STUDIES ON FOOT ROT OF BLACK PEPPER WITH SPECIAL REFERENCE TO SOIL SOLARIZATION

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON FOOT ROT OF BLACK PEPPER WITH SPECIAL REFERENCE TO SOIL SOLARIZATION"** Submitted by **Mr. SHANKAR G. HEGDE** for the degree of **MASTER OF SCIENCE** in **PLANT PATHOLOGY** of the UNIVERSITY OF AGRICULTURAL SCIENCES, DHARWAD, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for award of any degree, diploma, associateship, fellowship or other similar titles.

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Affectionately dedicated
to my beloved Doddamma
Late Smt. Mahadevi

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

I. INTRODUCTION

Black pepper (Piper nigrum L.) is the most important of all the fifty odd spices grown in India and contributed to about 71 per cent of our total foreign exchange earnings (1988-89), touching an export figure of 41,065 MT. During 1989-90, the total area under this crop was 155.78 thousand hectares with a production of 38.49 thousand tons (Paramjit Singh, 1991). In India, area is largely distributed in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh and North Eastern States especially Assam. This spice is also quite important in the international trade accounting for about 36.5 per cent of the world trade in spices. It is grown as pure crop trained on live tree supports of Erythrina indica, etc., in Kerala whereas in Karnataka, areca-pepper, cardamom-pepper and rubber-pepper mixed cropping systems are in vogue.

Among the factors which hinder the production of pepper in India and elsewhere are the diseases. Foot rot (Quick wilt), caused by Phytophthora capsici (Phytophthora palmivora MF_4), is the major disease affecting black pepper causing severe crop loss, thus limiting pepper production in Uttara Kannada and Shimoga districts where pepper is grown on arecanut standards. This disease has assumed epidemic

proportions resulting in total disappearance of black pepper in the gardens. In 1978, it became severe and from then onwards it has been on the increasing side (Sastry, 1982 and Dutta, 1984). Further this is aggravated by the conditions under which the crop is grown. The disease was characterised by rotting of leaves and wilting of the vines. It was suggested that spread of infection was mainly through soil and water (Nambiar and Sarma, 1977) and the soil-borne inoculum was of fundamental importance in initiating epiphytotics of the Phytophthora disease (Thorold, 1955; Holliday and Mowat, 1963; Okaisabor, 1971: and Onesirosan, 1971).

An integrated control which involves the rational use of biological, chemical, and physical methods of controlling plant diseases will have to be considered. The use of chemical (Ridomil MZ 72 wp), biological agent (Trichoderma spp.), and organic amendments (neem cake) have given control of foot rot of black pepper more than that when a single method was used (Subramanyam, 1993). Integration of chemicals and biotic agent for managing soil-borne diseases has been considered as a novel approach as it requires low amounts of chemicals, thereby reducing the cost of control as well as pollution hazards, with minimal interference of biological equilibrium (Papavizas, 1973).

Soil solarization of the soil (also referred to as solar heating, solar pasteurization, solar disinfestation or solar tarping) is a relatively new method of soil disinfestation for controlling soil-borne pathogens, weeds and other pests. Traditionally, the two basic approaches to soil disinfestation are the physical, e.g. artificially heating the soil by steam, and the chemical. Soil solarization is a third and new approach to soil disinfestation, based on solar heating of the soil by covering (mulching) it with polyethylene sheet during the hot season, thereby increasing the temperature and killing the pathogen. The polyethylene sheets laid on the soil serve as traps for capturing solar energy. Therefore, the concept of soil solarization combines the heating principle as a killing agent for pathogen control with that of soil heating by polyethylene mulching.

Many studies have shown that solarization effectively reduces pathogen populations and disease incidence in various regions. In many cases these effects lasted for the whole season or even longer.

Combining pesticides or biocontrol agents with solarization is expected to improve disease control. Whenever a pathogen is weakened by heating a synergistic effect is

expected, thus reduced dosages might suffice for improved control. Combining solarization with biocontrol agents might be especially effective in preventing reinfestation and extending the effectiveness of disease control.

With suitable climatic conditions, soil solarization controlled diseases caused by Verticillium sp., Rhizoctonia solani, Fusarium oxysporum f.sp. vasinfectum or melonis, Sclerotium rolfsii, Pyrenochaeta lycopersici, P. terrestris, many weeds and nematodes. It is very well known that Phytophthora species are highly sensitive to high temperature. Solar heating involves the use of heat as a lethal agent for pest control through the use of polyethylene mulches. Hence an attempt was made to integrate soil solarization with other methods to control this disease.

Soil solarization, as such, aims to eradicate or reduce the inoculum existing in the soil. The final goal is to achieve an economic reduction in disease incidence for at least one season.

The possibility of negative effects exerted on soil microorganisms and to antagonists by soil solarization are needed to be carried out.

The use of extracts of garlic and mustard is in practice in some areas. The detailed study on effect of these extracts on reduction of Phytophthora capsici in the soil is to be carried out.

Root knot nematode, Meloidogyne incognita and the burrowing nematode, Radopholus similis are highly pathogenic to black pepper and affect the growth and vigour of the vines resulting in significant reduction in yield. Plant parasitic nematodes belonging to twenty nine genera and fourty eight species are reported from black pepper (Sundararaju et al., 1979a&b) So far, only seventeen genera are reported in association with the crop in Kerala and Karnataka (Sundararaju et al., 1979a&b) But the information on plant parasitic nematodes associated with pepper in Sirsi plantations has to be carried out.

Therefore, an attempt was made with the following objectives to obtain control of foot rot or wilt of black pepper in Uttara Kannada district of Karnataka State.

1. To study the suppression and survival of Phytophthora capsici in soil by solarization.

2. To assess the influence of solarization on the survival and population dynamics of antagonistic organisms in the rhizosphere.

3. To study the combined effect of metalaxyl spraying, neem cake application, Trichoderma harzianum, garlic and mustard extract and soil solarization on the suppression of Phytophthora capsici in the soil.

4. To study the population of plant parasitic nematodes in the rhizosphere along with Phytophthora capsici.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

2.1 HISTORY AND DISTRIBUTION

The first report of sudden collapse and death of the pepper vines came from Lampung (Indonesia), in 1885. Muller (1936) identified the causal agent as Phytophthora sp. and named it as P. palmivora var. piperina. In Sarawak (Malaysia) the disease was reported in 1941 (Newman, 1941; Thompson, 1941) and its severe outbreak occurred in 1952 (Miller, 1953). The first outbreak record of wilt of black pepper due to Phytophthora in India was in 1966 (Samraj and Jose, 1966) from Kerala though the disease was noticed as early as in 1929 (Venkata Rao, 1929). However, in India, the report on the incidence of root diseases of black pepper dates back to 1902 (Menon, 1949) when Barber (1902, 1903, 1905) and later Butler (1906, 1918) investigated the disease in Wynad (Kerala). The disease was reported from Indonesia (Muller, 1936), Puerto Rico (Gregory, et al., 1960), Sarawak (Holliday and Mowat, 1963), Brazil (Holliday, 1965), Jamaica (Leather, 1967), Thailand (Tsao and Tummakate, 1977), and Malagasy Republic (de Waard, 1979). In recent years this disease has been observed in severe form in Uttar Kannada and Shimoga

districts of Karnataka State, India (Sastry, 1982; Hegde, 1983 and Dutta, 1984).

2.2 ECONOMIC IMPORTANCE

The disease is soil-borne, associated with high soil moisture and spreads through soil water. In India Samraj and Jose (1966) recorded vine death up to 20 per cent in Cannanore district (Kerala) while Nambiar and Sarma (1977) recorded 25 to 30 per cent loss in some gardens in Cannanore and Calicut districts (Kerala). In Sarawak, during 1953-56 the pepper loss was about 7000 tons amounting to £ 1.7 million (Holliday and Mowat, 1963). Leefmans (1934) recorded death of vines of about 10 per cent in then West Borneo. An outbreak of foot rot occurred during 1967-68 in Lampung area destroying 40 to 50 per cent of pepper area (de Waard, 1979). The overall loss due to foot rot in major pepper growing countries of the world, when estimated at 3 to 5 per cent loss of the total planted area, would amount to US $ 4.5 to 7.5 million per annum (de Waard, 1979). Heavy loss of pepper crop due to wilt disease has also been recorded from Uttar Kannada (Sastry, 1982) and Shimoga (Dutta, 1984) districts of Karnataka State. Recently, Subramanyam (1993) carried out surveys during 1989 and 1990 in five villages of Uttar Kannada district

(Karnataka) and recorded up to 60 to 80 per cent incidence in some gardens.

2.3 SYMPTOMATOLOGY

Nambiar and Sarma (1977) reported the infection due to species of Phytophthora on all parts of black pepper vine and thus described exclusive root rot, collar rot, aerial vine death and leaf and spike infection either singly or in different combinations.

Muller (1936) described lesions with grey centres surrounded by alternating dark and light brown zones with peripheral water soaked margins on black pepper leaves due to Phytophthora infection. According to him the zonations occurred in alternate wet and dry weather,but not in continuous wet condition. Holliday and Mowat (1963) reported uniform brown lesions with fimbriate margins on the leaves. Irrespective of the type of lesions, heavy defoliation occured due to leaf infection. Immature leaves were highly susceptible than mature ones and the lower surface of leaf was more susceptible than upper surface (Turner, 1969).

Spike infection culminating in its shedding is another common symptom of aerial infection. Usually, the distal end of the spike is affected and the lesions spread

towards the stalk. Occasionally a few berries only showed infection in a spike (Nambiar and Sarma, 1977).

The collar rot infection occurs either at the collar or just above or below the soil level. Early infections of collar rot or root rot usually go undetected until foliar yellowing starts. The initial symptom on the stem appears as water soaked area similar to that observed on the leaf. which later turn to brown to dark brown within two to three days. Flaccidity of younger leaves occur which is later followed by yellowing and flaccidity of mature leaves. The whole foliage turn yellow and all the leaves drop down. The infected regions appeared wet, discoloured, slimy to touch and in advanced stages, emitted a foul smell. Vascular discolouration observed in many cases, but not consistently (Nambiar and Sarma, 1977). With progress of the disease, the cortex gets disintegrated and peeled off. The infection of the collar gradually progress downwards and spreads to the root system and causes its rotting (Holliday and Mowat, 1963 and Nambiar and Sarma, 1977).

There are reports of exclusive root infection, although in most cases, root rot follows collar rot. The earliest visible symptom in such cases is foliar yellowing and interveinal chlorosis.

Interveinal chlorosis is the first foliar symptom of root and collar rot. Foliar yellowing, flaccidity, defoliation, breaking of the stems at nodal regions and spike shedding are the general aerial symptoms noticed in the case of root rot and collar rot (Muller, 1936 and Holliday and Mowat, 1963). Detailed symptomatology of the disease has been described (Sastry, 1982 and Anandaraj et al., 1988).

2.4 ISOLATION

Holliday and Mowat (1963) reported successful isolation of Phytophthora from fresh lesions of foot rot affected stems and roots of black pepper using plain agar medium. The fungus was isolated from soil using baits like black pepper leaf discs (Muller, 1936), apple (Holliday and Mowat, 1963) and castor seeds (Narasimhan and Ramakrishnan, 1969 and Sastry, 1982). A number of selective agar media containing antibacterial antibiotics and selective antifungal agents have been proved useful for isolation of Phytophthora from soil and plant tissues. (Eckert and Tsao, 1960; Kuhlman and Hendrix, 1965; Flowers and Hendrix, 1969; Tsao and Ocana, 1969; Sneh, 1972; Fujisawa and Masago, 1975; Masago et al., 1977 and Tsao and Guy, 1977). Leaflets of Albizia falcataria (L.) were used as baits to isolate black pepper Phytophthora from soil (Anandaraj and Sarma, 1990).

2.5 QUANTIFICATION OF *Phytophthora* IN SOILS

Various species of *Phytophthora* which cause black pepper wilt, black pod of cocoa and black shank of tobacco were generally isolated from the upper soil horizons and it was believed that soil-borne inoculum was of great importance in starting disease epiphytotics (Thorold, 1955; Holliday and Mowat, 1963; Okaisabor, 1971; Onesirosan, 1971; Flowers and Hendrix, 1972 and Nambiar and Sarma, 1977). Further, the relationship of inoculum levels of several soil-borne species of *Phytophthora* and *Pythium* to infection of several hosts has been very well correlated (Mitchell, 1978).

A number of selective agar media and baiting techniques were employed by several workers for the quantitative estimation of different *Phytophthora* spp. from soil. Different methods were applied for the quantitative estimation of different *Phytophthora* spp from infested soil. Tsao (1960) used a serial dilution end point method for estimating the disease potentials of *Phytophthora citrophthora* (Smith and Smith) Leonian and *P. parasitica* Dastur, in soil. According to Duncan (1976) the most probable number analysis (MPN) with the baiting technique allowed comparisons between the inoculum levels of different plots or treatments. Sastry (1982) found a direct relation between the percentage of baits

colonised by P.palmivora and inoculum level in soil. The Disease Potential Indexes (DPI), defined as the reciprocal of the highest dilution which produce positive baiting under test conditions (Tsao, 1960) were used by using Albizia falcataria leaflets to estimate the disease potential (Anandaraj and Sarma, 1990).

2.6 CHEMICAL CONTROL

Several workers have recommended spraying and drenching of Bordeaux mixture to control wilt of black pepper due to Phytophthora (Dastur, 1927; 1935; Uppal, 1931; Asthana, 1947; Subramaniyam and Venkat Rao, 1970 and Narasimhan et al., 1976). Among the ten different commercial formulations of fungicides tested as foliar sprays and soil drenches around the vines before and after south-west monsoon, only Bordeaux mixture spraying, application of Bordeaux paste to the stem from the collar region to a height of about one metre reduced the incidence (Nambiar and Sarma,1977)

In in vitro screening of fungicides against Phytophthora palmivora and P. meadii using poison food technique, Bordeaux mixture, Blitox, Bayer-5072, Terrazole and Metalaxyl were found effective to inhibit the growth and sporangial formation (Sastry, 1982). He also noted that

Terrazole and Bayer-5072 were effective soil fungicides to check sporangia, hyphae and chlamydospores of P.palmivora in soil under both soil drench and soil mix methods.

Studies on metalaxyl [DL methyl N (2,6 dimethyl phenyl) N (2-methoxy acetyl alaninate)], a systemic fungicide for the control of P.parasitica var nicotianae in tobacco by Vasilakakis et al., (1979) and P.infestans on tomato plants by Cohen et al., (1979) were extensively made.

According to Edgington et al., (1980), metalaxyl was effective against Pythium and Phytophthora. In vitro evaluation indicated that the growth and sporulation of P.parasitica var.nicotianae were totally suppressed by Ridomil @ 0.1, 0.2, 0.3 and 0.4 per cent concentrations and there was no growth of the fungus after 21 days in the treated petriplates (Reddy and Nagarajan, 1980).

Among the three systemic fungicides tested, namely metalaxyl (Ridomil), fosetyl-Al (Aliette) and ethazole (Terrazole) both as foliar sprays and as soil drenches, metalaxyl and fosetyl-Al were found to be highly effective in checking the disease incidence under field conditions. (Ramachandran and Sarma, 1985a; Ramachandran and Sarma, 1985b). Ramachandran et al. (1982) have also reported that

both Ridomil and Aliette are capable of inhibiting the growth of P. palmivora in vitro, Ridomil being more efficient in inhibiting the growth of the fungus than Aliette. Ridomil was reported to inhibit the growth and sporulation of P. cinnamomi (Benson, 1979) and P. parasitica (Staub and Young, 1980). Efficacy of metalaxyl in checking Phytophthora infection in black pepper has been reported (Sastry,1982). Besides soil application, granular formulations of metalaxyl (Ridomil 5 g) @ 20 g per vine, was equally effective (Anonymous, 1986).

Ramachandran et al., (1988) evaluated five systemic fungicides, namely metalaxyl, fosetyl-Al, ethazole, propamocarb and oxadixyl for their effect on different stages of the life cycle of P.palmivora and for the field performance of the first three fungicides. Under field conditions, metalaxyl among three fungicides tested, was highly effective in suppressing soil population of P. palmivora and no mortality was seen in seedlings planted in contaminated soil treated with 100 µg per ml of the fungicide.

Metalaxyl MZ at 250 ppm concentration, is sufficient to inhibit 100 per cent radial growth of P. capsici (Subramanyam, 1993). He also reported that spraying and drenching with metalaxyl MZ (@ 1.25 g/litre) has reduced the

population of P. capsici in the soil and per cent survival of vines was increased.

2.7 BIOLOGICAL CONTROL

Among many potentially antagonistic soil inhabitants, members of the genus Trichoderma have gained considerable success (Dennis and Webster, 1971). Books and review articles have been published on microbial antagonism (Wood and Tveit, 1955; Boosalis, 1964 ; Baker, 1968; Baker and Cook, 1974 and Cook, 1977).

Nambiar and Sarma (1977) isolated Trichoderma spp. from the roots of healthy pepper vines and also noted the lysis of mycelium of black-pepper isolate of Phytophthora when the Trichoderma spp. overgrew the test fungus. Trichoderma as biological control agent of betlvine wilt (Tiwari and Mehrotra, 1968), root rot of avocado (Zentmyer, 1963, 1967), and of many other Phytophthora diseases, has been reviewed (Baker and Cook, 1974). Effectiveness of Trichoderma harzianum and other species in controlling soil-borne pathogens has been reviewed (Chet, 1987). Both T. viride and T. harzianum overgrew and suppressed the growth of P. capsici (Subramanyam, 1993). He also used Trichoderma spp. in the field successfully.

Abd-El-Moity et al., (1982) developed selective medium containing allyl alcohol and the fungicide Vinclozolin for isolation of Trichoderma spp, but the medium must be prepared immediately before use, because of the volatilability of allyl alcohol. Elad et al., (1981) developed a Trichoderma - selective agar medium (TSM) for the quantitative isolation of Trichoderma spp. from soil. Selectivity was obtained by using chloromphenicol as a bacterial inhibitor and pentachloro nitrobenzene, p-dimethyl aminobenzenediazo sodium sulfonate, and rose bengal as selective fungal inhibitors. A semiselective medium with neither rose bengal nor PCNB has also been described for the isolation and enumeration of Trichoderma spp. from soil and plant rhizosphere (Papavizas, 1981). Papavizas and Lumsden (1982) improved the semi-selective medium for Trichoderma developed by Papavizas (1981), which is ineffective with soils containing Mucorales, by adding alkylaryl polyether alcohol alone or in combination with sodium propionate.

Mukhopadhyay (1987) has given a list of growth media used for mass production of inocula of Trichoderma spp. Elad et al., (1980) reported that under greenhouse conditions, incorporation of the wheat bran inoculum preparation of T.harzianum in pathogen infested soil significantly reduced

bean diseases caused by Sclerotium rolfsii, Rhizoctonia solani or both and also protected radish seedlings from damping off induced by Rhizoctonia solani (Henis et al., 1978). Sivan et al. (1984) observed the better survival of Trichoderma when it was multiplied on wheat bran and peat. Mukhopadhyay et al., (1986) used T.harzianum multiplied on mixture containing wheat bran, saw dust and tap water for control of damping off caused by Pythium aphanidermatum. Subramanyam (1993) used wheat bran, saw dust and tap water as a medium for mass multiplication of both T.viride and T.harzianum for soil application in control of foot rot of black pepper caused by Phytophthora capsici.

2.8 CONTROL BY USING ORGANIC SOIL AMENDMENTS

Suppression of root rot of avocado caused by P. cinnamomi by alfalfa meal (Zentmyer, 1963), suppression of root rot of citrus caused by P. nicotianae var. parasitica using several organic amendments (Tsao, 1977) are of greater relevance to the black pepper foot and root rot problem.

Besides naturally occurring disease suppression (Weste and Marks, 1987), certain nitrogenous organic amendments are known to suppress different Phytophthora species in soil (McIntosh, 1972; Tsao and Zentmyer, 1979;

Zentmyer, 1963; Tsao and Oster, 1981). Tsao and Oster (1981) attributed the population suppression of Phytophthora following urea and chicken manure amendments to formation of ammonia and nitrous acid which are toxic to the fungus. Different amendments are known to increase the activity of antagonistic microflora by increasing the organic matter content of the soil. Cotton seed meal and groundnut cake (Dutta, 1984) are reported to suppress P.palmivora in soil. Subramanyam (1993) reported 17.60 per cent reduction of population of P.capsici over control by application of neem cake alone.

2.9 SOIL SOLARIZATION

This technique for the control of the soil-borne plant pests (pathogens, weeds, and arthropods) refers to a new approach for soil disinfestation by means of solar energy (Katan et al.. 1976). At present covering (tarping or mulching) the soil with transparent polyethylene sheets when appropriate climatic conditions prevail, is the only means for capturing solar energy to heat soil under field conditions. During the last ten years appreciable research on control of several important soil-borne diseases was performed by using soil solarization technique. (Katan, et al., 1976; Katan, 1980; 1981; Pullman et al., 1981). Katan (1980) and his

co-workers were the first plant pathologists to extensively use this simple approach to control soil-borne diseases.

In 1976, Katan et al. reporting successful results using "solar heating by polyethylene mulching " in Israel, suggested the principles of this new approach to pathogen control. Indeed, within less than a decade, over 100 articles, reviews, and abstracts on solarization reported successful control of many pathogens in different countries (Katan, 1981; Stapleton and DeVay, 1985). Soil solarization is commercially used in Israel, the United States (Ashworth et al., 1983) and Japan (Horiuchi, 1984).

2.9.1 DISEASE CONTROL

Field experiments were carried out, since 1974, in naturally infested soils for evaluating the effectiveness of soil solarization in disease control under field conditions. In general soil solarization was effective against several soil-borne pathogens under varying conditions. The following diseases were effectively controlled:Verticillium diseases (tomato, potato, eggplant, cotton, peanuts), Rhizoctonia solani (Potato, Onion), Sclerotium rolfsii (peanuts), Pyrenochaeta lycopersici (tomato) Pyrenochaeta terrestris (onion), Fusarium diseases (cotton, melon, tomato, onion)

(Elad, et al., 1980; Grinstein et al., 1979; Katan et al., 1976 and 1980).

As far as Phytophthora diseases are concerned, soil solarization with transparent polyethylene sheets for 42 days in an avocado grove resulted in only 3 per cent of the solarized samples being infested by Phytophthora cinnamomi as against 69 per cent in control (Pinkas et al., 1984) Solarization for 3 weeks eliminated P.cinnamomi and solarization for 6 weeks completely eradicated the fungus in south Africa (Barbercheck and Broembsen, 1987). Wicks (1988) reported control of P.cambivora (Petri) Buisman,in cherry in Australia. Phytophthora cryptogea was not recovered from any of the precolonised gerbera roots burried at depths of 10 or 30cm in plots subjected to solarization (Kaewvuang et al., 1989).

Soil mulching with double layer polyethylene strongly reduced the percentage of carnation plants infected by P. nicotianae var. parasitica (Garibaldi and Tamietti 1989). No activity of P. cinnamomi was detected in infested soil after 2 weeks at 30-cm depth or after 4 weeks at 45-cm depth in solarized soil, whereas there was little or no reduction in survival in non-solarized soils (Juarez-Palacios

et al., 1991). They also reported that P. cactorum was killed within 2 weeks at 15-cm depth and P. megasperma was reduced after 4 weeks at 15-cm depth (Juarez-Palacios et al., 1991). In field experiments carried out during 1984-89 in Egypt, soil solarization gave good control of Sclerotium cepivorum in onions and Phytophthora nicotianae var. parasitica, Pyrenochaeta lycopersici, Pythium spp. and Rhizoctonia solani in tomotoes (Satour et al., 1991).

Duff and Barnaart (1992) reported that solarization by double layer clear polyethylene mulch killed Phytophthora nicotianae var nicotianae, Pythium myriotylum and Sclerotium rolfsii, in nursery potting mixes.

2.9.2 TEMPERATURE RISE DUE TO SOIL SOLARIZATION

Soil solarization is a method of heating the surface soil by mulching with polyethylene sheets on moist soil to trap solar radiation to increase the soil temperature. Direct thermal effects are probably the major phenomenon implicated in the control of soil-borne pathogens during solar heating, since the basic process involved in soil solarization is the heating of the soil.

Typical maximal soil temperature observed in solarized plots increased by 8-12°C over the corresponding

non-mulched plots (Katan, 1980). This increase in soil temperatue by transparent polyethylene is due to a decrease in the soil heat loss that mainly occurs through evaporation. Maximal increase in the soil temperature is observed in surface layers and decreases with increasing soil depths. The increase in soil temperatue in solarized plots was observed by many workers who have reported effective control of diseases (Katan et al., 1976; Elad et al.,1980; Pullman et al., 1981; Mihail and Alcorn, 1984; Dwivedi and Dubey, 1987; Chauhan et al., 1988; Stapleton and Garza- Lopez, 1988; Kaewruang et al., 1989; Lodha, 1989 and Deshpande and Tiwari, 1991).

The time for soil mulching varies with regions, the best being during hot summer days. Soil mulching should be carried out during the period of high temperature and intense solar radiation (Katan, 1981).

2.9.3 USE OF POLYETHYLENE SHEETS FOR SOLARIZATION

Polyethylene (also known as polythene), one of the most important plastic materials used in agriculture, was first introduced on a commercial scale in 1939 (Byrdson, 1970). Soil solarization, in its present form involves hydrothermal process.(Stapleton and DeVay, 1985). At present, covering (mulching) the soil with polyethylene sheets is the

means to capture solar energy under field conditions. When this is done, the mechanism of solar heating is attributed to the "greenhouse effect", elimination of evaporation from the soil and other mechanisms (Mahrer, 1979). As verified in several studies (Waggoner et al., 1960 and Horowitz, 1980), black polyethylene, though it is greatly heated by itself, is less efficient in heating the soil than transparent polyethylene (Katan, 1981). Further the thinnest polyethylene tarp possible (25-30 μm) is recommonded since it is both cheaper and somewhat more effecive in heating (Pullman, et al.,1979, and Horowitz and Regev, 1980) due to better radiation transmittance than the thicker one. However, the thinner the mulch, the faster it wears out. Very thin transparent mulches wore out within six weeks of solarization (Brighton, 1972).

Soil should be kept wet during mulching to increase thermal sensitivity of resting structures and improve heat conduction (Macfayden, 1967 and Katan, et al., 1976). Adequate soil mositure during solarization, for reasons specified earlier, can be obtained by irrigation shortly before tarping (single irrigation) (Grinstein et al., 1979). Additional irrigations during solarization (by a drip system) are usually not necessary except for very light soils and may

lower soil temperatures unless carried out during the night (Naot, 1984). Good results were achieved by the simpler single irrigation technique (Grinstein et al., 1979; Jacobsohn et al., 1980; Katan et al., 1980, 1983). However, solarization controlled Verticillium dahliae in pistachio grove with and without sprinkler irrigation before mulching (Ashworth and Gaona, 1982).

2.9.4 MECHANISMS INVOLVED IN DISEASE CONTROL

Whenever organisms, especially heat sensitive, are subjected to moist heat at temperatures exceeding the maximum for growth, their viability is reduced. Temperatures in the solarized soils reached levels considered to be lethal to many fungi (Baker and Cook,1974) at the 5 and 10 cm depths. Below 10cm, the temperature may have been high enough to delay germination of the fungal propagules. Sublethal heating probably decreases the ability of propagules to withstand further stress and to cause plant disease (Pullman et al., 1981).

Inoculum density is affected by solarization, either through the direct physical effect of the heat or by microbial processes induced in the soil. Changes in inoculum density (ID) at various depths of solarized as compared to non-treated

soil might serve as a simple and quick means of estimating the potential of solar heating in disease control. Effective disease control is correlated with a corresponding reduction in ID in solarized soils (Katan et al., 1976; Al-Raddad, 1979; Grinstein et al., 1979; Pullman et al., 1979 and Jacobsohn et al., 1980). The effective control, by solarization, of diseases caused by Rhizoctonia solani and Sclerotium rolfsii, was correlated with a reduced inoculum potential of the pathogens (Grinstein et al., 1979 and Elad et al., 1980).

2.9.5 BIOLOGICAL CONTROL IN THE SOLARIZED SOILS

Microbial processes induced by solarization may contribute to disease control in addition to the physical effect of heat. In the first study on solarization, the possible involvement of biological processes that would explain the unexpected, pronounced and lasting control was raised and discussed (Katan et al., 1976). Later studies carried out by various workers under different conditions, basically supported that hypothesis. Biological control may operate at any stage of pathogen survival or disease development, during or after solarization, through antibiosis, lysis, parasitism or competition (Papavizas and Lumsden, 1980).

Solarization reduced fungistasis toward Sclerotium rolfsii in various soils (Greenberger et al., 1985) and fungistasis to Fusarium (Katan et al., 1976). The populations of the potential antagonist, Trichoderma increased (Elad et al., 1980) in solarized plots. As expected (Elad et al, 1980), Trichoderma populations were much higher after T. harzianum was added to the soil (alone or combined with a solar heating treatment).

Extensive studies on microbial changes in the soil, during and after solarization, by Stapleton and DeVay (1982, 1984), showed that while populations of many microorganisms were reduced immediately following solarization, actinomycetes, thermophilic and thermotolerant fungi and Bacillus spp. were less affected and even increased. Fluorescent pseudomonads quickly colonised solarized soils and plant roots. Antagonists were frequently stimulated in solarized soils (Greenberger et al., 1985). Solarization reduced the populations of many fungi. However, tolerant fungi such as Talaromyces survived the treatment (Kodama et al., 1980). Kaewruang et al. (1989) reported increased soil microbial counts, except fungi which were reduced at the 0-10 cm depth. There were also increases in the population of

bacteria and actinomycetes at soil depths of 0-10 cm (Kaewruang et al., 1989).

2.9.6 SOLARIZATION OF PERENNIAL CROPS

Using solarization as a post-plant treatment for controlling soil-borne pathogens in existing plantings of trees, is a departure from the standard preplanting use of solarization for annual crops. This approach was pioneered by Ashworth and his associates and was tested for controlling Verticillium wilt in established pistachio nut groves (Ashworth and Gaona, 1982). The prerequisites for achieving an effective control by solarization in existing orchard/plantations are described (Ashworth and Gaona, 1982, Katan, 1981). It can be assumed that solarization in young orchard where the shaded area is small, will be more effective than in older one. A remarkable control of Verticillium in olive trees in Greece was reported on a small scale by Tjamos (1983). It appears that the use of solarization in existing orchards/plantations has great prospects but its realization requires continuous and tedious work (Katan, 1987).

2.10 INTEGRATED CONTROL

There is an increasing tendency in plant protection sciences to integrate various methods of control. The

expected benefits are an improved, more lasting, wider spectrum of control, a reduced dosage of chemicals without decreased effectiveness. Integrated control is a compatible system of control in which various methods are used in proper sequence and timing so as to create the least hazard to man and the environment. A number of toxicants induce an increase in antagonistic activity of the microflora to pathogens. In these cases the ultimate disease control is brought about by direct inhibition of pathogens as well as by an increased microbial antagonism. Therefore, it is generally indicated as integrated control (Baker and Cook, 1974). Curl et al. (1976) observed that ineffective amounts (1 to 2 μg/g of soil) of PCNB applied together with Trichoderma harzianum controlled Rhizoctonia solani more effectively than did T. harzianum alone in cotton seedling disease in the greenhouse. Henis et al. (1978) obtained greenhouse control of R. solani (damping off of radish)by integration of PCNB (4 μg/g of soil) and T. harzianum. Lewis and Papavizas (1981) have reported field control of root rot of cucumber caused by R. solani by integration of chlorothalonil with T harzianum and cultural practices. Lewis and Papavizas (1981) obtained field control of root rot of cucumber and crown rot of pepper by integration of chlorothalonil and metalaxyl respectively with T.

harzianum. Chandra (1984) reported that integration of both chemical and biological control measures has a synergistic effect on the control of damping off in sugar beet. Mukhopadhyay et al. (1986) and Mukhopadhyay and Chaturvedi (1986) also obtained successful control of damping off of tobacco and egg plants by application of Trichoderma preparation to soil and integrating it with metalaxyl seed treatment. Stankova - Opocenska and Dekker (1970) reported that treatment of cucumber seeds with fungicide (6 - azauracil) at lower dose resulted in significant increase in the number of bacteria in the rhizosphere and control of damping off of cucumber seedlings caused by Pythium debaryanum.

Soil solarization might be combined with many biological, chemical (especially at reduced dosages) and cultural methods of control. However, combining it with biological control agents is especially promising and tempting. Combining the antagonist T. harzianum with heating or solarization in Rhizoctonia solani infested soils improved disease and pathogen control and delayed inoculum build-up (Elad et al., 1980 and Chet et al., 1982). Combining solarization with a suitable crop sequence resulted in an improved and longer-lasting control of Fusarium wilt of cotton

(Katan et al, 1983). An effective control of the corky root disease of tomatoes was obtained by combining solarization with a reduced dosage of methyl bromide (Tjamos, 1984). Combining solarization with vapam resulted in a synergistic effect in controlling delimited shell spots of peanut pods (Frank et al, 1986). Subramanyam (1993) reported 56.03 per cent reduction in P. capsici population over control by integrating neem cake, Trichoderma spp. and one application of metalaxyl MZ.

2.11 MICROBIAL ANTAGONISM

Mehrotra and Tiwari (1976) found best control of foot-rot of Piper betle caused by Phytophthora parasitica var. piperina by organic amendments and antagonists in soil. Among different antagonists grown on corn -straw and til (Sesamum indicum Dc) oil cake amendments Trichoderma viride gave best control. Aspergillus terreus Thom. failed to control the disease although it showed great antifungal activity under controlled condition in petridishes.

Nambiar and Sarma (1977) isolated Trichoderma spp. from the roots of healthy pepper vines and also noted the lysis of mycelium of black pepper isolate of Phytophthora.

Penicillium spp. were antagonistic to P. cinnamomi (Krstic, 1954 and Gerrettson-Cornell, 1977), P. capsici Leonian (Atac, 1979) and P. cactorum (Lobert and Cohn), Schroeter (Macie Jowska and Williams, 1961). P. patulum Bain was also found to be antagonistic to P. parasitica (Williams et al., 1950) and P. cryptogea (El -Goorani et al., 1976).

Macie Jowska and Williams (1961) found that Aspergillus sp. was strongly antagonistic to P. cactorum. Chaurasia (1976) reported a good inhibitory activity of Aspergillus flavus Link and A. oryzae (Ahlberg) Cohn on P. parasitica var. piperina. Among the fungi, only Penicillium sp. inhibited the growth of P. palmivora. Other fungi, viz. Aspergillus niger, Fusarium oxysporum and another Fusarium sp. did not show any inhibition (Hegde, 1983).

Five fungi, namely Fusarium solani (Mart.) Sacc., Trichoderma viride Pers., Penicillium variable Sopp., Talaromyces wortmanni C.R. Benjamin, and Aspergillus niger isolated from amended soil showed antagonistic effect on Phytophthora palmivora (Dutta, 1984). Among these fungi T. viride, F. solani and A. niger overgrew and suppressed the growth of P. palmivora (Dutta, 1984).

Petri (1927) found a bacterium which impeded P. cambivora, P. parasitica and P. citrophthora. Ark and Hunt (1941) found Bacillus vulgatus Trevisan and another spore forming Bacillus sp. to be antagonistic to Phytophthora sp. Magdon (1955) found that five isolates of bacteria were highly antagonistic to P. infestans. Four bacteria were found antagonistic to P.nicotianae var. parasitica (Ahmed and Ahmed, 1964). Among the bacteria, B. subtilis (Ehrenberg) Cohn.was found to inhibit P. cinnamomi (Krstic, 1954) and P. cryptogea (El-Goorani et al., 1976). A Bacillus sp. was found to be antagonistic to P.cinnamomi (Malajczuk et al., 1977). Hegde (1983) reported that Bacillus sp. did not show any inhibitory effect on P. palmivora. Dutta (1984) reported Bacillus spp. and Xanthomonas sp. show inhibitory effect to P. palmivora.

Of 51 actinomycetes isolates evaluated, Magdon (1955) found that nine exerted strong, 14 moderate and 28 weak antagonistic influence on P. infestans. Lenzner (1964) found that actinomycetes were often antagonistic to P.cactorum. Kusarkari and Veyama (1975) found that lytic actinomycetes showed a strong degradation of phycomycetes such as Phytophthora and Pythium. Knauss (1976) investigated that the isolates of actinomycetes showed wide range of antagonism

towards Phytophthora and Pythium spp. Rose et al. (1980) reported that a variety of Streptomyces griseoalbus (Kudrina) Pridham, Hesseltine and Bendict, isolated from the rhizosphere of nitrogen fixing nodules of Ceanothus velutenus Dougles was a strong antagonist of P.cinnamomi. Hegde (1983) reported seven antagonistic actinomycetes to P. palmivora from Uttara Kannada soil. Dutta (1984) reported a Actinomycetes sp had an inhibitory effect on P. palmivora.

2.12 PLANT PARASITIC NEMATODES ASSOCIATED WITH BLACK PEPPER

As early as 1906, Butler reported root-knot nematode infestation on black pepper in Wynad, Kerala (Butler, 1906) and later by Ayyar (1926). Association of Radopholus similis with "yellows disease' of pepper was first reported by Van der Vecht (1950), and in India by D'Souza et al. (1970). Though 48 nematode species belonging to 29 genera were reported in association with black pepper (Sundararaju et al., 1979a), only 17 genera were found in Kerala and Karnataka (Sundararaju et al., 1979b). A widespread occurrence of Meloidogyne incognita and R. similis on black pepper in many parts of Kerala and Karnataka was reported (Kumar et al., 1971; Venkitesan, 1972; Koshy and Sosamma, 1975; Jacob and Kurien, 1979 and Ramana and Mohandas, 1983 and 1987). M. incognita, R. similis and

Helicotylenchus spp. are most commonly associated with the crop of which M. incognita is the predominant species in Kerala (Jacob and Kurien, 1979, Ramana and Mohandas, 1983). A more recent and detailed survey conducted during 1980-84 in all the major pepper growing areas in Kerala revealed the occurrence of 14 genera of plant parasitic nematodes in the rhizosphere soils of black pepper and two endoparasitic nematodes, viz. M. incognita and R. similis and a new species of a semi-endoparasitic nematode, Trophotylenchus piperis in the roots of black pepper (Ramana and Mohandas, 1987). This survey further showed that M. incognita, R. similis, T. piperis, Rotylenchulus reniformis and Helicotylenchus spp. were the major nematode species associated with black pepper and more than 50 per cent of the vines sampled harboured these nematodes in Kerala. Other genera of importance in their occurrence were Criconemoides, Xiphinema, Tylenchorhynchus, Pratylenchus, Hoplolaimus and Longidorus (Ramana and Mohandas, 1987). Acontylus sp., Aphelenchus sp. and Scutellonema sp. were very rare in their occurrence (Ramana and Mohandas, 1987).

In Karnataka, root knot nematode is widely distributed (73.3% in Dakshina Kannada, 66.6% in Uttara

Kannada) followed by R. similis (56.6% in Dakshina Kannada, 39.7% in Uttara Kannada). The occurrence of T. piperis in Karnataka was low (17.5%) compared to its occurrence in Kerala (50.9%) (Ramana and Mohandas, 1987).

MATERIAL AND METHODS

III. MATERIAL AND METHODS

3.1 LOCATION

The field experiment was conducted during 1992 and 1993 at Hulgol village in Sirsi taluka of Uttara Kannada district of Karnataka state. The village is situated in western ghat area where black pepper is grown on arecanut standards. The plantations are situated in valleys and multistoryed cropping system is followed comprising arecanut, black pepper, coconut, cardamom, cocoa and banana under different mixed cropping systems. The soil is lateritic type. The annual average rainfall in this area is 2534.6 mm and more than 90 per cent of which is received during South-West monsoon (June to September) (Plate 1).

3.2 COLLECTION AND ISOLATION

Direct tissue isolation techniques were employed for isolation of Phytophthora capsici, from black pepper vines showing typical symptoms of wilt. The samples were obtained from the experimental location at Hulgol village (Sirsi taluka) where black pepper was grown on arecanut standard. Isolations were made on oatmeal agar medium incorporated with pimaricin, vancomycin, pentachloronitrobenzene and hymexazole (PVPH), (Oat flakes-30g, Agar-20g, Dist. water (to make up)-1000ml).

Plate 1. Location of the study where black pepper is grown on arecanut standards.

Phytophthora capsici from soil underneath the black pepper vines was isolated by the castor seed (Ricinus communis L) baiting technique (Narasimhan and Ramakrishnan, 1969). Twenty five viable castor seeds cv. RC-8 were surface sterilized and burried in 100 g of wilt sick soil taken in 100 mm petriplates. The moisture of soil was adjusted to field capacity. After incubation for 72 hr at 25 ± 1°C, the castor seeds were removed from the soil and the soil particles on them were removed by washing them in running tap water. They were surface sterilized with 0.1 per cent mercuric chloride for two minutes, washed again two to three times in sterile distilled water to remove the traces of mercuric chloride and plated on two per cent agar after passing them once or twice over the flame. The growth obtained on the seeds were examined under a microscope to confirm the fungus as P. capsici and sub-cultured on oat meal agar slants and incubated at 25±1°C.

3.3 MAINTENANCE OF CULTURE

Phytophthora capsici culture after purification by hyphal tip isolation method was grown on oatmeal agar and then transferred on to slants of oat meal agar. The slants were incubated for five days at 25 ± 1°C and then kept in

refrigerator at 5°C which served as stock culture. Later on, subculturing was done once in a month.

3.4 EFFECT OF SOIL SOLARIZATION IN MANAGEMENT OF FOOT ROT OF BLACK PEPPER (Experiment No. I)

The field experiment was carried out during 1992 and 1993 by selecting one garden at Hulgol village. The experiment was arranged in a randomised block design with the following treatments.

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

The treatments were allotted randomly and three vines were selected for each treatment. Three replications were maintained for each treatment.

3.4.1 SOIL SOLARIZATION

The black and transparent polyethylene sheet (0.05 mm thick) of one metre length were spread over the base of the vine and tied (Plate 2A and 2B). Locally available dry grasses were used for mulching the base of the vine (Plate 2C). The mulching was done during first week of April during 1992 and 1993. In the treatments where irrigation was provided soil was moistened first by watering and then mulched with polyethylene sheets and grasses. The vines subjected to soil solarization were maintained under the sheets and grasses for nine weeks between 4 April and 6 June, 1992 and 1993, while the control vines was exposed at all times to the natural conditions.

3.4.2 TEMPERATURE MEASUREMENTS

Soil temperature was recorded near the base of the vine at 5 cm depth between 12.00 noon and 2.00 p.m. with digital temperature indicator. Soil temperatures were recorded before solarization and after solarization at three weeks interval until mulches were removed.

3.4.3 SOIL SAMPLING

Equal amount of soil samples were collected from root zone of all the three vines in each treatment and samples

Plate 2 A. Showing the soil solarization by mulching with black polyethylene sheet

Plate 2 B. Showing the soil solarization by mulching with transparent polyethylene sheet

Plate 2 C. Showing the soil solarization by mulching with dry grasses

were pooled to make one composite sample of each treatment. Soil sampling was done before solarization and at three weeks interval after solarization up to twenty-one weeks.

3.4.4 PHYTOPHTHORA POPULATION ESTIMATION

The studies on the estimation of population levels of Phytophthora capsici in the soil were carried out following the baiting technique using castor seeds. Castor seeds were burried in each soil sample were retrieved after sieving through 0.2 cm sieve, from each treatment as explained earlier and the number of seeds colonized by P. capsici was obtained by planting them on two per cent agar plates and percentage colonization was calculated. The population estimation was done first before solarization and at three weeks interval after solarization up to twenty-one weeks.

The per cent survival of pepper vines in each treatment was recorded by counting the number of vines that survived after solarization.

3.4.5 ESTIMATION OF RHIZOSPHERE MICROFLORA

Microbial populations (Trichoderma spp., other fungi, bacteria, and actinomycetes) in solarized and unsolarized soils were estimated by following serial dilution technique to know the effect of solarization on microbial

populations in the soil. The soil samples which were used for the estimation of P. capsici population were also used for estimation of microbial populations. Such estimation was carried out before solarization and at nine and twenty-one weeks after solarization.

After thorough mixing, 10 g of soil from each sample was transferred asceptically to 90 ml sterile distilled water contained in 250 ml flask separately and mixed by hand shaking for five minutes. Ten ml sample was drawn from the suspension and transferred to 90 ml sterile distilled water blank. The suspension thus obtained in dilution process was shaked for one minute before it was further diluted . One ml suspension from each of the appropriate dilution was transferred asceptically into sterile petriplates. Fifteen ml of appropriate medium melted and cooled to 45°C was added to petriplates and rotated manually to get uniform mixing. The plates were incubated at room temperature (25 ± 1°C) . Microbial counts were taken on the fifth day for bacteria, on seventh day for Trichoderma spp. and other fungi and on tenth day for actinomycetes and converted as colonies per gram of soil. The data were analysed statistically.

The dilutions used for	
Trichoderma spp.	10^{-3}
Other fungi	10^{-3}

Bacteria	10^{-4}
Actinomycetes	10^{-3}

Medium for Isolation of Trichoderma spp.

Magnesium sulphate ($MgSo_4$ 7 H_2O)	0.2 g
Dipotassium hydrogen phosphate (K_2HPO_4)	0.9 g
Ammonium nitrate (NH_4NO_3)	1.0 g
Potassium chloride (KCl)	0.5 g
Glucose ($C_6H_{12}O_6$)	3.0 g
Agar	15.0 g
Metalaxyl	0.3 g
Rose Bengal	0.15 g
Chloromphenicol	0.25 g
Distilled water (to make up)	1000 ml

Medium for fungal isolation.

Martin's rose bengal agar

Glucose ($C_6H_{12}O_6$)	10.00 g
Peptone	5.00 gm
Magnesium sulphate ($MgSO_4$ 7 H_2O)	0.50 g
Rose bengal	0.035 g
Agar	20.00 g
Distilled water (to make up)	1000 ml

pH was adjusted to 6.0. 100 ppm streptomycin sulphate was added asceptically just before pouring the medium.

Medium for bacterial isolation

Nutrient agar

Glucose ($C_6H_{12}O_6$)	5.0 g
Peptone	5.0 g
Beef extract	3.0 g
Agar	20.0 g
Distilled water (to make up)	1000 ml

pH was adjusted to 7.2.

Medium for actinomycetes isolation

Kuster's agar

Starch	10.0 g
Casein	0.3 g
Potassium nitrate (KNO_3)	2.0 g
Dipotassium hydrogen phosphate (K_2HPO_4)	2.0 g
Calcium carbonate ($CaCO_3$)	0.2 g
Ferrous sulphate ($FeSo_4 . 7H_2O$)	0.01 g
Agar	20.0 g
Distilled water (to make up)	1000 ml

pH was adjusted to 7.0.

3.4.6 ESTIMATION OF NEMATODE POPULATION IN SOIL

The soil samples were collected from the rhizosphere of the black pepper vines and used for estimation of nematode population. Soil was processed by modified Cobb's sieving and decanting technique. Two hundred cc of soil was processed and nematode population were counted and converted as number per cc of soil. The soil samples collected during April and July, 1993 months were processed.

3.5 INTEGRATED MANAGEMENT (Experiment No. II)

The field experiment was conducted during 1993 by selecting one garden at Hulgol. The components like neem cake, Trichoderma harzianum, fungicide (metalaxyl MZ 72 WP) and garlic and mustard extract were applied in combination with soil solarization. The experiment was arranged in a randomised block design with three replications. The treatments were

T_1 : Natural condition (control)

T_2 : Neem cake + Trichoderma harzianum + metalaxyl MZ

T_3 : Garlic and mustard extract

T_4 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract

T_5 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and

mustard extract + mulching with black polyethylene sheet.

T_6 : Neem cake +T. harzianum + metalaxyl MZ +Garlic and mustard extract + mulching with black polyethylene sheet + Irrigation

T_7 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet

T_8 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet + Irrigation

T_9 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses.

T_{10} : Neem Cake + T harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses + Irrigation.

Three vines were selected for each treatment and these treatments were allocated randomly in the garden.

3.5.1 SOIL SOLARIZATION

The base of the vines were covered by black and transparent polyethylene sheets of 0.05 mm thickness and by dry grasses as explained in experiment No. I for nine weeks

between 4 April and 6 June, 1993 while the control vines were exposed at all times to the natural conditions.

3.5.2 TEMPERATURE MEASUREMENTS

Soil temperature were recorded as explained in experiment No. I, before solarization and at three weeks interval upto nine weeks after solarization.

3.5.3 APPLICATION OF NEEM CAKE

Finely powdered neem cake was incorporated into top 10 cm layer of soil around the vines at 1 kg per vine during the month of February.

3.5.4 MASS MULTIPLICATION AND APPLICATION OF TRICHODERMA HARZIANUM

Trichoderma harzianum was mass multiplied on wheat bran: saw dust: water medium (Elad et al. 1980) during the month of March. Three parts of wheat bran + one part of saw dust + four parts of tap water were mixed thoroughly and this mixture was taken in autoclavable plastic bags (75 g per each bag) and these bags were sterilised at 121°C for one hour on two successive days. After sterilization, the bags were inoculated with five days old culture discs of T harzianum and were incubated at room temperature for 14 days. After 14 days of incubation, this inoculum was applied at 150 g/vine by

mixing thoroughly with the field soil to a depth of 7 to 10cm around each vine.

3.5.5 APPLICATION OF METALAXYL MZ

Metalaxyl MZ was applied during the month of June at 1.25g/l of water. Each vine was applied with five litres of solution, out of which, three litres as soil drench around root zone and remaining two litres as spray on the vines.

3.5.6 APPLICATION OF GARLIC AND MUSTARD EXTRACT

One kg of garlic was finely crushed and soaked in little water for overnight. Next day the solution was decanted. Likewise mustard extract was prepared out of 1/4 kg in little water and this extract was added to garlic extract and the volume was made to 100 litre by adding water. This solution was used for drenching the soil around root zone at 1 l/vine during June.

3.5.7 SOIL SAMPLING

Soil samples were collected as explained in experiment No. I. This soil sample was used for all observations.

3.5.8 PHYTOPHTHORA POPULATION ESTIMATION

The population of P. capsici was estimated by following castor seed baiting technique as mentioned in

experiment No. I . Likewise per cent survival of pepper vines in each treatment was recorded.

3.5.9 ESTIMATION OF RHIZOSPHERE MICROFLORA

Microbial populations (Trichoderma spp. other fungi, bacteria, and actinomycetes in each treatment were estimated by following serial dilution technique to know the impact of solarization combined with other treatments on microbial populations in the soil, as explained in experiment No. I.

3.5.10 ESTIMATION OF NEMATODE POPULATION IN SOIL

The population of nematodes in the soil was estimated by using the soil sample collected from the rhizosphere by modified Cobb's sieving and decanting technique as explained in experiment No. I.

3.6 STATISTICAL ANALYSIS

Standard methods were followed to analyse the data (Panse and Sulchatme) after the suitable transformation of the data.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

4.1 SYMPTOMATOLOGY

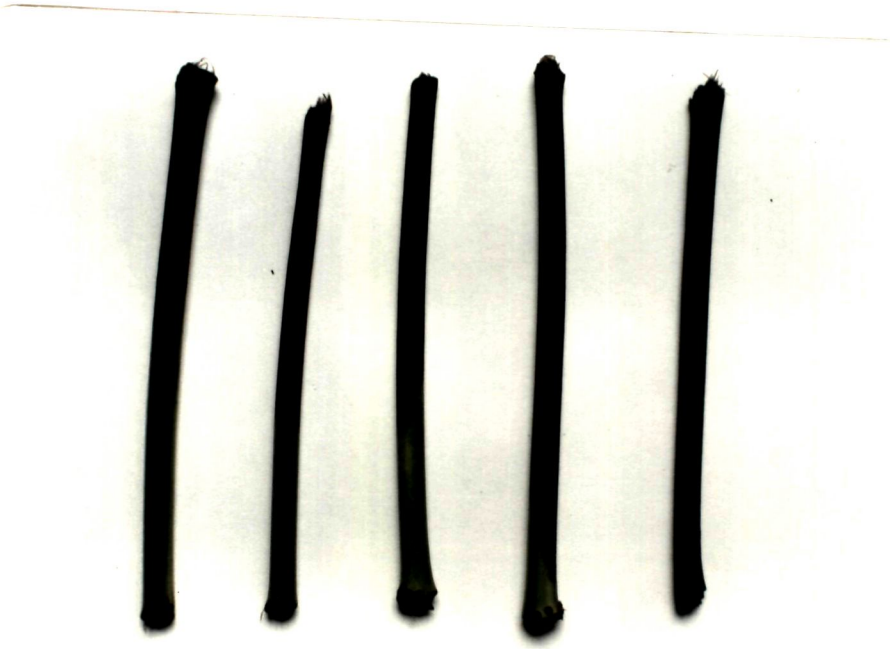
Black pepper vines were observed for the development of wilt symptoms when they were infected naturally. All parts of the black pepper vine were found susceptible to the attack by the pathogen. Phytophthora capsici was found to infect leaves, stems, collar region, spikes and roots of the pepper vine. Symptoms observed in the field are described in the following paragraphs.

The first infection started with runner shoots and later on symptoms on the foliage were observed owing to direct infection in the collar and/or root region. Direct invasion of the foliage was noticed during first week of July, about one month after the start of the South-West monsoon when the relative humidity was above 90 per cent. The leaf infection was characterised by the appearance of small circular to irregular black patches which rapidly enlarged in size and covered the entire leaf area (Plate 3A). Later, entire vine was infected and all the leaves turned brown and extensive defoliation was observed.

The initial symptom on the stem was first recognised by the appearance of a water soaked area similar to that

Plate 3 A. Black pepper leaves showing the lesions caused by *P. capsici*

Plate 3 B. Showing rotting of black pepper stems caused by *P. capsici*



observed on the leaf which later turned brown to dark brown within two to three days (Plate 3B). Yellowing and flaccidity of mature leaves was preceded by flaccidity of younger leaves and resulted in defoliation. When there was severe rotting of the internal tissues, the leaves started to fall off and twigs above the infected region either got seperated from the main stem or dried. The infection also occurred on the spikes and berries resulting in shedding.

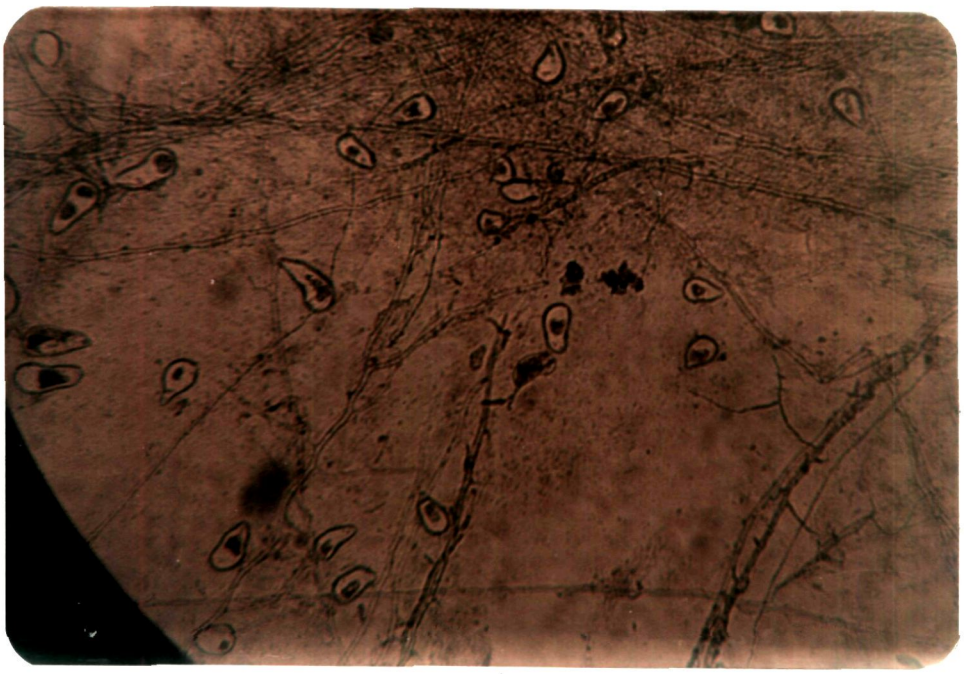
The symptoms noticed in the case of collar infection were yellowing of the foliage, flaccidity, defoliation, breaking off of the stem at nodal region and also spike shedding (Plate 4). When the collar was cut transversely at the infected region, necrotic patches were observed. With the progress of the disease, the cortex disintegrated and peeled off.

In some cases, there was partial or total defoliation. But in those cases where the infection occurred at the end of the rainy season, vines appeared quite healthy but leaves dried up and remained attached to the stem. Occasionally, such vines put fresh growth during next year after first showers of monsoon.

Plate 4 Photograph showing foliar yellowing of black pepper vine due to root infection by *P. capsici*

Plate 5 A. Photograph showing the growth of *P. capsici* on oat meal PVPH medium

Plate 5 B. Microphotograph showing the sporangia of *P. capsici*



4.2 ISOLATION

Isolation of P. capsici from the infected black pepper stem, leaves and roots was made successfully on oat meal agar medium incorporated with pimaracin, vancomycin, pentachloronitrobenzene and hymexazole (oat meal PVPH medium) as explained in `Material and Methods' (Plate 5A and 5B). The culture was purified by hyphal tip isolation on two per cent water agar.

Castor seeds baited in soil samples collected from the root zone of infected black pepper vines invariably yielded P. capsici.

4.3 SOIL SOLARIZATION

4.3.1 Effect of soil solarization on soil temperature.

The soil temperature recorded before solarization was not significant among the different treatments. Effect of solarization on soil temperature after three weeks, six weeks and nine weeks was significant during both the years (Table 1) and (Fig. 1).

The increase in temperature was observed in all the treatments after every observation during 1992 and 1993.

During 1992, maximum temperature was recorded in the treatment that received mulching with transparent polyethylene

Table 1. Effect of soil solarization on soil temperature

Treatments		Soil temperature (°C)											
		Before solarization			After solarization								
					3 weeks			6 weeks			9 weeks		
		1992	1993	Mean	1992	1993	Mean	1992	1993	Mean	1992	1993	Mean
Natural condition	(T1)	24.46	24.36	24.41	24.80	24.78	24.79	25.30	25.19	25.25	26.00	25.93	25.97
Mulching with black polyethylene sheet	(T2)	24.49	24.39	24.44	25.40	25.43	25.42	26.30	26.36	26.33	27.53	27.60	27.57
Mulching with transparent polyethylene sheet	(T3)	24.50	24.40	24.45	25.90	25.75	25.83	27.10	27.03	27.07	28.76	28.56	28.66
Mulching with dry grasses	(T4)	24.43	24.40	24.42	24.80	24.86	24.83	25.36	25.40	25.38	26.06	25.90	25.98
Mulching with black polyethylene sheet + Irrigation	(T5)	24.46	24.36	24.41	25.46	25.53	25.50	26.50	26.60	26.55	27.90	28.00	27.95
Mulching with transparent polyethylene sheet + Irrigation	(T6)	24.40	24.43	24.42	26.13	26.03	26.08	27.70	27.63	27.67	29.80	29.60	29.70
Mulching with dry grasses + Irrigation	(T7)	24.46	24.40	24.43	25.00	24.90	24.95	25.40	25.46	25.43	26.23	26.20	26.22
S.Em. ±		0.01	0.01		0.07	0.05		0.11	0.13		0.14	0.16	
C.D. at 5%		NS	NS		0.21	0.17		0.33	0.40		0.45	0.49	

Fig. 1. Showing the effect of soil solarization on soil temperature (mean of 1992 and 1993)

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

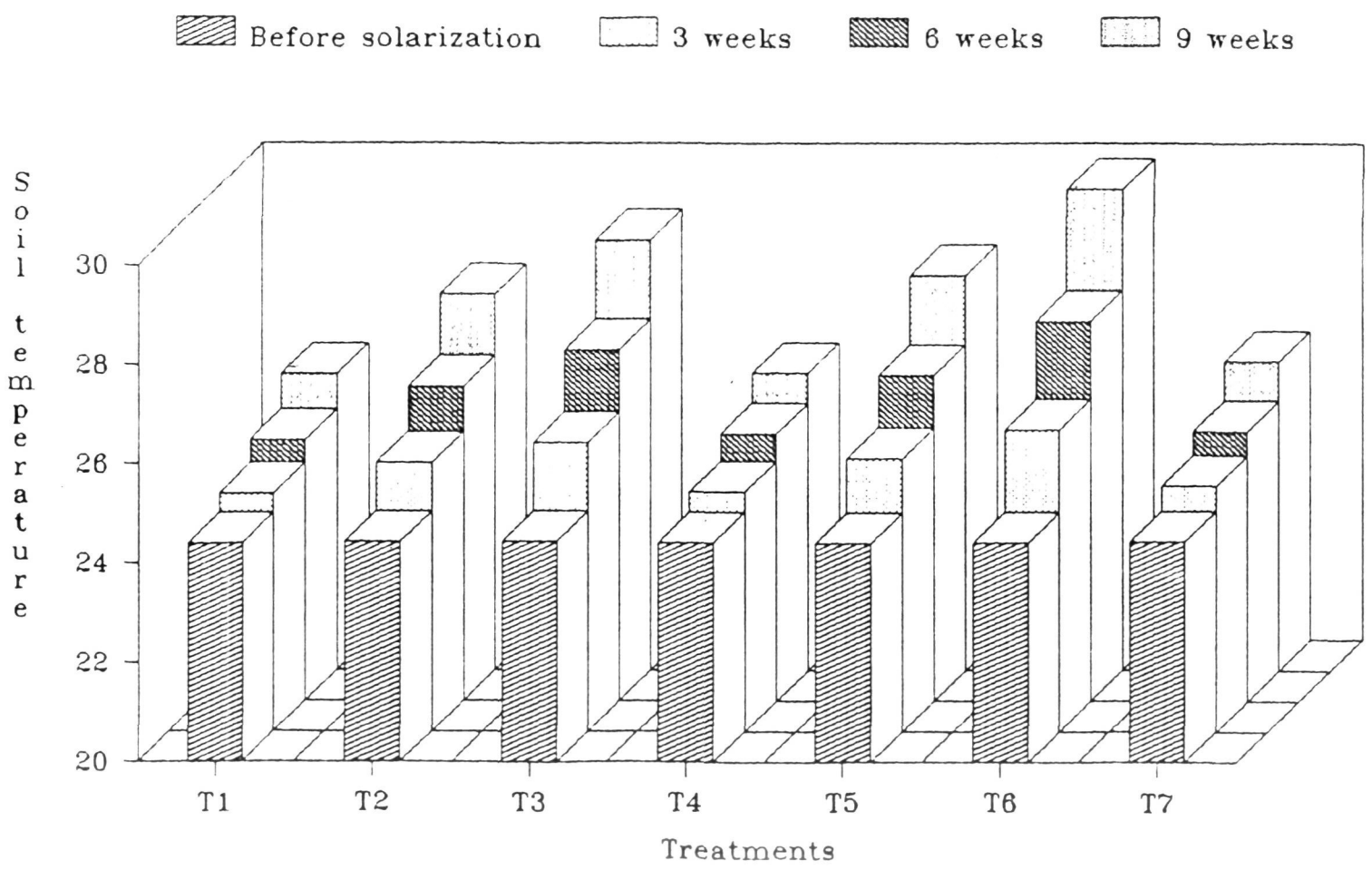


Fig. 1. Effect of soil solarization on soil temperature (mean of 1992 and 1993)

sheet + irrigation (T_6) after three weeks (26.13°C), after six weeks (27.70°C) and after nine weeks (29.80°C). During 1993 also, the same treatment recorded maximum temperature after three weeks (26.03°C), after six weeks (27.63°C) and after nine weeks (29.60°C). In both the years the said treatment differed significantly from the rest of the treatments. After nine weeks of solarization the increase in the soil temperature in this treatment (T_6) was 3.80°C and 3.67°C over the control (T_1) during 1992 and 1993 respectively, which was the maximum among the different treatments. This was followed by the treatment that received mulching with transparent polyethylene sheet (T_3) after three weeks (25.90°C), after six weeks (27.10°C) and after nine weeks (28.76°C) and this was followed by the treatment that received mulching with black polyethylene sheet + irrigation (T_5) after all the observations during both the years. The treatment that received mulching with transparent polyethylene sheet (T_3) was significant to all other treatments after all observations during both the years. The treatment that received mulching with black polyethylene sheet (T_2) and mulching with black polyethylene sheet + irrigation (T_5) was on par with each other after all the observations during both 1992 and 1993.

The soil temperature recorded in the treatment that was exposed to natural condition (T_1) during 1992, was 24.80°C, 25.30°C and 26.00°C after three, six and nine weeks respectively, was minimum in all the observations. In the same treatment minimum temperature was recorded during 1993 also (24.78°C, 25.19°C and 25.93°C, respectively) after all observations. This treatment was on par with the treatment that received the mulching with dry grasses + irrigation (T_7) and the treatment that received the mulching with dry grasses (T_4).

4.3.2 Effect of soil solarization on survival of black pepper vines

Effect of soil solarization on survival of pepper vines was significant among different treatments during both the years 1992 and 1993 (Table 2 and Fig.2). The treatment that received mulching with transparent polyethylene sheet + irrigation (T_6) recorded maximum per cent survival of vines (55.55 and 44.44) during 1992 and 1993 respectively, which was significant to control (T_1) (11.11 and 11.11). This was followed by the treatments, mulching with transparent polyethylene sheet (T_3) (33.33) and mulching with black polyethylene sheet + irrigation (T_5) (33.33) and mulching with black polyethylene sheet (T_2) (33.33) during 1992. Where as

Table 2. Effect of soil solarization on survival of pepper vines

Treatments		Per cent survial		
		Years (Means)		
		1992	1993	Mean
Natural condition	(T1)	11.11 (12.16)	11.11 (12.16)	11.11 (12.16)
Mulching with black polyethylene sheet	(T2)	33.33 (35.24)	22.22 (23.70)	27.78 (31.82)
Mulching with transparent polyethylene sheet	(T3)	33.33 (35.24)	33.33 (35.24)	33.33 (35.24)
Mulching with dry grasses	(T4)	22.22 (23.70)	22.22 (23.70)	22.22 (23.70)
Mulching with black polyethylene sheet + Irrigation	(T5)	33.33 (35.24)	33.33 (35.24)	33.33 (35.24)
Mulching with transparent polyethylene sheet + Irrigation	(T6)	55.55 (48.25)	44.44 (41.74)	49.99 (45.00)
Mulching with dry grasses + Irrigation	(T7)	22.22 (23.70)	22.22 (25.70)	22.22 (23.70)
S.Em. ±		7.57	7.66	
C.D. at 5%		23.34	23.62	

Figures in the parentheses indicate the transformed values

Fig. 2. Showing the effect of soil solarization on survival of pepper vines (mean of 1992 and 1993)

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

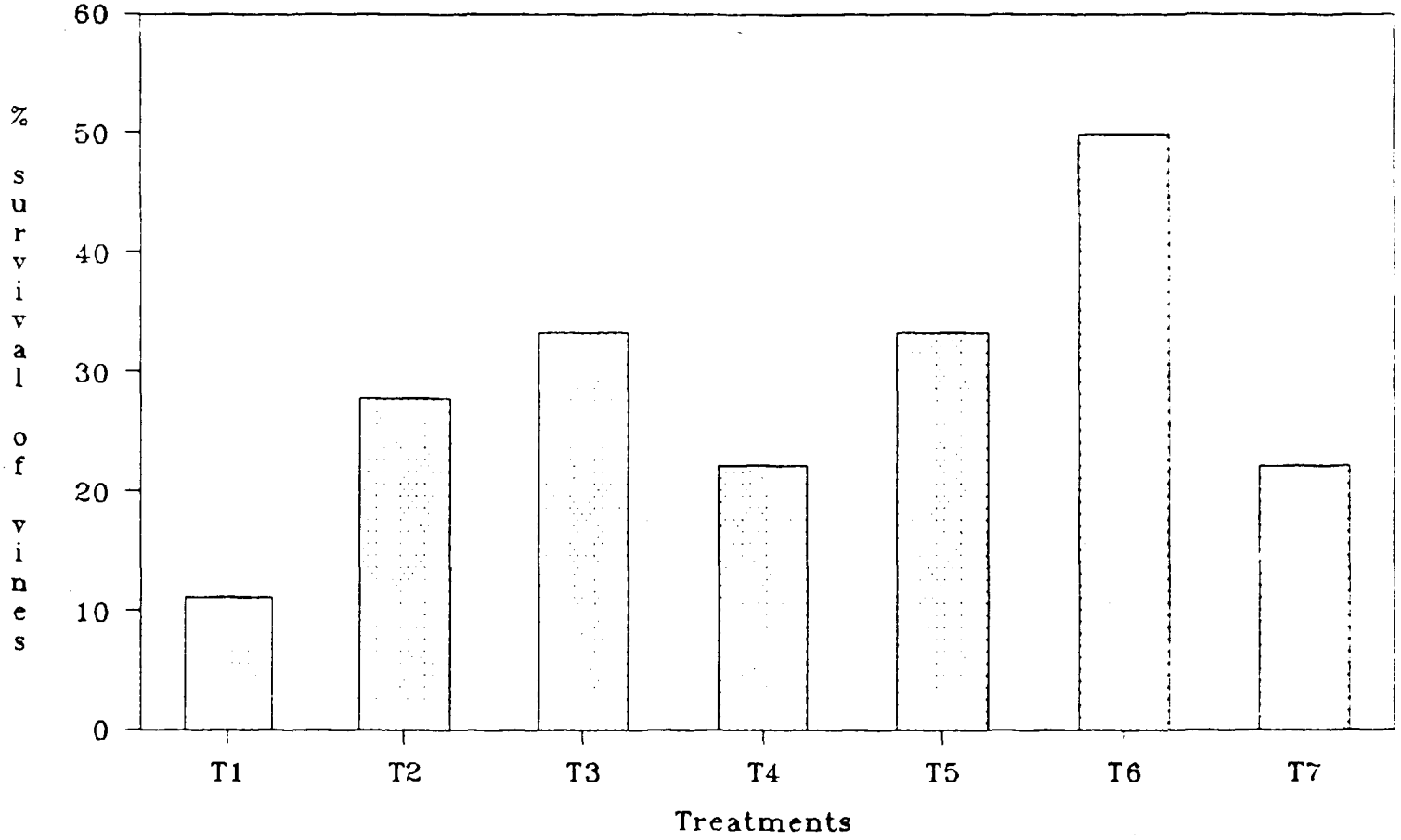


Fig. 2. Effect of soil solarization on survival of pepper vines (mean of 1992 and 1993)

during 1993 the treatment (T_6) was followed by mulching with black polyethylene sheet + irrigation (T_5) and mulching with transparent polyethylene sheet (T_3), both recorded 33.33 per cent survival of vines.

The minimum per cent survival of vines being 11.11 was observed in control during both 1992 and 1993. There was marginal increase in per cent survival in the treatments where dry grasses were used for mulching.

4.3.3 Effect of soil solarization on population of P. capsici

P. capsici population was estimated before solarization and at three weeks interval after solarization up to twenty-one weeks, by following castor seed baiting technique, during 1992 and 1993 as explained in 'Material and Methods' and the population was expressed in per cent colonisation of baits and data were analysed statistically (Table 3 and 4) and (Fig.3 and 4).

In both years 1992 and 1993, the per cent colonisation of baits observed before solarization and three weeks after solarization was found to be not significantly differing with each other. But after six weeks onwards the observations were found to be significant among treatments.

Table 3. Effect of soil solarization on per cent colonisation of castor baits by P. capsici, 1992

Treatments		Per cent colonisation of castor baits							
		Before solarization	After solarisation						
			3 weeks	6 weeks	9 weeks	12 weeks	15 weeks	18 weeks	21 weeks
Natural condition	(T1)	18.67 (25.58)	17.78 (24.92)	16.89 (24.24)	16.44 (23.91)	29.80 (33.05)	51.00 (45.57)	72.00 (58.06)	87.56 (69.46)
Mulching with black polyethylene sheet	(T2)	18.67 (25.56)	16.89 (24.26)	16.00 (23.58)	15.11 (22.89)	23.56 (28.98)	40.00 (39.22)	56.00 (48.45)	68.43 (55.85)
Mulching with transparent polyethylene sheet	(T3)	19.11 (25.93)	16.89 (24.25)	14.67 (22.55)	14.22 (22.16)	20.00 (26.53)	34.23 (35.78)	48.00 (43.84)	56.00 (48.45)
Mulching with dry grasses	(T4)	18.67 (25.58)	17.78 (24.92)	16.00 (23.58)	16.00 (23.58)	27.56 (31.64)	47.13 (43.35)	66.72 (54.88)	84.87 (67.23)
Mulching with black polyethylene sheet + Irrigation	(T5)	17.78 (24.92)	16.89 (24.24)	15.11 (22.89)	14.22 (22.16)	21.76 (27.77)	37.33 (37.65)	52.43 (46.40)	61.76 (51.81)
Mulching with transparent polyethylene sheet + Irrigation	(T6)	19.11 (25.93)	16.00 (23.58)	14.22 (22.16)	13.77 (21.77)	18.20 (25.21)	28.43 (32.18)	40.00 (39.22)	50.00 (45.00)
Mulching with dry grasses + Irrigation	(T7)	17.78 (24.94)	16.89 (24.25)	16.00 (23.58)	15.55 (23.23)	25.76 (30.49)	45.30 (42.56)	65.30 (53.93)	82.23 (65.09)
S.Em. ±		0.41	0.30	0.30	0.31	1.21	1.08	1.44	1.46
C.D. at 5%		NS	NS	0.92	0.96	3.72	3.32	4.43	4.50

Figures in the parentheses indicate the transformed values

Fig. 3. Showing the effect of soil solarization on per cent colonisation of castor baits by P. capsici, 1992

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

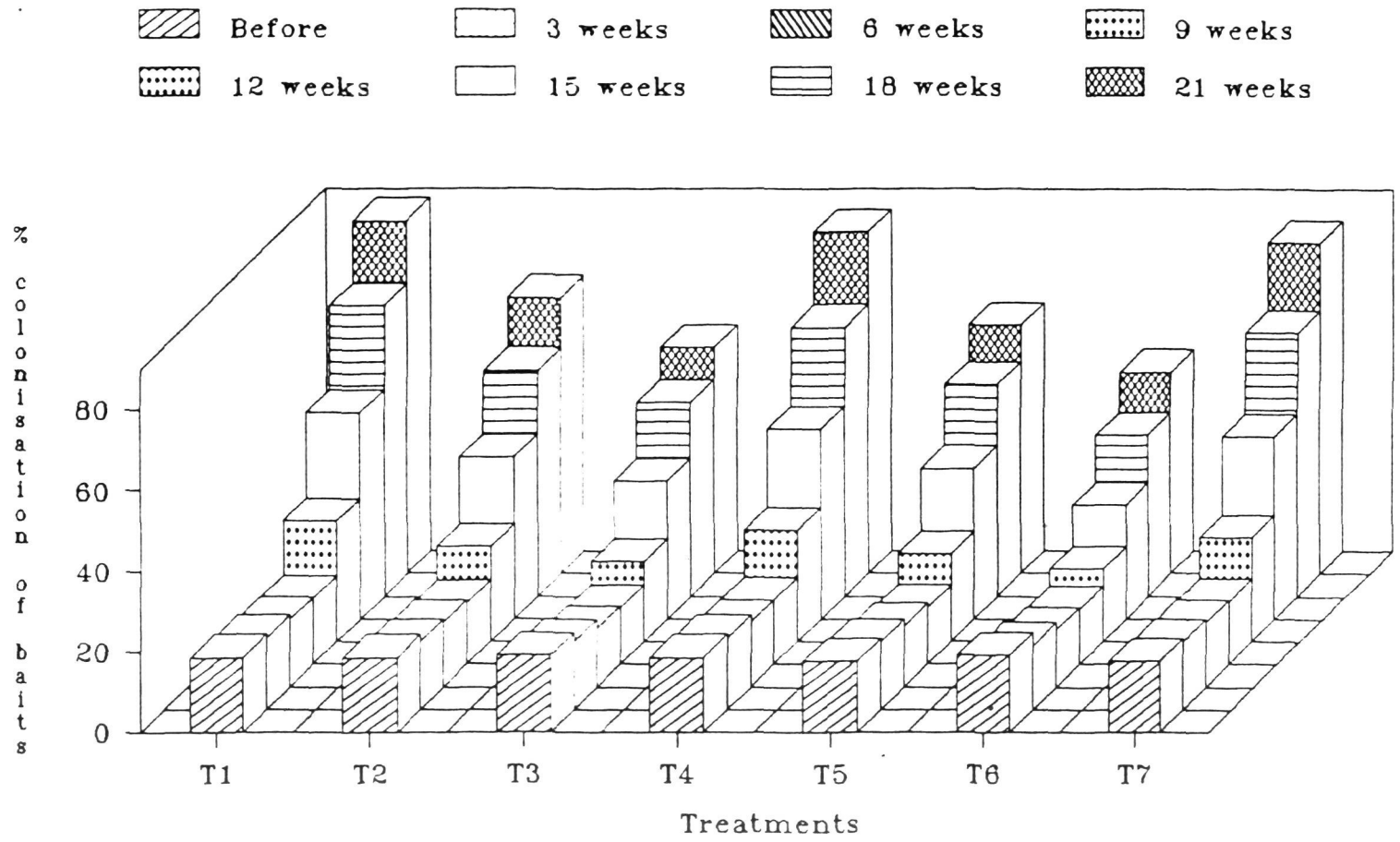


Fig. 3. Effect of soil solarization on per cent colonisation of castor baits by P. capsici, 1992

After six and nine weeks of solarization, the per cent colonisation of baits observed was less in solarized treatments than control. The minimum was observed in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6). But this was not significantly different from the treatments that received the mulching with transparent polyethylene sheet (T_3) and the mulching with black polyethylene sheet + irrigation (T_5) during both the years. In 1992, the minimum per cent colonisation of baits observed was 14.22 and 13.77 respectively after six and nine weeks of solarization and in 1993 it was 15.11 and 13.33 respectively. The maximum per cent colonisation of baits was recorded in control, 16.89 and 16.44 respectively, after six and nine weeks of solarization during 1992. In 1993 also the maximum per cent colonisation of baits was observed in the same treatment, 16.88 and 16.00 respectively, after six and nine weeks of solarization. The marginal difference, which was not significant, was observed in the treatments that received the mulching with dry grasses in both the years.

Twelve weeks after solarization, in both the years, the minimum per cent colonisation was observed in the treatment that received the mulching with transparent

Table 4. Effect of soil solarization on per cent colonisation of castor baits by *P. capsici*, 1993

Treatments		Per cent colonisation of castor baits							
		Before solarization	After solarization						
			3 weeks	6 weeks	9 weeks	12 weeks	15 weeks	18 weeks	21 weeks
Natural condition	(T1)	17.78 (24.92)	17.33 (24.58)	16.88 (24.24)	16.00 (23.58)	28.43 (32.20)	48.00 (43.84)	71.33 (57.64)	85.33 (67.53)
Mulching with black polyethylene sheet	(T2)	18.67 (25.58)	18.22 (25.27)	16.88 (24.24)	15.11 (22.89)	22.23 (28.11)	37.76 (37.90)	53.80 (47.18)	65.30 (53.93)
Mulching with transparent polyethylene sheet	(T3)	18.67 (25.62)	17.78 (24.92)	16.00 (23.58)	14.67 (22.55)	20.00 (26.53)	32.43 (34.70)	45.30 (42.56)	54.70 (47.70)
Mulching with dry grasses	(T4)	17.78 (24.92)	17.33 (24.58)	16.44 (23.91)	15.55 (23.23)	28.00 (31.92)	47.13 (43.35)	72.00 (58.06)	84.00 (66.47)
Mulching with black polyethylene sheet + Irrigation	(T5)	18.22 (25.24)	17.78 (24.92)	16.44 (23.91)	14.67 (22.55)	21.33 (27.48)	34.23 (35.78)	48.00 (43.85)	58.67 (49.99)
Mulching with transparent polyethylene sheet + Irrigation	(T6)	19.11 (25.93)	16.88 (24.24)	15.11 (22.89)	13.33 (21.39)	16.43 (23.91)	27.56 (31.64)	39.56 (38.96)	48.00 (43.85)
Mulching with dry grasses + Irrigation	(T7)	18.67 (25.62)	18.22 (25.27)	16.88 (24.24)	16.00 (23.58)	28.86 (32.47)	47.13 (43.35)	70.23 (56.94)	84.87 (67.23)
S.Em. ±		0.26	0.28	0.28	0.25	1.31	0.98	1.15	1.39
C.D. at 5%		NS	NS	0.86	0.77	4.03	3.02	3.54	4.27

Figures in the parentheses indicate the transformed values

Fig. 4. Showing the effect of soil solarization on per cent colonisation of castor baits by P. capsici, 1993

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

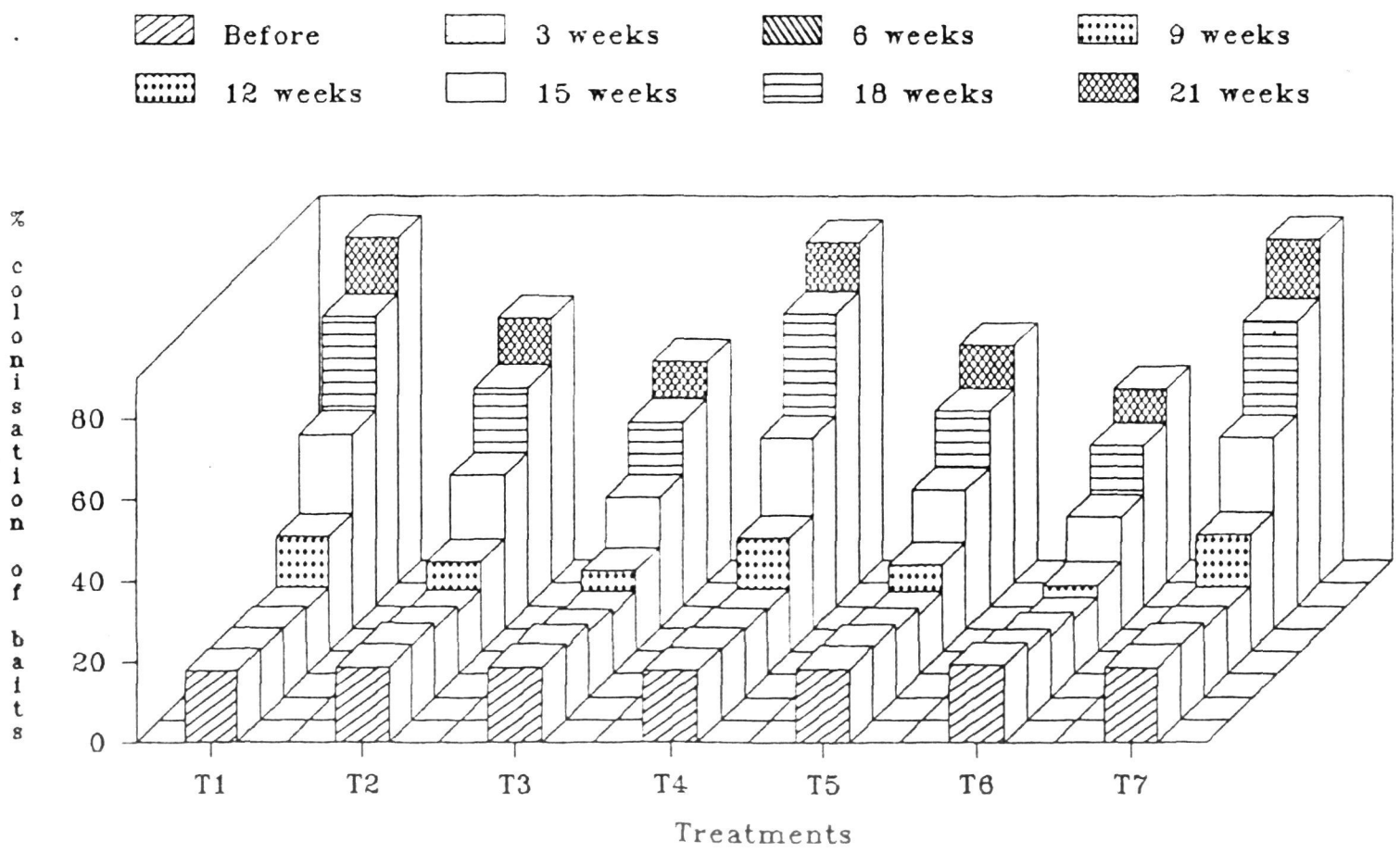


Fig. 4. Effect of soil solarization on per cent colonisation of castor baits by P. capsici, 1993

polyethylene sheet + irrigation (T_6) (18.20 and 16.43). This was on par with the other treatments namely, the mulching with transparent polyethylene sheet (T_3) (20.00 and 20.00) and the mulching with black polyethylene sheet + irrigation (T_5) (21.76 and 21.33). There was no significant difference between the treatments that received mulching with black polyethylene sheet + irrigation (T_5) and mulching with black polyethylene sheet (T_2).

The treatment that was exposed to natural condition (T_1) recorded the maximum per cent colonisation of baits, 29.80 and 28.43 respectively during 1992 and 1993. The per cent colonisation of baits observed in the treatments that received dry grasses mulching was on par with the control.

Fifteen weeks after solarization, the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) recorded the minimum per cent colonisation of baits, 28.43 and 27.56 respectively, in both the years which significantly differed from the rest of the treatments. This was followed by the treatment that received the mulching with transparent polyethylene sheet (T_3) (34.23 and 32.43) and mulching with black polyethylene sheet + irrigation (T_5)

(37.33 and 34.23) respectively in both the years, which were on par with each other.

There was no significant difference among the treatments that received the mulching with black polyethylene sheets in both the years. The minimum per cent colonisation of baits was observed in control (T_1), 51.00 and 48.00 respectively in 1992 and 1993, which was on par with the treatments that received mulching with dry grasses (T_4) and dry grasses + irrigation (T_7).

The per cent colonisation of baits recorded was 40.00 and 39.56 respectively in 1992 and 1993, in the treatment that received the mulching with transparent polyethylene sheet + irrigation(T_6), which was the minimum per cent colonisation of baits and differed significantly from rest of the treatments, eighteen weeks after solarization.

There was no significant difference between the treatments that received the mulching with transparent polyethylene sheet (T_3) and the mulching with black polyethylene sheet + irrigation (T_5) and the later treatment was on par with the treatment mulching with black polyethylene sheet (T_2).

The maximum per cent colonisation of baits observed was 72.00 and 71.33 respectively during 1992 and 1993, in control. The per cent colonisation of baits observed in the treatments, where dry grasses were used for mulching were on par with each other as well as with the control.

Twenty-one weeks after solarization also, the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) recorded the minimum per cent colonisation of baits in both the years (50.00 and 48.00) which differed significantly with rest of the treatments. This was followed by the treatment that received the mulching with transparent polyethylene sheet (T_3) (56.00 and 54.70), which was on par with the treatment that received the mulching with black polyethylene sheet + irrigation (T_5) (61.76 and 58.67), which in turn was not significantly differed from the mulching with black polyethylene sheet (T_2) (68.43 and 65.30).

The maximum per cent colonisation of baits was observed in control in both the years (87.56 and 85.33). The treatments where dry grasses were used for mulching showed marginal decrease in per cent colonisation, which were not significant to each other as well as to control.

4.3.4 Effect of soil solarization on the rhizosphere microflora

Effect of soil solarization on the populations of Trichoderma spp., other fungi, bacteria and actinomycetes were recorded for 1992 and 1993 and presented seperately in the Tables 5 to 8.

4.3.4.1 Trichoderma spp.

The Trichoderma spp. found naturally in the rhizosphere of the vines were recorded and found to be not significant among different treatments (Table 5 & Fig. 5). The T.viride and T.harzianum were frequently observed.

The Trichoderma spp. populations were estimated immediately after removal of mulching after nine weeks and second time after twenty-one weeks of solarization and were found to be significant during both the observations in both the years 1992 and 1993.

In the year 1992, the maximum number of colonies observed was 14.78×10^3 in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) after nine weeks of solarization. In 1993, also the same treatment recorded the maximum number of colonies (15.00×10^3) after nine weeks of solarization. In both the years this

Table 5. Effect of soil solarization on the population of Trichoderma spp.

Treatments		Number of colonies (in thousands per g of soil)								
		Before solarization			After solarization					
					9 weeks			21 weeks		
		1992	1993	Mean	1992	1993	Mean	1992	1993	Mean
Natural condition	(T1)	2.22	2.22	2.22	3.22	3.33	3.28	7.33	8.22	7.78
Mulching with black polyethylene sheet	(T2)	2.55	2.44	2.50	6.22	6.11	6.17	14.44	15.77	15.11
Mulching with transparent polyethylene sheet	(T3)	2.33	2.22	2.28	11.03	11.44	11.24	23.33	25.55	24.44
Mulching with dry grasses	(T4)	2.44	2.55	2.50	4.33	3.44	3.89	8.89	8.00	8.45
Mulching with black polyethylene sheet + Irrigation	(T5)	2.22	2.22	2.22	8.55	8.77	8.66	21.00	21.11	21.06
Mulching with transparent polyethylene sheet + Irrigation	(T6)	2.33	2.44	2.39	14.78	15.00	14.89	38.22	41.66	39.94
Mulching with dry grasses + Irrigation	(T7)	2.22	2.33	2.28	3.55	4.44	4.00	7.55	9.44	8.50
S.Em. ±		0.14	0.13		0.84	1.04		0.66	0.85	
C.D. at 5%		NS	NS		2.58	3.20		2.03	2.64	

was found to be significant to all other treatments. This was followed by the treatment that received the mulching with transparent polyethylene sheet (T_3) (11.03 x 10^3 and 11.44 x 10^3 respectively) in both the years, which was on par with the treatment, mulching with black polyethylene sheet + irrigation (T_5) (8.55 x 10^3 and 8.77 x 10^3 respectively).

The minimum number of colonies recorded was 3.22 x 10^3 and 3.33 x 10^3 during 1992 and 1993 respectively, which was recorded in the treatment that was exposed to natural condition (T_1). This was found to be on par with the treatments, the mulching with dry grasses + irrigation (T_7) (3.55 x 10^3 and 4.44 x 10^3 respectively) and the mulching with dry grasses (T_4) (4.33 x 10^3 and 3.44 x 10^3 respectively) in both the years 1992 and 1993 and in addition to the treatment that received the mulching with black polyethylene sheet (T_2) (6.11 x 10^3) during 1993. The treatments, the mulching with black polyethylene sheet (T_2) and mulching with black polyethylene sheet + irrigation (T_5) were found to be on par with each other in both the years.

After twenty-one weeks, the maximum number of colonies recorded was 38.22 x 10^3 in 1992, and 41.66 x 10^3 in 1993. This was recorded in the treatment that received the

mulching with transparent polyethylene sheet + irrigation (T_6) in both the years which was significant to all other treatments. This was followed by the treatment that received the mulching with transparent polyethylene sheet (T_3) (23.33 x 10^3 and 25.55 x 10^3 respectively) during both the years, which was found to be superior to other treatments.

The minimum number of colonies was recorded by the treatment that was exposed to natural condition (T_1) (7.33 x 10^3) in the year 1992, which was found to be on par with the treatments, the mulching with dry grasses + irrigation (T_7) (7.55 x 10^3) and the mulching with dry grasses (T_4) (8.89 x 10^3). But in the year 1993, the minimum number of colonies recorded was 8.00 x 10^3 in the treatment that received the mulching with dry grasses (T_4), which was on par with other treatment, exposed to natural condition (T_1) (8.22 x 10^3) and with the treatment, the mulching with dry grasses + irrigation (T_7) (9.44 x 10^3).

4.3.4.2 Other fungi

Effect of soil solarization on the population of other fungi was recorded before solarization and nine and twenty-one weeks after solarization in both the years 1992 and 1993 and was found to be not significant among the treatments

Table 6. Effect of soil solarization on the population of other fungi

Treatments		Number of colonies (in thousands per g of soil)								
		Before solarization			After solarization					
					9 weeks			21 weeks		
		1992	1993	Mean	1992	1993	Mean	1992	1993	Mean
Natural condition	(T1)	11.00	9.33	10.16	13.66	14.00	13.83	18.00	20.00	19.00
Mulching with black polyethylene sheet	(T2)	10.33	9.00	9.66	16.66	16.66	16.66	21.66	23.00	22.33
Mulching with transparent polyethylene sheet	(T3)	11.00	8.66	9.83	18.33	20.66	19.50	25.00	27.50	26.25
Mulching with dry grasses	(T4)	11.66	9.66	10.66	13.89	13.00	13.44	18.66	18.00	18.33
Mulching with black polyethylene sheet + Irrigation	(T5)	11.33	9.33	10.33	17.00	19.33	18.16	23.66	26.00	24.83
Mulching with transparent polyethylene sheet + Irrigation	(T6)	10.66	8.33	9.49	20.66	23.33	22.00	27.66	30.55	29.10
Mulching with dry grasses + Irrigation	(T7)	11.00	9.66	10.33	14.00	13.89	13.94	19.00	18.22	18.61
S.Em. ±		0.71	0.60		0.75	0.73		0.81	0.80	
C.D. at 5%		NS	NS		2.30	2.24		2.48	2.45	

in the observation recorded before solarization (Table 6). The fungi belonging to species of Aspergillus, Fusarium and Penicillium were frequently observed.

During 1992, the maximum number of colonies recorded was 20.66×10^3 nine weeks after solarization in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) and 27.66×10^3 colonies twenty-one weeks after solarization in the same treatment, which was significant with rest of the treatments. The minimum number of colonies was recorded in control (T_1) 13.66×10^3 and 18.00×10^3 respectively after nine and twenty-one weeks of solarization. The treatments that received the mulching of dry grasses did not differ significantly from control. The number of colonies observed in the treatments, the mulching with transparent polyethylene sheet (T_3) and the mulching with black polyethylene sheet + irrigation (T_5) did not show any significant difference among each other and the treatment (T_5) was also on par with the treatment, the mulching with black polyethylene sheet (T_2).

During 1993, the maximum number of colonies observed was 23.33×10^3 nine weeks after solarization in the treatment the mulching with transparent polyethylene sheet + irrigation

(T_6) and after twenty-one weeks also the same treatment recorded the maximum number of colonies (30.55 x 10^3) which differed significantly with rest of the treatments. The minimum number of colonies observed was 13.00 x 10^3 after nine weeks and 18.00 x 10^3 after twenty-one weeks in the treatment that received the mulching with dry grasses(T_4). The treatments that received the mulching with transparent polyethylene sheet (T_3) (20.66 x $10^3$and 27.50 x 10^3) and the mulching with black polyethylene sheet + irrigation (T_5) (19.33 x 10^3 and 26.00 x 10^3) recorded the number of colonies which were on par with each other. The treatments where dry grasses were used for mulching the number of colonies observed did not differ significantly with control.

4.3.4.3 Bacteria

Effect of soil solarization on the population of bacteria was observed before solarization and nine and twenty-one weeks after solarization in the years 1992 and 1993 (Table 7). The bacteria belonging to species of Bacillus, Pseudomonas and Xanthamonas were frequently observed.

In the year 1992, the maximum number of colonies observed was 26.00 x 10^4 in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6)

Table 7. Effect of soil solarization on the population of bacteria

Treatments		Number of colonies (in lakhs per g of soil)								
		Before solarization			After solarization					
					9 weeks			21 weeks		
		1992	1993	Mean	1992	1993	Mean	1992	1993	Mean
Natural condition	(T1)	15.00	19.00	17.00	16.00	20.66	18.33	18.00	22.00	20.00
Mulching with black polyethylene sheet	(T2)	14.66	19.33	17.00	20.00	24.33	22.16	28.66	33.66	31.16
Mulching with transparent polyethylene sheet	(T3)	14.33	20.33	17.33	24.00	27.66	25.83	32.33	36.66	34.50
Mulching with dry grasses	(T4)	15.33	18.66	16.99	15.66	21.33	18.50	17.66	22.66	20.16
Mulching with black polyethylene sheet + Irrigation	(T5)	15.33	19.00	17.16	22.66	25.66	24.16	30.33	34.00	32.16
Mulching with transparent polyethylene sheet + Irrigation	(T6)	14.66	19.66	17.16	26.00	30.00	28.00	36.33	40.00	38.16
Mulching with dry grasses + Irrigation	(T7)	14.00	20.00	17.00	16.66	20.66	18.66	18.00	22.33	20.16
S.Em. ±		0.72	0.78		0.55	0.64		0.56	0.70	
C.D. at 5%		NS	NS		1.69	1.96		1.72	2.15	

during nine weeks after solarization and it was also in the same treatment that recorded the maximum number of colonies (36.33×10^4) twenty-one weeks after solarization. The minimum number of colonies observed in the treatment that received the mulching with dry grasses (T_4) (15.66×10^4) nine weeks after solarization and it was 17.66×10^4 colonies which was the minimum recorded in the same treatment twenty-one weeks after solarization.

The number of colonies observed in the treatments, the mulching with transparent polyethylene sheet (T_3), the mulching with black polyethylene sheet (T_5) and the mulching with black polyethylene sheet (T_2) did not show much difference among each other, more number of colonies were observed in the treatment (T_3), which differed significantly with other treatments after twenty-one weeks of solarization.

During 1993, the maximum number of colonies of bacteria was observed in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) both during nine weeks (30.00×10^4) and twenty-one weeks (40.00×10^4) after solarization. Similarly the minimum number of colonies were recorded in control (20.66×10^4 and

22.00 x 10^4 respectively after nine and twenty-one weeks of solarization.

The next maximum number of colonies was observed in the treatment that received the mulching with transparent polyethylene sheet (T_3) (27.66 x 10^4 and 36.66 x 10^4) and followed by the treatment the mulching with black polyethylene sheets (T_5 and T_2). Where dry grasses were used for mulching the number of colonies did not differ significantly with control.

4.3.4.4 Actinomycetes

Effect of soil solarization on the population of the actinomycetes was recorded before and after solarization and presented in the Table 8 during 1992 and 1993. The Streptomyces spp. were frequently observed.

During the year 1992, the maximum number of colonies observed was 16.55 x 10^3 in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6), nine weeks after solarization and the minimum was 8.67 x 10^3 colonies in control. During twenty-one weeks after solarization, the maximum number of colonies were observed in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) (26.33 x 10^3) and the

Table 8. Effect of soil solarization on the population of actinomycetes

Treatments		Number of colonies (in thousands per g of soil)								
		Before solarization			After solarization					
					9 weeks			21 weeks		
		1992	1993	Mean	1992	1993	Mean	1992	1993	Mean
Natural condition	(T1)	6.55	5.11	5.83	8.67	8.11	8.39	12.00	10.89	11.44
Mulching with black polyethylene sheet	(T2)	6.11	6.00	6.05	11.33	12.66	12.00	15.00	13.89	14.44
Mulching with transparent polyethylene sheet	(T3)	7.11	5.33	6.22	14.77	16.66	15.71	22.66	20.33	21.50
Mulching with dry grasses	(T4)	6.78	5.00	5.89	9.44	7.67	8.55	12.55	10.66	11.60
Mulching with black polyethylene sheet + Irrigation	(T5)	6.33	5.78	6.05	12.00	15.11	13.55	19.55	17.33	18.44
Mulching with transparent polyethylene sheet + Irrigation	(T6)	6.00	5.55	5.78	16.55	18.33	17.44	26.33	25.00	25.66
Mulching with dry grasses + Irrigation	(T7)	7.00	6.11	5.55	10.00	9.00	9.50	12.33	11.33	11.83
S.Em. ±		0.42	0.32		0.52	0.35		0.56	0.42	
C.D. at 5%		NS	NS		1.60	1.07		1.72	1.29	

minimum number of colonies were observed in control (12.00×10^3).

There was no significant difference between the treatments those received black polyethylene sheet mulching during nine weeks after solarization but they differed significantly after twenty-one weeks of solarization.

In the year 1993, during nine weeks after solarization, the maximum number of colonies observed was 18.33×10^3 in the treatment that received the mulching with transparent polyethylene sheet + irrigation (T_6) and the minimum was 7.67×10^3 in the treatment that received the mulching with dry grasses (T_4). During twenty-one weeks after solarization, the maximum number of colonies observed was 25.00×10^3 and the minimum was 10.66×10^3 in the treatments that received the mulching with transparent polyethylene sheet + irrigation (T_6) and the treatment the mulching with dry grasses (T_4) respectively.

The next maximum number of colonies were observed in the treatment that received the mulching with transparent polyethylene sheet (T_3) followed by the mulching with black polyethylene sheet + irrigation (T_5). In those treatments

Fig. 5. Showing the effect of soil solarization on rhizosphere microflora (mean of 1992 and 1993)

Treatments

T_1 : Natural condition (control)

T_2 : Mulching with black polyethylene sheet.

T_3 : Mulching with transparent polyethylene sheet.

T_4 : Mulching with dry grasses.

T_5 : Mulching with black polyethylene sheet and irrigation.

T_6 : Mulching with transparent polyethylene sheet and irrigation.

T_7 : Mulching with dry grasses and irrigation.

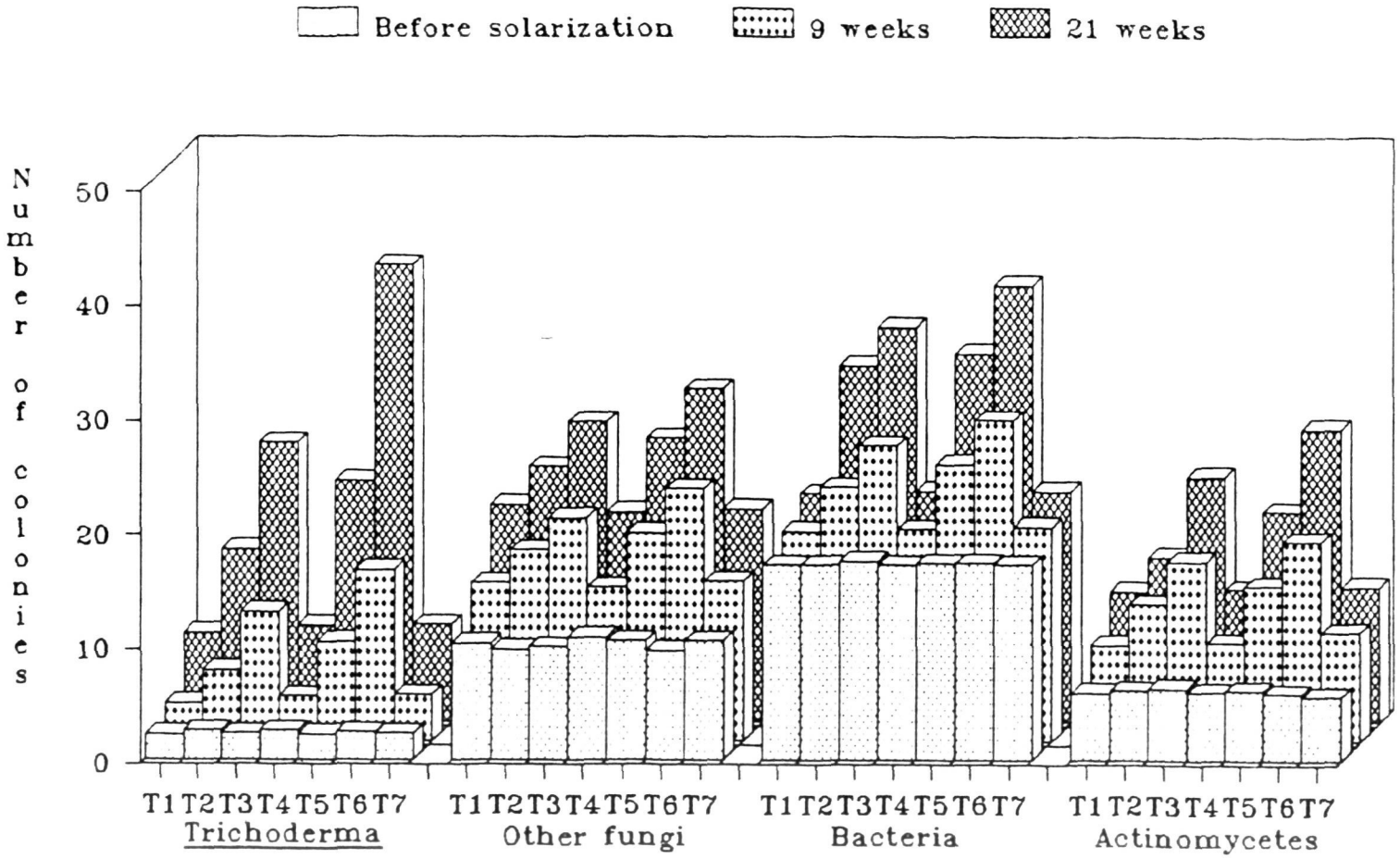


Fig. 5. Effect of soil solarization on rhizosphere microflora (mean of 1992 and 1993)

where dry grasses were used for mulching there was no significant increase in number of colonies over control.

4.4 INTEGRATED MANAGEMENT

Experiment on integrated management of black pepper wilt was carried out during 1993 by the integration of neem cake, Trichoderma harzianum, one application of metalaxyl MZ, garlic and mustard extract and soil solarization in combinations as explained in 'Material and Methods' and results are furnished hereunder.

4.4.1 Effect on soil temperature

Effect of different treatments on soil temperature was recorded and presented in Table 9 and Fig. 6. The soil temperature that recorded before solarization was found to be not significant among the treatments. However, the observations made after three, six and nine weeks after solarization was found to be significant among different treatments.

Three weeks after solarization , the maximum temperature recorded was 26.16°C in the treatment that received N+T+M+GM+ mulching with transparent polyethylene sheet + irrigation (T_8) which was significant to all other treatments and this was followed by the treatment that

Table 9. Effect of soil solarization and other treatments on soil temperature, 1993

Treatments		Soil temperature (°C)			
		Before solarization	After solarization		
			3 weeks	6 weeks	9 weeks
Natural condition	(T1)	24.43	24.73	25.20	25.90
Neem cake + T. harzianum + metalaxyl MZ (N+T+M)	(T2)	24.40	24.80	25.26	26.10
Garlic and mustard extract (GM)	(T3)	24.46	24.80	25.20	25.95
Neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	24.46	24.78	25.23	25.90
N+T+M+GM+mulching with black polyethylene sheet	(T5)	24.46	25.36	26.23	27.50
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	24.53	25.40	26.40	27.83
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	24.46	25.86	27.03	28.70
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	24.50	26.16	27.80	29.63
N+T+M+GM+mulching with dry grasses	(T9)	24.40	24.86	25.30	26.16
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	24.43	24.90	25.33	26.20
S.Em. ±		0.09	0.08	0.10	0.11
C.D. at 5%		NS	0.25	0.30	0.35

Fig. 6. Showing the effect of soil solarization and other treatments on soil temperature, 1993

Treatments

T_1 : Natural condition (control)

T_2 : Neem cake + Trichoderma harzianum + metalaxyl MZ

T_3 : Garlic and mustard extract

T_4 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract

T_5 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet.

T_6 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet + Irrigation

T_7 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet

T_8 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet + Irrigation

T_9 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses.

T_{10} : Neem Cake + T harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses + Irrigation.

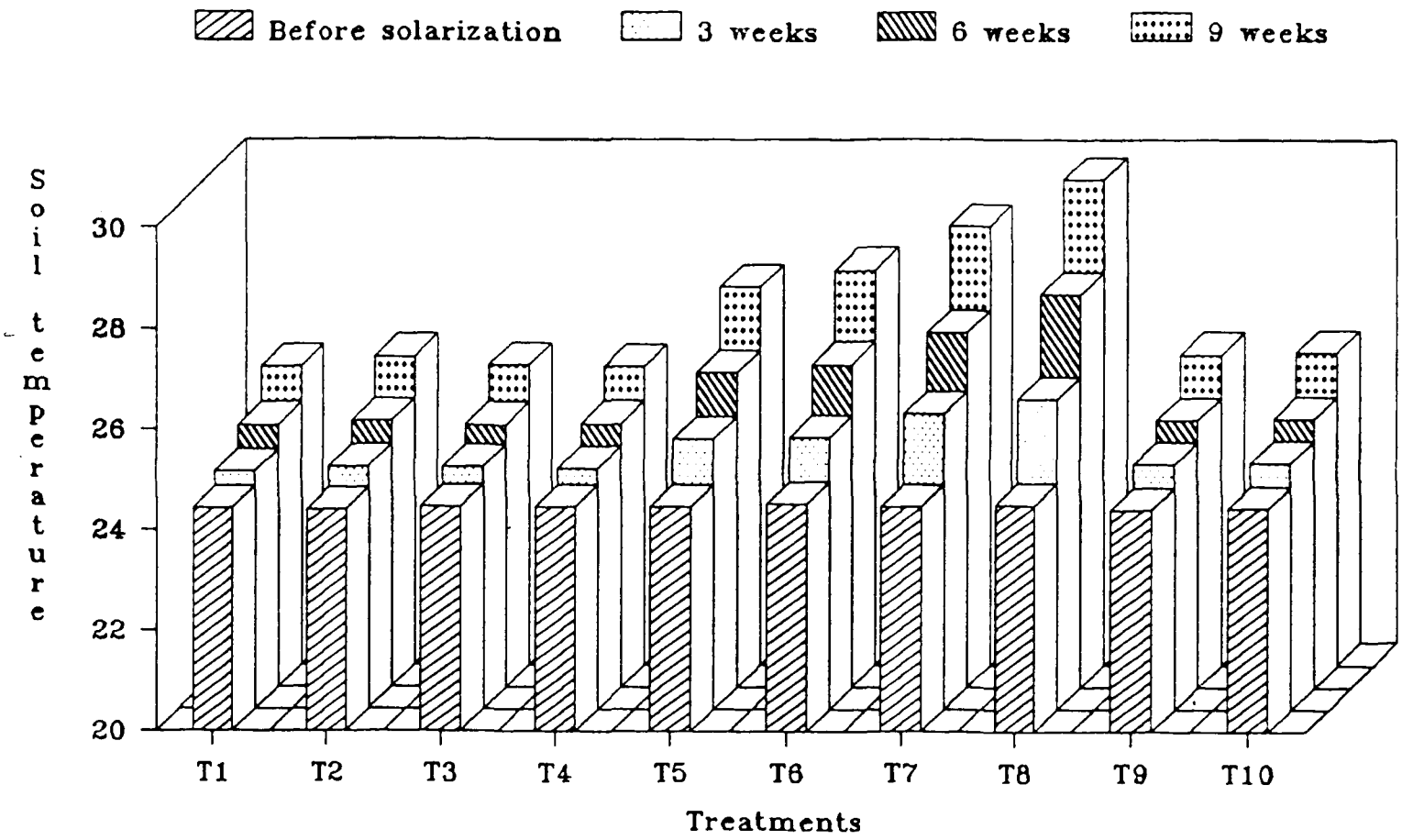


Fig. 6. Effect of soil solarization and other treatments on soil temperature, 1993

received N+T+M+GM+ mulching with transparent polyethylene sheet (T_7) (25.86°C) which was found to differ significantly with other treatments. The treatment where in black polyethylene sheets were used for mulching did not differ significantly with each other.

The minimum temperature recorded was 24.73°C in control. This treatment was on par with the remaining treatments wherein dry grasses were used for mulching (T_9 and T_{10}) and non-solarized treatments (T_2, T_3 and T_4).

Six weeks after solarization, the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) recorded the maximum temperature of 27.80°C which was significant to all other treatments. This was followed by the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (27.03°C), which was also significant to other treatments. The treatments that received N+T+M+GM and the mulching with black polyethylene sheet + irrigation (T_6) (26.40°C) and the treatment N+T+M+GM and the mulching with black polyethylene sheet (T_5) (26.23°C) were on par with each other.

During this week, the minimum temperature was recorded in control which was 25.20°C. This was on par with the remaining treatments namely, application of garlic and mustard extract (T_3) (25.20°C), application of neem cake + T.harzianum + metalaxyl MZ + garlic and mustard extract (T_4) (25.23°C) and also with the treatment that received the application of neem cake + T.harzianum + metalaxyl MZ (T_2) (25.26°C), N+T+M+GM and mulching with dry grasses (T_9) (25.30°C) and N+T+M+GM and the mulching with dry grasses + irrigation (T_{10}) (25.33°C).

After nine weeks of solarization, the maximum temperature recorded was 29.63°C in the same treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8). This was followed by the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (28.70°C). These two treatments were significant to each other as well as to all other treatments. Followed by this soil temperature recorded was 27.83°C in the treatment that received N+T+M+GM and the mulching with black polyethylene sheet +irrigation (T_6) which was at par with the treatment that received N+T+M+GM and the mulching with black polyethylene sheet (T_5) (27.50°C).

During this week, the minimum temperature recorded was 25.90°C in control and in the treatment (T_4). The next high temperature recorded was in the treatment that received garlic and mustard extract (T_3) (25.95°C). These treatments and other remaining treatments, namely application of neem cake + T.harzianum and metalaxyl MZ (T_2) (26.10°C), N+T+M+GM and the mulching with dry grasses (T_9) (26.16°C) and dry grasses with irrigation (T_{10}) (26.20°C) were on par with each other.

4.4.2 Effect on survival of pepper vines

Effect of different treatments on per cent survival of pepper vines was significant and the results are presented in the Table 10, Plate 6A and 6B and Fig.7.

The maximum per cent survival of vines recorded was 88.89 by the treatment that received N+T+M+GM and mulching with transparent polyethylene sheet + irrigation (T_8) and followed by the treatment that received N+T+M+GM and mulching with transparent polyethylene sheet (T_7) (77.78). In the treatments, that received N+T+M+GM and mulching with black polyethylene sheet + irrigation (T_6), N+T+M+GM and mulching with black polyethylene sheet (T_5), N+T+M+GM and mulching with dry grasses + irrigation (T_{10}), N+T+M+GM and mulching with dry

Table 10. Effect of soil solarization and other treatments on survival of pepper vines, 1993

Treatments		Mean
Natural condition	(T1)	11.11 (12.09)
Neem cake + T. harzianum + metalaxyl MZ (N+T+M)	(T2)	66.67 (54.76)
Garlic and mustard extract (GM)	(T3)	44.44 (41.74)
Neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	77.78 (66.50)
N+T+M+GM+mulching with black polyethylene sheet	(T5)	77.78 (66.50)
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	77.78 (66.50)
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	77.78 (66.50)
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	88.89 (78.25)
N+T+M+GM+mulching with dry grasses	(T9)	77.78 (66.50)
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	77.78 (66.50)
S.Em. ±		7.85
C.D. at 5%		23.33

Figures in parentheses indicate the transformed values

Fig. 7. Showing the effect of soil solarization and other treatments on survival of pepper vines, 1993

Treatments

T_1 : Natural condition (control)

T_2 : Neem cake + *Trichoderma harzianum* + metalaxyl MZ

T_3 : Garlic and mustard extract

T_4 : Neem cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract

T_5 : Neem cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet.

T_6 : Neem cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet + Irrigation

T_7 : Neem Cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet

T_8 : Neem Cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet + Irrigation

T_9 : Neem Cake + *T. harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses.

T_{10} : Neem Cake + *T harzianum* + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses + Irrigation.

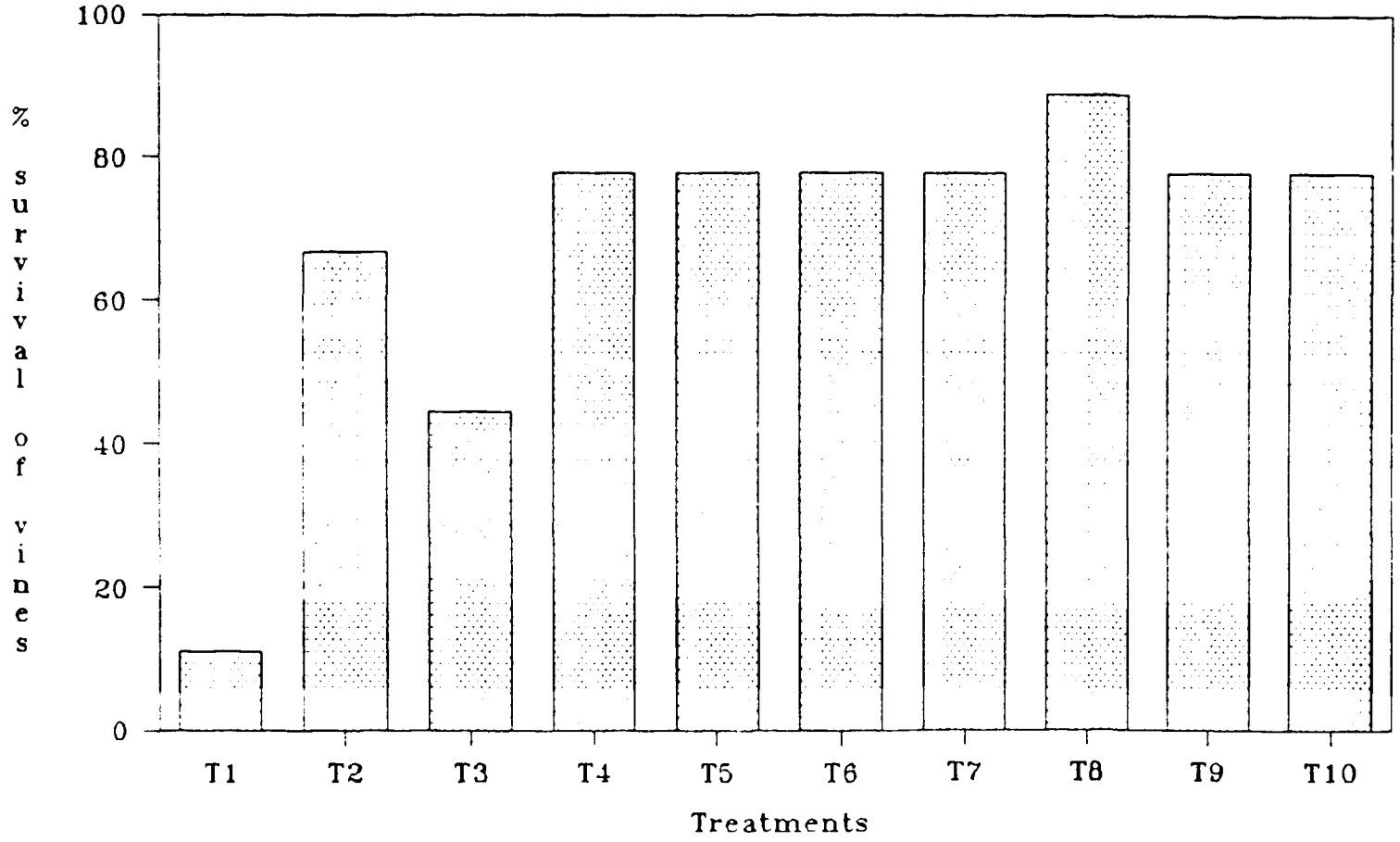


Fig. 7. Effect of soil solarization and other treatments on survival of pepper vines, 1993

Plate 6 A. Showing healthy pepper vine due to imposition of integrated management treatments

Plate 6 B. Showing wilted pepper vine in control treatment.

grasses (T_9) and application of neem cake + T. harzianum + metalaxyl MZ and garlic and mustard extract (T_4) the per cent survival of pepper vines was 77.78. These all treatments were on par with the treatments that received N+T+M+GM and mulching with transparent polyethylene sheet + irrigation(T_8) and N+T+M+GM and mulching with transparent polyethylene sheet (T_7). These all above treatments differed significantly with rest of the treatments.

The minimum per cent survival of pepper vines was recorded in the treatment that was exposed to natural condition (T_1) (11.11) and this differed significantly from rest of the treatments. In the treatments that received application of garlic and mustard extract (T_3) and application of neem cake + T.harzianum + metalaxyl MZ (T_2) 44.44 and 66.67 per cent survival of vines respectively, were recorded which were on par with each other.

4.4.3 Effect of different treatments on population of P.capsici

The population of P. capsici was estimated by using castor seed baiting technique before solarization and at three weeks interval up to twenty-one weeks after solarization and expressed as per cent colonisation of baits and data were analysed statistically (Table 11 and Fig.8).

Table 11. Effect of soil solarization and other treatments on per cent colonisation of castor baits by *P. capsici*, 1993

Treatments		Per cent colonisation of castor baits							
		Before solarization	After solarization						
			3 weeks	6 weeks	9 weeks	12 weeks	15 weeks	18 weeks	21 weeks
Natural condition	(T1)	18.22 (25.27)	18.22 (25.27)	16.88 (24.24)	17.33 (24.58)	30.23 (33.35)	52.43 (46.40)	72.00 (58.06)	89.76 (71.50)
Neem cake + *T. harzianum* + metalaxyl MZ (N+T+M)	(T2)	18.67 (25.58)	17.78 (24.94)	14.22 (22.16)	13.77 (21.77)	16.00 (23.58)	22.23 (28.11)	30.23 (33.35)	36.46 (37.14)
Garlic and mustard extract (GM)	(T3)	18.22 (25.27)	18.22 (25.27)	16.88 (24.24)	15.55 (23.23)	17.33 (24.58)	30.23 (33.35)	45.30 (42.56)	56.00 (48.45)
Neem cake + *T. harzianum* + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	18.67 (25.58)	18.22 (25.27)	13.77 (21.77)	12.44 (20.80)	14.22 (22.16)	20.00 (26.53)	25.76 (30.49)	32.00 (34.42)
N+T+M+GM+mulching with black polyethylene sheet	(T5)	18.22 (25.28)	17.33 (24.58)	12.44 (20.80)	10.67 (19.04)	12.89 (21.67)	18.22 (25.27)	24.00 (29.32)	31.56 (34.16)
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	18.67 (25.62)	16.88 (24.24)	12.00 (20.25)	10.23 (18.59)	12.46 (20.63)	17.78 (24.94)	23.53 (29.00)	30.23 (33.61)
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	18.22 (25.25)	16.43 (23.91)	10.67 (19.04)	9.78 (18.00)	10.67 (19.04)	16.90 (24.26)	23.10 (28.71)	29.76 (33.04)
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	18.22 (25.25)	14.67 (22.55)	9.78 (18.00)	8.46 (16.84)	9.78 (18.00)	15.11 (22.89)	20.46 (26.87)	25.76 (30.76)
N+T+M+GM+mulching with dry grasses	(T9)	17.78 (24.92)	16.88 (24.24)	13.33 (21.39)	12.44 (20.80)	14.67 (22.55)	20.46 (26.87)	26.20 (30.76)	32.43 (34.70)
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	17.78 (24.92)	16.43 (23.91)	12.90 (21.01)	12.00 (20.25)	13.77 (21.77)	19.56 (26.24)	25.76 (32.49)	32.00 (34.42)
S.Em. ±		0.39	0.34	0.35	0.30	0.30	0.85	0.81	0.75
C.D. at 5%		NS	NS	1.03	0.89	0.90	2.52	2.40	2.24

Figures in parentheses indicate the transformed values

The per cent colonisation of baits observed before solarization and at three weeks after solarization in different treatments was found to be not significantly differing from each other. However, at six weeks after solarization and onwards the observations recorded were found to be significantly differing among the different treatments.

Six weeks after solarization the reduction in the population was observed in solarized treatments particularly more in the treatment that received mulching with transparent polyethylene sheet + irrigation (T_8) (9.78). The maximum per cent colonisation was observed in control (16.88). There was marginal decrease in per cent colonisation of baits in other solarized treatments compared to non-solarized treatments.

Nine weeks after solarization, the minimum per cent colonisation of baits was observed in the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) (8.46) followed by the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (9.78) both differed significantly from rest of the treatments. This was followed by the treatments, where black polyethylene sheets were used for mulching (T_6 and T_5) (10.23 and 10.67).

Fig. 8. Showing the effect of soil solarization and other treatments on per cent colonisation of castor baits by P. capsici, 1993

Treatments

T_1 : Natural condition (control)

T_2 : Neem cake + Trichoderma harzianum + metalaxyl MZ

T_3 : Garlic and mustard extract

T_4 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract

T_5 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet.

T_6 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet + Irrigation

T_7 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet

T_8 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet + Irrigation

T_9 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses.

T_{10} : Neem Cake + T harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses + Irrigation.

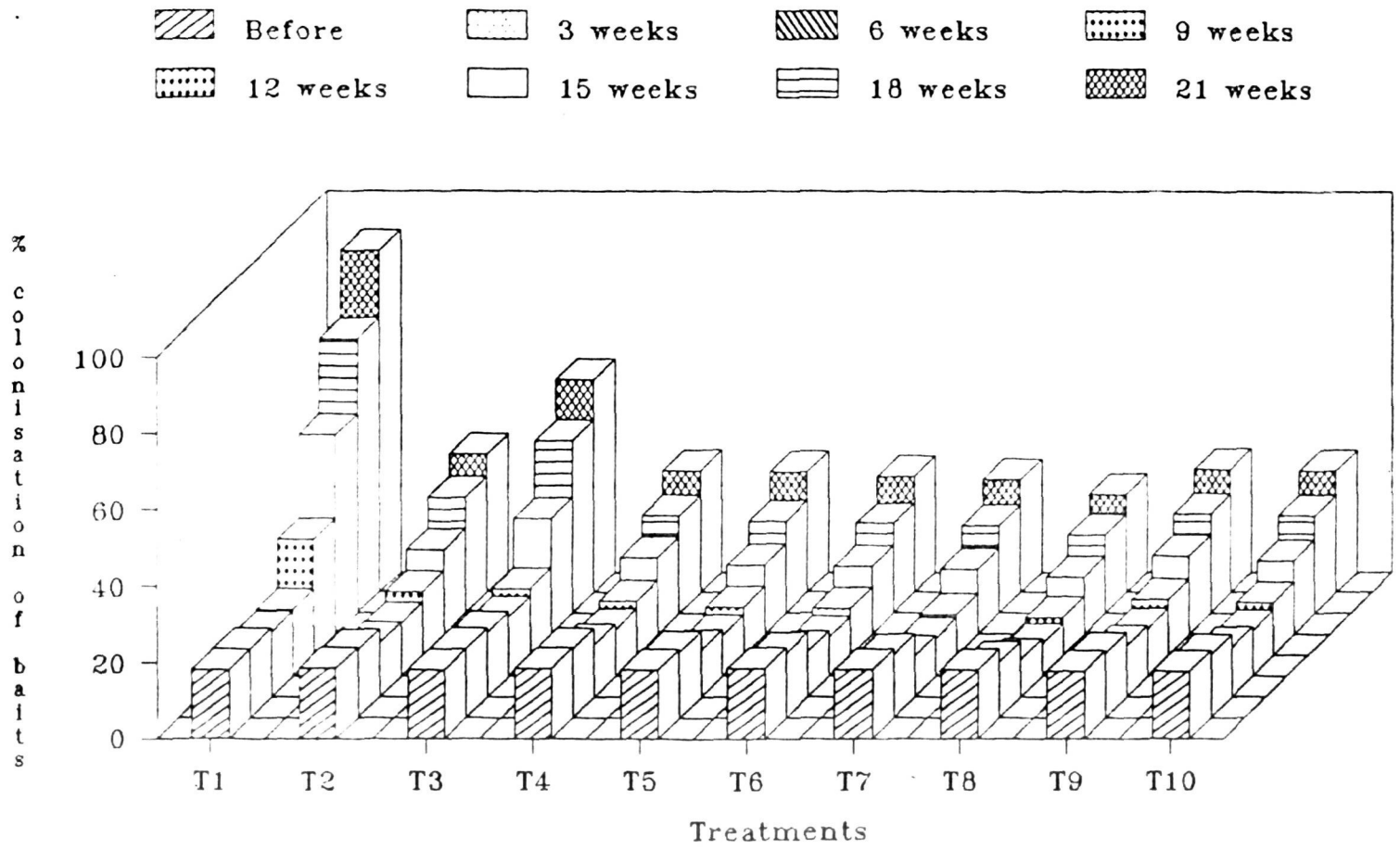


Fig. 8. Effect of soil solarization and other treatments on per cent colonisation of castor baits by P. capsici, 1993

The maximum per cent colonisation of baits was observed in control (T_1) (17.33), followed by the treatment application of garlic and mustard extract (T_3) (15.55).

Twelve weeks after solarization, the minimum per cent colonisation of baits observed was 9.78, in the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) (9.78) which differed significantly from rest of the treatments. Followed by this 10.67 per cent colonisation of baits was observed in the treatment, N+T+M+GM and the mulching with transparent polyethylene sheet (T_7). The other treatments where black polyethylene sheets and dry grasses were used did not differ significantly with each other.

The maximum per cent colonisation of baits observed was 30.23 in the treatment that was exposed to natural condition (T_1), which differ significantly from other treatments, followed by the treatments, application of garlic and mustard extract (T_3) (17.33) and application of neem cake + T.harzianum + metalaxyl MZ (T_2) (16.00) which were differing significantly with each other as well to rest of the treatments.

Fifteen weeks after solarization, the minimum per cent colonisation of baits was observed in the same treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) (15.11), followed by the treatment N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (16.90) and N+T+M+GM and the mulching with black polyethylene sheet + irrigation (T_6) (17.78) which were on par with each other.

The maximum per cent colonisation of baits observed was 52.43 in control (T_1) which differed significantly with rest of the treatments. In the treatments, application of garlic and mustard extract (T_3) and application of neem cake + T.harzianum + metalaxyl MZ (T_2), 30.23 and 22.23 per cent colonisation of baits was observed, which differ significantly with each other. There was no significant difference among the remaining treatments where black polyethylene sheet and dry grasses were used for mulching.

Eighteen weeks after solarization, the minimum per cent colonisation of baits (20.46) was observed again in the treatment that received N+T+M+GM and mulching transparent polyethylene sheet + irrigation (T_8) which differed significantly from rest of the treatments. The treatments

N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) and N+T+M+GM and mulching with black polyethylene sheet + irrigation (T_6) recorded 23.10 and 23.53 per cent colonisation of baits respectively which were on par with each other.

The maximum per cent colonisation of baits 72.00 was observed in control (T_1). The treatments application of garlic and mustard extract (T_3) and application of neem cake + T.harzianum + metalaxyl MZ (T_2) which recorded 45.30 and 30.23 per cent colonisation of baits respectively, differed significantly with each other and to control (T_1) and the remaining treatments. There was no significant difference observed among the treatments where black polyethylene sheets and dry grasses were used for mulching.

Twenty-one weeks after solarization, the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) recorded the minimum per cent colonisation of baits (25.76), which differed significantly from rest of the treatments. This was followed by the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (29.76) which was on par with the treatments where black polyethylene sheets and dry grasses were used for mulching (T_6, T_5, T_9 and T_{10}) and to the

treatment application of neem cake + T.harzianum + metalaxyl MZ + garlic and mustard extract (T_4).

The maximum per cent colonisation of baits observed was 89.76 recorded in the treatment that was exposed to natural condition (T_1), followed by the treatment that received the application of garlic and mustard extract (T_3) (56.00) which differed significantly from each other and also with rest of the treatments. The treatment that received application of neem cake + T.harzianum + metalaxyl MZ (T_2) recorded 36.46 per cent colonisation of baits which differed significantly from rest of the treatments.

4.4.4 Effect on rhizosphere microflora

Effect of different treatments on the populations of different rhizosphere microflora like Trichoderma spp., other fungi, bacteria and the actinomycetes were observed and the results are given hereunder (Fig. 9) and Table 12 to 15.

4.4.4.1 Trichoderma spp.

Effect of different treatments on the population of Trichoderma spp. was not significant with each other in the observation that recorded before solarization, but nine and twenty-one weeks after solarization they differ significantly

Table 12. Effect of soil solarization and other treatments on the population of *Trichoderma* spp., 1993

Treatments		Number of colonies (in thousands per g of soil)		
		Before solarization	After solarization	
			9 weeks	21 weeks
Natural condition	(T1)	2.55	5.89	8.89
Neem cake + *T. harzianum* + metalaxyl MZ (N+T+M)	(T2)	2.67	26.66	122.33
Garlic and mustard extract (GM)	(T3)	2.44	7.00	14.00
Neem cake + *T. harzianum* + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	3.11	27.00	124.00
N+T+M+GM+mulching with black polyethylene sheet	(T5)	3.66	28.66	136.77
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	3.55	27.66	140.33
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	3.00	29.30	144.66
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	3.33	36.67	155.55
N+T+M+GM+mulching with dry grasses	(T9)	2.77	27.00	121.33
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	4.00	28.30	123.89
S.Em. ±		0.53	1.35	3.16
C.D. at 5%		NS	4.03	9.38

(Table 12). The T. harzianum was observed more frequently but T. viride was also observed.

After nine weeks of solarization the maximum number of colonies observed was 36.67 x 10^3 in the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) which differed significantly from rest of the treatments. This was followed by the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (29.30 x 10^3). In the treatments where black polyethylene sheet and dry grasses were used for mulching (T_6, T_5, T_9 and T_{10}) and in the treatments (T_2 and T_4) the number of colonies observed were on par with each other and to the treatment (T_7). The minimum number of colonies recorded in control was 5.89 x 10^3.

Twenty-one weeks after solarization, the maximum number of colonies recorded was 155.55 x 10^3 in the treatment that received N+T+M+GM and mulching with transparent polyethylene sheet + irrigation (T_8) which was significant to all other treatments. There was no significant difference between the treatments N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (144.66 x 10^3) and in the treatments where black polyethylene sheets were used for

mulching (T_6 and T_5) (140.33 x10^3 and 136.77 x 10^3). The treatments where dry grasses were used for mulching and other non-solarized treatments were on par with each other but differed significantly to the rest of the treatments.

The minimum number of colonies recorded was 8.89 x 10^3 in control and this was on par with the treatment application of garlic and mustard extract (T_3) (14.00 x 10^3). However these two treatments differed significantly with rest of the treatments.

4.4.4.2 Other fungi

Effect of different treatments on the population of other fungi was recorded and presented in the Table 13. The fungi belonging to species of Aspergillus, Fusarium and Penicillium were frequently observed.

There was no significant difference among treatments during before solarization but the treatments differed significantly in nine and twenty-one weeks after solarization.

After nine weeks of solarization the maximum number of colonies recorded was 22.33 x 10^3 in the treatment that received N+T+M+GM and the mulching with transparent

Table 13. Effect of soil solarization and other treatments on the population of other fungi, 1993

Treatments		Number of colonies (in thousands per g of soil)		
		Before solarization	After solarization	
			9 weeks	21 weeks
Natural condition	(T1)	10.22	13.22	15.55
Neem cake + T. harzianum + metalaxyl MZ (N+T+M)	(T2)	9.77	16.33	30.55
Garlic and mustard extract (GM)	(T3)	11.66	13.55	16.00
Neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	10.00	16.66	32.00
N+T+M+GM+mulching with black polyethylene sheet	(T5)	9.66	17.33	36.89
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	10.78	18.00	37.00
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	11.44	18.44	40.33
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	10.33	22.33	47.33
N+T+M+GM+mulching with dry grasses	(T9)	11.00	17.22	31.00
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	11.22	17.33	31.66
S.Em. ±		0.90	1.12	1.57
C.D. at 5%		NS	3.33	4.68

polyethylene sheet + irrigation (T_8). All other treatments except the treatment (T_3) and control (T_1), were on par with each other.

The minimum number of colonies was recorded in control (13.22×10^3) and this was followed by the treatment application of garlic and mustard extract (T_3) (13.55×10^3), which were on par with each other.

Twenty-one weeks after solarization, the maximum number of colonies observed was 47.33×10^3 in the treatment that receive N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8), followed by the treatment N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (40.33×10^3).

The minimum number of colonies was observed in the treatment that was exposed to natural condition (T_1) (15.55×10^3), followed by the treatment that received application of garlic and mustard extract (T_3) (16.00×10^3). There was no significant difference between these two treatments but differed significantly with rest of the treatments.

4.4.4.3 Bacteria

Effect of different treatments on the population of bacteria was observed and presented in the Table 14.

Table 14. Effect of soil solarization and other treatments on the population of bacteria, 1993

Treatments		Number of colonies (in ten thousands per g of soil)		
		Before solarization	After solarization	
			9 weeks	21 weeks
Natural condition	(T1)	19.55	21.00	25.00
Neem cake + T. harzianum + metalaxyl MZ (N+T+M)	(T2)	20.33	22.00	63.00
Garlic and mustard extract (GM)	(T3)	19.11	21.55	24.00
Neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	20.11	22.55	63.33
N+T+M+GM+mulching with black polyethylene sheet	(T5)	19.78	22.66	74.66
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	19.11	23.66	76.00
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	20.28	29.66	78.00
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	20.34	31.00	85.00
N+T+M+GM+mulching with dry grasses	(T9)	20.00	23.11	65.66
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	19.00	23.00	62.89
S.Em. ±		0.51	1.19	1.31
C.D. at 5%		NS	3.54	3.90

There was no significant difference among treatments in the observations recorded before solarization. The observations recorded nine and twenty-one weeks after solarization, showed the significant difference among the treatments. The bacteria belonging to genera Bacillus, Pseudomonas and Xanthamonas were frequently observed.

After nine weeks of solarization, the treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) recorded the maximum number of colonies 31.00 x 10^4, followed by the treatment N+T+M+GM and the mulching with transparent polyethylene sheet (T_7) (29.66 x 10^4) which differed significantly from rest of the treatments. The same treatment (T_8) recorded the maximum number of colonies (85.00 x 10^4) followed by the treatment (T_7) (78.00 x10^4), also during twenty-one weeks after solarization.

The minimum number of colonies were recorded in control both during nine and twenty-one weeks after solarization (21.00 x 10^4 and 24.00 x 10^4). The remaining treatments did not differ significantly.

4.4.4.4 Actinomycetes

Effect of different treatments on the population of the actinomycetes was recorded and observed the Streptomyces spp. frequently (Table 15).

Table 15. Effect of soil solarization and other treatments on the population of actinomycetes, 1993

Treatments		Number of colonies (in thousands per g of soil)		
		Before solarization	After solarization	
			9 weeks	21 weeks
Natural condition	(T1)	4.00	5.33	6.33
Neem cake + T. harzianum + metalaxyl MZ (N+T+M)	(T2)	3.66	7.00	14.33
Garlic and mustard extract (GM)	(T3)	4.11	5.11	7.44
Neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract (N+T+M+GM)	(T4)	3.22	7.55	14.00
N+T+M+GM+mulching with black polyethylene sheet	(T5)	4.00	6.00	16.66
N+T+M+GM+mulching with black polyethylene sheet + Irrigation	(T6)	3.44	10.00	20.00
N+T+M+GM+mulching with transparent polyethylene sheet	(T7)	4.55	12.00	25.00
N+T+M+GM+mulching with transparent polyethylene sheet + Irrigation	(T8)	4.22	16.44	35.00
N+T+M+GM+mulching with dry grasses	(T9)	4.44	6.78	12.66
N+T+M+GM+mulching with dry grasses + Irrigation	(T10)	4.33	7.00	14.00
S.Em. ±		0.49	0.86	1.05
C.D. at 5%		NS	2.55	3.12

Fig. 9. Showing the effect of soil solarization and other treatments on rhizosphere microflora, 1993

Treatments

T_1 : Natural condition (control)

T_2 : Neem cake + Trichoderma harzianum + metalaxyl MZ

T_3 : Garlic and mustard extract

T_4 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract

T_5 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet.

T_6 : Neem cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with black polyethylene sheet + Irrigation

T_7 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet

T_8 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with transparent polyethylene sheet + Irrigation

T_9 : Neem Cake + T. harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses.

T_{10} : Neem Cake + T harzianum + metalaxyl MZ + Garlic and mustard extract + mulching with dry grasses + Irrigation.

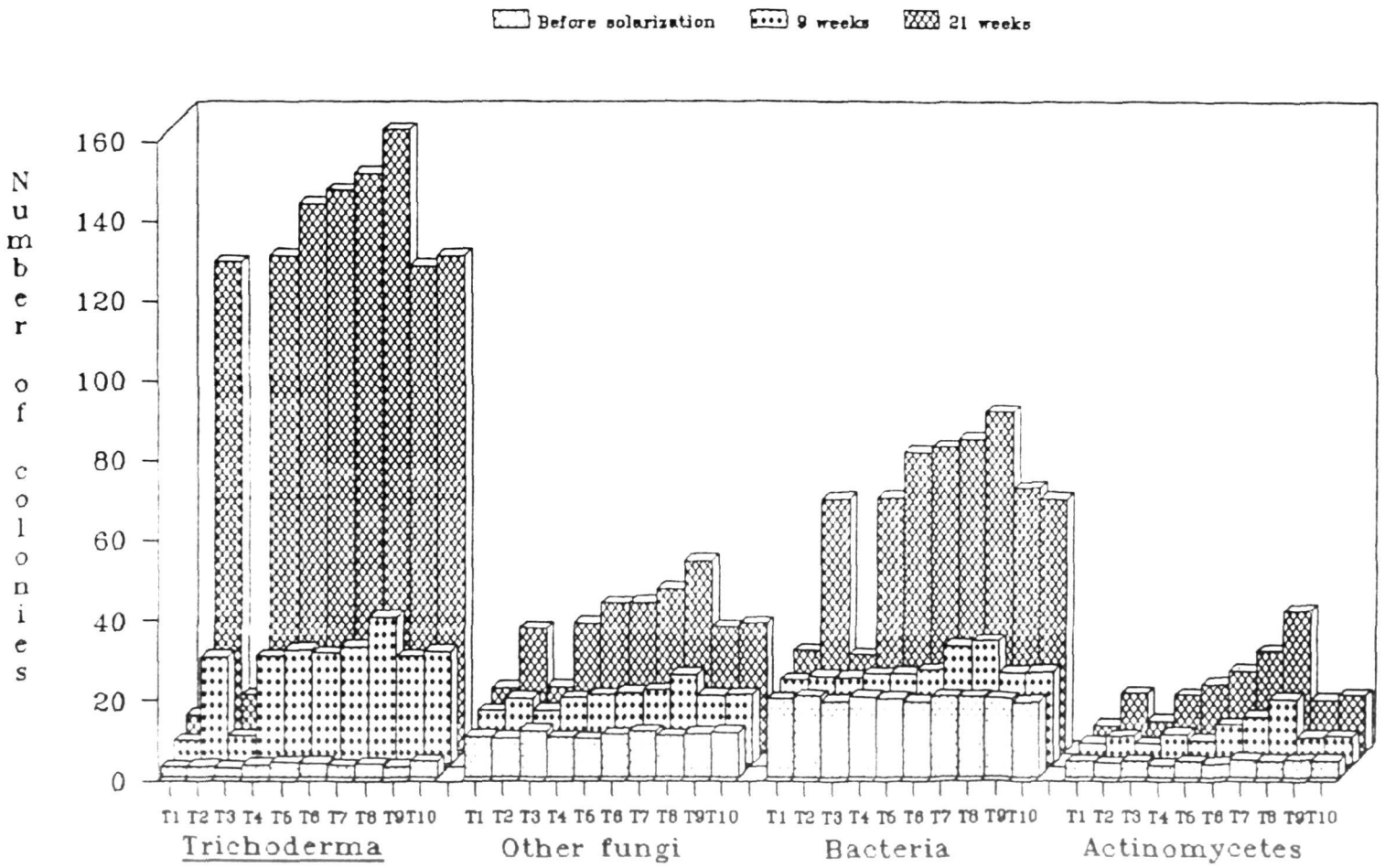


Fig. 9. Effect of soil solarization and other treatments on rhizosphere microflora, 1993

There was no significant difference among the treatments in the observation that recorded before solarization. After nine and twenty-one weeks of solarization the treatments differed significantly.

The treatment that received N+T+M+GM and the mulching with transparent polyethylene sheet + irrigation (T_8) recorded the maximum number of colonies, 16.44 x 10^3 and 35.00 x 10^3, after nine and twenty-one weeks of solarization respectively, which differed significantly from rest of the treatments. This was followed by the treatments where transparent polyethylene sheet (T_7) and mulching with black polyethylene sheet (T_6) during both the observations.

After nine weeks of solarization the minimum number of colonies were observed in the treatment that received application of garlic and mustard extract (T_3) (5.11 x 10^3), but after twenty-one weeks the minimum number of colonies were observed in control (T_1) (6.33 x 10^3).

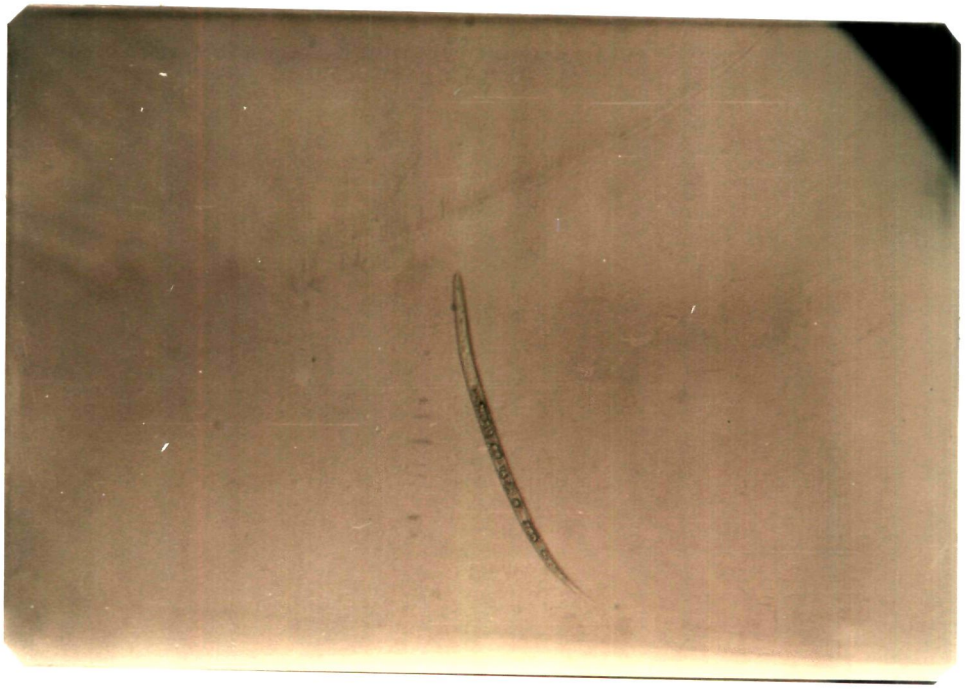
4.5 Plant parasitic nematodes associated with black pepper

Soil samples collected from the base of the pepper vines, was processed by Cobb's sieving and decanting technique and the results are presented in Table 16.

Table 16. Plant parasitic nematodes associated with black pepper in Uttara Kannada, 1993

Nematodes	Numbers per cc of soil	
	April (Out of 13 samples)	July (Out of 22 samples)
Aphelenchus sp.	0.04	0.16
Dorylaimids	0.20	0.20
Meloidogyne sp.	13.95	3.70
Rotylenchulus sp.	0.14	0.17
Tylenchus - like	0.01	0.11

Plate 7. Microphotograph showing the plant parasitic nematode, Meloidogyne sp. observed in the rhizosphere of black pepper vines.



Five genera of plant parasitic nematodes were found in the rhizosphere soils of black pepper. In the month of April, the numbers varied from 0.06 to 30.15 per cc of soil. Meloidogyne spp. was predominantly found (Plate 7), the maximum number of which was to the tune of 30.15 per cc of soil (average 13.95), followed by Dorylaimids (average 0.20) and Rotylenchulus spp. (average 0.14). In the month of July the nematode numbers varied from 0.06 to 8.66 per cc of soil. Maximum number of Meloidogyne spp. recorded was 8.66 per cc of soil (average 3.70) followed by Dorylaimids (average 0.20) and Rotylenchulus spp. (average 0.17). It was observed that the populations of Meloidogyne spp. was lower in July than April, but the populations of other genera increased from April to July. The lowest population was recorded in case of Tylenchus - like plant parasitic nematodes both during April and July months.

DISCUSSION

V. DISCUSSION

Black pepper, the world's most important spice, is one of the cash crops of Uttara Kannada. A major threat to the crop are the diseases, particularly "Foot rot" (Wilt) caused by Phytophthora capsici (P. palmivora MF_4) which has resulted in gradual disappearance of vines in the gardens. The epiphytotic of disease in this district in 1978 caused a heavy loss and from then onwards it has been on the increasing side (Sastry, 1982).

Several workers recommended various chemical, biological methods to control this disease. Integrating chemical (metalaxyl MZ), biological agent (Trichoderma spp.) and organic amendments like neem cake have been successfully used in managing this disease (Subramanyam, 1993). Soil solarization is a relatively new method of controlling soil-borne pathogens. Many soil-borne pathogens have been controlled by using soil solarization technique, but there are no reports with regard to its use in black pepper plantations. Since the pathogen P. capsici is sensitive to high temperature and solarization by mulching with polyethylene sheet increases the soil temperature, an attempt was made to find out the effect of soil solarization by using different mulches on

population of P. capsici and other rhizosphere microflora. An attempt has also been made to integrate soil solarization with neem cake, Trichoderma harzianum, metalaxyl MZ and garlic and mustard extract in managing the disease.

5.1 SYMPTOMATOLOGY

All the parts of the pepper vine are susceptible. The infection begins from runner shoots and spreads thereafter to the foliage and neighbouring vines. Root rot, collar rot, leaf rot and defoliation and spike infection occur singly or in different combinations. Major killing of vines during heavy monsoon (July - August) was mostly due to aerial infection. Wilting symptoms due to collar and root infection appeared at the end of rainy season. Delayed wilting may be due to abundant water supply early in the season which balanced the reduction in water supply owing to root decay and may also be due to uneven rains at the end of the season. Similar type of symptoms were also noticed by several workers (Nambiar and Sarma, 1977; Sastry, 1982 and Anandaraj et al., 1988).

5.2 ISOLATION

Isolation of P. capsici from the infected black pepper tissues was made on oat meal pimaracin-

vancomycin-pentachloronitrobenzene - Hymexazole (PVPH) medium (Tsao and Guy, 1977) successfully. The medium suppressed the growth of the Pythium and Fusarium spp. that usually contaminated the culture. P. capsici was also isolated from the soil collected from the root zone of wilted black pepper vines by castor seed baiting technique. Narasimhan and Ramakrishnan (1969) and Sastry (1982) also used this technique successfully to isolate P. capsici from wilt sick soil. The isolated P. capsici was found to resemble P. capsici isolate described by Sastry (1982).

5.3 SOIL SOLARIZATION

5.3.1 Effect on soil temperature

In both the years, the maximum temperature was observed in the treatment which received the mulching with transparent polyethylene sheet plus irrigation. The temperature increase over control in this treatment was 3.80°C and 3.67°C in 1992 and 1993 respectively. There was marginal increase in temperature in the treatments where black polyethylene sheets were used for mulching. The soil temperature was on par with control where dry grasses were used for mulching. Previously in several studies, typical maximal soil temperature observed in solarized plots increased by 8-12°C over the corresponding non-mulched plots (Katan,

1980). This much increase in soil temperature was not observed in the plantation because of low radiation that reaches the soil due to multistoryed cropping system followed. Soil solarization is a method of heating the surface soil by mulching with polyethylene sheets to trap solar radiation and thereby to increase the soil temperature. Since the solar radiation reaching the soil surface is comparatively low, the soil surface was heated up to increase the soil temperature to some extent. Dark soils absorb more radiation than light colored soils, this partly accounts for the higher maximum temperatures achieved in dark soils. Further, the soils are lateritic in the gardens and may have comparatively less heated than black soils.

In the present study, more increase in soil temperature was observed in transparent polyethylene sheet mulched on moist soil when compared to without irrigation. Further the increase in soil temperature is more in transparent polyethylene sheet mulching compared to black polyethylene sheet and dry grasses, because the thin transparent polyethylene sheet transmits most of the solar radiation that heats the soil and as a result of the formation of water droplets on the inner surface of the polyethylene

film, its transmitivity to long wave radiation is highly reduced resulting in better heating due to an increase in its greenhouse effect. Several studies (Waggoner et al., 1960 and Horowitz, 1980) have revealed that black polyethylene, although it is greatly heated by itself, is less efficient in heating the soil than transparent polyethylene (Katan, 1981), and the soil should be kept wet during mulching to increase thermal sensitivity) (Macfayden, 1967 and Katan et al., 1976). In the present study also, the results obtained are in confirmation of previous studies.

Soil mulching should be carried out during the period of high temperatures and intense solar radiation (Katan, 1981). In the present study soil mulching was done in summer only, but because of low sunshine that reaches the soil in the plantations which are situated in the western ghat valleys wherein multistoryed cropping system is in practice, the increase in soil temperature in solarized soils is not very high when compared to solarized soils in open fields. However, the thin transparent polyethylene sheets are more effective and are proportionally less expensive and even more effective if mulching is done on moist soil.

5.3.2 Effect on population of P.capsici and survival of pepper vines

In both years (1992 and 1993), mulching with transparent polyethylene sheet plus irrigation has resulted in more reduction in the population of P. capsici compared to others in all the observations. But this has not completely reduced the population of P. capsici and increased the survival of pepper vines. The reduction observed in the population of P. capsici, may be due to increase in soil temperature and also may be attributed to the increase in population of Trichoderma spp., which is antagonistic to P. capsici. Effective control of diseases where temperature in the solarized soils reached levels considered to be lethal to many fungi were reported (Baker and Cook, 1974; Katan et al., 1976; Elad et al., 1980 and Pullman et al., 1981). But in the present study, the maximum temperatures reached in solarized soils was 29.80°C and 29.60°C in 1992 and 1993 respectively, which may be responsible to suppress P. capsici.

Inoculum density is affected by solarization and an effective disease control is correlated with a corresponding reduction in inoculum density in solarized soils (Katan et al., 1976) and a definite relationship between the population of P. capsici in soil to the disease incidence were reported

(Sastry, 1982). In the present study, inoculum density in the solarized soils was reduced by soil solarization and increased the survival of vines and agrees with the earlier reports.

The other mulches used like black polyethylene sheet (with and without irrigation), transparent polyethylene sheet (without irrigation) and dry grasses were next best in reducing the population of P. capsici and increasing the survival of vines. The mulching with dry grasses has resulted in colonisation of baits on par with the control, which may be due to lower soil temperature and more soil moisture.

5.3.3 Effect on rhizosphere microflora (Trichoderma spp., other fungi, bacteria and actinomycetes)

Microbial activities occur in all agricultural soils and therefore a natural biological control, in various manners and to varying degrees apparently operates in those soils including the pathogen-infested ones. The microbial processes induced by solarization may contribute to disease control (in addition to the physical effect of heat), since the impacts of any lethal agent in the soil extend beyond the target organisms (Katan, 1981). High population of Trichoderma spp. observed in the solarized soils may be because of increased colonisation of the organism due to the warm temperature

created because of mulching with polyethylene sheets. The increased populations of the potential antagonist Trichoderma in solarized plots were reported (Elad et al., 1980). In the present study also, more number of colonies of Trichoderma spp. were observed in the solarized soils, particularly in transparent polyethylene sheet mulching with irrigation wherein the increase in soil temperature was more compared to other mulches.

Several studies have proved the potentiality of Trichoderma spp. as antagonistic to many soil-borne organisms including Phytophthora spp. (Weindling, 1932; Elad et al., 1980; Chet and Henis, 1985 and Subramanyam, 1993). Hence the reduction in the population of P. capsici observed in the solarized soils may also be attributed to increase in population of Trichoderma spp. But increase is not high enough to effectively control the disease in the solarized soils. However, the present study revealed that the population of Trichoderma spp. increased in solarized soils though to a small extent.

The study on the effect of soil solarization on other microflora like other fungi, bacteria and actinomycetes revealed that the population of the above organisms marginally

increased. Increased soil microbial counts of bacteria and actinomycetes at soil depth of 0-10 cm were reported except for fungi which were reduced at the 0-10 cm depth (Kaewruang et al., 1989). But in the present study soil solarization has no adverse effect on the microbial counts. This may be because as comparatively heat tolerant species of Aspergillus, Penicillium, Bacillus etc. were common.

5.4 INTEGRATED MANAGEMENT

The integrated management denotes the rational use of all available control measures such as chemical, biological and cultural methods, which may result in either synergistic or an additive effect. It offers the possibility of making up for the deficiencies of any single method.

Several workers integrated the chemical and biological agents (Trichoderma spp.) to control various diseases (Curl et al., 1976; Henis et al., 1978; Lewis and Papavizas, 1981; Chandra, 1984; Mukhopadhyay et al., 1986 and Mukhopadhyay and Chaturvedi, 1986). Soil solarization might be combined with biological, chemical (especially at reduced dosages) and cultural methods of control. However, combining with biological control agents is especially promising.

In the present study, soil solarization was combined with chemical (metalaxyl MZ), biological agent (T. harzianum), organic amendments (neem cake) and garlic and mustard extract in managing the disease.

The increase in temperature in transparent polyethylene sheet mulching was 3.73°C over the control reaching a maximum of 29.63°C, which may be responsible to suppress P. capsici combined with other treatments. As in the other soil temperature studies, the other mulches used like black polyethylene sheets with or without irrigation has resulted in marginal increase in soil temperature and the use of dry grasses with or without irrigation resulted in narrow increase in temperature over non-mulched ones. The reasons being similar as discussed earlier.

Application of 1 kg of neem cake plus one drenching and spraying of metalaxyl MZ , (@ 1.25 g/l) plus 150 g of cultures of T. harzianum plus garlic and mustard extract (@ 1 l/vine) combined with soil solarization by mulching with transparent polyethylene sheet plus irrigation has effectively reduced the population of P. capsici and controlled the disease. This has been more effective than the application of neem cake plus T. harzianum plus metalaxyl MZ as well than

the application of neem cake plus T. harzianum plus metalaxyl MZ plus garlic and mustard extract with or without solarization using mulches other than transparent polyethylene sheets. There has been a marginal decrease in the population of P. capsici in different mulches used like black polyethylene sheet and dry grasses. However, comparatively more reduction in population of P. capsici has been observed in transparent polyethylene mulching (dry) than black polyethylene and dry grass mulching. This may be attributed to the fact that the increase in soil temperature was more in mulching with transparent polyethylene sheet plus irrigation which has resulted in more increase in the population of Trichoderma spp. naturally available as well as introduced in the soil, which inturn has effectively reduced the population of P. capsici and increased the survival of pepper vines than solarization with other type of mulches and with non-solarized ones. It has already been discussed in the earlier para that the maximum soil temperature attained is more in the solarized soils mulched with transparent polyethylene sheet plus irrigation compared to other mulches, but this was not sufficient to completely suppress P. capsici to enhance the survival of vines and the population of Trichoderma spp. which increased must have reduced the population of P. capsici.

Application of neem cake (1 kg/vine) plus 150 g. of cultures of Trichoderma spp. (T. viride and T. harzianum) plus one application of metalaxyl MZ has effectively controlled the disease were reported (Subramanyam, 1993). It was found that for multiplication of Trichoderma spp. organic matter is needed and neem cake has indicated this potential effect and if sufficient time is allowed for decomposition the performance may be more effective. Hence the integration of neem cake plus Trichoderma spp. plus one application of metalaxyl MZ had the synergistic effect on the decrease in inoculum level of P. capsici in soil.

Soil solarization if combined with pesticides or biocontrol agents should improve disease control. Whenever a pathogen is weakened by heating a synergistic effect is expected so that reduced dosages might suffice for improved control. Combining with biocontrol agents might be especially effective in preventing reinfestation and in extending the effectiveness of disease control. Hence in the present study combining chemical, biological methods with soil solarization has resulted in synergistic effect in decreasing the inoculum level of P. capsici in soil and had an additive effect on disease control. The use of reduced dosages of chemicals will reduce the cost of control as well as pollution hazards. A

combination of the antagonist T. harzianum with solarization has been reported to delay Rhizoctonia solani inoculum buildup and improved disease control (Elad et al., 1980 and Chet et al., 1982). Also, solarization combined with chemical vapam has been reported to result in synergistic effect in controlling delimited shell spots of peanut pods (Frank et al., 1986).

The application of garlic and mustard extract is locally practiced in Sirsi area. The use of only garlic and mustard extract revealed that immediately after the application of the extract, the population of P. capsici was reduced to a greater extent. However, as the time passes, the population of P. capsici has increased, hence the disease control observed is less than in integrated treatments. This may be attributed that the extract might have been diluted due to heavy rainfall. This suggests that the application of the extract may be repeated two to three times in the season and at least once in a month will be more appropriate and this needs further study.

5.4.1 Effect of different treatments on rhizosphere microflora (Trichoderma spp., other fungi, bacteria and actinomycetes)

High population of Trichoderma spp. was observed in the treatments that received the inoculum of Trichoderma sp.

This suggests that when the Trichoderma spp. was introduced along with food base (wheat bran + saw dust + water medium), it multiplied well in the rhizosphere. Sivan et al., (1984) also observed a better survival of Trichoderma spp. when it was multiplied on wheat bran + peat and introduced into the soil. Among the treatments that received Trichoderma spp., the highest population was observed in the treatment where it was integrated with neem cake plus one application of metalaxyl MZ plus garlic and mustard extract and mulching with transparent polyethylene sheet plus irrigation compared to other mulches and to other treatments which did not receive solarization. This may be due to the fact that, as already discussed, the increased soil temperature due to transparent polyethylene sheet mulched on moist soil has resulted in more population of Trichoderma spp. compared to non-mulched ones and other mulches. Further Trichoderma spp. might possess inherent tolerant capacity to metalaxyl MZ which is not having adverse effect on it but has stimulatory action on native Trichoderma spp. (Subramnyam, 1993). Papavizas (1981) also observed the better survival and multiplication of T. harzianum in the rhizosphere when pea seeds were treated with metalaxyl MZ. Subramanyam (1993) observed that the neem cake alone did not support well the multiplication of Trichoderma

spp., but it increased when both neem cake and cultures of Trichoderma were added to the soil and when integrated with one application of metalaxyl MZ. This is attributed to the reason that besides encouraging the multiplication of Trichoderma spp., the neem cake also encouraged multiplication of other soil microflora. Further it is reported that the Trichoderma spp.added to the soil, although survived and multiplied well in the soil, it was unable to reduce the population of P. capsici and control the disease effectively (Subramanyam, 1993). The effective reduction in the population of P. capsici and satisfactory control of the disease by use of neem cake + T. harzianum + metalaxyl MZ + garlic and mustard extract and solarization with thin transparent polyethylene sheet plus irrigation, can be attributed that the mycelium of P. capsici might be weakened by metalaxyl MZ and rendered it more susceptible to destruction and displacement by Trichoderma spp. and also that the increase in soil temperature resulted in more increase in population of Trichoderma spp., and use of garlic and mustard extract might be detrimental to P. capsici. The concept that pathogens are less resistant to heat than many saprophytes and antagonists including Trichoderma spp. and Bacillus subtilis has been reported (Warcup, 1957; Olsen and Baker, 1968; Baker

and Cook, 1974; Munnecke et al., 1976 and Hoitnik, 1980). The net increase in the population of other fungi, bacteria and actinomycetes have also contributed in effective control of the disease.

In the present study, more population of other fungi, bacteria and actinomycetes was observed where neem cake, T. harzianum, metalaxyl MZ, garlic and mustard extract integrated with solarization, especially under irrigation was given. It was observed in the other experiment that soil solarization has no adverse effect on population of other fungi, bacteria and actinomycetes under such conditions. Hence the increase in the population might be due to use of neem cake which might have supported their multiplication in the soil including thermophilic ones. Dutta (1984) observed a high increase in population of other fungi, bacteria and actinomycetes when cotton seed meal and groundnut cakes were used as amendments. Subramanyam (1993) also observed more population in neem cake amended soils as well as a substantial increase in the population was observed when neem cake was integrated with Trichoderma spp. and metalaxyl MZ. The results observed in the preset study confirmed previous study. There was no increase in the population wherein garlic and mustard extract alone was used. The net increase in the

population of other fungi, bacteria and actinomycetes and a high increase in population of Trichoderma spp. might have suppressed the population of P. capsici and increased the survivability of pepper vines.

From the studies on integrated management of black pepper foot rot (wilt), it may be concluded that application of 1 kg of neem cake in the month of February + application of Trichoderma spp. in the month of March + application of metalaxyl MZ both soil drenching and spraying one week after the onset of monsoon + application of garlic and mustard extract in June first week and mulching with thin transparent polyethylene sheet in summer on moist soil will increase the soil temperature and enable the multiplication and buildup of Trichoderma spp. and other antagonistic organisms which will help in bringing down the population of P. capsici in the soil to a greater extent and control the disease effectively. However, multilocation testing of this technology may be undertaken before it is recommended.

5.5 PLANT PARASITIC NEMATODES ASSOCIATED WITH BLACK PEPPER

It has been observed from the study that a high population of plant parasitic nematodes are associated with black pepper. Among them, root knot nematodes are

predominantly found. As early as 1906, Butler reported root knot infestation on black pepper and later nematodes belonging to 17 genera were reported in Kerala and Karnataka (Sundararaju et al., 1979b). Among these Meloidogyne incognita, Radopholus similis and Helicotylenchus spp. are most commonly reported (Ramana and Mohandas, 1983). In the present study a high population of Meloidogyne sp. was found but R. similis and Helicotylenchus sp. were not observed. It has been reported that the nematode species Meloidogyne and Radopholus affect the growth and productivity of vines since most of the fibrous roots were lost leaving only few thick main roots (Mohandas and Ramana, 1991).

The high population of plant parasitic nematodes, particularly Meloidogyne sp. found in the rhizosphere of black pepper vine reveal that the damage caused to the root system by the nematodes might help the P. capsici to enter the roots easily through injuries or because of loss of fibrous roots due to infestation by the nematodes might render the pepper vine to become susceptible to the infection by P. capsici. It suggests that a more detailed study regarding association of plant parasitic nematodes with black pepper and their role in foot rot disease needs to be undertaken.

A more detailed study has to be carried out to find out wheather any interaction effect is existing between nematodes and P. capsici and the role of nematodes in causing the disease and efforts are to be made to include nematicides like phorate combinations that can keep the nematode population under check in the integrated management programme of foot rot of black pepper.

SUMMARY

VI. SUMMARY

There is evidence that soil solarization can suppress many soil borne pathogens in the field. This new technique is more useful if the pathogen is heat sensitive. The Phytophthora capsici which causes foot rot of black pepper is sensitive to high temperature and soil solarization by means of mulching the soil with polyethylene sheet may help in the integrated management of foot rot.

The present investigation include: to study the effect of soil solarization alone in reducing the population of P capsici and control the disease and integrating soil solarization with chemical (metalaxyl MZ), organic amendment (neem cake), biological agent (Trichoderma harzianum) and garlic-mustard extract in management of the disease.

The foot rot of black pepper comprises of mainly two types of infection: (i) foliar infection leading to leaf, twig and stem rot and defoliation and (ii) collar rot or foot rot infection expressed as foliar yellowing, flaccidity, defoliation, breaking up of the stem at the nodal region and finally the wilting and death of the vines.

Successful isolation of P. capsici was obtained from the infected tissues on oatmeal PVPH medium. Also the isolation of the same was obtained from the soil by castor seed baiting technique. The culture was preserved in refrigerator at 5°C for further study and subcultured once in a month.

Out of the different mulches used transparent polyethylene sheet mulched on the moist soil was the best and temperature increase was from 26.00°C to 29.80°C over the control and the suppression of P. capsici was from 87.56 to 50.00 per cent and thus increased the survival of pepper vines from 11.11 to 55.55 per cent during 1992. In 1993, the temperature increased from 25.93 °C to 29.60 °C and population of P. capsici was suppressed from 85.33 to 48.00 per cent and survival of pepper vines increased from 11.11 to 44.44 per cent.

The population of Trichoderma spp., other fungi, bacteria and actinomycetes were also increased in the solarized soils mulched with transparent polyethylene sheet on the moist soil over the control.

In the integrated disease management study, solarization with mulching by transparent polyethylene sheet

on the moist soil has resulted in an increase of soil temperature by 3.73°C over the control from 25.90°C to 29.63°C . In the same treatment, 71.30 per cent reduction in the population of P. capsici was observed and the survival of pepper vines increased from 11.11. to 88.89 per cent.

The population of Trichoderma spp. was increased from 8.89 x 10^3 to 155.55 x 10^3 number of colonies in the treatment where neem cake, T. harzianum, metalaxyl MZ and garlic-mustard extract were applied and mulched with transparent polyethylene sheet on the moist soil. Similarly the number of colonies of other fungi (from 15.55 x 10^3 to 47.33 x 10^3), bacteria (from 25.00 x 10^4 to 85.00 x 10^4) and actinomycetes (from 6.33 x 10^3 to 35.00 x 10^3) was also increased and resulted in effective control of the disease.

Five genera of the plant parasitic nematodes were found to be associated with the black pepper. The number of nematodes varied from 0.06 to 30.15 per cc of soil. Out of these a high population of Meloidogyne sp. was observed and its number varied from 0.97 to 30.15 per cc of soil.

Future line of work

A detailed study has to be carried out regarding the role of plant parasitic nematodes in causing the disease.

Further, study has to be undertaken to include nematicides to check nematode population and its effect on other beneficial organisms is also to be studied. The soil solarization practice may be undertaken in different locations before it is recommended.

REFERENCES

VII. REFERENCES

ABD-EL MOITY, T.H., PAPAVIZAS, G.C. AND SHATLA, M.N., 1982, Introduction of new isolates of Trichoderma harzianum tolerant to fungicides and their experimental use for control of white rot of onion. Phytopathology, 72: 396-400.

AHMED, N. AND AHMED, Q.A., 1964, Selection of antagonistic soil microbe against a few fungal pathogens of Piper betle. Mycopathologia., 21: 334-340.

*Al-RADDAD, A.M.M., 1979, Soil disinfection by plastic tarping. M.Sc. Thesis. University of Jordan. pp.95.

ANANDARAJ, M., RAMACHANDRAN, N. AND SARMA, Y.R., 1988, Epidemiology of foot rot disease of black pepper (Piper nigrum L.) in India. Proceedings of International Workshop on Wilt Diseases of Black pepper held on 27-29 December, 1988 at Panaji, Goa, India.

ANANDARAJ AND SARMA, Y.R., 1990, A simple baiting technique to detect and isolate Phytophthora capsici (P.

palmivora, MF_4) from soil. Mycological Research, 94(7): 1003-1004.

ANONYMOUS, 1986, Central Plantation Crops Research Institute. Annual Report for 1986, Kasargod, Kerala.

ARK, P.A. AND HUNT, M.L., 1941, Saprophytes antagonistic to phytopathogenic and other microorganisms. Science N.S., 93: 354-355.

ASHWORTH, L.J., Jr. AND GAONA, S.A., 1982, Evaluation of clear polyethylene mulch for controlling Verticillium wilt in established pistachio nut groves. Phytopathology, 72: 243-246.

*ASHWORTH, L.J., Jr., MORGAN, D.P., GAONA, S.A. AND McCAIN, A.H., 1983, Control of Verticillium wilt of pistachio. Plasticulture, 58: 33-44.

ASTHANA, R.P., 1947, The role of cuttings in the dissemination of foot rot of Piper betle. Indian J. Agric. Sci., 17: 223-225.

*ATAC, A., 1979, In vitro and in vivo investigations on the antagonism of Aspergillus flavus Link. and Penicillium sp. against Phytophthora capsici Leon. J. of Turkish Phytopath., 8(1): 41-46.

AYYAR, P.N.K., 1926, A preliminary note on the root gall nematode, Heterodera radicicola and its economic importance in South India. Madras Agric. J., 14: 113-118.

BAKER, R., 1968, Mechanisms of biological control of soilborne pathogens. Ann. Rey. Phytopathol., 6: 263-294.

BAKER, K.F. AND COOK, R.J., 1974, Biological control of plant pathogens. W.H. Freeman, San Fransisco, pp.443.

*BARBER, C.A., 1902, Ann. Rep. for 1901-1902. Dep. Agric., Madras.

*BARBER, C.A., 1903, Pepper diseases in the Wynad. Trop. Agric. (Colombo), 22: 206.

*BARBER, C.A., 1905, The Government pepper farm in Malabar. Trop. Agric. (Colombo), 25: 564.

BARBERCHECK, M.E. AND BROEMBSEN, S.C., 1987, Effects of soil solarization on plant parasitic nematodes and Phytophthora cinnamomi in South Africa. Plant Dis., 70(10): 945-950.

BENSON, D.M., 1979, Efficacy and in vitro activity of two systemic acylalanines and ethazole for control of

Phytophthora cinnamomi root rot of Azalea. Phytopathology., 69: 174-178.

BOOSALIS, M.G., 1964, Hyperparasitism. Ann. Rev. Phytopathol., 2: 363-376.

*BRIGHTON, C.A., 1972, Degradation and disposability of plastic. Fifth International Colloquium on Plastic in Agriculture, Budapest, June, 1972, 1: 203-208.

BUTLER, E.J., 1906, The wilt disease of pigeonpea and pepper. Agric. J. India, 1: 25-26.

BUTLER, E.J., 1918, Fungi and diseases in plants. 598 pp. Thacker and Spink, Calcutta.

*BYRDSON, J.A., 1970, Plastic materials. London: Iliffe Books. 597 pp. 2nd ed.

*CHANDRA, I., 1984, Studies on Damping-off of sugarbeet caused by Pythium aphanidermatum (Edson) Fitz. Ph.D. Thesis, G.B. Pant University of Agriculture and Technology, Pantnagar, India, 131.

CHAUHAN, Y.S., NENE, Y.L., JOHANSEN, C., HAWARE, M.P., SAXENA, N.P., SARDARSING AND SHARMA, S.B., 1988, Effects of

soil solarization on pigeon pea and chickpea ICRISAT. Res. Bull., 11.

*CHAURASIA, S.C., 1976, Studies on the foot rot and leaf rot disease of pan (Piper betle L.) with special reference to pathogenesis and control measures. Ph.D. Thesis, University of Saugar, M.P., India.

CHET, I., 1987, Trichoderma - application mode of action and potential as a biocontrol agent of soil-borne plant pathogenic fungi, In Innovative Approaches to Plant Disease Control, Edited by Ilan Chet. A Wiley - Interscience Publication. 1987, pp. 137-160.

*CHET, I., ELAD, Y., KALFON A., HADAR, Y. AND KATAN, J., 1982, Integrated control of soilborne and bulborne pathogens in iris. Phytoparasitica, 10: 229-236.

*CHET, I. AND HENIS, Y., 1985, Trichoderma as a biocontrol agent against soilborne root pathogens. Proceedings of the 4th International Congress of Plant Pathology, Melbourne, Australia.

COHEN, Y., REUVERI, M. AND EYAL, H., 1979, The systemic antifungal activity of Ridomil against Phytophthora

infestans on tomato plants. Phytopathology, 69: 645-649.

COOK, R.J., 1977, Management of the associated microbiota. Plant Disease: An Advance Treatise: IED. J.G. Horsfall, E.B. Cowling. New York. Academic Press, 465 pp.

CURL, E.A., WIGGIND, E.A. AND ANDERS, S.C., 1976, Interaction of Rhizoctonia solani and Trichoderma with PCNB and herbicides affecting cotton seedlings diseases. Proc. Ann. Phytopathol. Soc., 3: 221.

DASTUR, J.F., 1927, A short note on the foot rot disease of pan in central provinces. Agric. J. India, 22: 105-108.

DASTUR, J.F., 1935, Diseases of pan (Piper betle) in the central provinces, Proc. Indian Acad. Sci. Sect. B., 1: 778-815.

dE WAARD, P.W.F., 1979, Evaluation of the results of research on eradication of Phytophthora foot rot of black peppr (Piper nigrum L.) pp. 1-47. Circulated during the first meeting of the pepper community

permanent panel on Techno Economic Studies - 31 January - 4 February, 1979, Cochin, India.

DENNIS, C. AND WEBSTER, J., 1971, Antagonistic properties of species - groups of Trichoderma. Trans Br. Mycol. Soc., 57: 363-369.

DESHPANDE, A.L. AND TIWARI, R.K.S., 1991, Effect of solarization on sclerotia of Sclerotium rolfsii causing collar rot in betelvine. Indian Phytopath., 44(3): 353-355.

D'SOUZA, G.I., KUMAR, A.C., VISWANATHAN, P.R.K. AND SHAMANNA, H.V., 1970, Relative distribution and prevalence of plant parasitic nematodes in coffee tracts of South Western India. Indian Coffee, 34: 329-330 and 342.

DUFF, J.D. AND BARNAART, A., 1992, Solarization controls soilborne fungal pathogens in nursery potting mixes. Australian Plant Pathology, 21(1): 20-23.

DUNCUN, J.M., 1976, The use of bait plants to detect Phytophthora fragariae in soil. Trasn. Br. Mycol. Soc., 66: 85-89.

DUTTA, P.K., 1984, Studies on two Phytophthora diseases (Koleroga of arecanut and black pepper wilt) in

Shimoga district, Karnataka State. Ph.D. Thesis, Univ. Agric. Sci., Bangalore, Karntaka State.

DWIVEDI, R.S. AND DUBEY, R.C., 1987, Effect of soil solarization on the population dynamics of Macrophomina phaseolina (Tassi) Goid. and general soil microflora. Int. J. Tropical Plant Diseases, 5: 67-73.

ECKERT, J.W. AND TSAO, P.H., 1960, A preliminary report on the use of Pimaricin to the isolation of Phytophthora spp. from root tissues. Pl. Dis. Reptr., 44: 660-661.

EDGINGTON, L.V., MARTIN, R.A., BRVIN, G.C. AND PARSONS, I.M., 1980, Systemic fungicides - A perspective after 10 years Pl. Dis. Reptr., 64: 19-23.

ELAD, Y., CHET, I. AND KATAN, J., 1980, Trichoderma harzianum: A biological agent effective against Sclerotium rolfsii and Rhizoctonia solani. Phytopathology, 70: 119-121.

*ELAD, Y., CHET, I. AND HENIS, Y., 1981, A selective medium for improving quantitative isolation of Trichoderma spp. from soil. Phytoparasitica, 9: 59-67.

EL GOORANI, M.A., FARAG, S.A. AND SHEHATA, M.R.A., 1976, The effect of Bacillus subtilis and Penicillium platulum on in vitro growth and pathogenicity of Rhizoctonia solani and Phytophthora cryptogea. Phytopathology, 66: 345-352.

FLOWERS, R.A. AND HENDRIX, J.W., 1969, Gallic acid in a procedure for isolation of Phytophthora parasitica var. nicotianae and Pythium spp. from soil. Phytopathology, 59: 725-731.

FLOWERS, R.A. AND HENDRICX, J.W., 1972, Population density of Phytophthora parasitica var. nicotianae in relation to pathogenesis and season. Phytopathology, 62: 474-477.

*FRANK, Z.R., BEN YEPHET, Y. AND KATAN, J., 1986, Synergistic effect of metham and solarization in controlling delimited shell spots of peanut pods. Crop Prot.

*FUJISAWA, Y. AND MASAGO, H., 1975, Investigations on the selective medium for the isolation of Phytophthora spp. Ann. Phytopath. Soc. Japan., 41: 267.

GARIBALDI, A. AND TAMMIETTI, G., 1989, Solar heating: Recent results obtained in Northern Italy. Acta Horticulture (1989), 255: 125-130.

GERRETTSON - CORNELL, L., 1977, Difference in reaction to an antagonist in cultures of Phytophthora cinnamomi. APPS. Newsletter, 6: 6-7.

GREENBERGER, A., YOGEV, A. AND KATAN, J., 1985, Induced suppressiveness in solarized soils. Phytopathology, 75: 1291 (Abstr.).

*GREGORY, L.E., ALMEYDA, N. AND THEIS, T., 1960, The black pepper research programmes in Puerto Rico. Proc. Amer. Soc. Hort. Sci., 4: 64-65.

GRINSTEIN, A., ORION, D., GREENBERGER, A. AND KATAN, J., 1979, Solar heating of the soil for the control of Verticillium dahliae and Pratylenchus thornei in potatoes. In Soilborne Plant Pathogens (B. Schippers and W. Gams. eds.). Academic, New York. pp. 431-438.

HEGDE, A.N., 1983, Studies on wilt of black pepper (Piper nigrum L.) caused by Phytphthora palmivora (Butler) Butler. M.Sc. Thesis, Univ. Agric. Sci., Bangalore, Karnataka State.

HENIS, Y., GHAFFAR, A. AND BAKER, R., 1978, Integrated control of Rhizoctonia solani damping off of radish: Effect

of successive planting, PCNB and Trichoderma on pathogen and disease. Phytopathology, 68: 900.

HOITNIK, H.A.J., 1980, Compostd bark, a light weight growth medium with fungicidal properties. Plant Dis., 64: 85-111.

HOLLIDAY, P., 1965, A wilt of Piper nigrum L. in Brazil. Commonwealth Phytopath. News, 5: 4.

HOLLIDAY, P. AND MOWAT, W.P., 1963, Foot rot of Piper nigrum L. (Phytophtopra palmivora). Phytopath. Paper No. 5, 62 pp. Commonwealth Mycol. Inst. Kew, Surrey, England.

*HOROUCHI, S., 1984, Soil solarization for suppressing soilborne diseases in Japan. FFTC Book Series No. 26, Soilborne Crop Diseases in Asia. Food and Fertilizer Technology Center, Taiwan, ROC, pp.11-23.

HOROWITZ, M., 1980, Weed research in Isreal. Weed Sci., 28: 457-460.

*HOROWITZ, M. AND REGEV, Y., 1980, Mulching with plastic sheet as a method of weed control. Hassadeh, 60: 395-399 (In Hebrew).

JACOB, A. AND KURIEN, J., 1979, Survey of nematodes associated with pepper in Kerala. Agric. Res. J. Kerala., 17: 270-271.

JACOBSOHN, R., GREENBERGER, A., KATAN, J., LEVI, M. AND ALON, H., 1980, Control of Egyptian broomrape (Orobanche aegyptiaca) and other weeds by means of solar heating of the soil by polyethylene mulching. Weed. Sci., 28: 312-316.

JUAREZ-PALACOIS, C., FELIX-GASTELUM, R., WAKEMAN, R.J., PAPLOMATAS, E.J. AND DEVAY, J.E., 1991, Thermal sensitivity of three species of Phytophthora and the effect of soil solarization on their survival. Plant Dis., 75(11): 1160-1164.

KAEWRUANG, W., SIVASITHAMPARAM, K. AND HARDY, G.E., 1989, Use of soil solarization to control root rots in gerberas (Gerbara jamesonii). Biol. Fertil. Soils, 8: 38-47.

KATAN, J., 1980, Solar pasteurization of soils for disease control: Status and prospects. Plant Dis., 64: 450-454.

KATAN, J., 1981, Solar heating (Solarization) of soil for control of soilborne pests. Ann. Rev. Phytopathol., 19: 211-236.

KATAN, J., 1987, Soil solarization. In: Innovative Approaches to Plant Disease Control. Edited by I. Chet. pp. 77-105. A Wiley - Interscience Publication, 1987.

KATAN, J., GREENBERGER, A., ALON, H. AND GRINSTEIN, A., 1976, Solar heating by polyethylene mulching for the control of diseases caused by soilborne pathogens. Phytopathology, 76: 683-688.

KATAN, J., ROTEM, I., FINKEL, Y. AND DANIEL, J., 1980, Solar heating of the soil for the control of pink root and other soilborne diseases in onions. Phytoparasitica, 8: 39-50.

KATAN, J., FISHLER, G. AND GRINSTEIN, A., 1983, Short-and long-term effects of soil solarization and crop sequence on Fusarium wilt and yield of cotton in Israel. Phytopathology, 73: 1215-1219.

KNAUSS, J.F., 1976, In vitro anatagonistic activity of several Streptomyces spp. against species of Pythium and Phytophthora. Pl. Dis. Reptr., 60: 846-850.

* KODAMA, T., FUKAI, T. AND MATSUMOTO, Y., 1980, Solar heating sterilization in the closed vinyl houses against soilborne diseases. III. Influence of the treatment on the population level of soil microflora and the behaviour of strawberry yellows pathogen, Fusarium oxysporum f.sp. fragariae. Bull. Nara Pref. Agric Exp. Sta., 11: 41-52.

KOSHY, P.K. AND SOSAMMA, V.K., 1975, Host range of Radopholus similis (Cobb, 1893) Thorne, 1949. Indian J. Nematol., 5: 255-257.

KRSTIC, M., 1954, Note on the inhibitory activity of some microorganisms against Phytophthora cinnamomi. Pl. Dis. Reptr., 38: 879-881.

* KUHLMAN, E.G. AND HENDRIX, F.F., 1965, Direct recovery of P. cinnamomi from field soil. Phytopathology, 55: 500 (Abstr.).

KUMAR, A.C., VISWANATHAN, P.R.K. AND D'SOUZA, G.I., 1971, A study of plant parasitic nematodes of certain commercial crops in coffee tracts of South India. Indian coffee., 35: 222-224.

*KUSARKARI, S. AND VEYAMA, A., 1975, Effect of lytic actinomycetes to several soil-borne pathogenic fungi. Trans. Mycol. Soc., Japan, 16: 63-68.

LEATHER, R.I., 1967, The occurrence of a phytophthora root and leaf disease of black pepper in Jamaica. F.A.O. Pl. Prot. Bull., 15: 15-16.

*LEEFMANS, F., 1934, Diseases and pests of cultivated crops with Dutch East Indies, 1931, Meded. Inst. Voor. Pl. Ziekten, 82: 92 pp.

*LENZNER, H., 1964, Untersechungen Zur Wirkung Organischer Dunger auf Phytophthora cactorum (leb. et cotin.) Schroet and die Mikroflora des Podens unter Beruckaichtigung antibiotischer Substanzen. Garten bauwissens Chaft, 29! 347-390.

LEWIS, J.A. AND PAPAVIZAS, G.C., 1981, Biological control in crop production, Papavizas, G.C. Ed. Hanheld Osrnum Publishers, Granada, 461.

LODHA, S., 1989, Soil solarization for the control of Macrophomina phaseolina in arid soils. Indian Phytopathol., 42: 170-171.

*MACFAYDEN, A., 1967, Thermal energy as a factor in the biology of soils. In Thermobiology, ed. A.H. Rose. pp. 535-553. London and New York: Academic. 653pp.

*MACIE JOWSKA, A. AND WILLIAMS, E.B., 1961, The isolation and identification of soil fungi and their relation to root rot of apple. Proc. Ind. Acad. Sci., 70: 52-53 (Abstr.).

*MAGDON, E., 1955, Uber die Keltur der Phytophthora infestans (Monts) de Bary ouf junstlichem Nahrbodan und uber Antibiouten des Pizes. Zbl. Bakt. Abt., 2: 703-716.

MALAJCZUK, N., NESBITT, H.J. AND GLENN. A.R., 1977, A light and electron microscope study of the interaction of soil bacteria with Phytophthora cinnamomi Rands. Can. J. Microbiol., 23: 1518-1525.

MASAGO, H., YOSHIKAWA, M. FUKADA, M. AND NAKANISHI, N., 1977, Selective inhibition of Pythium spp. on a medium for direct isolation of Phytophthora spp. from soils and plants. Phytopathology, 67: 425-428.

MCINTOSH, D.L., 1972, Effects of soil-water suction, soil temperature, carbon and nitrogen amendments and

host root-lets on survival in soil of zoospores of Phytophthora cactorum. Can. J. Bot., 50: 269-272.

*MEHRER, Y., 1979, Prediction of soil temperature of a soil mulched with transparent polyethylene. J. Appl. Meteorol., 18: 1263-1267.

MEHROTRA, R.S. AND TIWARI, D.P., 1976, Organic amendments and control of foot rot of Piper betle caused by Phytophthora parasitica var. piperina. Ann. Microbiol. (Inst. Posteur), 127:A: 415-421.

MENON, K.K., 1949, Survey of pollu (Hollow berry disease) and root diseases of pepper. Indian J. Agric. Sci., 119: 89-136.

MIHAIL, J.D. AND ALCORN, S.M., 1984, Effects: soil soloarization on Macrophomina phaseolina and Sclerotium rolfsii. Plant dis., 68: 156-159.

*MILLER, R.W.R., 1953, Ann. Rep. Dep. Agric. Sarawak for 1952. Pl.

MITCHELL, D.J., 1978, Relationship of inoculum levels of several soil-borne species of Phytophthora and Pythium to infection of several hosts. Phytopathology, 68: 1754-1759.

MOHANDAS, C. AND RAMANA, K.V., 1991, Pathogenicity of Meloidogyne incognita and Radopholus similis on black pepper (Piper nigrum L.). J. Plant. Crops, 19(1): 41-53.

MUKHOPADHYAY, A.N., 1987, Biological control of soilborne plant pathogens by Trichoderma spp. Indian J. Mycol. and Plant Pathol., 17: 1-10.

MUKHOPADHYAY, A.N. AND CHATURVEDI, C., 1986, Biological control of damping off by Trichoderma harzianum. In Proc. Annum. Meet. Soc. Mycol. Plant Pathol., Coimbatore, India.

MUKHOPADHYAY, A.N., PATEL, G.J. AND BRAHMABHAT, A.B., 1986, Trichoderma harzianum - a potential biocontrol agent for damping off. Tob. Res., 12: 26.

MULLER, H.R.A., 1936, The phytophthora foot rot of pepper in Dutch East Indies (Dutch). Meded Inst. Plzukt, Batavia, No. 88, 73p. Rev. appl. Mycol., 16: 559-560.

MUNNECKE, D.E., WILBUR, W. AND DARLEY, E.F., 1976, Effect of heating or drying on Armillaria mellae or

Trichoderma viride and the relation to survival of A. mellea in soil. Phytopathology, 66: 1363-1368.

NAMBIAR, K.K.N. AND SARMA, Y.R., 1977, Wilt diseases of black pepper. J. Plant Crops, 5(2): 92-103.

NARASIMHAN, V. AND RAMAKRISHNAN, K., 1969, Studies on wilt disease of betelvine. Madras Agric. J., 56: 68-73.

NARASIMHAN, V., VENKATA RAO, A., SUBRAMANIAN, K.S. AND VIDYASEKHARAN, P., 1976, Fungicidal control of betelvine wilt. Pesticides, 10: 34-35.

*NAOT, O., 1984, The effect of transparent polyethylene mulches on soil moisture and temperature regimes in solar heating: numerical and experimental studies. M.Sc. Thesis, The Hebrew University of Jerusalem, pp. 67.

*NEWMAN, C.L., 1941, Ann. Rep. Dep. Agric., Sarawak, for 1940.

*OKAISABOR, E.K., 1971, The mechanism of initiation of pod rot epiphytotics. Proceedings 3rd International Cocoa Conference, Accra, Ghana. 1969: 398-404.

OLSEN, C.M. AND BAKER, F.K., 1968, Selective heat treatment of soil and its effect on the inhibition of

Rhizoctonia solani by Bacillus subtilis. Phytopathology, 58: 79-87.

ONESIROSAN, P.T., 1971, The survival of Phytophthora palmivora in a cocao plantation during the dry season. Phytopathology, 61: 975-977.

PAPAVIZAS, G.C., 1973, Status of applied biological control of soil-borne plant pathogens. Soil Biol. Biochem., 5: 709.

PAPAVIZAS, G.C., 1981, Survival of Trichoderma harzianum in soil and in pea and bean rhizospheres. Phytopathology, 71: 121-125.

PAPAVIZAS, G.C. AND LUMSDEN, R.D., 1980, Biological control of soilborne fungal propagules. Ann. Rev. Phytopathol., 18: 389-413.

PAPAVIZAS, G.C. AND LUMSDEN, R.D., 1982, Improved medium for isolation of Trichoderma spp. from soil. Plant Dis., 66: 1019-1020.

PARAMJIT SINGH, 1991, An overview of black pepper production in India. Ministry of Agril. Departments (A and C) Krishi Bhavan, New Delhi. Indian Cocoa. Arecanut and Species J., 15(1): 2-4.

*PETRI, L., 1927, Un batterie parassita di alcane Phytophthoreae. Boll. Staz. Pat. Veg. N.S., 7: 457-464.

PINKAS, Y., KARIV, A. AND KATAN, J., 1984, Soil solarization for the control of Phytophthora cinnamomi : thermal and biological effects. Phytopathology, 74: 796 (Abstr.).

PULLMAN, G.C., DEVAY, J.E., GARBER, R.H. AND WEINHOLD, A.R., 1979, Control of soilborne pathogens by plastic tarping of soil. In Soilborne Plant Pathogens, pp. 439-446. ed. B. Schippers and W. Gams, London, New York, San Francisco : Academic. 686 pp.

PULLMAN, G.S., DEVAY, J.E., GARBER, R.H. AND WEINHOLD, A.R., 1981, Soil solarization: Effects on Verticillium wilt of cotton and soilborne populations of Verticillium dahliae. Pythium spp., Rhizoctonia solani and Thielaviopsis basicola. phytopathology, 71: 954-959.

RAMACHANDRAN, N., SARMA, Y.R. AND NAMBIAR, K.K.N., 1982, Effect of two systemic fungicides, Aliette and Ridomil on Phytophthora palmivora isolate of Piper

nigrum. In: Proc. of the workshop on Phytophthora diseases of tropical cultivated plants, 19-23 September, 1980, pp. 248-251. (Ed. K.K.N. Nambiar) Central Plantation Crops Research Institute, Kasargod and Calicut. Kerala, India.

RAMACHANDRAN, N. AND SARMA, Y.R., 1985a, Efficacy of three systemic fungicides in controlling Phytophthora infection of black pepper. Indian Phytopath., 38: 160-162.

RAMACHANDRAN, N. AND SARMA, Y.R., 1985b, Uptake and persistence of metalaxyl in black pepper (Piper nigrum L.). J. Plant. Crops, 13(1): 38-40.

RAMACHANDRAN, N., SARMA, Y.R. AND ANANDARAJ, M., 1988, Management of Phytophthora infections in black pepper. Proceedings of International workshop on wilt diseases of black pepper, held from 27-29, December, 1988, at Panaji, Goa, India.

*RAMANA, K.V. AND MOHANDAS, C., 1983, Plant parasitic nematodes associated with black pepper (Piper nigrum L.) in Calicut district, Kerala. Third Nematology Symposium held at Himachal Pradesh

Krishi Viswa Vidyalaya, Solan, May 24-26, 1983. pp. 9-10.

RAMANA, K.V. AND MOHANDAS, C., 1987, Plant parasitic nematodes associated with black pepper (Piper nigrum L.) in Kerala. Indian J. Nematol., 17: 62-66.

REDDY, T.S.N. AND NAGARAJAN, K., 1980, Evaluation of germplasm and chemical control of Phytophthora parasitica var. nicotianae on tobacco. Proceedings of the workshop on Phytophthora diseases of tropical cultivated plants, 19-23, September, 1980. pp.185-190.

ROSE, S.L., LI, C-Y. AND HUTCHINS, A.S., 1980, A streptomycete antagonist to Phellinus weirii, Fomes annosus and Phytophthora cinnamomi. Can. J. Microbiol., 26: 583-587.

SAMRAJ, J. AND JOSE, P.C., 1966, A Phytophthora wilt of pepper Sci. and Cult., 32: 90-92.

SASTRY, M.N.L., 1982, Studies on species of Phytophthora affecting plantation crops in Karnataka with special reference to koleroga of arecanut and wilt

of black pepper. Ph.D. Thesis, Univ. Agric. Sci., Bangalore, Karnataka State.

*SATOUR, M.M., EL-SHERIF, E.M., EL-GHAREEB, L., EL-HADAD, S.A. AND WAKIL, H.R., 1992, Achievements of soil solarization in Egypt. F.A.O. Plant production and Protection paper (1991) No. 109. pp.200-212. Pl. Path. Research Institute, Agril. Res. Centre. Giza, Egypt.

SIVAN, A.A., ELAD, Y. AND CHET, I., 1984, Biological control effects of a new isolate of Trichoderma harzianum on Pythium aphanidermatum. Phytopathology, 74: 498-501.

SNEH, B., 1972, An agar medium for the isolation and macroscopic recognition of Phytophthora spp. from soil on dilution plates. Can. J. Microbiol., 18: 1389-1392.

STANKOVA-OPOCENSKA, E. AND DEKKAR, J., 1970, Indirect effect of 6 azauracil on Pythium debaryanum in cucumber. Neth. J. Plant. Pathol., 76: 152.

*STAPLETON, J.J. AND DEVAY, J.E., 1982, Effect of soil solarization on populations of selected soilborne

microorganisms and growth of deciduous fruit tree seedlings. Phytopathology, 72: 323-326.

STAPLETON, J.J. AND DEVAY, J.E., 1984, Thermal components of soil solarization as related to changes in soil and root microflora and increased plant growth response. Phytopathology, 74: 255-259.

STAPLETON, J.J. AND DEVAY, J.E., 1985, Soil solarization as a post-plant treatment to increase growth of nursery trees. Phytopathology, 75: 1179(Abstr.).

STAPLETON, J.J. AND GARZA-LOPEZ, J.G., 1988, Mulching of soils with transparent (Solarization) and black polyethylene films to increase growth of annual and perennial crops in southwestern Mexico. Trop. Agric. (Trinidad), 65(1): 29-33.

STAUB, T.H. AND YOUNG, T.R., 1980, Fungitoxicity of metalaxyl against Phytophthora parasitica var. nicotiana. Phytopathology, 70: 797-781.

SUBRAMANIAN, K.S. AND VENKATA RAO, A., 1970, Some experiments on the betelvine wilt at Pothanur in Tamil Nadu. Indian Phytopath., 23: 603-605.

SUBRAMANYAM, K., 1993, Integrated management of foot rot (wilt) of black pepper caused by Phytophthora capsici Leonian. Ph.D. Thesis. University of Agril. Sciences, Dharwad, Karntaka.

SUNDARARAJU, P., KOSHY, P.K. AND SOSAMMA, V.K., 1979a, Plant parasitic nematodes associated with spices. J. Plant. Crops, 7: 15-26.

SUNDARARAJU, P., KOSHY, P.K. AND SOSAMMA, V.K., 1979b, Survey of plant parasitic nematodes associated with species in Kerala and Karnataka. In Proc. PLACROSYM-II, 1979, pp.39-44 (ED.), C.S. Venkataram.

*THOMPSON, A., 1941, Notes on the plant diseases in 1940. Malay. Agric. J., 24: 245.

THOROLD, C.A., 1955, Observations on black pod disease (Phytophthora palmivora) of cocoa in Nigeria. Trans. Br. Mycol. Soc., 38: 435-452.

TIWARI, D.P. AND MEHROTRA, R.S., 1968, Rhizosphere and rhizoplane studies of Piper betle L. with special reference to biological control of root rot

disease. Bull. Indian Phytopath. Soc., No. 4: 79-89.

*TJAMOS, E.C., 1983, Prospects for controlling wilt of olive trees by soil solarization. Hellenic Congree on Plant Diseases and Pests, Athens, pp. 15.

TJAMOS, E.C., 1984, Control of Pyrenochaeta lycopersici by combined soil solarization and low dose of methyl bromide in Greece. Acta. Hortic., 152: 253-258.

TSAO, P.H., 1960, A serial dilution end point method for estimating disease potentials of citrus Phytophthoras in soil. Phytopathology, 50: 717-724.

*TSAO, P.H., 1977, Prospects of biological control of citrus root disease fungi. Proc. Ist Soc. Citriculture, 3: 857-863.

TSAO, P.H. AND GUY, S.O., 1977, Inhibition of Mortierella and Pythium in a Phytophthora isolation medium containing Hymexazole. Phytopathology, 67: 796-801.

TSAO, P.H. AND OCANA, G., 1969, Selective isolation of species of Phytophthora from natural soils. Nature. Lond., 223: 636-638.

TSAO, P.H. AND OSTER, J.J., 1981, Relation of ammonia and nitrous acid to suppression of Phytophthora in soils amended with nitrogenous organic substance. Phytopathology, 11: 53-59.

TSAO, P.H. AND TUMMAKATE, 1977, The identity of a Phytophthora species from black pepper in Thailand, Mycologia, 69: 631-637.

TSAO, P.H. AND ZENTMYER, G.A., 1979, Suppression of Phytophthora cinnamomi and P. parasitica in urea amended soils. pp. 191-199. In soilborne plant pathogens (Eds.) B. Schippers and W. Gams, Academic Press, London, England.

TURNER, G.J., 1969, Leaf lesions associated with foot rot of Piper nigrum and P. betle caused by Phytophthora palmivora. Trans. Br. Mycol. Soc., 53: 407-415.

UPPAL, B.N., 1931, Appendix L. summary of the work done under the plant pathologist to Government, Bombay Presidency, Poona, for the year 1930-31, Ann. Rept. Dept. of Agric., Bombay for the year 1930-31, pp. 209-213 (Abstr.). Rev. Appl. Mycol., 11: 282-283.

*VAN DER VECHT, J., 1950, "Op Planten parasiterende aaltjes (Tylenchida) Plagen Van de Culturgew assen in Indonesia P. 16-42. S. Gravenchage W. Van Hoeve".

*VASILAKAKIS, C.H.O.B., HADZISTAVROS, C.S. AND STERGIANOPOLUS, G.N., 1979, The use of systemic fungicides in soil application for the control of Phytophthora parasitica var. nicotianae in tobacco fields in Greece - a preliminary report. Coresta Phytopathology Agronomy Study Group Report, 201-207.

*VENKATA RAO, M.K., 1929, Ann. Rept. for 1927-28, 19pp, Dept. Agric. Mysore.

VENKITESAN, T.S., 1972, On the occurrence of plant parasitic nematodes associated with different crops in Cannanore district, Kerala. Agric. Res. J. Kerala, 10: 179-180.

*WAGGONER, P.E., MILLER, P.M. AND DEROO, H.C., 1960, Plastic mulching principles and benefits. Connecticut Agricultural Experiment Station Bulletin, 634: pp.44.

WARCUP, J.H., 1957, Chemical and Biological aspects of soil sterilization. Soils Fert., 20: 1-5.

WEINDLING, R., 1932, Trichoderma lignorum as a parasite of other soil fungi. Phytopathology, 22: 837-845.

WESTE, G. AND MARKS, G.C., 1987, The biology of Phytophthora cinnamomi in Australarian forests. Ann. Rev. Phytopathol., 25: 207-229.

*WICKS, T.J., 1988, Effect of solarization on the control of Phytophthora cambivora in almond and cherry. Aust. J. Exp. Agric., 28: 539-545.

*WILLIAMS, P.H., EBBEN, M., HOWLES, R., GROSSBARD, E., OWEN, O. AND MESSING, J.H.L., 1950, Plant diseases chemical problems. Rep. Exp. Res. Sta. Cheshumt. pp. 24-27.

WOOD, R.K.S. AND TVIET, M., 1955, Control of plant diseases by use of antagonistic organisms. Bot. Rev., 21: 441-492.

ZENTMYER, G.A., 1963, Biological control of Phytophthora root rot of avacado with alfalfa meal. Phytopathology, 53: 1383-1385.

ZENTMYER, G.A., 1967, Recent advances in the control of soil fungi. F.A.O. Pl. Prot. Bull., 15: 1-5.

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* Original not seen