilt in an established (6-year-old)

pistachio nutgrove. Soil temperatures in tarped shaded plots were only slightly higher than those in the non-solarized plots (Sztejnberg *et al.*, 1987).

Villapudua and Munnecke (1986) found that solar heating alone and cabbage amendment plus mulching under shade were effective but not as the combination of both.

Chandran (1989) could not effectively control *R. solani* causing web blight of cowpea by solarization under partially shaded conditions in a coconut garden while, it was effective under open sun.

Freeman *et al.* (1990) observed higher temperature in solarized soil compared to solarized shaded plots. Solarization eradicated *R. necatrix* at a depth of 30 cm while partial destruction of pathogens was obtained in solarized shaded plots.

Organic and inorganic matter content of the soil

Incorporation of organic matter into the soil to be solarized improved the efficiency of solarization.

According to Horiuchi *et al.* (1983), the presence of organic matter in the soil intensified the effect of heating by solarization. Horiuchi (1984) also reported that organic matter combined with water and calcium materials improved the effect of solarization. Villapudua and Munnecke (1987) obtained maximum control of cabbage yellows caused by *F. o.* f. sp. *conglutinans* by solarizing soil amended with cabbage residues.

Tu *et al.* (1987, 1991) found that addition of green manure gave increased control of *S. rolfsii* on tomato. Chicken compost amendment of the soil before solarization effectively controlled *P. ultimum* on lettuce (Gamliel and Stapleton, 1993a). They also found that solarization of compost amended soil

effectively controlled *Meloidogyne incognita*. Gamliel and Stapleton (1993b) reported that solarized soil amended with cabbage residues generated a wide range of volatiles and reduced the propagule numbers of *P. ultimum* and *S. rolfsii*.

Arya and Mathew (1993) obtained maximum reduction in micro-organisms in the neem leaf amended solarized soil followed by eucalyptus and oak leaf amended solarized soil. Wajid *et al.* (1995) reported that solarization of soil amended with neem cake was more effective in controlling damping off in tobacco nursery.

According to Vilasini (1996), *Trichoderma* incorporated neemcake amended 30 days solarized treatment was highly effective and recorded cent per cent control of rhizome rot disease in ginger. However, Kurian and Peethambaran (1994) failed to get better control of damping off of chillies in neem cake amended solarized soil.

The heating effect by solarization was improved with fertilizer concentration. Dubey (1992) observed that treatment with Bavistin, Dithane M-45 and PCNB enhanced the effectiveness of solarization. Lodha (1995) reported that soil amended with urea (@ 20 kg N/ha) and FYM improved the effectiveness of solarization.

Ridging

Covering ridged field plots with polyethylene sheets easily raised the soil temperature than levelled ones (Horiuchi, 1984). Higher ridges were more effective than lower ones, because higher ridges have greater surface area to receive solar radiation. Chellemi *et al.* (1997) recorded higher soil temperatures, when solarization was performed on a raised bed as opposed to on a flat surface.

Effect of solarization on soil microbes

Covering of moist soil with polyethylene film significantly reduced population densities of several groups of micro-organisms.

Elad *et al.* (1980) observed an increase in the population of *T. harzianum* in solarized soil. Stapleton and DeVay (1984) observed a reduction in the population of fungi immediately after solarization, while thermophilic and thermotolerant fungi like *Aspergillus* spp. and *Penicillium* sp. were less affected or were increased. Similar findings were also observed by Arya and Mathew (1993), Triolo *et al* (1988) and Shukla *et al* (1990).

Greenberger *et al.* (1987) reported that soil solarization has got pronounced effect on microbial activities in soil and may result in increased antagonistic activity.

Tjamos and Paplomatas (1987, 1988) found that soil solarization increased *Talaromyces flavus* and *A. terreus* in soil.

General reduction in fungal population in solarized soil was reported by ICRISAT (1986), Chandran (1989), Kurian (1992), Vilasini (1996) and Mahmoud (1996).

Stapleton and DeVay (1982) found that population densities of *Agrobacterium* spp., flourescent pseudomonads and Gram-positive bacteria were greatly reduced immediately following solarization. Fluorescent pseudomonads got rapidly recolonized in the treated soil, but there was no significant difference among treatments after three to six months. However, *Agrobacterium* spp. and population of Gram-positive bacteria failed to recolonize in the solarized soil even after six to twelve months.

Stapleton and DeVay (1984) observed a twenty fold increase in the colonization of Gram-positive bacteria showing *in vitro* antibiosis against *Geotrichum candidum* in solarized soil.

Ristaino *et al.* (1991) observed a reduction in the population of fluorescent pseudomonas immediately after solarization. Solarization reduced the total bacterial population in the soil (Kurian, 1992; Mahmoud, 1996; Vilasini, 1996).

However, Raio *et al.* (1997) reported that solarization did not consistently affect the population of fluorescent pseudomonas and spore forming bacteria in soil.

Stapleton and DeVay (1982) reported that actinomycetes were sometimes reduced to a much lesser extent (45-58%) or even increased (26-158%) following solarization. Kaewruang *et al.* (1989b) also observed an increase in the total number of actinomycetes by solarization. Chandran (1989) and Kurian (1992) observed a slight increase in the population of actinomycetes in the solarized soil. However, Vilasini (1996) reported that solarization reduced the total actinomycetal population in the soil.

Gamliel and Katan (1991) and Raio *et al* (1997) observed that actinomycete population was less affected by solarization.

Effect of solarization on beneficial micro-organisms

Pullman *et al.* (1981b) reported that *Glomus fasciculatus* survived solarization and colonized the cotton roots after solarization. Stapleton and DeVay (1984) observed no visible difference in the extent of root infections by VAM (*Glomus* spp.) between solarized and non-solarized roots of almond trees. Similar results were also observed by Triolo *et al.* (1988) in lettuce plants.

Nair *et al.* (1990) found 20.0 per cent increase in mycorrhizal colonization in cowpea by 30 days of solarization. Afek *et al.* (1991) noticed that VAM colonization of roots of cotton, onion and pepper was maximum in non-fumigated solarized plots. They also suggested that VAM combined with solarization can be one of the best approach to replace or atleast reduce the use of chemicals in agriculture. According to Kurian (1992) colonization of VAM was more in roots of chilli plants grown in solarized soil. Similar results were also obtained by Vilasini (1996) in ginger plants.

Bendavid-Val *et al.* (1997) reported that solarization reduced root colonization by indigenous AM fungi in onion and carrot. However, solarization did not affect the viability of *Glomus intraradices*.

Solarization caused a four fold reduction in the native rhizobium (ICRISAT, 1985; Abdel-Rahim *et al.*, 1988). While, Nair *et al.* (1990) obtained 104.7 per cent increase in the root nodule count in cowpea grown in solarized field. Ginger plants grown in solarized soil showed better colonization of *Azospirillum* (Vilasini, 1996).

Control of nematodes by solarization

The use of heat as a method of killing nematodes is well established.

The extent of control of nematodes depends upon (1) degree of solar heating; (2) crop and cropping history; (3) nematode taxa involved; (4) nematode distribution in the soil and (5) soil depth (Stapleton and DeVay, 1983).

According to Grinstein *et al.* (1979) population of *Pratylenchus thornei* was markedly reduced by solarization. Siti *et al.* (1982) observed excellent control of *Ditylenchus dipsaci* in garlic crop by soil solarization. Stapleton and DeVay

(1983) observed 42-100.0 per cent reduction in the nematode population by soil solarization.

The major phytophagous nematodes affected by solarization were *Meloidogyne, Heterodera, Pratylenchus, Paratrichodorus, Criconemella, Xiphinema, Helicotylenchus* and *Paratylenchus* (Stapleton and DeVay, 1983, 1986; LaMondia and Brodie, 1984; Katan, 1987; Abdel-Rahim *et al.*, 1988; Gamliel and Stapleton, 1993a; Rao and Krishnappa, 1995; Vilasini, 1996; Chellemi *et al.*, 1997).

Effect of solarization on physical and chemical properties of soil

Soil solarization caused an increase in both nitrate and ammoniacal nitrogen in the soil (Stapleton *et al.*, 1985; Daelmans, 1989; Kaewruang *et al.*, 1989a & b). Hori *et al.* (1979) observed a decline in both nitrate and ammoniacal nitrogen of the soil. Increase in the available nitrogen content of the solarized soil was reported by Chandran (1989), Rao and Krishnappa (1995) and Vilasini (1996).

Stapleton *et al.* (1985) reported an increase in the available phosphorus content in the solarized soil. Similar results were obtained by Kaewruang *et al.* (1989a), Chandran (1989), Rao and Krishnappa (1995) and Vilasini (1996). Whereas, Kurian (1992) observed no change in the phosphorus content of the solarized soil.

Chandran (1989), Kurian (1992), Rao and Krishnappa (1995) and Vilasini (1996) observed increased potassium content of solarized soil.

Solarization increased the calcium and magnesium concentrations of the soil (Chen and Katan, 1980; Stapleton *et al.*, 1985; Kurian, 1992). However, Stapleton *et al.* (1985) reported that solarization did not consistently affect available iron, manganese, zinc, copper and chlorine concentrations in soil.

According to Alkayssi *et al.* (1989) and Kurian (1992), solarization increased the organic carbon content in the soil. While, Stapleton *et al.* (1985) and Vilasini (1996) observed that solarization did not consistently affect the organic matter content of the soil.

Vilasini (1996) observed an increase in the pH of the soil by solarization.

Solarization increased the Electrical conductivity (EC) of the soil (Chen and Katan, 1980; Kurian, 1992) while, Chandran (1989) and Vilasini (1996) observed that EC of the soil was not affected by solarization.

Increased plant growth response by solarization

Solarization of soil, apparently free of known pathogens often results in improved plant growth. Following mechanisms have been suggested to explain the increased growth response of plants in solarized soil.

1. Increased micro and macro elements in the soil;
2. Elimination of minor pathogens or parasites;
3. Destruction of phytotoxic substances in the soil (Katan, 1981b);
4. Release of growth regulatory substances like fulvic acid (Davis and Sorensen, 1986);
5. Stimulation of mycorrhizae and other beneficial organisms (Nair *et al.*, 1990).

Improved plant growth and yield in case of egg plant (Katan *et al.*, 1976), tomato (Katan *et al.*, 1976; Gamliel and Katan, 1992a), onion (Katan *et al.*, 1980, Hartz *et al.*, 1989), sorghum (Pullman *et al.*, 1981b), cotton (Katan *et al.*, 1983), carrot (Stapleton *et al.*, 1987), chickpea (Arora and Pandey, 1989), cowpea (Chandran, 1989; Nair *et al.*, 1990) and chilly (Kurian, 1992) have been reported in solarized soil.

According to Kulkarni (1992), soil solarization increased leaf and root yield of periwinkle. Basallote-Ureba and Melero-Vara (1993) reported that

solarization increased growth response and yield increase of garlic by 40.6-155.5 per cent greater than untreated control.

Increased growth response of ginger plants and significant yield increase were obtained through solarization (Vilasini, 1996). Raj *et al.* (1997) observed 12-18.3 per cent higher seed germination and better seedling vigour of different vegetable crops in solarized soil.

Weed control by solarization

Control of a wide spectrum of weeds is one of the more visible results of solarization. Solarization results in an effective weed control lasting in some cases for whole year or even longer. According to Katan (1981b), the possible mechanisms of weed control are

(a) Direct killing of weed seeds by heat

(b) Indirect microbial killing of seeds weakened by sublethal heating

(c) Thermal killing of seeds induced to germinate

(d) Breaking of seed dormancy and subsequent killing of the germinating seed.

And the role of volatiles in weed control was suggested by Horowitz *et al.* (1983).

Weeds controlled by solarization include *Portulaca oleracea* (Horowitz *et al.*, 1983; Tjamos and Paplomatas, 1988); *Sonchus oleraceus* and *Tribulus terrestris* (Rubin and Benjamin, 1983); *Digitaria ciliaris* (Porter and Merriman, 1983); *Ageratum conyzoides, Alysicarpus* sp., *Alternanthera sessilis, Amaranthus* sp., *Cassia* sp. and *Centrosema* sp. (Chandran, 1989; Kurian, 1992); *Cleome viscosa, Desmodium tridentata, Hemidesmus indicus, Hyptis suaveolens, Indigofera hirsuta, Knoxia* sp. and *Phyllanthus niruri* (Chandran, 1989; Kurian, 1992; Vilasini, 1996) and *Stachytarpheta indica* (Kurian, 1992; Vilasini, 1996).

According to Rubin and Benjamin (1983) and Rao and Krishnappa (1995), perennial weeds which propagate vegetatively were only partially controlled by solarization. Horowitz *et al.* (1983) also suggested that established perennials escaped solarization.

Weeds like *Cynodon dactylon, Cyperus rotundus* were not effectively controlled by solarization (Vilasini, 1996). Chellemi *et al.* (1997) observed significant control of yellow and purple nutsedge with solarization. Bhaskar and Nanjappa (1997) found that soil solarization with transparent polyethylene sheets effectively controlled dicot weeds.

Long term effect of solarization

Katan (1987) observed the long term effect of solarization on disease control and/or yield increase extending for a second crop or even to a third crop in various regions with a variety of pathogens and crops.

Pullman *et al.* (1981b) reported that solarization for four weeks or more resulted in control of *Verticillium* wilt in cotton in two successive crops. Similar results were also obtained by Davis and Sorensen (1986). According to Katan *et al.* (1983), incidence of *Fusarium* wilt of cotton was significantly lower in the third year after solarization.

Effect of solarization lasted for the second season and the damping off of lupin was less in solarized plots (Osman *et al.*, 1986).

Tjamos and Paplomatas (1987, 1988) reported that beneficial effect of solarization in globe artichoke and olive trees lasted for two to three years. The long term effect of solarization in reducing corky root disease of tomato and broom rape control was reported by Abdel-Rahim *et al.* (1988).

Long term effect of solarization for the control of *R. necatrix* in apple lasted up to three years (Freeman *et al.*, 1990). Gamliel *et al.* (1993) observed the long term effect of solarization on yield increase in *Gypsophila paniculata* over two to five successive crop cycles.

However, the long term effect of solarization in reducing pre and post-emergence rotting in ginger was not observed by Vilasini (1996).

Integrated management of *P. capsici* in black pepper

Phytophthora foot rot being a major soil-borne disease of black pepper, an integrated approach involving cultural, chemical and biological control are followed, in addition to development of disease resistance.

Sarma *et al.* (1994) and Anandaraj and Sarma (1995, 1998) suggested integrated management as the only answer to manage the *Phytophthora* infections in black pepper. They suggested spraying of Bordeaux mixture (1%) during June and August-September and soil drenching with copper oxychloride (0.2%) and foliar spray of Ridomil / Potassium phosphonate (0.3%) during the monsoon period and application of biocontrol agents such as *Trichoderma*, *Gliocladium* and VAM to prevent population build up of the pathogen along with phytosanitation measures.

According to Anandaraj and Sarma (1995), and integrated approach should be followed from the nursery to manage *Phytophthora* infection. They suggested solarization of the nursery mixture and incorporation of VAM and biocontrol agents such as *Trichoderma* and *Gliocladium* in the nursery mixture to produce disease free planting material. Sarma *et al.* (1996) found that solarized nursery mixture when fortified with VAM propagules and *Trichoderma* and *Gliocladium* mixtures ensured healthy and robust rooted cuttings in the nursery.

MATERIALS AND METHODS

MATERIALS AND METHODS

Location

The present study "Integrated management of *Phytophthora* rot in black pepper nursery", was conducted at the Department of Plant Pathology, College of Horticulture, Vellanikkara during January 1998 to August 1998. Field trial was carried out at the experimental plot of the Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara, located at an altitude of 22.5 m above MSL, between 10°32'N latitude and 76°16'E longitude. The area enjoys a warm humid tropical climate.

Isolation and purification of the pathogen

The pathogen, *Phytophthora capsici* Leonian, emend. Alizadeh and Tsao, causing *Phytophthora* rot of black pepper, used for the study was isolated from the naturally infected plants using standard isolation technique (Riker and Riker, 1936) and purified by hyphal tip method.

The pure culture of the fungus was maintained in potato dextrose agar medium. Koch's postulates were established using the isolate, on Panniyur-1 variety of pepper.

Nursery experiment

An experiment was carried out to study the effectiveness of soil solarization and efficacy of selected antagonists viz. *Trichoderma viride* and *T. harzianum* for the control of *Phytophthora* rot in the black pepper nursery.

The experiment was laid out in the pepper nursery during January 1998. The details are as follows.

Variety	- Panniyur-1
Design	- CRD
Treatments	- 19
Replications	- 6
Number of bags/replication	- 5
Number of plants/bag	- 5

Treatments

T_1 - Soil solarization for 30 days

T_2 - Soil solarization for 45 days

T_3 - *Trichoderma viride* alone

T_4 - *Trichoderma harzianum* alone

T_5 - Soil solarization for 30 days + *T. viride*

T_6 - Soil solarization for 30 days + *T. harzianum*

T_7 - Soil solarization for 45 days + *T. viride*

T_8 - Soil solarization for 45 days + *T. harzianum*

T_9 - Fytolan (copper oxychloride @0.3%) drenching at one month after planting

T_{10} - Soil solarization for 30 days + Fytolan (0.3%) drenching at one month after planting

T_{11} - Soil solarization for 45 days + Fytolan (0.3%) drenching at one month after planting

T_{12} - *T. viride* + Fytolan (0.3%) drenching at one month after planting

T_{13} - *T. harzianum* + Fytolan (0.3%) drenching at one month after planting

T_{14} - Soil solarization for 30 days + *T. viride* + Fytolan (0.3%) drenching at one month after planting

T_{15} - Soil solarization for 30 days + *T. harzianum* + Fytolan (0.3%) drenching at one month after planting

T_{16} - Soil solarization for 45 days + *T. viride* + Fytolan (0.3%) drenching at one month after planting

T_{17} - Soil solarization for 45 days + *T. harzianum* + Fytolan (0.3%) drenching at one month after planting

T_{18} - Control (non-solarized, *Phytophthora* inoculated soil)

T_{19} - Absolute control

Mass multiplication of the pathogen and antagonists

a. Mass multiplication of *P. capsici*

The pathogen *P. capsici* was mass multiplied on sand oats medium, sterilized rice grains, sterilized hulled red rice and potato dextrose agar medium.

Sand oats medium

Sand oats medium was prepared by mixing washed white sand with oat meal in the ratio 19:1. This mixture was moistened with water and then taken in 500 ml conical flasks and sterilized by autoclaving at 1.02 kg cm^{-2} pressure for 20 minutes. Actively growing culture bits of *P. capsici* were aseptically transferred into the flasks containing sterilized sand oats medium and were incubated for two weeks at room temperature (28±2°C) before incorporating in the potting mixture.

Rice grains

Fifty grams of rice grains with 25 ml of water were taken in 250 ml conical flasks and sterilized by autoclaving at 1.02 kg cm^{-2} pressure for 20 minutes. These flasks were inoculated with actively growing culture bits of *P. capsici* and incubated at room temperature for two weeks and was used for the inoculation of potting mixture.

Hulled red rice

Fifty grams of hulled red rice with 50 ml water were taken in 250 ml conical flasks and sterilized by autoclaving at 1.02 kg cm^{-2} pressure for 20 minutes. Actively growing culture bits of *P. capsici* was aseptically transferred into the flasks

with sterilized red rice and were incubated at room temperature for two weeks. This was used for inoculation of potting mixture.

Potato dextrose agar

Fifteen-day-old culture of *P. capsici* grown on potato dextrose agar was mixed with soil at the rate of ten culture plates (9 cm diameter) per kg of soil. The soil after mixing with the culture was sieved twice in order to get uniform distribution of the pathogen.

b. Mass multiplication of *T. viride* and *T. harzianum*

T. viride and *T. harzianum* available in the Department of Plant Pathology, College of Horticulture, Vellanikkara were used for this study. Antagonistic property of *T.viride* and *T. harzianum* were tested under laboratory conditions. These organisms were mass multiplied on sterilized rice bran (Henis *et al.*, 1979).

Preparation of potting mixture

The potting mixture was prepared by mixing garden soil, sand and dried powdered cowdung in the ratio 1:1:1.

Inoculation of potting mixture with *P. capsici*

For the inoculation of potting mixture, the fungus *P. capsici,* grown on sand oats medium, rice grains, hulled red rice and potato dextrose agar were used. All the four types of inocula obtained from the above media were mixed thoroughly and applied in the potting mixture. After incorporating the pathogen, the potting mixture was mixed well and watered. Soil inoculation was carried out on the same day of mulching with polyethylene sheets in solarized as well as non-solarized potting mixture.

Mulching with polyethylene sheet

The potting mixture was solarized on the same day after inoculation with *P. capsici*. The potting mixture was made into a raised bed of height 25 cm and size 3 x 1 m. The bed was levelled and watered with a rose can. The potting mixture was then mulched with 150 gauge transparent polyethylene sheet as shown in Fig.1. The sides of the sheet were covered with soil to keep the sheet in position. Adequate care was taken to keep the sheet in close contact with the soil to prevent formation of air pockets between potting mixture and the sheet. The polyethylene sheets were removed 30 and 45 days after mulching depending on the treatment.

Soil temperature

Soil temperatures of solarized and non solarized soil at a depth of 10 cm were recorded. For recording temperature, soil thermometers were installed in the centre of the bed at a depth of 10 cm. In solarized bed, the hole made for inserting the thermometer was perfectly sealed with cellophane tape. Soil temperatures were recorded daily at 8.30 am and 2.30 pm.

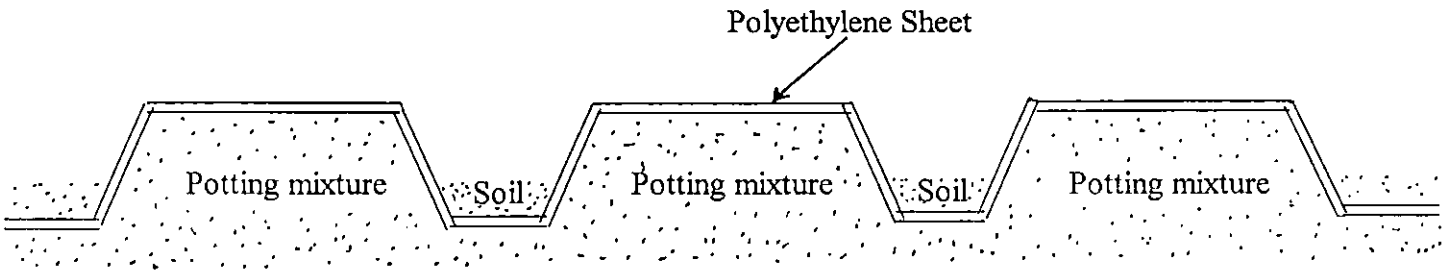
Soil inoculation with *T. viride* and *T. harzianum*

Five grams of *T. viride* or *T. harzianum* grown on rice bran were incorporated into potting mixture in a polyethylene bag (10 x 15 cm) requiring its inoculation, just before planting.

Soil application of Fytolan

Fytolan (0.3% @500 ml per bag) was drenched into the polyethylene bags, at one month after planting, as per the treatment.

Fig.1. Potting mixture mulched with polyethylene sheet



Planting

Planting material of pepper variety Panniyur-1 obtained from the pepper garden of the Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara was used for the study. Polyethylene sheets were removed from the potting mixture 30 or 45 days after mulching according to the treatment and the potting mixture was moistened, mixed well and then used for filling in polyethylene bags. Polyethylene bags of size 10 x 15 cm were used for filling the potting mixture. Five numbers of two noded cuttings of pepper were planted in each polyethylene bag. All the agricultural operations were carried out as per the Package of Practices Recommendations, 'Crops' 1996 (KAU, 1996).

Sprouting

The number of cuttings sprouted in each treatment was counted up to 60 days after planting to calculate the sprouting percentage.

Disease incidence

Per cent mortality of non-sprouted cuttings

The non-sprouted dead cuttings were carefully removed from the polyethylene bags and the association of *P. capsici* with these cuttings was established by isolating the causal organism. The per cent mortality due to the pathogen was calculated using the formula

$$\text{Per cent mortality} = \frac{\text{Number of non-sprouted dead cuttings due to } \textit{P. capsici}}{\text{Number of cuttings planted}} \times 100$$

Percentage mortality of rooted cuttings

Observations on the number of dead rooted cuttings were recorded at weekly intervals and the per cent mortality was calculated. The association of

P. capsici with dead rooted cuttings was confirmed by isolating the pathogen in potato dextrose agar.

Percentage disease incidence of rooted cuttings

The percentage incidence of *Phytophthora* rot in nursery was recorded at weekly intervals. The identity of the causal agent was established by isolating the pathogen from infected plant parts. The percentage of disease incidence was calculated by the formula:

$$\text{Per cent disease incidence} = \frac{\text{Number of cuttings infected}}{\text{Total number of cuttings}} \times 100$$

Biometric observations

Five plants were randomly tagged in each replication of different treatments for recording the biometric observations. Observations from these plants were taken at monthly intervals.

Height of the plant

Distance from the base of the cutting to the growing point was taken as the height of the plant.

Number of leaves per plant

Number of leaves was recorded by counting the number of fully opened leaves of the plant.

Length and breadth of the leaf

Length and breadth of the last fully opened leaf were recorded. Length was measured as the distance between the base of the petiole to the tip of the leaf. While, the breadth was taken at the centre of the leaf.

Number and length of roots

Number and length of roots were recorded by uprooting the plants after five months of planting. The cuttings were carefully uprooted from the polyethylene bags and the roots were washed gently in tap water to remove the adhering soil particles. The total number of roots produced by the plants was recorded separately and their mean was calculated. Five roots were selected at random from each plant for measuring the root length.

Laboratory studies

Collection of soil samples

Soil samples were collected from all the polyethylene bags in a replication and were mixed well. This was used for the estimation of microbial population and for chemical analysis.

Estimation of *Phytophthora* population

Phytophthora capsici population from the soil samples was estimated by serial dilution plate technique (Johnson and curl, 1972). Corn meal agar PVPH selective medium (Tsao and Guy, 1977) was used for estimating the *Phytophthora* population. Population of *P. capsici* was estimated before mulching, immediately after mulching and at fortnightly intervals for five months.

Estimation of *Trichoderma* spp. population

Population of *Trichoderma* from the soil was estimated by serial dilution plate technique using Martin's rose bengal streptomycin agar medium. *Trichoderma* population was estimated before mulching, after removing polyethylene sheets and at monthly intervals for five months.

Estimation of total microflora

Population of fungi, bacteria and actinomycetes from the soil samples was estimated by serial dilution plate technique. Martin's rose bengal streptomycin agar, Thornton's standardized agar medium and Kenknights agar were used for estimating fungi, bacteria and actino mycetes respectively. Microbial population was estimated before mulching, immediately after removal of polyethylene sheet and at monthly intervals for five months.

Estimation of VA Mycorrhizae colonization

The VAM colonization was estimated by observing 100 root bits at random, of approximately one centimetre length from each treatment at five months after planting. The root bits were stained with 0.5 per cent trypan blue following the procedure by Phillips and Hayman (1970) and the per cent colonization was calculated.

Estimation of *Azospirillum* association

Azospirillum was isolated from the root samples of pepper cuttings using Nitrogen free Bromothymol blue (NFb) semi solid medium according to the procedure of Dobereiner *et al.* (1976) at five months after planting.

Chemical analysis of soil sample

To find out the effect of solarization on the nutrient status of the potting mixture, major plant nutrients viz., available nitrogen, available phosphorus and available potassium were estimated before and after solarization.

Nitrogen

Available nitrogen was estimated by alkaline permanganate distillation (Subbiah and Asija, 1956).

Phosphorus

Available phosphorus in the potting mixture was extracted using Bray extractant No.1 (Bray and Kurtz, 1945) and estimated by ascorbic acid blue colour method (Watnabe and Oleson, 1965). The intensity of blue colour was measured by spectrophotometer.

Potassium

Available potassium was estimated by extraction with neutral normal ammonium acetate (1:5) and using flame photometer (Jackson, 1958).

Weed population

Weeds present in the polyethylene bags were counted at monthly intervals. All the weeds present in the polyethylene bags were removed after recording the weed count.

Meteorological data

Atmospheric temperature, sunshine hours and rainfall during the period of solarization were collected from the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara.

Statistical analysis

Data related to this experiment were statistically analysed as described by Panse and Sukhatme (1978).

RESULTS

Isolation of the pathogen

The pathogen causing *Phytophthora* foot rot in black pepper was isolated from the naturally infected pepper plants. The isolate was purified by hyphal tip method and maintained in potato dextrose agar slants by periodic subculturing. Koch's postulates were confirmed on black pepper variety Panniyur-1. Based on the morphological characters, the fungus causing *Phytophthora* foot rot in black pepper was identified as *Phytophthora capsici* Leonian, emend. Alizadeh and Tsao

Temperature

Temperatures of the solarized and non-solarized potting mixture were recorded during the entire period of soil solarization by installing soil thermometers at 10 cm depth.

Atmospheric temperature, soil temperatures at 8.30 am and 2.30 pm and sunshine hours from the date of mulching to the last day of solarization are presented in the Table 1. After mulching, heat build up occurred within 24-48 h in the solarized potting mixture.

The atmospheric temperature during the period (17-1-98 to 2-3-98) ranged from 21.6°C to 35.8°C. There was considerable difference between soil temperature in the solarized and non-solarized potting mixture. The soil temperature in the solarized potting mixture was always higher than that of the non-solarized. During the period of solarization, the soil temperature ranged from 30.0 to 51.0°C in the solarized potting mixture and 26.5 to 42.0°C in non-solarized potting mixture. The variation in the soil temperature in the non-solarized potting mixture was 15.5°C while, in solarized potting mixture it was 21°C. The corresponding variation in the atmospheric temperature was 14.2°C.

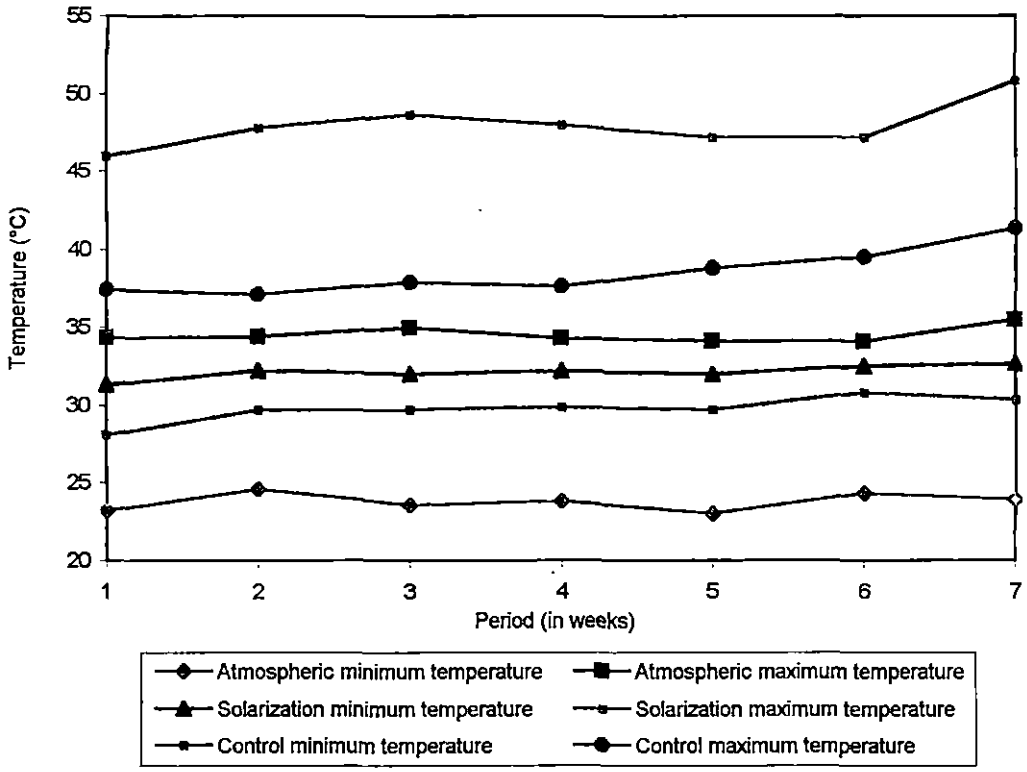
Table 1. Maximum and minimum atmospheric temperature, soil temperature, rainfall and sunshine hours during the solarization period (17-1-98 to 2-3-98)

Date	Atmospheric temperature ° C		Soil temperature °C at 10 cm depth				Rainfall (mm)	Sunshine (h)
			Solarized soil		Non solarized soil			
	Minimum	Maximum	8.30 am	2.30 pm	8.30 am	2.30 pm		
17-1-98	22.8	32.8	30.0	43.5	26.5	36.5	0	8.7
18-1-98	22.8	34.2	30.5	44.5	27.0	37.0	0	9.2
19-1-98	22.8	34.8	31.0	46.0	27.5	37.5	0	9.9
20-1-98	22.8	34.8	31.5	47.0	28.0	38.0	0	9.9
21-1-98	23.2	33.8	32.0	47.5	28.5	37.5	0	10.1
22-1-98	23.4	34.5	32.0	45.5	29.0	37.0	0	9.4
23-1-98	24.4	35.0	32.0	47.5	29.5	38.0	0	9.8
24-1-98	25.0	34.5	32.5	47.0	29.0	37.5	0	10.0
25-1-98	24.6	33.5	32.5	47.5	30.0	35.5	0	8.1
26-1-98	24.2	34.0	31.5	48.0	29.0	37.5	0	10.4
27-1-98	23.6	34.4	32.0	48.0	29.5	37.5	0	10.1
28-1-98	25.1	34.8	32.5	46.5	30.0	36.5	0	10.0
29-1-98	24.7	34.7	32.0	48.5	30.0	37.5	0	10.9
30-1-98	24.8	34.6	32.5	49.0	30.0	37.5	0	10.9
31-1-98	24.7	34.5	33.5	48.0	30.5	37.5	0	10.8
1-2-98	25.0	34.2	32.5	48.0	30.5	37.5	0	10.5
2-2-98	24.6	34.5	32.0	48.5	30.0	38.0	0	10.4
3-2-98	23.5	35.2	31.5	49.0	29.5	38.5	0	10.0
4-2-98	22.8	35.6	31.5	49.0	29.0	37.5	0	10.3
5-2-98	22.7	35.7	31.5	49.0	30.0	38.0	0	10.5
6-2-98	21.7	35.0	31.5	49.0	28.5	38.0	0	10.0
7-2-98	22.5	33.8	32.5	45.0	29.0	37.0	0	8.0
8-2-98	21.6	34.5	31.0	49.0	29.0	38.0	0	10.0
9-2-98	23.4	34.6	32.0	48.0	29.0	37.5	0	10.0
10-2-98	26.0	34.3	32.5	48.5	30.5	37.5	0	10.4
11-2-98	25.2	34.5	32.5	48.5	30.5	37.5	0	10.4
12-2-98	24.2	33.5	32.5	48.5	30.5	38.0	0	10.5
13-2-98	23.6	34.9	32.5	48.5	30.5	38.0	0	10.3
14-2-98	24.2	34.9	32.5	49.0	30.5	38.5	0	9.4
15-2-98	23.2	34.8	32.5	48.5	29.5	41.0	0	10.0
16-2-98	22.0	35.0	32.5	48.5	29.5	39.0	0	10.1
17-2-98	22.9	33.9	32.0	43.0	29.0	37.0	0	8.5
18-2-98	23.5	31.6	31.5	43.0	30.0	36.5	0	5.8
19-2-98	23.5	33.2	31.5	49.0	30.0	39.5	0	9.8
20-2-98	21.8	35.4	31.5	49.5	29.5	40.0	0	10.5
21-2-98	25.6	32.6	34.0	43.5	31.0	37.0	0	6.8
22-2-98	22.0	33.6	31.0	48.5	29.5	41.0	0	10.5
23-2-98	22.1	33.4	31.5	47.0	29.5	39.0	0	10.0
24-2-98	25.4	34.2	33.0	46.0	31.5	39.0	0	7.6
25-2-98	25.7	35.2	32.5	48.5	31.0	40.0	0	9.0
26-2-98	24.8	34.5	32.5	47.0	31.5	39.5	0	9.4
27-2-98	24.6	35.0	33.0	50.0	31.5	41.0	0	9.7
28-2-98	23.7	35.0	32.5	50.5	29.5	41.5	0	10.5
1-3-98	23.6	35.6	32.5	51.0	30.0	42.0	0	9.9
2-3-98	24.3	35.8	33.0	51.0	31.5	40.5	0	9.2

Table 2. Atmospheric temperature, soil temperature, rainfall and sunshine hours during the solarization period (weekly mean)

Date	Atmospheric temperature ° C		Soil temperature °C at 10 cm depth				Rainfall (mm)	Sunshine (h)
			Solarized soil		Non solarized soil			
	Minimum	Maximum	8.30 am	2.30 pm	8.30 am	2.30 pm		
1	23.17	34.27	31.29	45.93	28.00	37.36	0	9.57
2	24.57	34.36	32.21	47.79	29.64	37.07	0	10.06
3	23.57	34.96	32.00	48.64	29.71	37.86	0	10.36
4	23.79	34.30	32.21	48.00	29.86	37.64	0	9.94
5	23.01	34.11	32.0	47.21	29.71	38.79	0	9.16
6	24.31	34.07	32.50	47.21	30.79	39.50	0	9.00
7	23.87	35.47	32.67	50.83	30.33	41.33	0	9.87
Mean	23.76	34.51	32.13	47.94	29.72	38.51	0	9.71

Fig.2. Atmospheric and soil temperature during the solarization period (weekly mean)



Maximum temperature variation observed during a day in solarized potting mixture was 18.5°C (on 1-3-98) compared to 12°C (on 28-2-98 and 1-3-98) in non-solarized potting mixture. The minimum daily variation in solarized and non-solarized potting mixtures were 9.5°C (on 21-2-1998) and 5.5°C (on 25-1-98) respectively (Table 1).

The maximum temperature (at 2.30 pm) in the non-solarized potting mixture ranged from 35.5°C to 42.0°C compared to 43.0°C to 51.0°C in solarized potting mixture. Similarly, the temperature at 8.30 am ranged from 26.5°C to 31.5°C in non-solarized compared to 30.0°C to 34.0°C in solarized potting mixture.

In the solarized potting mixture, the maximum temperature of 51.0°C was recorded on 1-3-98 and 2-3-98. It was 9.0°C higher than that of the non-solarized potting mixture and 15.4°C higher than the atmospheric temperature on 1-3-98 while, it was 10.5°C higher than the temperature of non-solarized potting mixture and 15.2°C higher than the atmospheric temperature on 2-3-98. During the course of the study the maximum temperature difference at 2.30 pm between solarized and non-solarized potting mixture was 12.0°C on 25-1-1998 and the minimum difference was 6.0°C on 17-2-1998. However, the minimum temperature variation in solarized and non-solarized potting mixture at 8.30 am were 3.5°C (7-2-1998) and 1°C (26-2-1998) respectively.

The maximum soil temperature in solarized potting mixture was above 40.0°C for the entire period of solarization and above 45.0°C for 40 days and above 50.0°C for four days. While, in non-solarized soil the temperature was above 40.0°C for only eight days and the maximum temperature reached was only 42.0°C.

The weekly average temperature of the solarized potting mixture during the period of solarization ranged from 31.29 to 50.83°C. The corresponding values in the non-solarized potting mixture were 28.0°C to 41.33°C (Table 2 and Fig.2). The weekly average atmospheric temperature during the period ranged from 23.01

to 35.47°C. The temperature fluctuation in the weekly average atmospheric temperature (at 2.30 pm) was only 1.4°C, while, this fluctuation in the solarized soil was 4.9°C, and in the non-solarized potting mixture it was 4.26°C.

The weekly average maximum temperature at 2.30 pm in solarized potting mixture ranged from 45.93°C to 50.83°C with a mean of 47.94°C. The corresponding values in non-solarized potting mixture were 37.07 to 41.33°C and 38.51°C respectively. In solarized potting mixture the average weekly mean temperature difference was 15.81°C (32.13 to 47.94°C) and it was 8.79°C (29.72-38.51°C) in non-solarized potting mixture.

The sunshine hours during the period ranged from 5.8 to 10.9 h (Table 1). There was no rain during the solarization period.

Influence of solarization on the sprouting of pepper cuttings

The number of sprouted pepper cuttings in each treatment was counted upto 60 days of planting for recording the percentage of sprouting. In general, solarization increased the rate of sprouting of pepper cuttings (Table 3 and Fig.3). There was considerable variation in the rate of sprouting of pepper cuttings among solarized and non-solarized treatments. Maximum sprouting (76.67%) was recorded in the treatment, which received 30 days solarization and *T. harzianum*, which was significantly superior to all the non-solarized treatments. Among the solarized treatments, least sprouting (68.0%) was observed in 30 days solarized control. However, there was no significant difference in the sprouting between 30 and 45 days of solarization. In the non-solarized treatments, sprouting per cent of pepper was less than 61 per cent.

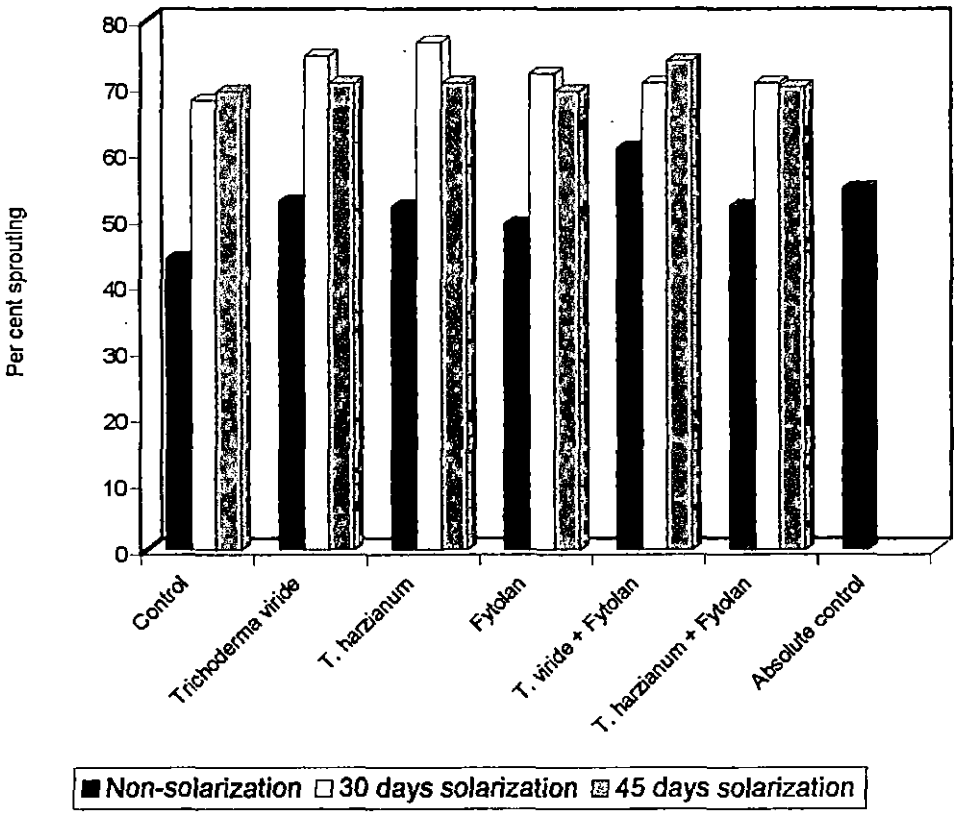
Among the non-solarized treatments, maximum sprouting (60.67%) was recorded in *T. viride* incorporated Fytolan drenched treatment (Table 3). While, the minimum sprouting (44.0%) was observed in non-solarized control. In general, the

Table 3. Influence of solarization on the sprouting of pepper cuttings

Treatments	Per cent sprouting		
	Non - solarization	Solarization	
		30 days	45 days
Control	44.00^{d}	68.00^{ab}	69.33^{ab}
Trichoderma viride	52.67^{cd}	74.67^{a}	70.67^{ab}
Trichoderma harzianum	52.00^{cd}	76.67^{a}	70.67^{ab}
Fytolan	49.33^{cd}	72.00^{ab}	69.33^{ab}
Trichoderma viride + Fytolan	60.67^{bc}	70.67^{ab}	74.00^{a}
Trichoderma harzianum + Fytolan	52.00^{cd}	70.67^{ab}	70.00^{ab}
Absolute control	54.67^{cd}		

Values having different superscripts differ significantly at 5% level

Fig.3. Influence of solarization on the sprouting of pepper cuttings



Trichoderma incorporated treatments recorded higher sprouting. Absolute control had 54.67 per cent sprouting.

Effect of solarization on mortality of pre-sprouted pepper cuttings due to *P. capsici*

The effect of the different treatments on the mortality of pre-sprouted pepper cuttings was recorded and the data are presented in Table 4 and Fig.4. The pre-sprouted dead cuttings were carefully removed from the polyethylene bags and examined for the presence of *P. capsici.*

There was considerable variation in the rate of the mortality of non-sprouted pepper cuttings among solarized and non-solarized treatments (Table 4). Solarization was highly effective in reducing pre-sprouting mortality.

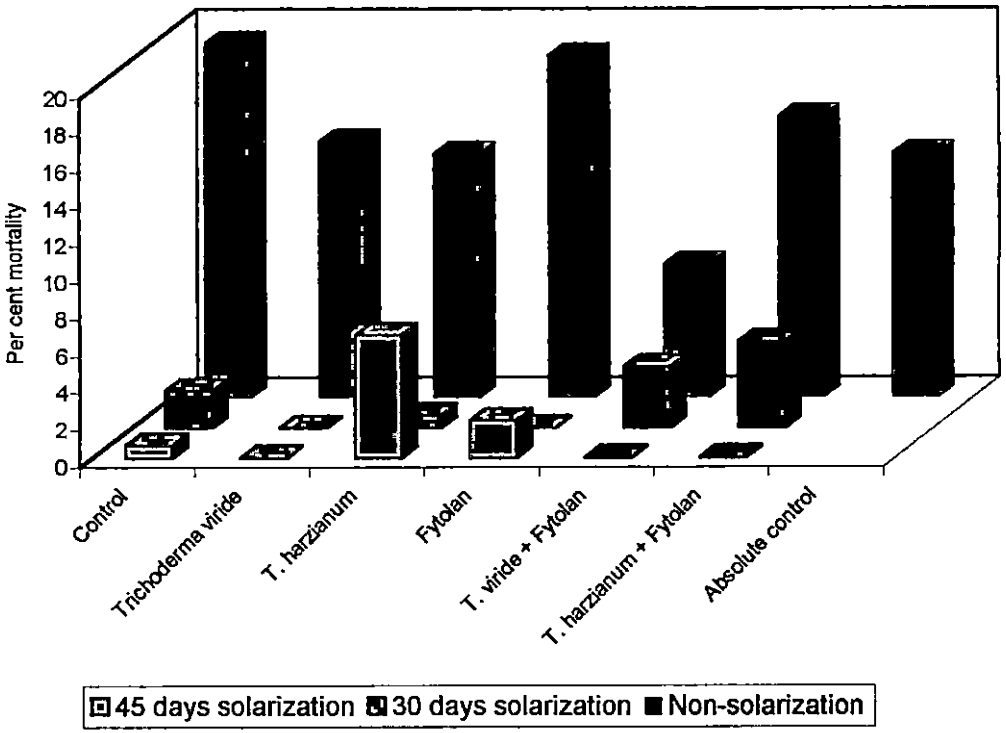
Mortality of pre-sprouted pepper cuttings was less than 7.0 per cent in all the solarized treatments. Both 30 and 45 days solarized, *T. viride* incorporated treatments, 30 days solarized Fytolan drenched one and 45 days solarized antagonist incorporated and Fytolan drenched treatments were highly effective in reducing the mortality of the pre-sprouted pepper cuttings and recorded complete control. Among the solarized treatments, maximum pre-sprouting mortality (6.67%) was observed in 45 days solarized *T. harzianum* incorporated treatment (Table 4). Whereas, the treatment which received 30 days solarization and *T. harzianum* recorded only 0.67 per cent mortality of pepper cuttings. The per cent pre-sprouting mortality of pepper cuttings was 2.0 and 0.67 respectively in 30 and 45 days solarized controls.

Pre-sprouting mortality of pepper cuttings ranged from 7.33 to 19.33 per cent in all the non-solarized treatments (Table 4). Maximum mortality was recorded in control (19.33%) followed by Fytolan drenched (18.67%) potting mixture. Minimum mortality of 7.33 per cent was observed in the treatment which received *T. viride* and Fytolan drenching.

Table 4. Effect of solarization on mortality of pre-sprouted pepper cuttings due to *P. capsici*

Treatments	Per cent mortality		
	Non solarization	Solarization	
		30 days	45 days
Control	19.33	2.00	0.67
Trichoderma viride	14.00	0	0
Trichoderma harzianum	13.33	0.67	6.67
Fytolan	18.67	0	2
Trichoderma viride + Fytolan	7.33	3.33	0
Trichoderma harzianum + Fytolan	15.33	4.67	0
Absolute control	13.33		

Fig.4. Effect of solarization on mortality of pre-sprouted pepper cuttings due to *P. capsici*



Pre-sprouting mortality of pepper cuttings in the absolute control was 13.33 per cent.

Effect of solarization on the mortality of rooted cuttings of pepper due to *P.capsici*

The effect of soil solarization on the mortality of the rooted cuttings of pepper was recorded daily and the data are presented in Table 5 and Fig.5.

Solarization was highly effective in reducing the mortality of the rooted cuttings due to *P. capsici.* Considerable variation in the mortality was observed between the solarized and non-solarized treatments.

In the non-solarized treatments, per cent mortality of the rooted cuttings ranged from 8.4 to 23.46. Non-solarized control recorded the highest mortality (23.46%).

Solarization for both 30 and 45 days was effective in reducing the mortality of the rooted cuttings of pepper. In all the solarized treatments, mortality of cuttings due to *P. capsici* was less than 9.0 per cent. Among the solarized treatments, 45 days solarized, *T. viride* incorporated, Fytolan drenched treatment was highly significant, which recorded cent per cent control. Compared to 30 days solarization, 45 days solarization was more effective.

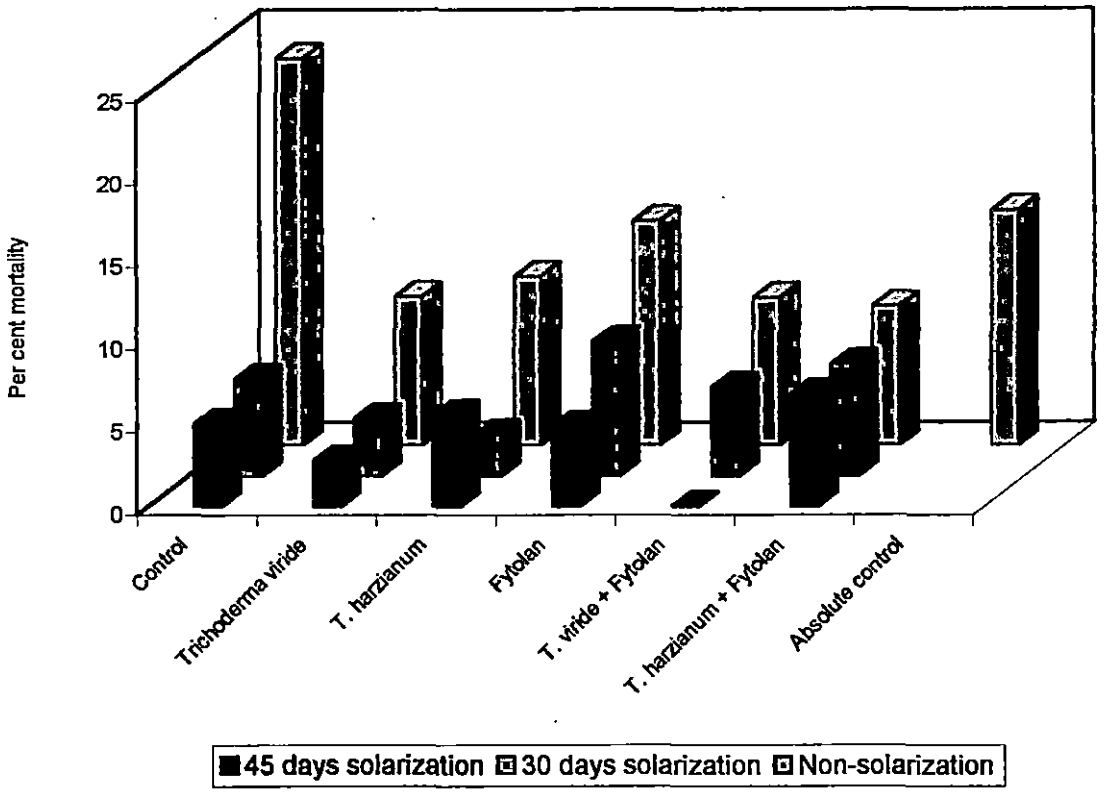
In 45 days solarized treatments, mortality ranged from zero to 6.81 per cent compared to 2.51 to 8.10 per cent in 30 days solarization. Among the solarized treatments, maximum mortality was observed in 30 days solarized Fytolan drenched treatment (8.1%). A mortality of 14.19 per cent was recorded in absolute control.

Table 5. Effect of solarization on mortality of rooted pepper cuttings due to *P. capsici*

Treatments	Per cent mortality		
	Non solarization	Solarization	
		30 days	45 days
	NS	30 S	45 S
Control	23.46^{a}	5.87^{bcd}	5.02^{bcd}
Trichoderma viride	8.99^{abcd}	3.48^{bcd}	2.78^{d}
Trichoderma harzianum	10.21^{abcd}	2.51^{cd}	5.57^{bcd}
Fytolan	13.56^{ab}	8.10^{abcd}	4.85^{bcd}
Trichoderma viride + Fytolan	8.90^{abcd}	5.36^{bcd}	0
Trichoderma harzianum + Fytolan	8.40^{abcd}	6.74^{abcd}	6.81^{abcd}
Absolute control	14.19^{abc}		

Values having different superscripts differ significantly at 5% level

Fig.5. Effect of solarization on morality of rooted pepper cuttings due to *P. capsici*



Effect of solarization on the incidence of foot rot disease (foliar infection) in black pepper nursery

Data on the incidence of foot rot disease incited by *P. capsici* in the nursery of black pepper are presented in Table 6 and Fig.6.

Solarization was highly effective in controlling the foot rot incidence in the nursery. Disease incidence was first noticed in the nursery during the seventh fortnight after planting and continued up to twelfth fortnight after planting. The disease incidence was severe during eighth and ninth fortnights after planting.

Among the non-solarized treatments maximum disease incidence was recorded in the non-solarized control during the entire period of observation. Antagonists incorporated, Fytolan drenched non-solarized treatments recorded minimum foliar infection by *P. capsici* during the entire period.

In the non-solarized control, a disease incidence of 27.51 per cent was recorded during the seventh fortnight and this gradually increased to 36.33, 51.90, 62.18 and 69.82 per cent during eighth, ninth, tenth and eleventh fortnights. During the twelfth fortnight further increase in the disease was observed only in non-solarized treatments and 45 days solarized control. The non-solarized control recorded a maximum incidence of 87.58 per cent during the twelfth fortnight. A similar trend was observed in all the other treatments. During the twelfth fortnight, *T. viride* incorporated Fytolan drenched treatment had the minimum disease incidence (21.69%).

In 30 days solarized control, 1.11 per cent foliar infection was recorded during the seventh fortnight and it increased to 11.75 per cent during the eleventh fortnight and there was no further increase. This treatment was significantly superior to non-solarized control (Table 6). There was no significant difference among the 30 days solarized treatments. In 30 days solarized treatments, *T. harzianum* inoculation was found to be effective in reducing the foliar infection. First incidence of 1.8 per

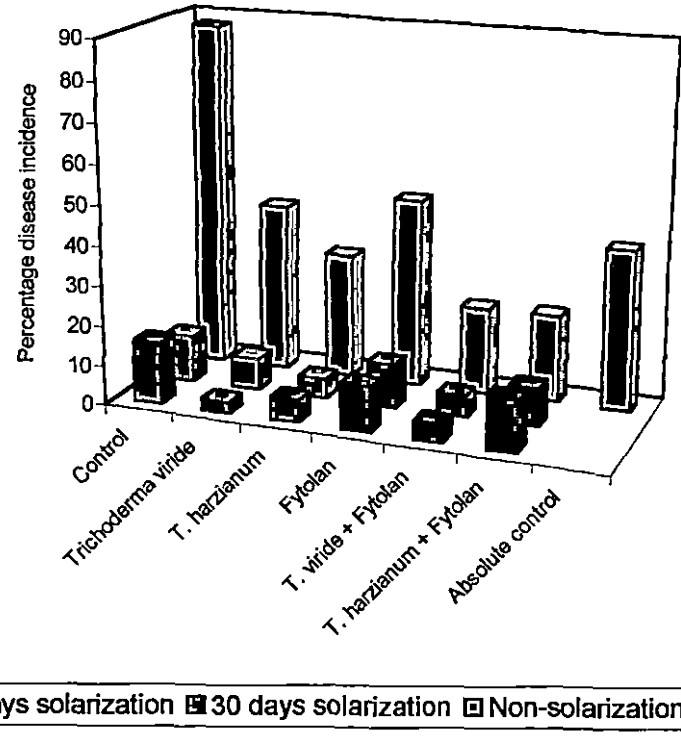
Table 6. Effect of solarization on the incidence of foot rot disease in black pepper nursery (Disease incidence at fortnightly intervals)

Treatments	Per cent incidence								
	7th fortnight			8th fortnight			9th fortnight		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	27.51	1.11	1.96	36.33 ^{a}	10.08 ^{abcdef}	7.74 ^{cdefg}	51.90 ^{a}	10.82 ^{bcdef}	13.52 ^{abcdef}
Trichoderma viride	18.39	0	0	27.53 ^{ab}	6.28 ^{defg}	0.93 ^{g}	32.87 ^{ab}	7.16 ^{defg}	1.85 ^{g}
Trichoderma harzianum	12.16	1.80	0.88	23.49 ^{abcd}	3.33 ^{defg}	4.53 ^{fg}	27.56 ^{abc}	4.86 ^{defg}	5.51 ^{fg}
Fytolan	17.08	0	1.80	23.14 ^{abc}	7.17 ^{cdefg}	3.66 ^{efg}	34.00 ^{ab}	10.97 ^{cdefg}	11.34 ^{bcdef}
Trichoderma viride + Fytolan	5.34	0	0	11.90 ^{abcdef}	2.68 ^{fg}	2.82 ^{fg}	15.70 ^{abcde}	5.31 ^{fg}	3.71 ^{efg}
Trichoderma harzianum + Fytolan	4.62	0	0	10.90 ^{bcdefg}	5.70 ^{defg}	7.98 ^{cdefg}	15.34 ^{cdefg}	6.53 ^{efg}	11.51 ^{bcdef}
Absolute control	7.99			19.91 ^{abcde}			29.41 ^{abcd}		

Treatments	Per cent incidence								
	10th fortnight			11th fortnight			12th fortnight		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	62.18 ^{a}	10.82 ^{cdef}	13.52 ^{bcdef}	69.82 ^{a}	11.75 ^{cdef}	13.52 ^{bcdef}	87.58 ^{a}	11.75 ^{defg}	15.54 ^{bcdef}
Trichoderma viride	35.67 ^{ab}	8.03 ^{efg}	2.78 ^{g}	38.62 ^{ab}	8.03 ^{efg}	2.78 ^{g}	42.51 ^{ab}	8.03 ^{efgh}	2.78 ^{h}
Trichoderma harzianum	27.56 ^{abcd}	4.86 ^{fg}	5.51 ^{fg}	30.06 ^{abcd}	4.86 ^{fg}	5.51 ^{fg}	31.45 ^{abcd}	4.86 ^{fgh}	5.51 ^{gh}
Fytolan	35.19 ^{ab}	10.97 ^{defg}	11.34 ^{cdef}	44.71 ^{ab}	10.97 ^{defg}	11.34 ^{cdef}	47.50 ^{ab}	10.97 ^{defgh}	11.34 ^{defg}
Trichoderma viride + Fytolan	20.76 ^{abcde}	5.31 ^{fg}	4.53 ^{fg}	20.76 ^{abcde}	5.31 ^{fg}	4.53 ^{fg}	21.69 ^{bcde}	5.31 ^{gh}	4.53 ^{fgh}
Trichoderma harzianum + Fytolan	16.73 ^{defg}	8.50 ^{defg}	12.83 ^{bcdef}	16.73 ^{defg}	9.54 ^{defg}	12.83 ^{bcdef}	21.86 ^{cdefg}	9.54 ^{defgh}	12.83 ^{bcdefg}
Absolute control	34.87 ^{abc}			34.87 ^{abc}			40.35 ^{abc}		

Values having different superscripts differ significantly at 5% level

Fig.6. Effect of solarization on the incidence of foot rot disease in black pepper nursery



cent was noticed in this treatment, which gradually increased to 3.33 and 4.86 per cent respectively during eighth and ninth fortnights and there was no further increase afterwards.

Increasing the period of solarization from 30 to 45 days did not consistently decrease the disease incidence. *T. viride* incorporated treatments were effective in reducing the foliar infection of pepper cuttings (Table 6). In the 45 days solarized control a disease incidence of 1.96 per cent was observed during seventh fortnight, which gradually increased to 7.74, 13.52 and 15.54 per cent respectively during eighth, ninth and twelfth fortnights. Minimum disease incidence 2.78 per cent was recorded in *T. viride* incorporated treatment followed by *T. viride* and Fytolan drenched one (4.53%). Among the solarized treatments, 45 days solarized *T. viride* incorporated treatment was highly effective in controlling the foliar infection by rooted pepper cuttings. A disease incidence of 0.93 per cent was recorded in this treatment during eighth fortnight, which gradually increased to 2.78 per cent during tenth fortnight and there was no further increase afterwards.

During seventh fortnight, a disease incidence of 7.99 per cent was observed in absolute control and it increased to 19.91, 29.41, 34.87 and 40.35 during eighth, ninth, tenth and twelfth fortnights.

Effect of solarization on *Phytophthora* population

Potting mixture was artificially inoculated with the mass multiplied *P. capsici* propagules on the day of polyethylene mulching. Initial population of *Phytophthora* in the potting mixture on the day of mulching was 54.04 x 10^3 cfu g^{-1} of potting mixture.

Marked reduction in the population of *Phytophthora* was observed in solarized as well as non-solarized treatments, immediately after removing the mulch (Table 7). This reduction was more pronounced in solarized treatments.

Table 7. Influence of solarization on *Phytophthora* population in the potting mixture (10^3 cfu g^{-1})

	After solarization			1 fortnight after planting			2 fortnights after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	12.59 ^{abc}	2.80 ^{de}	1.43 ^{ef}	18.14 ^{a}	2.49 ^{b}	1.75 ^{bc}	18.04 ^{a}	4.50 ^{cde}	3.63 ^{cdef}
Trichoderma viride	7.99 ^{c}	2.14 ^{def}	3.02 ^{def}	13.32 ^{a}	2.00 ^{bc}	1.38 ^{cd}	7.85 ^{cd}	2.42 ^{efgh}	2.22 ^{efgh}
Trichoderma harzianum	10.14 ^{bc}	3.01 ^{d}	1.43 ^{f}	13.75 ^{a}	1.83 ^{bc}	2.18 ^{bc}	8.02 ^{cd}	2.89 ^{efg}	3.00 ^{efg}
Fytolan	10.33 ^{bc}	2.28 ^{def}	2.27 ^{def}	18.27 ^{a}	2.21 ^{bc}	1.90 ^{bc}	15.11 ^{ab}	3.49 ^{def}	3.11 ^{efg}
Trichoderma viride + Fytolan	13.82 ^{ab}	2.41 ^{def}	2.75 ^{de}	14.92 ^{a}	2.31 ^{bc}	1.80 ^{bc}	7.77 ^{cd}	1.95 ^{fgh}	0.93 ^{h}
Trichoderma harzianum + Fytolan	16.06 ^{a}	2.78 ^{de}	2.18 ^{def}	15.29 ^{a}	2.60 ^{b}	2.42 ^{b}	7.70 ^{bc}	1.73 ^{fgh}	1.35 ^{gh}
Absolute control	1.39 ^{ef}			0.82 ^{d}			2.40 ^{efg}		

	3 fortnights after planting			4 fortnights after planting			5 fortnights after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	9.56 ^{g}	2.09 ^{ef}	0.90 ^{cde}	8.24 ^{e}	1.77 ^{de}	1.40 ^{cd}	4.46 ^{g}	0.94 ^{bcde}	1.44 ^{cdef}
Trichoderma viride	5.24 ^{fg}	0.95 ^{bcde}	0.66 ^{abcd}	2.41 ^{de}	0.59 ^{abc}	0.24 ^{a}	3.38 ^{fg}	0.41 ^{abcd}	0.52 ^{abcd}
Trichoderma harzianum	4.46 ^{fg}	0.75 ^{abc}	0.78 ^{abcde}	1.42 ^{abcd}	0.23 ^{a}	0.54 ^{abc}	3.12 ^{fg}	1.13 ^{bcde}	0.06 ^{a}
Fytolan	1.27 ^{def}	0.29 ^{ab}	0.54 ^{abc}	1.15 ^{bcd}	1.01 ^{abcd}	0.48 ^{abc}	1.18 ^{def}	0.63 ^{abcde}	0.87 ^{abcd}
Trichoderma viride + Fytolan	1.93 ^{ef}	0.25 ^{ab}	0.19 ^{abc}	2.34 ^{de}	0.55 ^{ab}	0.47 ^{abc}	1.67 ^{efg}	0.80 ^{abcde}	0.24 ^{abc}
Trichoderma harzianum + Fytolan	2.26 ^{efg}	0.47 ^{abc}	0.58 ^{abc}	2.45 ^{d}	0.70 ^{abc}	0.59 ^{abc}	3.00 ^{fg}	0.82 ^{abcde}	0.18 ^{ab}
Absolute control	0.17 ^{a}			0.78 ^{abcd}			0.77 ^{bcde}		

Contd.

Table 7. Continued

	6 fortnights after planting			7 fortnights after planting			8 fortnights after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	11.79 [a]	2.08 [defg]	0.90 [gh]	13.68 [a]	1.68 [f]	2.51 [def]	15.00 [a]	3.68 [cde]	2.54 [de]
Trichoderma viride	7.07 [ab]	2.43 [de]	1.05 [fgh]	8.84 [ab]	2.24 [ef]	1.79 [ef]	8.72 [ab]	2.03 [e]	2.93 [de]
Trichoderma harzianum	7.48 [ab]	0.64 [h]	0.89 [fgh]	7.63 [bc]	2.89 [ef]	2.39 [ef]	9.18 [ab]	3.51 [cde]	3.09 [e]
Fytolan	5.53 [bc]	2.28 [def]	1.23 [efgh]	8.09 [ab]	3.52 [def]	3.51 [cdef]	14.21 [a]	3.29 [cde]	2.77 [de]
Trichoderma viride + Fytolan	3.11 [cd]	0.81 [gh]	0.70 [gh]	9.24 [ab]	4.57 [bcde]	1.86 [ef]	9.52 [ab]	1.64 [e]	4.03 [cde]
Trichoderma harzianum + Fytolan	7.02 [ab]	0.70 [h]	0.64 [h]	8.99 [ab]	3.13 [def]	1.25 [f]	6.56 [bc]	2.81 [de]	3.80 [cde]
Absolute control	4.77 [bcd]			6.20 [bcd]			5.45 [bcd]		

	9 fortnights after planting			10 fortnights after planting		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	18.15 [a]	7.74 [bcde]	3.89 [fgh]	14.87 [a]	5.13 [cde]	2.82 [defg]
Trichoderma viride	9.59 [bc]	4.83 [efgh]	2.62 [h]	10.89 [ab]	3.17 [def]	2.34 [efg]
Trichoderma harzianum	10.62 [bc]	5.52 [defgh]	2.96 [gh]	11.55 [a]	3.55 [def]	1.54 [fg]
Fytolan	9.11 [bc]	9.15 [bcd]	5.49 [cdefg]	11.12 [ab]	6.05 [bcd]	4.97 [cde]
Trichoderma viride + Fytolan	11.76 [b]	8.04 [bcd]	4.36 [fgh]	10.37 [ab]	4.01 [cde]	3.67 [cde]
Trichoderma harzianum + Fytolan	9.68 [b]	7.01 [bcdef]	4.92 [defgh]	10.40 [ab]	1.55 [g]	1.48 [g]
Absolute control	4.61 [efgh]			8.81 [abc]		

Values having different superscripts differ significantly at 5% level

Initial population – 54.04 x 10^3 cfu g^{-1}
Initial population in absolute control – 0.68 x 10^3 cfu g^{-1}

In solarized treatments, reduction in the propagules of *Phytophthora* ranged from 94.41-97.35 per cent. Among the 30 days solarized treatments, maximum reduction (96.04%) was observed in *T. viride* incorporated treatment while, the least reduction (94.43%) was recorded in the *T. harzianum* incorporated treatment.

In 45 days solarized treatments, maximum reduction (97.35%) in the population of *Phytophthora* was noticed in *T. harzianum* incorporated treatment and in solarized control (Table 7).

In the non-solarized control, 76.7 per cent reduction in the propagules of *Phytophthora* over the initial count was recorded compared to 94.82 and 97.35 per cent respectively in 30 and 45 days solarized control.

Population of *Phytophthora* was less in solarized treatments. The population build up in all the treatments was less than the initial count during the entire period of observation.

Significant increase in the population count was recorded in the non-solarized treatments during the first fortnight after planting. However, the population count was less than the original count of 54.04×10^3 cfu g^{-1}.

At this stage, reduction in the population was noticed in the 30 days solarized treatments. Whereas, slight increase in the population was recorded in 45 days solarized control and 45 days solarized *T. harzianum* incorporated treatments. During this period, maximum population (18.14×10^3 cfu g^{-1}) was recorded in non-solarized control (Table 7). While, 45 days solarized *T. viride* incorporated treatment had the least population (1.38×10^3 cfu g^{-1}).

During the second fortnight after planting, a decrease in the population count was observed in the non-solarized treatments. Similar trend was noticed till the end of fifth fortnight after planting. Whereas, slight increase in the population

was recorded in all the solarized treatments except in the *T. viride* and *T. harzianum* incorporated Fytolan drenched ones.

A decrease in the population count of *Phytophthora* was noticed in the solarized as well as non-solarized treatments during the third, fourth, fifth and sixth fortnights after planting.

The population of *Phytophthora* showed an increasing trend during seventh, eighth and ninth fortnights after planting. Non-solarized control supported the maximum population during these four fortnights (Table 7).

Significant difference in the population was observed during the seventh fortnight after planting. Minimum population of 1.25 x 10^3 cfu g^{-1} was recorded in 45 days solarized *T. harzianum* incorporated Fytolan drenched treatment.

At the end of eighth fortnight after planting, 30 days solarized *T. viride* incorporated Fytolan drenched treatment had the least population (1.64 x 10^3 cfu g^{-1}), which was significantly superior in reducing the population.

During ninth fortnight, pronounced increase in the population was observed in 30 days solarized treatments compared to 45 days of solarization (Table 7). Increase in the population ranged from 57.25 to 390.24 per cent in 30 days solarized treatments. At this stage, the minimum population (2.62 cfu g^{-1}) was recorded in 45 days solarized *T. viride* incorporated treatment.

At the end of tenth fortnight after planting, a decrease in the population over the previous count was noticed in all the solarized treatments (Table 7). Non-solarized control supported the maximum population (14.87 x 10^3 cfu g^{-1}) compared to 5.13 and 2.82 x 10^3 cfu g^{-1} respectively in 30 and 45 days solarized controls. The least population of 1.48 x 10^3 was recorded in 45 days solarized *T. harzianum* incorporated Fytolan drenched treatment.

In absolute control also, maximum population of *Phytophthora* was noticed during the seventh, eighth, ninth and tenth fortnights after planting. The population of *Phytophthora* in this treatment showed 12 fold increase over the initial count (0.68 x 10^3 cfu g^{-1}) during the tenth fortnight after planting.

Effect of solarization on population of *Trichoderma* spp. in the potting mixture

The population of *Trichoderma* spp. was estimated, at the time of planting and at monthly intervals for five months using serial dilution plate method. The data are presented in the Table 8.

At the time of planting, the population count in the non-solarized potting mixture was 0.35 x 10^3 cfu g^{-1} of potting mixture while, *Trichoderma* was not observed in the solarized potting mixture.

An increase in the population of *Trichoderma* was noticed in all the treatments when the population was estimated during one month after planting. This increase was more pronounced in *Trichoderma* incorporated solarized as well as non-solarized treatments. Maximum population of 11.0 x 10^3 cfu g^{-1} was recorded in 30 days solarized *T. viride* incorporated treatment, which was significantly superior to all the treatments. The effect of solarization was not observed in the population build up in the non-inoculated solarized treatments. All the other treatments were statistically on par. The least population of 0.19 x 10^3 cfu g^{-1} was recorded in solarized controls which were on par with non-solarized control (0.38 x 10^3 cfu g^{-1}). Similar trend was noticed during the entire period of observation.

At the end of second month after planting, maximum population of 11.14 x 10^3 cfu g^{-1} was recorded in 45 days solarized *T. harzianum* incorporated treatment. While, 30 days solarized Fytolan drenched treatment had the least population (0.18 x 10^3 cfu g^{-1}).

Table 8. Influence of solarization on *Trichoderma* population in the potting mixture (10^3 cfu g^{-1})

	1 month after planting			2 months after planting			3 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	0.38 ^{d}	0.19 ^{d}	0.19 ^{d}	0.74 ^{g}	0.30 ^{g}	0.20 ^{g}	1.22 ^{f}	1.14 ^{fg}	1.13 ^{fg}
Trichoderma viride	4.24 ^{bc}	11.00 ^{a}	5.19 ^{bc}	2.58 ^{ef}	8.03 ^{abc}	10.75 ^{ab}	4.25 ^{de}	9.41 ^{ab}	7.58 ^{abc}
Trichoderma harzianum	2.97 ^{c}	6.64 ^{b}	5.75 ^{b}	5.09 ^{cd}	8.26 ^{abc}	11.14 ^{a}	5.74 ^{cd}	9.48 ^{ab}	10.02 ^{a}
Fytolan	0.35 ^{d}	0.30 ^{d}	0.24 ^{d}	0.48 ^{g}	0.18 ^{g}	0.24 ^{g}	0.72 ^{fg}	0.64 ^{g}	0.52 ^{g}
Trichoderma viride + Fytolan	5.12 ^{bc}	5.94 ^{bc}	4.89 ^{bc}	2.80 ^{f}	4.76 ^{cd}	5.30 ^{cd}	3.36 ^{e}	6.89 ^{bc}	5.69 ^{cd}
Trichoderma harzianum + Fytolan	3.91 ^{bc}	6.09 ^{bc}	6.09 ^{b}	4.30 ^{de}	5.96 ^{cd}	6.00 ^{bcd}	5.46 ^{cd}	8.01 ^{abc}	7.25 ^{abc}
Absolute control	0.36 ^{d}			0.06 ^{g}			0.70 ^{fg}		

	4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	1.16 ^{h}	2.24 ^{fgh}	1.97 ^{gh}	2.31 ^{e}	0.11 ^{g}	0.11 ^{g}
Trichoderma viride	3.65 ^{def}	10.18 ^{a}	10.51 ^{a}	3.68 ^{d}	8.12 ^{ab}	10.16 ^{ab}
Trichoderma harzianum	5.64 ^{bcd}	8.58 ^{ab}	7.95 ^{abc}	8.09 ^{ab}	9.60 ^{ab}	10.78 ^{a}
Fytolan	1.29 ^{h}	2.59 ^{fgh}	4.72 ^{cde}	1.00 ^{f}	0.24 ^{fg}	0.29 ^{fg}
Trichoderma viride + Fytolan	2.78 ^{efg}	10.85 ^{a}	8.44 ^{ab}	4.57 ^{cd}	8.24 ^{ab}	9.59 ^{ab}
Trichoderma harzianum + Fytolan	5.50 ^{bcd}	10.24 ^{a}	7.25 ^{abc}	6.77 ^{bc}	8.35 ^{ab}	8.38 ^{ab}
Absolute control	1.28 ^{h}			0.24 ^{fg}		

Values having different superscripts differ significantly at 5% level

Initial population - 0.35 x 10^3 cfu g^{-1}

During the third month after planting, an increase in the population was noticed in all the treatments except in 45 days solarized *Trichoderma* incorporated treatments. Among the solarized treatments, the population varied from 0.52 to 10.02 cfu g^{-1} compared to 0.72 to 5.74 x 10^3 cfu g^{-1} in the non-solarized treatments. At this stage, 45 days solarized *T. harzianum* incorporated potting mixture supported the maximum population (10.02 x 10^3 cfu g^{-1}) while, 45 days solarized Fytolan drenched treatment had the least count (0.52 x 10^3 cfu g^{-1}).

At the end of four months after planting, 30 days solarized *T. viride* incorporated Fytolan drenched treatments had the highest population (10.85 x 10^3 cfu g^{-1}). Non-solarized control supported the least population (1.16 x 10^3 cfu g^{-1}).

During the fifth month after planting, population count of 2.31 x 10^3 cfu g^{-1} was recorded in non-solarized control compared to 0.11 x 10^3 cfu g^{-1} in solarized controls. At this stage 45 days solarized *T. harzianum* incorporated potting mixture had the highest population (10.78 x 10^3 cfu g^{-1}) which was significantly superior to all the non-inoculated treatments. Absolute control recorded a population count of 0.24 x 10^3 cfu g^{-1}.

Effect of solarization on soil microflora in the potting mixture

The effect of solarization on the population of soil microflora viz. fungi, bacteria and actinomycetes in the potting mixture were estimated. The population counts of the micro-organisms were taken before solarization, on the day of removal of polyethylene sheets and at monthly intervals for five months.

Fungi

In general, a reduction in the population of fungi was observed in all the treatments, when the population was estimated immediately after removing the polyethylene mulch (Table 9).

Table 9. Influence of solarization on total fungal population in the potting mixture (10^3 cfu g^{-1})

Treatments	After solarization			1 month after planting			2 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	36.47 [a]	5.37 [bc]	5.26 [bc]	21.30 [ab]	11.58 [bcde]	14.81 [bcde]	65.42 [a]	13.31 [bc]	7.66 [d]
Trichoderma viride	32.39 [a]	4.65 [bc]	5.10 [bc]	23.05 [ab]	18.18 [abcd]	8.17 [cde]	49.43 [a]	11.24 [cd]	15.57 [bc]
Trichoderma harzianum	30.55 [a]	5.63 [bc]	3.26 [c]	19.06 [abc]	14.10 [abcd]	7.14 [de]	48.25 [a]	15.03 [bc]	16.07 [bc]
Fytolan	25.95 [a]	3.06 [c]	3.89 [c]	23.71 [ab]	11.36 [bcde]	6.47 [e]	43.66 [a]	12.27 [bc]	13.88 [bc]
Trichoderma viride + Fytolan	32.48 [a]	4.89 [bc]	7.11 [b]	26.64 [a]	8.87 [cde]	11.81 [cde]	45.13 [a]	15.98 [bc]	16.49 [bc]
Trichoderma harzianum + Fytolan	30.18 [a]	4.89 [bc]	5.44 [bc]	23.62 [ab]	14.21 [abcd]	7.30 [de]	67.39 [a]	16.02 [bc]	21.98 [b]
Absolute control	5.43 [bc]			27.90 [a]			18.09 [bc]		

Treatments	3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	39.97 [a]	15.50 [c]	14.44 [cd]	47.37 [a]	10.84 [d]	8.36 [d]	35.68 [bc]	15.74 [d]	12.09 [d]
Trichoderma viride	48.86 [a]	12.95 [cde]	11.38 [cde]	51.86 [a]	15.80 [bc]	12.48 [cd]	42.78 [b]	14.09 [d]	15.64 [d]
Trichoderma harzianum	40.85 [a]	11.88 [cde]	11.50 [cde]	34.74 [a]	10.15 [cd]	8.39 [d]	33.57 [c]	15.43 [d]	11.67 [d]
Fytolan	39.74 [ab]	11.76 [cde]	8.80 [e]	49.21 [a]	9.12 [d]	10.53 [cd]	34.46 [c]	11.27 [d]	14.54 [d]
Trichoderma viride + Fytolan	46.25 [a]	15.42 [cd]	12.33 [cde]	41.60 [a]	22.67 [b]	11.64 [cd]	55.21 [a]	14.49 [d]	15.17 [d]
Trichoderma harzianum + Fytolan	49.76 [a]	10.85 [cde]	9.37 [de]	41.17 [a]	12.12 [cd]	10.07 [d]	35.93 [bc]	13.31 [d]	11.28 [d]
Absolute control	26.80 [b]			23.12 [b]			17.85 [d]		

Values having different superscripts differ significantly at 5% level

Initial population - 43.16 x 10^3 cfu g^{-1}

Initial population in absolute control - 6.19 x 10^3 cfu g^{-1}

Significant reduction in the fungal population was recorded in solarized treatments compared to the initial count (43.16 x 10^3 cfu g^{-1} of potting mixture). More than 87.0 per cent reduction was recorded in almost all the solarized treatments. The population count in the solarized treatments ranged from 3.06 x 10^3 cfu g^{-1} (30 days solarized Fytolan drenched treatment) to 7.11 x 10^3 cfu g^{-1} (45 days solarized *T. viride* incorporated Fytolan drenched treatment).

During this period fungal population of the non-solarized treatments varied from 25.95 - 36.47 x 10^3 cfu g^{-1}. Maximum population was recorded in non-solarized control (36.47 x 10^3 cfu g^{-1}). Absolute control recorded a fungal population of 5.43 x 10^3 cfu g^{-1}.

A change in the pattern of population build up of fungi was observed one month after planting (Table 9). All the solarized treatments showed marked increase in the population build up, compared to the count on the day of removal of the polyethylene mulch. Among the solarized treatments, maximum population of 18.18 x 10^3 cfu g^{-1} was recorded in 30 days solarized *T. viride* incorporated treatment. While, 45 days solarized Fytolan drenched treatment had the least population (6.47 x 10^3 cfu g^{-1}) during this period.

All the non-solarized treatments except absolute control showed a reduction in the fungal population at the end of one month after planting compared to previous count. However, maximum fungal population was observed in the non-solarized treatments (Table 9). At this stage absolute control recorded highest population of fungi (27.9 x 10^3 cfu g^{-1}).

During second month after planting, significant increase in the fungal population was observed in all the non-solarized treatments. The population ranged from 43.66 - 67.39 x 10^3 cfu g^{-1} (Table 9). *T. harzianum* incorporated Fytolan drenched treatment had the highest population 67.39 x 10^3 cfu g^{-1}.

The population of fungi in solarized treatments also showed a gradual increase except in 45 days solarized control (7.66 x 10^3 cfu g^{-1}) and in 30 days solarized *T. viride* incorporated treatment (11.24 x 10^3 cfu g^{-1}).

Population build up of fungi in the solarized treatments were significantly different from the non-solarized treatments. Similar trend was observed till the end of five months after planting. Significant difference in the fungal population was observed in 45 days solarized control compared to 30 days solarized control. Similar trend was also observed during the third month after planting. At this stage also, significantly higher population of fungi was recorded in the non-solarized treatments. Significantly higher population of 49.76 x 10^3 cfu g^{-1} was noticed in *T. harzianum* incorporated non-solarized Fytolan drenched treatment. Whereas, 45 days solarized Fytolan drenched treatment had the least population (8.8 x 10^3 cfu g^{-1}).

The population of fungi at the end of four months after planting ranged from 34.74 - 51.86 x 10^3 cfu g^{-1} in the non-solarized treatments. *T. viride* incorporated non-solarized treatments recorded the highest population (51.86 x 10^3 cfu g^{-1}). The least population of 8.36 x 10^3 cfu g^{-1} was observed in 45 days solarized control (Table 9).

Significant difference in the fungal population was observed in the non-solarized treatments during the fifth month after planting (Table 9) while, the solarized treatments did not differ significantly from one another. At this stage, all the treatments except *T. viride* incorporated Fytolan drenched treatment showed a reduction in the population over the initial count of 43.16 x 10^3 cfu g^{-1}. Least population of 11.27 x 10^3 cfu g^{-1} was observed in 30 days solarized, Fytolan drenched treatment (Table 9). Absolute control recorded a population count of 17.85 x 10^3 cfu g^{-1} at this stage.

Bacteria

A decrease in the bacterial population over initial count (7.72 x 10^5 cfu g^{-1}) was observed in all the solarized as well as non-solarized treatments except in *T. viride* incorporated Fytolan drenched treatments (Table 10). Significant reduction in the population of bacteria was recorded in solarized treatments on the day of removal of mulch. However, there was no significant difference among the solarized treatments. More than 88.0 per cent reduction in the population of bacteria was noticed in majority of the solarized treatments. In 30 days solarized treatments, the population ranged from 0.33 (*T. viride* incorporated treatment) to 1.07 x 10^5 cfu g^{-1} of potting mixture (*T. harzianum* incorporated treatment).

Whereas, in 45 days solarized treatments, the population of bacteria ranged from 0.49 x 10^5 cfu g^{-1} (*T. harzianum* incorporated treatment) to 1.39 x 10^5 cfu g^{-1} (*T. viride* incorporated Fytolan drenched treatment). Highest population of bacteria was recorded in non-solarized treatments and similar trend was observed till the end of five months after planting. In non-solarized treatments, the reduction was maximum in *T. harzianum* incorporated treatment (73.06%), whereas no change in the population was observed in absolute control (3.09 x 10^5 cfu g^{-1}).

An increase in the population of bacteria was noticed in all treatments except in Fytolan drenched non-solarized treatment during the first month after planting. At this stage also non-solarized control had significantly higher population (20.33 x 10^5 cfu g^{-1}). Eventhough, there was increase in the population over previous month in 30 days solarized treatments, the count was less than that of 45 days and non-solarized treatments. The minimum population of 2.85 x 10^5 cfu g^{-1} was observed in 30 days solarized *T. viride* incorporated Fytolan drenched treatment, which significantly differed from non-solarized control.

A general reduction in the population was observed during the second month after planting compared to the previous month (Table 10). Maximum population during this period (7.22 x 10^5 cfu g^{-1}) was observed in Fytolan drenched

Table 10. Influence of solarization on total bacterial population in the potting mixture (10^5 cfu g^{-1})

Treatments	After solarization			1 month after planting			2 months after planting		
	Non-solarization	Solarization 30 days	Solarization 45 days	Non-solarization	Solarization 30 days	Solarization 45 days	Non-solarization	Solarization 30 days	Solarization 45 days
Control	6.89 ^{e}	0.48 ^{ab}	0.83 ^{ab}	20.33 ^{a}	6.27 ^{bcde}	8.52 ^{abcd}	5.62 ^{ab}	2.45 ^{efg}	2.38 ^{efg}
Trichoderma viride	5.06 ^{e}	0.33 ^{ab}	0.53 ^{ab}	9.45 ^{abcd}	6.57 ^{bcde}	5.41 ^{bcde}	4.76 ^{abcde}	1.23 ^{g}	2.44 ^{efg}
Trichoderma harzianum	2.08 ^{cde}	1.07 ^{ab}	0.49 ^{ab}	6.72 ^{bcde}	3.13 ^{e}	8.91 ^{bcde}	5.10 ^{abcd}	2.85 ^{cdefg}	3.84 ^{abcde}
Fytolan	4.61 ^{de}	0.81 ^{abc}	0.78 ^{ab}	3.99 ^{de}	5.94 ^{de}	9.08 ^{abcd}	7.22 ^{a}	2.14 ^{efg}	2.22 ^{efg}
Trichoderma viride + Fytolan	9.52 ^{e}	0.92 ^{ab}	1.39 ^{bcd}	10.38 ^{abcd}	2.85 ^{e}	5.07 ^{de}	5.20 ^{abc}	2.86 ^{defg}	2.94 ^{fg}
Trichoderma harzianum + Fytolan	5.03 ^{e}	0.55 ^{ab}	0.61 ^{ab}	11.98 ^{abc}	3.87 ^{e}	16.05 ^{ab}	5.65 ^{ab}	1.96 ^{efg}	2.20 ^{efg}
Absolute control	3.09 ^{e}			6.84 ^{cde}			3.37 ^{bcdef}		

Treatments	3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization 30 days	Solarization 45 days	Non-solarization	Solarization 30 days	Solarization 45 days	Non-solarization	Solarization 30 days	Solarization 45 days
Control	7.03 ^{a}	2.99 ^{defg}	6.78 ^{ab}	5.20 ^{ab}	4.99 ^{ab}	4.65 ^{ab}	4.80 ^{abcde}	2.10 ^{cdef}	1.90 ^{def}
Trichoderma viride	6.36 ^{abc}	2.47 ^{defg}	1.73 ^{g}	2.77 ^{ab}	4.29 ^{ab}	4.86 ^{ab}	5.84 ^{a}	2.80 ^{bcdef}	2.50 ^{bcdef}
Trichoderma harzianum	4.61 ^{abcde}	4.84 ^{abcde}	3.38 ^{bcdefg}	4.10 ^{ab}	7.69 ^{a}	5.40 ^{ab}	5.13 ^{ab}	1.68 ^{f}	2.50 ^{bcdef}
Fytolan	4.97 ^{abcd}	1.78 ^{g}	2.38 ^{fg}	4.29 ^{ab}	4.14 ^{ab}	4.14 ^{ab}	6.24 ^{a}	2.15 ^{cdef}	2.42 ^{bcdef}
Trichoderma viride + Fytolan	4.58 ^{abcde}	2.19 ^{efg}	2.96 ^{cdefg}	2.69 ^{b}	3.05 ^{b}	4.93 ^{ab}	5.57 ^{a}	1.81 ^{def}	1.31 ^{f}
Trichoderma harzianum + Fytolan	4.18 ^{abcdef}	2.91 ^{cdefg}	4.25 ^{abcdef}	2.46 ^{b}	4.13 ^{ab}	4.70 ^{ab}	4.70 ^{abc}	2.31 ^{cdef}	1.59 ^{ef}
Absolute control	2.75 ^{defg}			2.86 ^{b}			4.38 ^{abcd}		

Values having different superscripts differ significantly at 5% level

Initial population - 7.72 x 10^5 cfu g^{-1}

Initial population in absolute control – 3.09 x 10^5 cfu g^{-1}

treatment , while it was minimum (1.23 x 10^5 cfu g^{-1}) in 30 days solarized *T. harzianum* incorporated treatment, and was significantly superior in reducing the population count compared to the non-solarized treatments.

During the third month after planting also, majority of the non-solarized treatments exhibited reduction in the bacterial population (Table 10). Maximum population was recorded in non-solarized control (7.03 x 10^5 cfu g^{-1}), which was on par with 45 days solarized control.

A general increase in the population of bacteria over the previous month's count was observed in all the solarized treatments except in 45 days solarized control during the fourth month after planting while, the non-solarized treatments showed reduction in the population count (Table 10). At this stage the population ranged from 2.46 x 10^5 cfu g^{-1} (*T. harzianum* incorporated Fytolan drenched potting mixture) to 7.69 x 10^5 cfu g^{-1} (30 days solarized *T. harzianum* incorporated potting mixture).

At the end of the fifth month after planting, a decrease in the population of bacteria was noticed in all the solarized treatments, compared to previous month. While, bacterial count was increased in the non-solarized treatments. There was significant difference between solarized and non-solarized treatments.

Actinomycetes

The initial count of actinomycetes in the potting mixture was 7.37 x 10^5 cfu g^{-1} of potting mixture. Solarization was found to inhibit the population of actinomycetes.

A significant reduction in the population of actinomycetes was observed in the solarized treatments just after the removal of polythene mulch compared to pre-solarization count (Table 11). Population reduction was more pronounced in 30 days solarized treatment (91.04 to 96.7%) compared to (79.65 to 91.86%) 45 days

Table 11. Influence of solarization on actinomycetal population in the potting mixture (10^5 cfu g^{-1})

Treatments	After solarization			1 month after planting			2 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	2.38 ^{bcdef}	0.66 ^{abc}	1.50 ^{abcdef}	3.01 ^{g}	1.22 ^{abcdefg}	0.38 ^{abc}	2.26 ^{abc}	1.59 ^{bc}	1.94 ^{abc}
Trichoderma viride	2.35 ^{def}	0.24 ^{a}	0.94 ^{abcde}	2.04 ^{efg}	0.82 ^{abcde}	1.02 ^{abcde}	2.50 ^{abc}	1.20 ^{c}	1.41 ^{bc}
Trichoderma harzianum	2.12 ^{def}	0.24 ^{a}	1.04 ^{abcdef}	1.39 ^{defg}	0.80 ^{abcdef}	0.45 ^{abcd}	2.53 ^{ab}	1.60 ^{bc}	1.32 ^{bc}
Fytolan	2.95 ^{ef}	0.57 ^{a}	0.60 ^{abcd}	3.01 ^{fg}	1.03 ^{bcdefg}	0.12 ^{a}	2.53 ^{abc}	1.58 ^{bc}	2.16 ^{abc}
Trichoderma viride + Fytolan	2.73 ^{cdef}	0.34 ^{a}	0.74 ^{abcd}	1.54 ^{bcdefg}	1.02 ^{abcdef}	0.96 ^{bcdefg}	3.46 ^{a}	1.97 ^{abc}	1.60 ^{bc}
Trichoderma harzianum + Fytolan	3.23 ^{f}	0.43 ^{ab}	0.64 ^{a}	1.57 ^{cdefg}	0.30 ^{ab}	0.41 ^{abc}	2.09 ^{abc}	1.23 ^{c}	1.90 ^{abc}
Absolute control	0.49 ^{a}			0.88 ^{abcdefg}			1.85 ^{abc}		

Treatments	3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	1.09 ^{abcd}	1.15 ^{abcde}	2.08 ^{cde}	1.49 ^{c}	0.73 ^{abc}	1.59 ^{c}	2.82 ^{a}	2.11 ^{ab}	1.30 ^{b}
Trichoderma viride	0.82 ^{ab}	1.27 ^{abcde}	1.79 ^{bcde}	0.55 ^{abc}	0.37 ^{a}	0.84 ^{abc}	1.81 ^{ab}	1.55 ^{b}	1.43 ^{ab}
Trichoderma harzianum	0.76 ^{abc}	0.91 ^{abcd}	1.42 ^{abcde}	0.90 ^{abc}	1.53 ^{bc}	1.00 ^{abc}	1.49 ^{ab}	1.34 ^{b}	1.65 ^{ab}
Fytolan	0.60 ^{a}	2.15 ^{de}	1.45 ^{abcde}	0.90 ^{abc}	0.31 ^{a}	0.92 ^{abc}	1.35 ^{b}	1.43 ^{ab}	2.12 ^{ab}
Trichoderma viride + Fytolan	1.11 ^{abcde}	0.86 ^{abcd}	2.85 ^{e}	1.10 ^{abc}	0.60 ^{abc}	1.15 ^{abc}	1.74 ^{ab}	1.17 ^{b}	1.38 ^{b}
Trichoderma harzianum + Fytolan	1.11 ^{abcde}	1.86 ^{cde}	2.81 ^{e}	0.42 ^{ab}	0.43 ^{abc}	0.97 ^{abc}	2.20 ^{ab}	1.56 ^{ab}	1.60 ^{ab}
Absolute control	1.07 ^{abcd}			0.49 ^{abc}			1.86 ^{ab}		

Values having different superscripts differ significantly at 5% level

Initial population - 7.37 x 10^5 cfu g^{-1}

Initial population in absolute control - 2.40 x 10^5 cfu g^{-1}

solarization. However, there was no significant difference among the solarized treatments.

Non-solarized treatments also showed reduction in the actinomycetal count. Maximum population (3.23 x 10^5 cfu g^{-1}) was observed in *T. harzianum* incorporated Fytolan drenched soil, while the least count of 0.24 x 10^5 cfu g^{-1} was observed in both 30 days solarized *T. viride* and *T. harzianum* incorporated treatments. Absolute control recorded 80 per cent reduction in the actinomycetal population.

One month after planting, the population of actinomycetes varied from 0.12 x 10^5 cfu g^{-1} (45 days solarized Fytolan drenched treatment) to 1.22 x 10^5 cfu g^{-1} (30 days solarized control). while, the variation in non-solarized treatments was 1.39 (*T. harzianum* incorporated treatment) to 3.01 x 10^5 cfu g^{-1} (Fytolan drenched treatment and non-solarized control).

During the second month after planting, increase in the population of actinomycetes was noticed in all the treatments except in non-solarized control and Fytolan drenched treatment (Table 11). This increase was maximum in non-solarized treatments. Thirty days solarized *T. viride* incorporated treatment had the least count (1.2 x 10^5 cfu g^{-1}) of actinomycetes. It was significantly superior in reducing the population at this stage. Maximum population (3.46 x 10^5 cfu g^{-1}) was recorded in *T. viride* incorporated Fytolan drenched non-solarized treatment.

At the end of third month after planting, all the 45 days solarized treatments showed increase in the actinomycetes count except the Fytolan drenched one (Table 11). While, the non-solarized treatments exhibited reduction in the population over the previous months' count. At this stage, Fytolan drenched non-solarized treatment recorded the least population (0.6 x 10^5 cfu g^{-1}).

The actinomycetal population showed a decrease during the fourth month after planting in all the solarization treatments except in 30 days solarized *T.*

harzianum incorporated one (Table 11). This reduction ranged from 23.56 to 85.58 per cent. Significant difference in the population was observed among 30 days solarized treatments. At this stage, maximum population (1.59 x 10^5 cfu g^{-1}) was recorded in 45 days solarized control while, the minimum population (0.31 x 10^5 cfu g^{-1}) was noticed in 30 days solarized Fytolan drenched treatment.

When the actinomycetal population was recorded at fifth month after planting, a general increase was noticed in almost all the treatments compared to the previous observations (Table 11). *T. harzianum* incorporated Fytolan drenched treatment recorded the highest increase of 423.81 per cent. Among the solarized treatments, the maximum increase of 361.29 per cent was recorded in 30 days solarized Fytolan drenched one, compared to 130.43 per cent in 45 days solarized Fytolan drenched treatment.

There was no significant difference in the population of actinomycetes among solarized treatments while, the variation among the non-solarized treatments were significant. At this stage, the least count (1.17 x 10^5 cfu g^{-1}) was observed in 30 days solarized *T. viride* incorporated Fytolan drenched potting mixture.

Effect of solarization on VAM colonization

Colonization of VAM with roots of pepper cuttings was recorded at the end of five months after planting (Table 12). Non-solarized treatments recorded increased colonization compared to solarized treatments. Maximum colonization (84%) was observed in non-solarized control. Thirty days solarized treatments gave better colonization than 45 days solarized treatments. Among the solarized treatments, plants grown in 30 days solarized and Fytolan drenched treatment gave maximum colonization (66%). Least colonization (20%) was noticed in the plants grown in 45 days solarized *T. harzianum* incorporated treatment. Solarized control treatments had better colonization of VAM (55 and 47%) compared to other solarized treatments.

Table 12. Influence of solarization on the association by mycorrhizal fungi in pepper cuttings

Treatments	Per cent association		
	Non-solarization	Solarization	
		30 days	45 days
Control	84	55	47
Trichoderma viride	60	39	26
Trichoderma harzianum	59	47	20
Fytolan	46	66	27
Trichoderma viride + Fytolan	68	53	53
Trichoderma harzianum + Fytolan	64	50	38
Absolute control	68		

Influence of solarization on association of *Azospirillum*

Azospirillum was isolated from the roots of five months old pepper cuttings. Formation of thin, white subsurface pellicular growth in nitrogen free bromothymol blue (NFb) semisolid medium indicated the presence of *Azospirillum*.

Solarization promoted the per cent colonization of *Azospirillum* with roots of pepper cuttings (Table 13). And this increase was more in 30 days solarized treatments. Maximum colonization (90%) was observed in solarized controls, whereas non-solarized control gave only 30 per cent colonization of *Azospirillum* with the roots of pepper cuttings.

Effect of solarization on plant characters

Plant characters like height, number of leaves per plant, length and breadth of leaves of rooted pepper cuttings were taken for studying the effect of solarization on growth of pepper. Observations were recorded at monthly intervals from two months after planting upto five months. In general solarization promoted growth of pepper.

Height of the plant

During the second month after planting, maximum plant height (12.25 cm) was observed in plants grown in 30 days solarized, *T. harzianum* incorporated treatment (Table 14). However, there was no significant variation among the treatments. A similar pattern was noticed during the third month also. At this stage also, plants grown in 30 days solarized *T. harzianum* incorporated potting mixture had the maximum height (15 cm).

After four months of growth, maximum plant height (18.83 cm) was recorded in the 30 days solarized *T. harzianum* incorporated and Fytolan drenched

Table 13. Influence of solarization on the association by *Azospirillum* in pepper cuttings

Treatments	Per cent association		
	Non-solarization	Solarization	
		30 days	45 days
Control	30	90	90
Trichoderma viride	50	80	70
Trichoderma harzianum	40	60	50
Fytolan	30	80	90
Trichoderma viride + Fytolan	30	70	80
Trichoderma harzianum + Fytolan	60	80	50
Absolute control	50		

Table 14. Influence of solarization on plant characters in pepper cuttings

Treatments	Plant height (cm)											
	2 months after planting			3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	10.00 [a]	9.67 [a]	10.83 [a]	11.50 [ab]	10.50 [b]	12.67 [ab]	13.17 [a]	13.33 [a]	15.58 [a]	14.83 [ef]	18.83 [bcdef]	21.33 [abcd]
Trichoderma viride	10.69 [a]	9.33 [a]	11.00 [a]	11.33 [ab]	12.27 [ab]	11.50 [ab]	12.17 [a]	15.67 [a]	17.33 [a]	16.33 [def]	20.17 [abcde]	24.33 [ab]
Trichoderma harzianum	10.50 [a]	12.25 [a]	11.50 [a]	10.67 [ab]	15.00 [a]	12.17 [ab]	12.00 [a]	17.33 [a]	16.17 [a]	14.17 [f]	25.00 [a]	20.17 [abcde]
Fytolan	10.50 [a]	10.83 [a]	9.58 [a]	12.17 [ab]	11.67 [ab]	9.80 [b]	15.67 [a]	14.00 [a]	12.00 [a]	18.83 [bcdef]	24.17 [ab]	19.63 [abcdef]
Trichoderma viride + Fytolan	9.67 [a]	9.50 [a]	10.42 [a]	11.17 [ab]	11.67 [ab]	11.83 [ab]	12.50 [a]	15.00 [a]	12.83 [a]	14.50 [ef]	23.67 [ab]	21.83 [abcd]
Trichoderma harzianum + Fytolan	10.88 [a]	10.83 [a]	9.14 [a]	11.50 [ab]	12.60 [ab]	12.62 [ab]	15.87 [a]	18.83 [a]	15.67 [a]	16.50 [def]	23.00 [ab]	22.45 [abc]
Absolute control	9.63 [a]			12.00 [ab]			12.50 [a]			17.00 [cdef]		

Values having different superscripts differ significantly at 5% level

treatment. Least growth (12.00 cm) was observed in *T. harzianum* incorporated non-solarized potting mixture and 45 days solarized Fytolan drenched potting mixture.

Observations taken at the fifth month showed that solarization increased the height of rooted cuttings of pepper. However, there was not much variation among 30 and 45 days of solarization. At this stage, plants grown in 30 days solarized *T. harzianum* incorporated potting mixture exhibited maximum growth (25 cm), which was significantly superior to the non-solarized treatments while, rooted cuttings grown in *T. harzianum* incorporated non-solarized treatment recorded least growth (14.17 cm). Plants grown in the absolute control had 17.0 cm height.

Number of leaves per plant

Leaf production by the plants was found to be influenced by solarization (Table 15).

During the second month after planting, maximum number of leaves (2.17) was produced by the plants grown in 30 days solarized *T. harzianum* incorporated treatment, which was significantly superior to majority of the treatments. The least number of leaves (1.17) was in *T. viride* and *T. harzianum* incorporated Fytolan drenched non-solarized treatments.

At the end of three months after planting also, maximum leaf production was observed in 30 days solarized *T. harzianum* incorporated treatment, which was significantly superior to all treatments.

During fourth month after planting, solarized treatments showed significant increase in the leaf production (Table 15). However, significant difference was not observed among the treatments receiving solarization. Maximum leaf production (3.45) was observed in 30 days solarized *T. harzianum* incorporated

Table 15. Influence of solarization on plant characters in pepper cuttings

Treatments	Number of leaves / plant											
	2 months after planting			3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	1.39 ^{bcd}	1.61 ^{bcd}	1.78 ^{ab}	1.65 ^{b}	2.00 ^{b}	2.06 ^{b}	2.06 ^{c}	2.78 ^{abc}	3.00 ^{ab}	3.00 ^{d}	3.95 ^{abcd}	3.92 ^{abcd}
Trichoderma viride	1.45 ^{bcd}	1.39 ^{bcd}	1.39 ^{bcd}	1.72 ^{b}	1.72 ^{b}	2.00 ^{b}	2.39 ^{bc}	3.06 ^{ab}	3.00 ^{ab}	3.45 ^{bcd}	4.78 ^{a}	4.06 ^{abcd}
Trichoderma harzianum	1.75 ^{abc}	2.17 ^{a}	1.39 ^{bcd}	1.92 ^{b}	2.84 ^{a}	1.67 ^{b}	2.00 ^{c}	3.11 ^{ab}	3.06 ^{ab}	3.17 ^{cd}	4.39 ^{ab}	4.39 ^{ab}
Fytolan	1.28 ^{cd}	1.72 ^{abc}	1.56 ^{bcd}	1.47 ^{b}	1.78 ^{b}	1.61 ^{b}	2.33 ^{bc}	3.11 ^{ab}	3.00 ^{ab}	3.33 ^{bcd}	4.22 ^{abc}	4.17 ^{abc}
Trichoderma viride + Fytolan	1.17 ^{d}	1.50 ^{bcd}	1.58 ^{bcd}	1.50 ^{b}	1.81 ^{b}	1.81 ^{b}	2.47 ^{bc}	3.17 ^{ab}	3.06 ^{ab}	3.03 ^{d}	3.45 ^{bcd}	3.67 ^{bcd}
Trichoderma harzianum + Fytolan	1.17 ^{d}	1.67 ^{bc}	1.33 ^{bcd}	1.50 ^{b}	2.06 ^{b}	1.50 ^{b}	2.03 ^{c}	3.45 ^{a}	3.00 ^{ab}	3.19 ^{cd}	4.06 ^{abcd}	3.83 ^{abcd}
Absolute control	1.61 ^{bcd}			1.89 ^{b}			1.97 ^{c}			3.72 ^{abcd}		

Values having different superscripts differ significantly at 5% level

Fytolan drenched treatment. While, the least leaf production (2.0) was in *T. harzianum* incorporated non-solarized treatment.

At the end of five months after planting, 30 days solarized *T. viride* incorporated treatment was the most effective in increasing the leaf number (4.78), which was significantly superior to all the non-solarized treatments. Whereas, minimum leaf production (3.0) was observed in non-solarized control. Plants grown in the absolute control produced 3.72 leaves.

Leaf length

In general, solarization influenced the length of leaves of the plants (Table 16). During the second month after planting, maximum leaf length (6.53 cm) was recorded in plants grown in 45 days solarized *T. viride* incorporated treatment. While, the minimum leaf length (4.75 cm) was in the *T. viride* incorporated non-solarized treatment.

During the third month, leaf length was better in 30 days solarized treatments and was on par with 45 days solarization. Maximum leaf length (9.14 cm) was recorded in 30 days solarized *T. harzianum* incorporated treatment, which was significantly superior to all the non-solarized treatments. At this stage, the minimum leaf length (6.33 cm) was observed in plants grown in *T. harzianum* incorporated non-solarized treatment.

During fourth month after planting, 30 days solarized *T. viride* incorporated treatment was significantly superior in producing maximum leaf length (10.67 cm) while, the minimum leaf length (7.11 cm) was noticed in *T. harzianum* incorporated non-solarized treatment.

At the end of fifth month, plants grown in 45 days solarized control produced maximum leaf length (12.44 cm), which was significantly superior to almost all non-solarized treatments. At this stage, the least leaf length (8.7 cm) was

Table 16. Influence of solarization on plant characters in pepper cuttings

Treatments	Leaf length (cm)											
	2 months after planting			3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-Solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	4.90 ^{cd}	6.00 ^{ab}	5.70 ^{abcd}	7.39 ^{cdef}	8.89 ^{ab}	8.07 ^{abcd}	7.95 ^{cd}	10.03 ^{ab}	9.00 ^{abc}	10.06 ^{cdef}	12.17 ^{abc}	12.44 ^{a}
Trichoderma viride	4.75 ^{d}	6.30 ^{a}	6.53 ^{a}	7.22 ^{def}	8.36 ^{abcd}	8.92 ^{ab}	7.96 ^{cd}	10.67 ^{a}	9.08 ^{abc}	9.56 ^{ef}	11.86 ^{abcd}	11.70 ^{abcd}
Trichoderma harzianum	4.93 ^{cd}	6.28 ^{a}	6.33 ^{a}	6.33 ^{f}	9.14 ^{a}	8.26 ^{abcd}	7.11 ^{d}	9.64 ^{abc}	9.72 ^{abc}	8.78 ^{f}	12.25 ^{ab}	11.00 ^{abcde}
Fytolan	5.58 ^{abcd}	6.27 ^{a}	6.20 ^{a}	6.52 ^{ef}	8.75 ^{abc}	7.72 ^{bcde}	7.92 ^{cd}	9.33 ^{abc}	9.47 ^{abc}	10.75 ^{abcdef}	11.26 ^{abcde}	11.78 ^{abcd}
Trichoderma viride + Fytolan	5.49 ^{abcd}	6.38 ^{a}	6.26 ^{a}	7.67 ^{bcde}	8.42 ^{abcd}	7.78 ^{bcde}	8.19 ^{bcd}	8.97 ^{abc}	8.92 ^{abcd}	8.70 ^{f}	11.19 ^{abcde}	11.56 ^{abcde}
Trichoderma harzianum + Fytolan	5.05 ^{bcd}	6.33 ^{a}	5.84 ^{abc}	7.67 ^{bcde}	8.46 ^{abcd}	8.25 ^{abcd}	8.10 ^{cd}	9.17 ^{abc}	9.50 ^{abc}	10.14 ^{bcdef}	12.32 ^{a}	11.47 ^{abcde}
Absolute control	4.85 ^{cd}			8.20 ^{abcd}			8.51 ^{bcd}			9.78 ^{def}		

Values having different superscripts differ significantly at 5% level

recorded in *T. viride* incorporated Fytolan drenched treatment. Plants grown in absolute control produced a leaf length of 9.78 cm.

Leaf breadth

In general, plants grown in solarized treatments produced maximum leaf breadth. At the end of two months of planting, maximum leaf breadth (5.69 cm) was observed in 45 days solarized *T. viride* incorporated and Fytolan drenched treatment (Table 17). This was significantly superior to almost all the non-solarized treatments except the Fytolan drenched one. Plants grown in *T. viride* incorporated non-solarized potting mixture produced leaves of least breadth (4.27 cm).

During third month after planting also, maximum leaf breadth (5.85 cm) was recorded in 45 days solarized *T. viride* incorporated Fytolan drenched treatment (Table 17). While, the minimum leaf breadth (4.58 cm) was noticed in *T. viride* incorporated non-solarized treatment. Plants grown in 45 days solarized *T. viride* incorporated potting mixture was highly effective in producing maximum leaf breadth (7.11 cm) during fourth month of planting, which was significantly superior to almost all the non-solarized treatments except the Fytolan drenched one.

During the fifth month after planting, maximum leaf breadth (8.31 cm) was observed in 30 days solarized control. This was significantly superior to majority of the non-solarized treatments. At this stage, minimum leaf breadth (5.72 cm) was recorded in *T. viride* incorporated Fytolan drenched treatment. Absolute control recorded a leaf breadth of 7.1 cm.

Average number of roots

Observations on number of roots and average root length were taken at five months after planting.

Table 17. Influence of solarization on plant characters in pepper cuttings

Treatments	Leaf breadth (cm)											
	2 months after planting			3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-Solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	4.63 bcd	5.35 abc	4.63 bcd	5.49 abc	5.58 ab	5.01 abc	5.75 cd	6.50 abc	5.79 cd	6.08 de	8.31 a	7.75 abc
Trichoderma viride	4.27 d	5.06 abcd	5.05 abcd	4.58 c	5.64 ab	5.42 abc	5.59 cd	6.17 abcd	7.11 a	6.53 cde	7.77 abc	7.70 abc
Trichoderma harzianum	4.68 bcd	4.86 bcd	4.72 bcd	5.00 abc	5.72 ab	5.25 abc	5.95 bcd	6.17 abcd	5.83 cd	6.14 de	8.28 ab	7.20 abcd
Fytolan	4.94 abcd	5.31 abc	5.34 abc	4.96 abc	5.42 abc	5.55 ab	6.22 abcd	6.28 abcd	7.00 ab	6.89 abcde	7.47 abcd	7.53 abcd
Trichoderma viride + Fytolan	4.62 bcd	4.67 bcd	5.69 a	4.83 bc	5.25 abc	5.85 a	5.45 cd	6.42 abcd	6.08 abcd	5.72 e	6.83 bcde	7.36 abcd
Trichoderma harzianum + Fytolan	4.57 cd	5.39 ab	5.38 ab	4.86 bc	5.64 ab	5.75 ab	5.26 d	6.56 abc	6.38 abcd	6.83 abcde	8.03 ab	7.03 abcde
Absolute control	4.82 bcd			5.61 ab			5.83 cd			7.10 abcde		

Values having different superscripts differ significantly at 5% level

Table 18. Influence of solarization on plant characters in pepper cuttings

Treatments	Number of roots			Average root length (cm)		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	8.39^{b}	14.22^{a}	9.89^{ab}	13.17^{ef}	17.43^{bcd}	17.76^{bcd}
Trichoderma viride	7.71^{b}	11.44^{ab}	11.92^{ab}	14.43^{def}	19.27^{bc}	18.83^{bc}
Trichoderma harzianum	9.86^{ab}	11.50^{ab}	11.89^{ab}	14.43^{def}	22.72^{a}	17.63^{bcd}
Fytolan	8.25^{b}	10.19^{ab}	11.47^{ab}	12.20^{f}	17.73^{bcd}	17.82^{bcd}
Trichoderma viride + Fytolan	10.67^{ab}	10.61^{ab}	9.61^{ab}	14.83^{def}	15.42^{cdef}	16.14^{cde}
Trichoderma harzianum + Fytolan	10.09^{ab}	12.08^{ab}	10.67^{ab}	13.52^{ef}	20.63^{ab}	15.91^{edef}
Absolute control	8.83^{b}			14.41^{def}		

Values having different superscripts differ significantly at 5% level

In general, pepper cuttings grown in solarized treatments produced more number of roots compared to non-solarized treatments (Table 18). Highest root number (14.22) was observed in plants grown in 30 days solarized control, which was significantly superior to non-solarized control. Least root number (7.71) was noticed in the *T. viride* incorporated non-solarized treatment. Plants grown in absolute control produced 8.83 roots.

Average length of roots

Increased root length was found in the solarized treatments (Table 18). Maximum root length (22.72 cm) was recorded in 30 days solarized *T. harzianum* incorporated potting mixture, which was significantly superior to almost all the treatments. Plants grown in Fytolan drenched non-solarized soil produced shortest roots (12.2 cm). Pepper cuttings grown in absolute control gave a root length of 14.41 cm.

Effect of solarization on nutrient status of potting mixture

Results of the chemical analysis of the potting mixture are presented in Table 19. Availability of all three major nutrients was influenced by solarization.

The available nitrogen content of the potting mixture was 235.53 ppm. Solarization had significant effect in increasing the availability of nitrogen. There was no significant difference among 30 and 45 days of solarization. Maximum availability of nitrogen (278.6 ppm) was recorded in 45 days solarized potting mixture, which was on par with 30 days solarization (270.2 ppm). The increase in the availability of nitrogen in 30 and 45 days of solarization was 14.72 and 18.29 per cent respectively over control.

The available phosphorus content of the potting mixture on the day of solarization was 145.0 ppm. Significant increase in the availability of phosphorus was found in the solarized treatments (Table 19). However, 45 days of solarization

Table 19. Effect of solarization on the nutrient status of potting mixture (ppm)

Treatments	Available nitrogen	Available phosphorus	Available potassium
Control	235.53[b]	145.00[c]	362.50[b]
30 days solarization	270.20[a]	162.08[b]	398.33[b]
45 days solarization	278.60[a]	188.33[a]	452.50[a]

Values having different superscripts differ significantly at 5% level

showed a maximum availability of 188.33 ppm, which was 29.88 per cent more than control. Whereas, 30 days solarized treatments recorded 11.8 per cent increase in the availability of phosphorus over the non-solarized potting mixture.

Solarization was found to increase the available potassium in the potting mixture (Table 19). This increase was more pronounced in 45 days solarization (452.5 ppm) and was significantly superior to 30 days of solarization (398.33 ppm) and control (362.5 ppm). Fortyfive days solarization recorded 24.83 per cent increase in the available potassium over control while, the increase was 9.88 per cent in 30 days solarization.

Effect of solarization on weed population

The weed population was recorded at monthly intervals for a period of five months. For the purpose of taking the total weed count, six treatments were counted as one unit and the total count of weeds from this was made. Thus, there were 180 bags for each under non-solarized, 30 days solarized and 45 days solarized treatments.

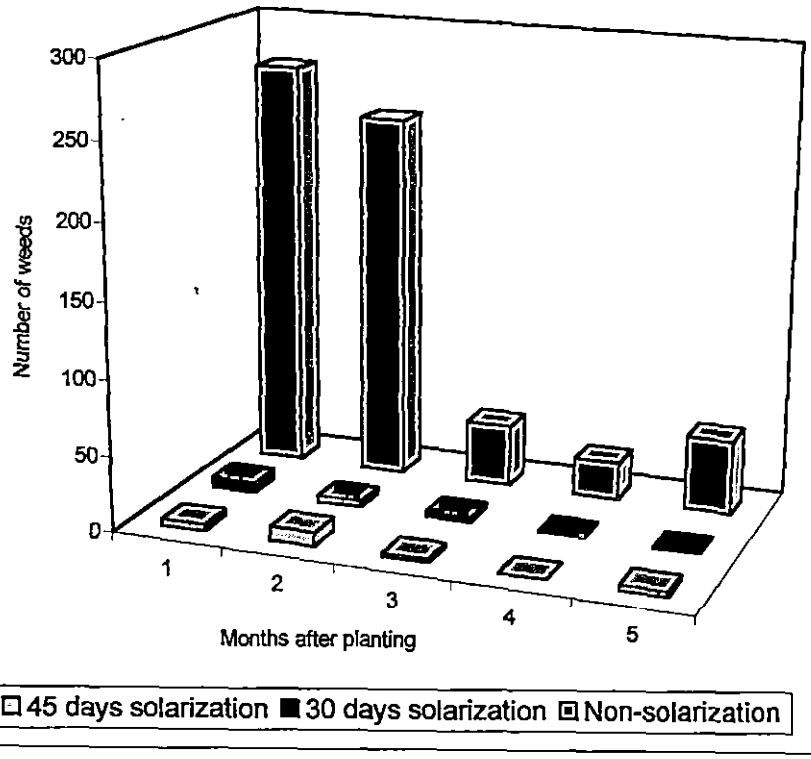
In the pepper nursery, 18 different types of weeds were observed (Table 20 and Fig.7), out of which four were monocots and the remaining were dicots. At the time of planting, there were no weeds in the treatments. Maximum population of weeds was observed during the first and second month after planting. In general, solarization was highly effective in reducing weeds.

When the weed population was recorded one month after planting, a total of 270 weeds were observed in non-solarized treatments, of which 91 were monocots and the remaining dicots (179). *Cyperus rotundus* was the major monocot and *Borreria hispida, Phyllanthus niruri, Cleome viscosa, Mimosa pudica* and *Emelia sonchifolia* were the predominant dicot weeds observed during this period (Table 20). Significant control of weeds was observed in solarized treatments (Table 20). At this stage, the solarized treatments recorded a total weed count of

Table 20. Influence of solarization on weed population

Weeds	Number of weeds														
	1 month after planting			2 months after planting			3 months after planting			4 months after planting			5 months after planting		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Monocots															
1. *Commelina jacobi*	31	0	0	10	0	0	3	0	0	4	0	0	0	0	0
2. *Cyperus rotundus*	40	3	2	27	0	2	4	1	0	0	0	0	2	0	2
3. *Dactyloctenium aegyptium*	13	1	0	15	0	0	11	0	0	0	0	0	0	0	0
4. *Echinochloa colona*	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**91**	**4**	**2**	**52**	**0**	**2**	**18**	**1**	**0**	**4**	**0**	**0**	**2**	**0**	**2**
Dicots															
1. *Biophytum sensitivum*	7	0	0	21	0	0	1	0	0	3	0	0	2	0	0
2. *Borreria hispida*	35	0	1	25	0	3	4	0	0	5	0	0	2	0	1
3. *Cleome viscosa*	24	0	0	2	0	0	0	0	0	0	0	0	0	0	0
4. *Desmodium trifolium*	15	1	0	0	0	0	0	0	0	0	0	0	9	0	0
5. *Emelia sonchifolia*	21	0	0	0	0	0	4	0	0	0	0	0	0	0	0
6. *Lindernia crustacea*	4	0	0	21	4	2	0	0	2	0	0	0	12	0	0
7. *Mimosa pudica*	21	1	1	0	0	0	1	2	0	0	0	0	0	0	0
8. *Mollugo sp*	0	1	0	19	0	0	7	0	0	12	0	0	0	0	0
9. *Phyllanthus niruri*	35	0	0	26	0	0	1	0	0	0	0	0	0	0	0
10. *Scoparia dulcis*	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
11. *Stachytarpheta indica*	0	0	0	14	0	0	3	0	0	0	0	0	5	0	0
12. *Synedrella nodiflora*	7	0	0	46	0	2	0	0	0	1	0	0	3	0	0
13. *Triumpheta rhomboidea*	10	0	0	3	0	0	0	0	0	0	0	0	7	0	0
14. *Vernonia cinera*	0	0	0	12	0	0	2	0	0	0	0	0	2	0	0
Total	**179**	**3**	**2**	**189**	**4**	**7**	**23**	**2**	**2**	**21**	**0**	**0**	**47**	**0**	**1**
Grand total	**270**	**7**	**4**	**241**	**4**	**9**	**41**	**3**	**2**	**25**	**0**	**0**	**49**	**0**	**3**

Fig.7. Influence of solarization on weed population in the black pepper nursery



seven and four respectively in 30 and 45 days of solarization. Same trend was also observed during the second month after planting. At this stage, the non-solarized treatments had 241 weeds compared to four and nine respectively in 30 and 45 days of solarization.

From the third month onwards population of weeds showed a decreasing trend. A total of 49 weeds in the non-solarized treatments compared to three weeds in 45 days of solarization were observed, when the population was estimated at the time of five months after planting.

The total weed population per treatment was 104.33, 2.33 and 3.0 respectively for non-solarized, 30 days solarized and 45 days solarized treatments, of which 76.5, 1.5 and 2.0 were dicots (Table 20 and Fig.7). Thus, the reduction in total weed population in 30 and 45 days solarized treatments were 97.76 and 97.12 per cent respectively over control. In 30 days solarized treatments, per cent reduction of monocots and dicots over control was 97.01 and 98.0 per cent respectively while, it was 96.41 and 97.38 per cent respectively, in 45 days solarized treatments.

DISCUSSION

DISCUSSION

Solar sterilization of nursery soil offers an in-expensive and non-hazardous method to combat soil-borne pathogens. Other sterilants like steaming of soil and fumigation etc. have never been widely used owing to economic considerations and practical difficulties. Similarly, fungicide application has also got many limitations. Therefore, mulching of soil offers a non-chemical approach for controlling soil-borne pathogenic fungi (Stapleton and DeVay, 1986). The efficacy of solarization is due to a combination of thermal and biological factors. In addition to reduction in the population of soil-borne pathogens, solarization also controls weeds and improves emergence, growth and stand of the plants (Katan and DeVay, 1991).

Katan *et al.* (1980) and Hilderbrand (1985) have used transparent plastic sheet as a mulch. Mulching increases the temperature of soil (Katan *et al.*, 1975). One of the major mechanisms by which the solarization reduces the disease and increases the plant growth is by increasing the soil temperature under the mulch (Katan *et al.*, 1976). In the present study, maximum temperature attained at 10 cm depth under mulch was 51.0°C. While, in non-solarized soil it was 42.0°C. The increase in soil temperature in solarized potting mixture over the control ranged from 6.0 to 12.0°C. Such a difference in temperature under mulched and non-mulched soil was also noticed by many workers (Kaewruang *et al.*, 1989a; Chandran, 1989; Kurian, 1992; Dwivedi, 1993).

The difference in the temperature under solarized and non-solarized potting mixture in the present study was higher than that reported by other workers (Rao and Krishnappa, 1995; Wajid *et al.*, 1995; Vilasini, 1996; Bhaskar and Nanjappa, 1997).

However, it was lower than those reported by Tjamos and Paplomatas (1988), Tjamos *et al.* (1991) and Kulkarni *et al.* (1992). The increase in

temperature by transparent polyethylene mulching is due to the green house effect exerted by the polyethylene film and varies with the air temperature, humidity, radiation, wind velocity and soil characteristics (Waggoner *et al.*, 1960; Mahrer, 1979; Katan, 1981b).

Katan (1981b) suggested that the soil temperature fluctuations in solarized and non-solarized soil depend on several factors like atmospheric temperature, thickness of polyethylene film, moisture content of the soil, soil type, colour etc.

Solarization significantly increased the rate of sprouting of pepper cuttings. However, there was no significant difference in the rate of sprouting of pepper in 30 days solarized and 45 days solarized potting mixture. In the present study, sprouting of pepper cuttings in solarized treatments ranged from 68.0 to 76.67 per cent compared to 44.0 to 60.67 per cent in non-solarized treatments. Similar results were also reported in case of other crops by Shukla *et al.* (1990), Kurian (1992), Wajid *et al.* (1995), Vilasini (1996) and Raj *et al.* (1997).

Solarization was highly effective in reducing the pre-sprouting mortality of pepper cuttings incited by *Phytophthora capsici.* The pre-sprouting mortality of pepper cuttings in solarized treatments ranged from 0-6.67 per cent compared to 7.33 to 19.33 per cent in non-solarized treatments. There was not much variation in the reduction of the pre-sprouting mortality of pepper cutting in the non-solarized treatments except in the treatment, which received *Trichoderma viride* and Fytolan.

Thermal death studies of various microorganisms *in vitro* have shown that at or above 50°C (a temperature often exceeded in the upper soil layers during solarization), survival is limited to a maximum of a few hours. At temperature of 37-50.0°C eradication or marked reductions in populations occur within 2-5 weeks (Pullman *et al.*, 1981a & b; Porter and Merriman, 1983). Pullman *et al.* (1981a)

observed that 90 per cent of *P. ultimum* propagules could be destroyed on exposing the fungus grown on PDA, to 47.0°C for 180 minutes or 37.0°C for 20 days. They also found that propagule survival was a function of time x temperature relationships.

The thermal death point of plant pathogens may vary from organism to organism depending upon the stage of the organism, nutrient status of the growing media,etc.

Benson (1978) determined the thermal inactivation of two isolates of *P. cinnamomi* (from a root of Fraser fir and the other from a rhododendron root) by exposing agar discs that contained mycelium of the isolates to hot water at various temperatures for different periods. He found that the time required for 50 per cent inactivation were 26.3 minutes and 51.7 minutes for two isolates at 39.0°C and were 2.7 minutes and 3.3 minutes respectively at 43.0°C for two isolates. Thermal inactivation of *P. cinnamomi* was inversely related to the exposure time and treatment temperature.

Juarez-Palacios *et al.* (1991) conducted studies on heat sensitivity and effect of soil solarization on the survival of hyphae and spores of *P. cinnamomi, P. cactorum* and *P. megasperma* in inoculated soil. They showed that viable chlamydospores of *P. cinnamomi* were completely inactivated in infested soil exposed to 45.0°C for 20 minutes. Oospores of higher temperature isolate of *P. megasperma* survived exposure for 30 minutes at 45.0°C, whereas *P. cactorum* was killed within 30 minutes at 45.0°C.

In the present investigation the average maximum temperature in the solarized potting mixture at 10 cm depth was 47.94°C which was 9.43°C more than that of non-solarized potting mixture. This high temperature in the solarized potting mixture could have killed or inactivated large numbers of *P. capsici* propagules which lead to reduced incidence of the mortality of pre-sprouted pepper

cuttings in the solarized potting mixture. Similar observations were recorded in the case of *Pythium aphanidermatum* by Kulkarni *et al.* (1992), Kurian (1992) and Vilasini (1996).

Increasing the period of solarization from 30 to 45 days did not consistently result in reducing the pre-sprouting mortality of pepper cuttings. In 45 days of solarization, the pre-sprouting mortality ranged from 0-6.67 per cent. This may be due to the fact that thirty days of solarization might have eradicated the *P. capsici* propagules present in the upper strata and the remaining might have escaped the longer period of exposure for 45 days.

Pre-disposition of pathogen propagules to damage from anaerobes by exposing the propagules to low redox potentials also may be one of the reasons for their accelerated death rate in soil tarped with polyethylene sheets (Cook and Baker, 1983). The tarps elevated the soil temperature, increased soil respiration and served as a barrier to oxygen diffusion into the soil and carbon dioxide diffusion out of it. The hydrothermal effect of the solarization process is probably the most critical for effective soil disinfestation and the treatment becomes more effective as heating of moist soil is increased (Stapleton and DeVay, 1986).

In addition to direct thermal death, the effects of sub lethal heating result in delayed propagule germination, reduced growth rates, greater sensitivity to soil fumigants and possible induced biological control of several phytopathogenic fungi (Pullman *et al.*, 1981a; Lifshitz *et al.*, 1983; Greenberger *et al.*, 1984). The greatest reductions in soil biota during soil solarization and the longest duration of reductions after the treatment occur near the soil surface because of higher soil temperature.

In the non-solarized soil nearly 80 per cent control of the pre-sprouting mortality was obtained and this may be due to the high temperature obtained in the non-solarized soil. In the non-solarized soil, the maximum temperature ranged

from 35.5°C to 42.0°C. This high temperature might have resulted in a reduction in the population of *P. capsici*. The temperature required to kill the vegetative structures of *P. capsici* is usually less than that required to kill the sexual spores.

Solarization was effective in reducing the per cent mortality of rooted cuttings of pepper. The mortality in solarized treatments ranged from 0-8.1 per cent compared to 8.4 to 23.46 per cent in non-solarized treatments. No significant difference could be noticed among the various solarized treatments. However, solarization for 45 days and incorporation of *T. viride* and Fytolan was found superior to other treatments in reducing the mortality of rooted cuttings of pepper as it recorded cent per cent control.

Disease incidence was observed during the seventh fortnight after planting. Percentage foliar infection of foot rot was low in solarized treatments compared to non-solarized treatments. The disease incidence ranged from 21.69 to 87.58 per cent in non-solarized treatments; while, it was 2.78 to 15.54 per cent in the solarized treatments. With regard to the efficacy of the antagonists, both *T. viride* and *T. harzianum* were found equally effective against *P. capsici*.

Severe incidence of the disease occurred during eighth and ninth fortnights after planting. This period coincides with the south west monsoon and the climatic conditions are highly congenial for the multiplication of the pathogen and development of the disease. This may be the reason for the severe incidence of the disease.

An increase in the population of *P. capsici* was observed during the eighth and ninth fortnights after planting and this might have contributed to the increased disease incidence.

A partially viable propagule may recover and resume its course of development, if provided with normal conditions and sufficient time (Pullman *et al.*, 1981a). The build up of inoculum from survived propagules of *P. capsici*

takes time to reach a level to cause disease. Development of the disease incidence in the solarized treatments may be due to this reason. Similar effects were observed by Munnecke *et al.* (1976), Pullman *et al.* (1981a), Chandran (1989) and Vilasini (1996).

Sublethal heating caused delays in germination, which varied with temperature and duration of exposure. The longer a propagule was heated and still survived, the longer it required to germinate. Sublethal heating decreases the ability of a propagule to withstand further stress and cause plant disease.

Pullman (1979) observed that surviving propagules of *V. dahliae* by soil solarization, caused less disease than similar inoculum densities of non-heated propagules. Sublethal heating may increase the sensitivity of fungal propagules to antagonistic microflora as shown with *Armillaria mellea* (Munnecke *et al.*, 1976). This may be one of the possible reasons for the low disease incidence in the solarized treatments. Soil temperature under the polyethylene mulch was 51.0°C at 10 cm depth which also resulted in a marked reduction in pathogen propagules. Similar results were observed in carnation plants (Garibaldi and Tamietti, 1989), in gerbera (Kaewruang *et al.*, 1989a & b), in tobacco (Wajid *et al.*, 1995) and in avocado (Lopez-Herrera *et al.*, 1997).

Survival of microorganisms under the mulch is related with time, species, soil depth and soil characters. *P. cinnamomi* could be completely inactivated within two weeks of solarization at 15 and 30 cm depth while, *P. megasperma* survived the solarization for four weeks (Juarez-Palacios *et al.*, 1991). Zentmyer (1980) observed 35.0°C is the maximum temperature that allows the survival of *P. cinnamomi.* Three weeks of solarization completely eradicated *P. cinnamomi* up to 45 cm in avocado.

Trichoderma spp. caused inhibition of *P. capsici* in the laboratory conditions as well as under field conditions. The ability of the *Trichoderma* to

inhibit the disease increased under solarized conditions. There was 97.2 per cent control of the disease in the 45 days solarized *T. viride* incorporated treatment. The effectiveness of solarization may thus be increased by incorporating *Trichoderma* spp. This finding is in conformity with the results of Elad *et al.* (1980), Sivan and Chet (1989), Wajid *et al.* (1995) and Vilasini (1996). The involvement of heat resistant antagonists like *Talaromyces flavus* of *V. dahliae* in the longer range effect of soil solarization on globe artichoke has been reported by Tjamos and Paplomatas (1988).

Combining solar heating of the soil with a biocontrol agent either in the field or in the green house further improved their efficiency (Elad *et al.*, 1980). The synergistic phenomenon involved in the approach of an integrated control; i.e., pathogens weakened by sublethal doses might be controlled more efficiently and for longer periods by antagonists (Chet *et al.*, 1979; Munnecke *et al.*, 1973; Ohr *et al.*, 1973; Katan, 1974; Hadar *et al.*, 1979). In such a situation, population of antagonists may increase since the weakened or dead cells of the pathogen serve as an enrichment medium. Elad *et al.* (1982) reported the lytic activity of extracellular enzymes of *T. harzianum* when grown on fungal cell wall components of pathogenic soil-borne fungi. However, this may not be the only biological control mechanism.

The disease incidence in the 45 days solarized treatments was more than that of 30 days solarized treatments, but there was no significant difference. The reductions in the population of *P. capsici* immediately after solarization, in 45 days solarized control was 97.35 per cent compared to 94.82 per cent in 30 days solarized control. The reduction in the propagules of *P. capsici* between 30 and 45 days solarized treatments was 2.55 per cent more in 45 days. However, the per cent variation in the disease development was 3.81 more in 45 days.

Apart from decreasing the viability of propagules, solarization may also reduce the capacity of the propagules to cause disease. This is evident from the fact

that even if the same number of viable propagules taken from the solarized and non-solarized treatments are allowed to infect same number of plants, the infection per cent may vary. This may be due to the fact that solarized viable propagules causing disease is less compared to viable propagules from non-solarized treatments.

Permeability of polyethylene to many gases is low. The mulch cover seals the soil and causes an accumulation of volatiles such as carbon dioxide, ethylene and possibly other substances (Horowitz *et al.*, 1983; Rubin and Benjamin, 1983; Greenberger *et al.*, 1984). Certain volatiles accumulated to high amounts and heated under the mulch play a role in pathogen control (Katan, 1981b). The lethal effect of increased quantities of volatiles is more on pathogenic fungi than on saprophytes (Peethambaran, 1975; Gamliel and Stapleton, 1993a & b). Thus, it is presumed that accumulation of volatiles under polyethylene might have also resulted in the inactivation of *P. capsici* and thereby reducing the disease.

The results of the population of *P. capsici* in the potting mixture is highly variable. Thermal sensitivity of *P. capsici* under various temperature conditions at different depths has to be studied to find out the exact period of solarization for eradication of the pathogen.

Solarization inhibited the total microbial population in the soil. Similar findings were reported previously by Katan (1980, 1981b), Stapleton and DeVay (1982), Patel and Patel (1998).

Reductions in the populations of bacteria and actinomycetes were more in 30 days solarized treatments than 45 days solarized treatments. However, a marked difference in the fungal population was not observed between 30 and 45 days solarized treatments.

Solarization was found to reduce the population of fungi in the present study. Similar results were reported by various workers (Stapleton and DeVay, 1982, 1984; Shukla *et al.*, 1990; Kurian, 1992; Vilasini, 1996; Raj *et al.*, 1997; Patel and Patel, 1997, 1998).

The reduction in the population of bacteria under mulch observed in the present study was in agreement with those reported by Stapleton and DeVay (1982), Gamliel and Katan (1991), Kurian (1992) and Vilasini (1996).

Solarization inhibited the actinomycetes population in the present study. Reduction in the population densities of actinomycetes following solarization was reported previously by Stapleton and DeVay (1984) and Vilasini (1996).

Maximum soil temperature at 10 cm depth under the polyethylene mulch reached above 45°C for most of the days and above 50°C for few days. And soil under the mulch retained moisture during the entire period of solarization and thus enhanced the killing of the propagules of the microorganism. These are the possible reasons lead to the reduction in the population densities of microorganisms.

The natural population of the antagonists in the soil was low (0.35×10^3 cfu g^{-1}). Solar heating increased the *Trichoderma* population in the incorporated treatments compared to non-solarized treatments. Thirty days solarization enhanced the population to $5.94 - 11.0 \times 10^3$ cfu g^{-1} compared to $4.89 - 6.09 \times 10^3$ cfu g^{-1} in 45 days solarized treatments at one month after planting while, it was $2.97 - 5.12 \times 10^3$ cfu g^{-1} in non-solarized treatments. These results are in agreement with the findings of Elad *et al.* (1980); Katan *et al.*, (1981) and Sivan and Chet (1993).

Population of *Trichoderma* spp. increased in the solar heated treatments. Incidence of disease caused by *P. capsici* remained low apparently due to a shift in

the biological equilibrium in the soil in favour of the antagonists. Such a shift in the solar heated soil may explain the reduction in inoculum potential in the field, the slow down of inoculum build up and the more efficient control where this treatment is combined with *T. viride*.

Present study showed that fertility of the potting mixture was improved by solarization. An increase in the status of available nitrogen, phosphorus and potassium was observed in the solarized potting mixture. Amount of soluble and organic minerals generally increased by solarization. Significant increase in the nitrogen due to solarization was reported by Stapleton *et al.* (1985), Kaewruang *et al.* (1989a), Chandran (1989), Rao and Krishnappa (1995) and Vilasini (1996). Significant increases in the phosphorus and potassium were found in solarized soil by Stapleton and DeVay (1986), Kaewruang *et al.* (1989a), Gamliel and Katan (1991), Kurian (1992) and Vilasini (1996).

The increases in the nutrients occurred in solarized potting mixture might be due to the increased soil temperature. Stapleton *et al.* (1985) suggested that the increase resulted from soil heating rather than from containment of moisture or other non-thermal effects under the polyethylene. The increase in temperature is known to catalyse the chemical and biological process that takes place in a soil, which may lead to the increased status of available nutrients.

It may be possible that the increase in available nitrogen and phosphorus might have resulted from decomposition of the organic matter (Kaewruang *et al.*, 1989a).

Reduction of weeds was another positive feature of solarization. At the time of removal of the polyethylene sheets, there were no weeds in the solarized potting mixture and the population of weeds was low in solarized treatments. Excellent weed control with solarization was reported by Rubin and Benjamin

(1983, 1984), Kurian (1992), Yaduraju (1993), Rao and Krishnappa (1995), Vilasini (1996), Bhaskar and Nanjappa (1997) and Chellemi *et al.* (1997).

Basic phenomenon helping the weed control is the direct thermal killing of weed seeds or direct effect of increased temperature. During solarization period, eventhough weed seeds germinate, because of high temperature of the soil and absence of air they desiccate (Bhaskar and Nanjappa, 1997).

In this study maximum soil temperature under the mulch during the period of solarization was 51.0°C and the soil under mulch was wet throughout the period of solarization, which reduced the heat resistance of hydrated seeds. This may be the reason for the reduction of weeds in the solarized treatments. The changes in carbon dioxide/oxygen levels in soil under polyethylene mulch may play an important role in partial or complete breaking of seed dormancy thus enhancing germination followed by thermal killing (Rubin and Benjamin, 1984).

The reduction in weed population in the solarized treatments may not be due to a single factor. A combination of factors involved in weed control using solarization are, direct thermal killing of germinating or even dormant seeds (Egley, 1981; Horowitz *et al.*, 1983; Rubin and Benjamin, 1983), thermal breaking of seed dormancy followed by thermal killing, thermally induced changes in carbon dioxide or oxygen, ethylene and other volatiles which are involved in seed dormancy release followed by thermal killing (Katoh and Esashi, 1975; Taylorson and Hendricks, 1981), direct effect of high temperature interacting with toxic volatiles released from decomposing organic matter (Pavlica *et al.*, 1978) and microbial attack of seeds weakened by sublethal temperatures (Hendricks and Taylorson, 1976).

Increased plant growth response is frequently observed following soil solarization. The response of pepper cuttings to solarization in the present investigation is expressed as increase in the height of plants, number of leaves per

plant, length and breadth of leaves and development of better root system. These responses are typical to improved fertility of the soil. Similar findings were observed in Chinese cabbage (Stapleton *et al.*, 1985), wheat (Cook *et al.*, 1987), eucalyptus (Shukla *et al.*, 1990), eggplant and pepper (Gamliel and Katan, 1991), periwinkle (Kulkarni *et al.*, 1992), Chillies (Kurian, 1992), ginger (Vilasini, 1996) and cauliflower, tomato and brinjal (Raj *et al.*, 1997).

Increased growth response following solarization may be partially due to increase in the concentration of available forms of some mineral nutrients (Chen and Katan, 1980) as well as to a reduction in a number of soil-borne pathogens and pests and population shift in favour of beneficial soil microorganisms, especially when crops are planted shortly after solarization (Stapleton and DeVay, 1984), destruction of phytotoxic compounds and release of growth regulator like compounds (Katan, 1981b).

In the present study, pepper cuttings grown in solarized potting mixture showed better colonization of *Azospirillum* (50-90%) compared to non-solarized treatments (30-60%). Increased *Azospirillum* colonization in ginger plants grown in solarized soil was reported by Vilasini (1996).

Root colonization of pepper cuttings by VAM in the solarized treatments was low (20-66%) compared to non-solarized treatments (46-84%). These results are in agreement with Tjamos *et al.* (1991) and Bendavid-Val *et al.* (1997). However, Nair *et al.* (1990), Afek *et al.* (1991), Kurian (1992) and Vilasini (1996) observed increased colonization of VAM in solarized soil.

The direct effect of high temperature induced during solarization is a significant factor in reducing the indigenous VAM. However, several other explanations for this phenomenon can also be suggested: (i) the inhibition of VAM colonization could result from a temporary alteration in the chemical, physical and microbial properties of the soil during solarization (Chen *et al.*, 1991); (ii) some of

the VAM inoculum in the soil was in the form of hyphae (vegetative stages) and was thus devastated by high temperature developed during solarization and (iii) a longer time is needed for the few remaining propagules (mainly as spores) to properly infect plant roots (Bendavid-Val *et al.*, 1997).

This study clearly demonstrates that solarizing the potting mixture for 30 days prior to planting of pepper cuttings is a practical and economical measure not only for decreasing foot rot disease incidence but also for improving the health and vigour of pepper cuttings. This effect could be further exploited by combining solarization with the addition of *Trichoderma viride* and *T. harzianum*, antagonistic to *Phytophthora capsici*.

SUMMARY

SUMMARY

The study 'Integrated management of *Phytophthora* rot in black pepper nursery' was conducted at the experimental plot of the Department of Plantation Crops and Spices, College of Horticulture, Vellanikkara during January to August 1998. Before mulching with polyethylene sheets, potting mixture was inoculated with *Phytophthora capsici* Leonian, emend. Alizadeh and Tsao.

Potting mixture was mulched with 150 guage transparent polyethylene sheets during 17-1-1998 to 2-3-1998. Two durations of solarization, viz., 30 and 45 days were tried. Soil temperatures were recorded daily at 8.30 am and 2.30 pm at 10 cm depth.

The atmospheric temperature during the period of solarization ranged from 21.6°C to 35.8°C. Soil temperature in solarized potting mixture ranged from 30.0 to 51.0°C while, it was 26.5 to 42.0°C in non-solarized potting mixture.

The maximum temperature at 10 cm depth in solarized potting mixture ranged from 43.0 to 51.0°C compared to 35.5°C to 42.0°C in non-solarized potting mixture.

The difference in maximum temperature in solarized potting mixture over non-solarized ranged from 6.0°C to 12.0°C.

Soil temperature variation in solarized potting mixture was 21.0°C as against 15.5°C in non-solarized potting mixture. In the solarized potting mixture, temperature was 1.0 to 12.0°C and 6.5 to 15.8°C above the non-solarized and atmospheric temperature respectively.

Maximum temperature variation during a day in solarized potting mixture was 18.5°C (1-3-'98) while in non-solarized potting mixture, it was 12.0°C (28-2-'98 and 1-3-'98).

The weekly average maximum temperature at 10 cm depth in solarized soil ranged from 45.93 to 50.83°C with a mean of 47.94°C as against 37.07 to 41.83°C and 38.51°C respectively in non-solarized soil.

Soil temperature in solarized potting mixture was above 40.0°C for the entire solarization period and above 45.0°C for 40 days and above 50.0°C for four days.

In treatments requiring the incorporation of *Trichoderma viride* and *Trichoderma harzianum*, five grams of the antagonists were applied in each bag at the time of planting.

One month after planting, Fytolan (0.3%) was drenched in required treatments.

Solarization enhanced the sprouting of pepper cuttings. In the solarized treatments, per cent sprouting ranged from 68.0 to 76.67 per cent compared to 44.0 to 60.67 in the non-solarized treatments.

Solarization was highly effective in reducing the pre-sprouting mortality of pepper cuttings. Mortality of cuttings ranged from 0-6.67 per cent in solarized treatments as against 7.33 to 19.33 per cent in non-solarized treatments.

Solarization was effective in reducing the mortality of rooted pepper cuttings caused by *P. capsici*. Mortality ranged from 8.4 to 23.46 per cent in non-solarized treatments. While, it was 0-8.1 per cent in solarized treatments. Fortyfive days solarized, *T. viride* incorporated, Fytolan drenched treatment was highly effective and there was cent per cent control of the disease.

Foliar infection by *Phytophthora capsici* occurred in solarized as well as non-solarized treatments during seventh fortnight after planting. Severe

incidence of the disease was observed during eighth and ninth fortnights. Marked reduction in the disease was observed in solarized treatments.

Disease incidence ranged from 2.78 to 15.54 per cent in solarized treatments while, it was 21.69 to 87.58 per cent in non-solarized treatments. Solarization for 45 days and incorporation of *T. viride* was highly effective as it recorded 97.22 per cent control of the disease. Maximum disease incidence (87.58%) was noticed in the non-solarized control. When the effectiveness in the duration of solarization is considered, solarization for 30 days recorded minimum disease incidence as compared to 45 days in which the disease incidence were 11.75 and 15.54 per cent respectively.

Solarization reduced the population of *P. capsici* in the potting mixture. The reduction was more in the solarized treatments immediately after removing the polyethylene sheets. Population reduction of *P. capsici* ranged from 94.41 to 97.35 in solarized potting mixture compared to 70.28 to 85.21 per cent in non-solarized potting mixture.

Solarization resulted in reduction of fungal, bacterial and actinomycetal population in the potting mixture. As the period of solarization increased, there was no corresponding reduction in the microbial population.

Increase in the population of *Trichoderma* spp. was noticed in the antagonists incorporated solarized treatments compared to incorporated non-solarized treatments.

Better colonization of *Azospirillum* with the pepper roots was noticed in solarized treatments. However, root colonization of pepper cuttings with VAM was less in solarized treatments.

Availability of nutrients like available nitrogen, phosphorus and potassium was increased by solarization.

Solarization had a detrimental effect on weeds. Weed population remained low in solarized treatments. The per cent reduction of weeds over control was 97.76 and 97.12 per cent respectively for 30 and 45 days of solarization.

Increased growth response of rooted pepper cuttings was observed in solarized treatments. All growth parameters like height of plants, number of leaves, length and breadth of leaves, and development of root system were better in plants grown in solarized treatments.

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INTEGRATED MANAGEMENT OF *Phytophthora* ROT IN BLACK PEPPER NURSERY

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Studies on the 'Integrated management of *Phytophthora* rot in black pepper nursery' was conducted at the College of Horticulture, Vellanikkara during January to August 1998. Potting mixture was inoculated with *Phytophthora capsici* Leonian, emend. Alizadeh and Tsao before solarization. Transparent, 150 guage polyethylene sheets were used for solarization of the potting mixture.

Maximum soil temperatures recorded at 10 cm depth in solarized potting mixture was 51.0°C while, it was 42.0°C in non-solarized one.

Soil temperature of solarized potting mixture was more than 45°C for 40 days and above 50°C for four days.

Solarization enhanced the sprouting of pepper cuttings. Solarization was effective in reducing the pre-sprouting mortality and mortality of rooted cuttings by the pathogen. Fortyfive days solarized, *Trichoderma viride* incorporated Fytolan drenched treatment exerted cent per cent control of the mortality of rooted cuttings.

Solarization significantly reduced the foliar infection of rooted cuttings. Forty five days solarized, *T. viride* incorporated treatment was highly effective and recorded 97.22 per cent control of the disease. Maximum disease incidence (87.58%) was noticed in the non-solarized control.

Reduction in *Phytophthora* population ranged from 94.41 to 97.35 per cent in solarized potting mixture immediately after the removal of polyethylene sheets.

Maximum population of *Trichoderma* spp. was observed in solarized *Trichoderma* spp. incorporated treatments.

Solarization reduced fungal, bacterial and actinomycetes population of potting mixture.

Plants grown in solarized potting mixture exhibited better colonization of *Azospirillum*. However, root colonization of VAM in pepper cuttings was less in solarized treatments.

Availability of nitrogen, phosphorus and potassium was increased by solarization.

Solarization effectively reduced the weed population in the pepper nursery.

Solarization resulted in increased growth response of rooted pepper cuttings. All growth parameters like height of plants, number of leaves, length and breadth of leaves and development of root system were influenced by solarization.