EFFECTIVENESS OF SOIL SOLARIZATION FOR THE CONTROL OF SOFT ROT DISEASE IN GINGER

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Effectiveness of soil solarization for the control of soft rot disease in ginger**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title of any other University or Society.

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T.N.VILASINI

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ABBREVIATIONS

AS	-	After solarization
c.f.u.	-	Colony forming units
MAP	-	Months after planting
NC	-	Neem cake
NL	-	Neem leaves
NS	-	Non-solarization
S	-	Solarization
Tri.	-	*Trichoderma*
VAM	-	Vesicular-arbuscular mycorrhiza

Introduction

INTRODUCTION

Intensive farming of high value crops often involves continuous planting of the same crop (monoculture). One consequence of monoculture is depressed plant growth and yield decline resulting from the accumulation of harmful biotic and abiotic agents (Chen *et al.*, 1991). Often in such systems soil borne pests increase and in severe cases the farmers may be forced to abandon the field or to replace the crop by a less profitable one. Thus soil borne pests not only cause an immediate crop loss but they also have long term effects especially in regions where both crop options and land are limited. Controlling these pests by physical, chemical or biological means present many problems.

Problems associated with soil disinfestation such as reaching the inoculum and eradicating it effectively at desired depth, reinfestation, detrimental effects on non-target and beneficial organisms, residual effects on the plant, application, hazards, and costs should be considered, as well as the extent of disease control and yield increase, before opting for any one of the methods of soil disinfestation. Search for new, effective, simple, inexpensive and non-hazardous methods for soil disinfestation is a continuous one.

Soil disinfestation was developed as a method for controlling soil borne pathogens more than 100 years ago. Until recently, only two approaches have been followed; a physical one - steaming and a chemical one - fumigation. "Soil solarization" is the third and most recent approach for soil disinfestation.

Soil solarization is a non-chemical method. It utilizes solar irradiation for soil disinfestation by capturing it under clear plastic mulch. Solarization aims at the eradication or reduction of the inoculum existing in the soil prior to planting. The treatment has been referred to in various publications as solar pasteurization, solar heating, soil polyethylene mulching, soil tarping and soil solarization. However, the term soil solarization is the one which is widely used.

Solarization as a technique of plant disease control was first used by Jones *et al.* (1966) against southern blight of tomatoes. However, the credit for developing the finer details and popularising the method goes to Katan *et al.* (1976). During the last 20 years, this method has become popularised in over 40 countries.

The exact mechanism of the action of solarization has not been completely worked out. It was originally regarded as a means of physical control through thermal killing of the pathogen. A number of biological effects have also been attributed to solarization in controlling the pathogen (Katan, 1981; Horiuchi, 1984; Chandran, 1989; Sainamol, 1992). Solarized soil undergo significant changes in temperature, moisture, physical structure and the inorganic and organic composition of the solid, liquid and gaseous phase, all of which in turn affect the biotic and abiotic components (Stapleton and DeVay, 1984; Katan, 1987).

Apart from controlling the pathogens in the soil, solarization has been found effective in controlling nematodes and weeds. It has also been found to increase the plant growth through better nutrient availability. In certain cases, the long term effect of solarization on disease control and/or yield increase, extending for a second or even upto the third crop was observed in various regions with a variety of pathogens.

In India, solarization is not yet popular. However, successful control of *Fusarium* in chickpea (ICRISAT, 1985), *Macrophomina phaseolina* in cluster beans (Lodha, 1989), *Rhizoctonia solani* in cowpea (Chandran, 1989), collar rot in betelvine (Deshpande and Tiwari, 1991), *Pythium aphanidermatum* in periwinkle (Kulkarni

Review of Literature

et al., 1992) and in chillies (Sainamol, 1992) and wilt disease in guava (Dwivedi, 1993) have been reported.

India is the foremost country in the production, consumption as well as export of a wide range of spices, earning substantial foreign exchange. Ginger is an important seasonal spice of India having an area of 58.08 thousand hectares and a production of 189.44 thousand metric tonnes. Although ginger is grown in almost all parts of India, Kerala is the most important ginger producing state, contributing to about 30.0 per cent of the total production. Ginger is subjected to a number of diseases leading to various levels of crop damage and yield reduction. Soft rot is the most serious disease and it causes a loss to the tune of 50.0 per cent. Several chemical fungicides and amendments have been tried to manage the disease with varying degrees of success. Several instances have been noticed wherein both fungicides and amendments are ineffective against the disease and at the same time resulting in serious environmental hazards.

With this background, the present investigation has been undertaken to find out the effectiveness of soil solarization for the control of soft rot in ginger and its effect on beneficial microorganisms and plant growth response.

REVIEW OF LITERATURE

Crop plants are attacked by numerous soil borne pathogens, insects and weeds, causing heavy crop losses. They may be controlled by chemical, physical or biological means. The most commonly used methods for controlling soil borne pathogens are soil fumigation, soil drenching with various chemicals, heat treatment of the soil by steam and burning or cultural methods. These methods are never been widely used owing to economic considerations and practical difficulties. Thus, the search for a new, simple, inexpensive and eco-friendly (non-hazardous) method for disease and pest control resulted in the development of a new technique called "soil solarization".

Soil solarization (solar heating) is a significant departure from the old disinfestation procedures used against soil borne pathogens (Katan, 1981). Soil solarization is a method of hydrothermal disinfestation accomplished by covering moist soil with polyethylene sheets during the summer months. In addition to reducing numbers of fungi, bacteria, nematodes, insects and weeds, soil solarization often results in increased plant growth response (Chen and Katan, 1980; DeVay, 1991).

The technique of solarization has been used to manage different crop diseases in different parts of the world *viz.*, England (White and Buczacki, 1979), Greece (Ursad, 1977); Italy (Tamietti and Garibaldi, 1981), Japan (Kodama and Fukui, 1979), Jordan (Al-Raddad, 1979), Korea (Kye and Kim, 1985), USA (Pullman *et al.*, 1981a).

Principles of solarization

Mulching of soil with polyethylene during winter to increase soil temperature for better crop growth in glass houses and open field is common where root/collar diseases caused by *Pythium* sp. is severe. Unlike this, solarization involves the use of heat as a lethal agent for pest control by capturing solar energy and increasing the soil temperature. Solarization is done during the hottest period of the year when there is no crop in the field.

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

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

Pathogen control

Several experiments have been conducted to evaluate the effectiveness of solarization on the control of plant pathogens from 1966 onwards.

Pythium

Control of rot syndrome of sugarcane associated with *Pythium arrhaenomanes* and *P. graminicola* in Australia (Chen and Katan, 1980) was the first report of successful control of a disease caused by *Pythium* spp. by solarization. Pullman *et al.* (1981b) reported that propagules of *Pythium* sp. could be reduced or completely eliminated at 0-46 cm depth in soil tarped for 14-66 days. According to Stapleton and DeVay (1984), soil and root population densities of *Pythium* spp. could be reduced by 38.0 per cent after post-plant soil solarization of a two years old almond orchard. However, the treatment was not effective in a six year old peach orchard.

Successful control of diseases caused by *Pythium* by solarization has been reported by different workers - wheat root rot (Cook *et al.*, 1987), damping off of cucumber (Al-Khafuji, *et al.*, 1988), root rot of snap beans (Meron *et al.*, 1989), damping off in tomatoes (Satour *et al.*, 1991) die back and collar rot of periwinkle (Kulkarni *et al.*, 1992) and damping off of chillies (Sainamol, 1992).

Phytophthora

Mulching with polyethylene sheets was found to be very effective in controlling *Phytophthora* infection of orchard plants and annual crops. Solarization for the control of *P. cambivora* in almond and cherry orchards was effective only in irrigated plots (Wicks, 1988). Tjamos (1991) reported the effectiveness of post-plant solarization for the control of *P. cinnamomi* in avocadoes.

According to Garibaldi and Tamietti (1989), soil mulching with double layer of polyethylene was effective in checking *P. nicotianae* var. *parasitica* infection of carnation plants. The effectiveness of solarization in controlling *Phytophthora* disease of capsicum and tomatoes was reported by Moens and Ben-aicha (1990) and Satour *et al.* (1991).

Macrophomina

A marked reduction in survival of *Macrophomina phaseolina* of soya-bean was observed in solarized soil by Dwivedi and Dubey (1987). Pre-planting mulching of moist soil with black and transparent polyethylene films for six weeks reduced population of *M. phaseolina* by 62-100.0 per cent (Stapleton and Garzalopez, 1988). This was contradicted by Stapleton (1991). According to him, solarization although markedly increased soil temperature, did not reduce soil inoculum of *M. phaseolina* associated with muskmelon and sesame.

The effectiveness of solarization in reducing *M. phaseolina* propagules in soil was also reported by Hasan (1989) and Lodha *et al.* (1991).

Rhizoctonia

Solar heating of the soil significantly reduced diseases caused by *R. solani* in potato (Elad *et al.*, 1980; Katan, 1981; Davis, 1991; Satour *et al.*, 1991), onion (Katan, 1981), cucumber (Al-Sammaria *et al.*, 1988), cowpea (Chandran, 1989), beans (Tamietti and Garibaldi, 1989), gerbera (Kaewruang *et al.*, 1989a and b) and radish (Triolo *et al.*, 1989).

Sclerotium

Jones *et al.* (1966) obtained significant control of southern blight of tomatoes caused by *S. rolfsii*, with solarization. Solarization effectively reduced the Peanut rot caused by *S. rolfsii* (Grinstein *et al.*, 1979; Katan, 1981), lettuce rot caused by *Sclerotinia minor* and *Sclerotinia sclerotium* (Porter and Merriman, 1985), *S. oryzae* on rice (Chaffer, 1984), *S. rolfsii* on beans (Greenberger *et al.*, 1987), *S. cepivorum* on onion (Satour *et al.*, 1989, 1991) and *S. rolfsii* on tomato (Tu *et al.*, 1991).

According to Usmani and Ghaffer (1982), polyethylene mulching reduced 95-100 per cent viability of the sclerotia of *S. oryzae* in the soil. Deshpande and Tiwari (1991) obtained control of collar rot of *Piper betle* cuttings caused by *S. rolfsii* when it was planted after five days of solarization. Soil solarization for 8-11 weeks resulted in the reduction of *S. cepivorum*, white rot pathogen of garlic to undetectable levels in the upper 20 cm layer of infested soil (Basallotte-Ureba and Melero-Vara, 1993). According to Ghini (1993), the period of solarization could be reduced if a solar collector is used to increase the radiation intensity (> 1 cal/cm^2/min). He could disinfect the soil infested with *S. rolfsii* and *Sclerotinia sclerotiorum* within a period of one day by using this technique.

Verticillium

Mulching with polyethylene sheets increased soil temperature and resulted in reduction of *Verticillium* wilt by 25-95.0 per cent in egg plant and tomato (Katan *et al.*, 1976; Tjamos, 1991; Besri, 1991).

Solarization was also found to be efficient in the control of *Verticillium dahliae* on potato (Grinstein *et al.*, 1979; Davis and Sorensen, 1986; Davis, 1991; Lazarovits *et al.*, 1991b), capsicum (Gil-Ortega *et al.*, 1990), cotton (JimenezDiaz *et al.*, 1991), aubergines (Cartia *et al.*, 1991) and olive (Tjamos, 1991).

Skoudridakis and Bourbos (1989) reported that soil solarization by covering the soil around 15 to 20 years old olive trees of the variety Mastisdis with a 0.05 mm transparent polyethylene film for 12 weeks reduced the number of

V. dahliae microsclerotia by 97.3, 95.0, 90.9 and 85.8 per cent at depths of 0-10, 11-20, 21-30, 31-40 and 41-50 cm respectively. The incidence of foliar symptoms due to *V. dahliae* was reduced by 80-100.0 per cent in apricot and almond trees by covering the soil with black as well as transparent polyethylene mulch. Incidence of vascular discolouration symptoms of branches was similarly reduced by both type of mulches (Stapleton *et al.*, 1993).

Fusarium

Solarization was highly effective in controlling *Fusarium* disease of crop plants - *Fusarium oxysporum* f. sp. *vasinfectum* on cotton (Katan *et al.*, 1983), *F. oxysporum* f.sp. *ciceri* on chickpea (Arora and Pandey, 1989), *F. oxysporum* f. sp. *lupini* on lupin (Osman *et al.*, 1986), *F. oxysporum* on Gerbera (Kaewruang *et al.*, 1989a and b), *F. oxysporum* f. sp. *lycopersici* on tomato (Greenberger *et al.*, 1987), *F. oxysporum* f. sp. *lini* on conifer seedlings (Mc-Cain *et al.*, 1986), *F. oxysporum* f. sp. *niveum* on watermelon (Ioannou and Poullis, 1990), *F. oxysporum* f. sp. *conglutinans* on cabbage (Villapudua and Munnecke, 1986) and *F. solani* on capsicum (Moens and Ben-aicha, 1990). Experiments conducted at ICRISAT with transparent 110 μm thick polyethylene sheeting for six to eight weeks revealed that solarization could reduce population of *F. udum* on *Cajanus cajan* and *F. oxysporum* f. sp. *ciceris* on *Cicer arietinum* (Choughan *et al.*, 1988). Combining soil solarization for 11 weeks with a single treatment of solar heated water (75-90°C) applied at the beginning or end of the solarization reduced *Fusarium* propagules in the soil (Abu-Gharbieh *et al.*, 1991).

Arya and Mathew (1993) suggested that when *Fusarium* wilt pathogen was incorporated in non-rhizosphere soil of pigeon pea, it could not be recovered after mulching for 45 days. According to them, combined use of *Trichoderma harzianum* and soil solarization or a reduced dose of methyl bromide resulted in significant control of *Fusarium* crown and root rot of tomato induced by *F. oxysporum* f. sp. *radicis-lycopersici*. However, *T. harzianum* and soil solarization alone were ineffective in protecting the tomato plants from disease.

Other Pathogens

Solarization was also found to be effective against *Thielaviopsis basicola* in cotton (Pullman *et al.*, 1981b), *Plasmodiophora brassicae* (Myers *et al.*, 1983), *Pyrenochaeta lycopersici* in tomato (Katan, 1981), *Rosellinia necatrix* in apple (Sztenjnberg *et al.*, 1987) and *Neovossia indica* in wheat (Singh *et al.*, 1991).

Mechanism of Solarization

Mode of action of solarization is complex involving direct thermal destruction of propagules, shift in microbial populations and activity and changes in the soil's physical and chemical properties (Katan *et al.*, 1976).

Various studies have been conducted to clarify the mechanism by which solarization controls soil borne diseases and identified the following three major aspects of mechanisms of disease control and yield increase.

1. Thermal inactivation of pathogens - the physical effect

The effect of temperature on microorganisms has been well documented. However, the lethal temperature for organisms have been worked out mostly by exposing the organisms to high temperature for short periods. The effect of exposure of organisms to low temperature for long periods and the effect of fluctuating temperature have not been studied in detail.

The thermal death rate of a population of an organism depends on both the temperature level and exposure time. At a given temperature and exposure time, mortality is related to the inherent heat sensitivity of organism and vary with environmental conditions. Baker (1962) suggested that exposing fungi to heat mainly involved - denaturation of proteins (including enzymes), lipid liberation, destruction of hormones and asphyxiation of fungal tissues.

According to Katan *et al.*, (1976), the effectiveness of sub lethal temperature on pathogens might be due either to a direct cumulative effect of temperature or to a combination of thermal and biological factors. They worked out a linear relationship between logarithms of exposure duration required to kill 90.0 per cent of the pathogen when plotted against the temperature level in the range of 37.0 to 50.0°C.

Katan (1980) opined that the fungal resting structures exposed to sub lethal temperatures were weakened and therefore attacked even by the microorganisms that ordinarly could not attack them. Pullman *et al.* (1981a) observed relatively low temperatures resulted in enzyme inactivation, phase change in fatty acids and membrane components and a slow turn over of heat sensitive proteins. They also suggested that this heat damage accumulated gradually and at sublethal temperatures, pathogen propagules delayed their germination.

Horiuchi *et al.*, (1983) reported that resting structures of *Plasmodiophora brassicae* lost infectivity when heated at 45.0°C for one day and that artificially infested soil in a slurry state failed to retain infectivity after five days at 45.0°C. They also found that periodical heating as well as continuous heating caused a disease suppressing effect. Lifshitz *et al.*, (1983) reported that heat treatment of sclerotia of *S. rolfsii* at 50.0°C for 30 min. increased sclerotial leakage of organic substances which apparently stimulated the reproduction of soil microorganisms, extensive colonization of sclerotia by bacteria and streptomycetes and the formation of cracks. All these apparently weakened the sclerotia and finally reduced their inoculum potential in soil. Isolates of *R. solani* were killed after 20 days and 60 min. when exposed to 39.0 and 50.0°C respectively (Bicici and Erkilic, 1986). Sztenjnberg *et al.*, (1987) observed that *Rosellinia necatrix* was highly sensitive to heat and 50-100 per cent mortality was recorded an exposure of four hours at 38.0°C.

According to Katan (1987), while analysing the physical effect of solarization on inoculum density and inoculum potential of the pathogen and on disease control, the points to be taken into consideration are

1. The thermal death rate of an organism depends on both the temperature level and exposure time, which are inversely related.

2. Propagules, which survive sub lethal heating may be partially damaged or weakened.

3. The course and pattern of heating during soil solarization vastly differ from those usually established for heat mortality curves under controlled conditions, since with soil solarization, propagules are subjective to varying temperatures in daily cycles in a split alternate heating mode which contracts with conditions.

4. The extent of damage inflicted on the propagules depend on its inherent heat sensitivity, prevailing environmental conditions, moisture level, protective effect of the soil, inoculum density, quality and age, nutritional conditions and presence of toxic substances.

5. When a pathogen infested soil is solarized or heated, three process may simultaneously occur; reduction in propagule vulnerability; increase in propagule vulnerability to potential antagonists (Henis and Papavizas, 1983; Lifshitz *et al.*, 1983) and activity of the antagonist on the pathogens.

II. Biological control

In addition to physical effect of heat, microbial process induced by solarization may also contribute to disease control, since the impacts of any lethal agent in soil extend beyond the target organisms. 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).

The mechanisms of biological control which may be created or stimulated by solarization (or any disinfestation method) are summarised by Katan (1981) as follows:

I. Effect on the inoculum existing in the soil

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

1. Microbial killing of the pathogen already weakened by sublethal heat

2. Partial or complete annulment of fungistasis and subsequent lysis of the germinating propagule

3. Parasitism or lysis by antagonists stimulated by solarization

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

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

II. Suppressing inoculum introduced to soil after solarization from deeper soil layers of adjacent non-treated plots, ie., preventing reinfestation through activity of microorganisms possessing above mentioned mechanisms (A_2, A_3, B and C).

III. The effect on the host due to cross protection

Katan *et al.* (1976) showed that soil fungistasis to *Fusarium* diminished as a result of soil heating and this in turn reduced population level of the fungus in soil. Elad *et al.* (1980) reported that population of *T. harzianum* increased in the solar heated soils and the incidence of disease caused by *R. solani* remained low throughout the season. Significant reduction of *Fusarium* wilt was exhibited by tomato seedlings planted in a previously solarized soil compared to non-treated soil indicating the development of a temporary suppressiveness in the solarized soil due to a favourable shift in microbial population towards antagonists (Katan, 1981). He observed the antagonistic fungus *T. harzianum* aggressively colonising the solarized soil. These observations suggest that solarization causes changes in biota and substrate that provide a favourable environment for colonisation by microorganisms with greater competitive ability. He further stated that these organisms are saprophytes rather than phytopathogens which tend to have more specialised group. Many of these saprophytes may subsequently inactivate surviving phytopathogenic fungi, bacteria, nematodes and weed seeds that even damaged or weakened by solarization. He also observed that the mulched soil retained adequate soil moisture for such microbial activity for several weeks.

Lifshitz *et al.* (1983) found that sublethal heating increased the leakage of water soluable organic compounds from *S. rolfsii* sclerotia which increased their colonization by bacteria and streptomyces by 574 and 1470 fold respectively thus reducing their pathogenic activity. Scanning electron microscopic observations revealed that heating increased the frequency of surface cracks on the sclerotia and the concentration of bacteria on and around those cracks increased by about 10 times. A partial or complete nullification of fungistasis in the absence of heat is regarded as harmful to resistant resting structures. Solarization reduced fungistasis in *S. rolfsii* in various soils (Greenberger *et al.*, 1985).

Tjamos and Paplomatas (1987, 1988) reported that population of *Talaromyces flavus*, an antagonist of *V. dahliae* increased in the rhizosphere of solarized artichoke plants and olive trees with the histories of wilt as compared with untreated control soils. The beneficial effect of soil solarization lasted for three years and this could be at least partially attributed to the activity of *T. flavus* in inhibiting germination of microsclerotia causing their death. *Aspergillus terreus*, another beneficial antagonist of *V. dahliae* was also found to survive and occassionally increase with solarization. Solar heating activated growth of saprophytic fungi such as *Trichoderma* (Hasan, 1989; DeVay, 1991). Kaewruang *et al.* (1989b) found that solarization increased bacterial and fungal antagonists in the solarized soil at 0-10 cm depth and the activity of these microbes may have been responsible for the suppression of pathogens causing root rot in gerbera and the subsequent increase in growth and productivity.

According to Stapleton and DeVay (1984), the percentage of colonies of gram positive bacteria exhibiting *in vitro* antibiosis against *Geotrichum candidum* increased nearly 20 fold in solarized soil but not at all in shaded soil. They also reported that six strains of fluorescent pseudomonads, plant growth promoting rhizobacteria colonised sugarbeet and radish roots more in solarized soils. Increased population of pseudomonads in solarized plots were also observed by Meron *et al.* (1989) and Gamliel and Katan (1991). Contrary to the above observations, Ristanio *et al.* (1991) reported a decrease in the population of fluorescent pseudomonads in solarized plots. Gamliel and Katan (1992a and b) suggested that addition of antimicrobial agents to non-solarized soil supplemented with seed and root exudates reduced populations of soil microorganisms and increased population of fluorescent pseudomonads. They also reported that the rapid establishment of fluorescent pseudomonads in the rhizosphere of plants in solarized soil was due to an improved capacity of these bacteria to compete for exudates.

Preventing reinfestation is vital for proper disease control. Drastic soil disinfestation measures may result in islands of reduced biological activity which enhance recolonisation (Harper, 1974). Olsen and Baker (1968) showed that severe reinfestation occurred with *R. solani* when soils were disinfested by artificial heating at 80-100.0°C. Treating the soil at lower temperatures (50-60.0°C) reduced reinfestation. Aerated steam at 60-70.0°C was successfully used by Baker (1962; 1970) and Baker and Cook (1974) for controlling *R. solani* and this did not enhance reinfestation. Solarization is usually carried out at temperatures that are even lower than aerated steam and it thus reduces chances of biological vacuum (Katan, 1981).

Freeman *et al.* (1990) found no reinfestation of *R. necatrix* in solarized soil and no death of replanted apple trees occurred in the solarized plots upto two years after the treatment. In one of the studies, Tjamos (1991) observed that the rate of recovery of olive trees affecting by *V. dahliae* in solarized soil significantly exeeded natural recovery of untreated control and he attributed this to the lack of root reinfestation.

III. Volatiles

Apart from increased temperature and biological control, volatiles of the soil also involved in the reduction of pathogens by solarization. The mulch cover causes the accumulation of volatiles such as carbondioxide, ethylene and other substances. Volatiles in the soil play a vital role in the fungistasis and biological control (Papavizas and Lumsden, 1980). Polyethylene is not permeable to most gases (Byrdson, 1970). Gases such as sulphur containing volatile compounds and ammonia were found to be toxic to *R. solani* and *Aphanomyces eutiches* (Lewis and Papavizas, 1974). Carbondioxide accumulation under mulch is upto 35 fold over non-mulched soil (Rubin and Benjamin, 1981). Reductive soil condition under the mulch may cause oxygen starvation which in turn affect the survival of pathogen propagules (Horiuchi, 1984). Laboratory experiments conducted by Villapudua and Munnecke (1988) recorded nearly 100 per cent reduction in the population of *F. oxysporum* f. sp. *conglutinans* by gases arising from decomposing cabbage residues in the soil in closed containers. According to Kaewruang *et al.* (1989b), solarization of soil in plastic bags was more effective than in the field as the fungitoxic volatile compounds such as carbondioxide, ethylene and carbondisulphide were more effectively trapped within plastic bags resulting in the better control of *F. oxysporum, Phytophthora cryptogea* and *R. solani* causing root rot in gerbera.

Heated cabbage amended soil generated a wide range of volatile compounds including alcohols, aldehydes, sulphides and isothionates. The level of isothionates and aldehydes generated in heated soils were significantly correlated with reduced propagule numbers of *Pythium ultimum* and *S. rolfsii* (Gamliel and Stapleton, 1993). The propagule numbers of the two fungi were reduced by more than 95.0 per cent when they were exposed for 14 days to volatile compounds generated from heated cabbage amended soil. They also reported that the microbial activity of soil exposed to volatile compounds from heated cabbage amended soil increased suggesting selective toxicity of the volatile compounds to soil microbiota.

Factors influencing efficiency of solarization

The effectiveness of solarization has been found to be influenced by various factors like soil moisture, soil type, duration of solar heating, season, sun-light/shade, type of materials used as covering, ridging, organic matter content of the soil etc.

Soil moisture

Maintenance of high soil moisture is necessary for increasing soil conduction of heat and for increasing the sensitivity of organisms to high temperature and for providing better condition for the activity of the natural antagonists in the soil. Katan *et al.* (1976) obtained better control of *V. dahliae* and *F. oxysporum* on tomato and egg plant by irrigating the soil before mulching with drip irrigation. Later studies by them showed that only a single irrigation just before (1-4 days) covering the soil with polyethylene is necessary to get good control of the soil borne plant pathogens. Grinstein *et al.* (1979) and Katan (1980) reported successful control of *S. rolfsii, V. dahliae* and *Fusarium* by pre-tarping irrigation.

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

According to Arora and Pandey (1989), there was no significant difference in mean maximum temperatures in solarized irrigated and non-irrigated treatments at 5, 15 and 30 cm depth. But, maximum soil temperatures at 5-15 cm depth were achieved after five to seven days in solarized irrigated soil compared to 15-20 days in solarized non-irrigated soil. They also observed that the role of moisture on the survival of the pathogen and the incidence of disease appears minimal when solarization was conducted for longer duration (30-40 days).

Lodha *et al.* (1991) found that reduction in viable propagules of *F. oxysporum* f. sp. *cumini* was 53.4 per cent in dry and 60.8 per cent in wet plots at a depth of 15 cm and 23.0 and 39.0 per cent respectively at 30 cm depth. Matrod *et al.* (1991) reported a reduction in the number of viable sclerotia of *S. cepivorum* causing white rot in garlic by 75.2 to 83.2 per cent in moist plots covered with clear plastic compared to 1.6 to 10.4 per cent in dry covered soils and 1.6 per cent in the control.

Soil type

Influence of soil type on solarization has not been studied in detail. However, there are indications that soil type plays an important role in temperature fluctuations in a solarized soil. Absorption of solar radiation varies according to colour, moisture and texture of the soil.

Stapleton and DeVay (1982) conducted experiments with fine sandy loam with some clay strata (heavy soil), sandy loam (light soil) and sandy soil and recorded a soil temperature of 49.0°C in light soil at 15 cm depth (10°C higher than non-solarized soil), 46.0°C in heavy soil (7°C higher than non-solarized soil) and 45.0°C in sandy soil (8°C higher than non-solarized soil). Similar findings were also reported by Rubin and Benjamin (1983); Stapleton and DeVay (1984); Stapleton *et al.* (1985); Ioannou and Poullis (1990) and Tjamos *et al.* (1991).

Duration of solar heating

Since, temperatures at the deeper layers of soil are lower than at the upper layers, the mulching period should be sufficiently extended, in order to achieve pathogen control at all desired depths. Katan *et al.* (1976) obtained 52.0°C at 5 cm depth in mulched soil as against 38.0°C at 20 cm depth. They observed that at 5 cm depth, five days of solar heating was sufficient to eliminate 100.0 per cent of *V. dahliae* sclerotia. While at 25 cm depth, only a slight killing of the pathogen was noticed. However, an additional exposure for eight days enabled the complete killing of the sclerotia even at 25 cm depth.

Elad *et al.* (1980) reported that mortality rates of *S. rolfsii* at 5 and 20 cm depth were 100.0 and 25.0 per cent after 19 days of solarization and 100.0 and 80.0 per cent after 21 additional days of exposure. Bicici and Erkilic (1986) found that propagules of *R. solani* were killed to a depth of 5 cm with mulching for four to eight weeks, while at 15 cm depth it was unaffected. Duff and Barnarrt (1992) observed that solarization of a 25 cm potting mixture mound with a double layer of clear polyethylene killed *P. myriotylum*, *P. nicotianae* var. *nicotianae* and *C. rolfsii* within seven, three and seven days at 10 cm and within seven, seven and 10 days respectively at 25 cm depth.

Season

To get best results, solarization should be carried out during the hottest months of the year. This will enable to increase the maximal temperature in the hope of reaching lethal levels. Mahrer (1979) developed one diamensional numerical model which enabled the evaluation of the relative importance of the various factors involved in solarization namely type of mulching material, type of soil, moisture and climate. The model enabled to choose suitable climatic region and time of the year most adequate for soil solarization taking into account the temperature that would develop under a set of conditions.

Malathrakis and Kambourakis-Tzagaroulakis (1989) observed that soil solarization increased the soil temperature to 45.0°C at 10 cm depth during July. While, the experiment was repeated in August, the maximum temperature observed was only 40.0°C. Morgan *et al.* (1991) conducted experiments with mulching during different times. They found that mulches applied on 25th June were less effective in controlling *V. dahliae* than when mulched on 17th April.

Type of mulching material

The effectiveness of solarization is influenced by the type of polyethylene material used. According to Katan *et al.* (1976), transparent and not black polyethylene should be used for solarization, because it transmits most of the solar radiation that heat the soil. According to Pullman *et al.* (1981b), tarps of 25 μm thick were more effective in heating soils and in killing soil borne fungi than 100 μm tarps. Watermelon and rockmelon plants mulched with reflective (aluminium coated) polyethylene were less infected (21-72%) with watermelon mosaic virus than those without mulch (McLean *et al.*, 1982). Black polyethylene mulch also produced the same effect but to a lesser degree.

According to Ben-yephet *et al.* (1987), solarization with two layers of 25 μm polyethylene film increased soil temperature by 12.7°C and 3.6°C over those in non-covered soil or soil covered with one layer of film. Viability of *F. oxysporum* f. sp. *vasinfectum* at 30 cm depth was reduced by 97.5 per cent and 58.0 per cent under a double and single film respectively. The insulating effect of double layer of film improved heat retension in soil.

Tamietti and Garibaldi (1989) observed a temperature of 36.9 - 44.5°C under single polyethylene film (0.05 mm thick) at 24 cm depth compared to 42.5°C under double film containing small bubbles (Tristan), which was 2-2.5°C higher than with single film because double film prevented heat dispersal more efficiently.

Duff and Connelly (1993) reported that solarization of potting mixture was raised to 51.0° and 44.6°C under a double and single layer of clear plastic mulch respectively at 25 cm depth. Three soil borne plant pathogens namely *P. myriotylum*, *P. nicotianae* var. *nicotianae* and *S. rolfsii* were eliminated under a double layer of plastic within two to eight days. While, 4-20 days were required to eliminate the same pathogens using a single layer of plastic. Garibaldi (1987) and Milevoj (1989), reported that PVC was more effective than polyethylene in maintaining soil temperature when used for solarization. Double layer bubble plastic raised soil temperature of 1-2°C higher than those obtained with PVC. Malathrakis and Loulakis (1989) used low density polyethylene sheet (LDPE), Walloplast and Thermoplast for solarization and found that all polyethylene sheets were equally effective against *C. rolfsii*.

Horowitz *et al.* (1983) found that black plastic was less effective than transparent and the maximum temperature increase at 5 cm depth was only 9.3°C for black and 17-19.0°C for transparent plastic. According to Stapleton *et al.* (1989), at a depth of 15-23 cm where transparent plastic sheet raised temperature upto 10-18.0°C, it was only 8-12.0°C for black plastic tarp. Matrod *et al.* (1991) observed that viable number of sclerotia decreased by 75.2 to 83.2 per cent in plots covered by clear plastic mulches compared with a decrease of 49.6 - 59.2 per cent with black plastic. Eventhough soil solarization using black and transparent plastic tarping reduced *F. oxysporum, F. solani* and *Meloidogyne javanica*, transparent tarping was slighty more effective (Abu-Gharbieh *et al.*, 1991). This was contradicted by the findings of Stapleton *et al.* (1991). They suggested that mulching of moist soil with black polyethylene was as effective as transparent in controlling diseases and weeds. Further studies by Stapleton *et al.* (1991) showed that mulching with transparent or black polyethylene during summer increased soil temperature, 46.0, 41.0 and 33.0°C under a clear film, black film and control respectively at 18 cm depth and mulching with black film gave better over all results than with clear film.

Ridging

Horiuchi (1984) reported that covering ridged field plots with polyethylene sheets easily raised soil temperature than in levelled ones. Higher ridges were more effective than lower ones because ridges have a greater surface area to receive solar radiation which is the primary source of energy for heating the soil.

Organic and inorganic matter content of soil

Addition of fertilizers and organic amendments especially compost can suppress soil borne plant pests in various cropping systems.

Horiuchi *et al.* (1983) reported that the presence of organic matter in soil, intensified the effect of heating by solarization. Villapudua and Munnecke (1987) found that population of *F. oxysporum* f. sp. *conglutinans* were greatly reduced and cabbage yellows was undetected when cabbage leaf amended soils were solarized. The efficacy of solarization to control southern blight of tomatoes was improved when green manure was incorporated before solarization (Tu *et al.*, 1987). According to Gamliel and Stapleton (1993a), chicken compost amendment of soil before solarization increased soil temperature by approximately 2.0°C compared with temperature of non-amended solarized soil. They also observed that solarization of compost amended soil was very effective in controlling *M. incognita* in lettuce.

The solarized neem leaf amended plot showed maximum reduction in microorganisms followed by Eucalyptus and oak leaf amendments (Arya and Mathew, 1993). However, Sainamol and Peethambaran (1994) failed to get better control of damping off of chillies when neem cake amended plot was solarized.

The heating effect by solarization, was improved with fertilizer concentration. Better control of club root was obtained when calcium cynamide fertilized plot was solarized (Horiuchi *et al.*, 1983). Dubey (1992) tested the effect of solarization on the survival of *M. phaseolina* in fungicide amended soil. He observed that treatment with Bavistin, Dithane-M45 and PCNB enhanced the effect of solarization. Solarization with carbendazim was the most effective. While, PCNB was the least effective treatment.

Effect of solarization on soil microbes

Fungi

Extensive studies by Stapleton and DeVay (1982, 1984) on microbial changes in the soil during and after solarization have showed that population of fungi was greatly reduced immediately followed solarization, while thermophilic and thermotolerant fungi like *Aspergillus* spp. and *Penicillium* sp. were less affected or even increased. Similar observations were also recorded by Abu-Gharbieh *et al.* (1991) and Arya and Mathew (1993). Martyn and Hartz (1985) reported that saprophytic fungi increased greatly in the deeper layers in solarized soil. The saprophytic *Fusarium* population in solarized soil in 30 days was eight times more than that of non-solarized soil, while after 60 days, it was decreased but still three to five times more than that in the control.

Studies conducted at ICRISAT (1986) revealed a general reduction in the fungal population in solarized soil. However, one species (*Penicillium pinophillum* was relatively abundant in the solarized soil and it was antagonistic to *F. udum*. Soil populations of *Acrophialophora fusispora, A. niger, A. terreus, T. viridae* and Sterile mycelia were increased after 45 days of solarization (Dwivedi and Dubey, 1987). Tjamos and Paplomatas (1987, 1988) reported that soil solarization increased *Talaromyces flavus* and *A. terreus*, potential antagonists to *V. dahliae* in the rhizosphere soil of artichoke plants. Triolo *et al.* (1988) suggested that the numbers of different colonising species were reduced in solarized soil but prevalence of *Aspergillus, Fusarium, Penicillium* and *Trichoderma* was increased. According to Chandran (1989) and Sainamol (1992) fungal population was reduced by solarization.

Bacteria

Some species of soil-borne bacteria are sensitive to soil solarization; their thermal sensitivity depends upon the nature of the individual taxa. Population density of *Agrobacterium* spp., fluorescent pseudomonads, pectolytic pseudomonads and certain gram-positive bacteria were reduced by 69-98.0 per cent immediately after solarization. Fluorescent pseudomonads got rapidly recolonised in the treated soils and no significant difference among treatments was apparent, three to six months later. However, *Agrobacterium* spp. and some gram-positive bacteria failed to recolonise in the solarized soil even 6-12 months after treatment (Stapleton and DeVay, 1982, 1984).

Actinomycetes and *Bacillus* spp., many of which are thermotolerant were some times reduced to a much lesser extent (45-58%) or were even increased (26-158%) following solarization (Stapleton and DeVay, 1982). Increases in these thermo-tolerant bacteria may also increase disease resistance and crop growth (Stapleton and DeVay, 1984). Increased colonisation of (183-631%) of plant roots by plant growth promoting fluorescent pseudomonads from inoculated seed also occurred following soil solarization (Stapleton and DeVay, 1984). Increased count of pseudomonads in solarized soil was also observed by Meron *et al.* (1989) and Gamliel and Katan (1991).

Katan (1987) reported that saprophytic bacteria survive much better than fungi in heated soil. According to Kaewruang *et al.* (1989b) and Gamliel *et al.* (1989), solarization significantly increased the population of bacteria antagonistic to *F. oxysporum*, *F. solani* and *R. solani* at 0-10 cm depth, while Chandran (1989) and Sainamol (1992) failed to get an increased population of bacteria in solarized soil. According to Prakash and Mani (1991), bacterial populations increased during the first 30 days in both covered and uncovered soil but got decreased to 71.0 per cent in covered soil after 45 days.

Actinomycetes

Actinomycetes, many of which are thermotolerant, were some times reduced to a much lesser extent (45.58%) or were even increased (26-158%) following solarization (Stapleton and DeVay, 1984). Kaewruang *et al.* (1989b) reported that solarization significantly increased the population of actinomycetes (1.2 fold) antagonistic to *F. oxysporum, F. solani* and *R. solani* at 0-10 cm depth. Chandran (1989) and Sainamol (1992) noticed a slight increase in the actinomycetes population in solarized plots. Whereas, Gamliel and Katan (1991) reported that actinomycetes were less affected by solarization.

Effect of solarization on nematode population

Several workers have reported that there was effective control of nematodes in soil covered with polyethylene mulches (Grinstein *et al.*, 1979; Siti *et al.*, 1982; Choughan *et al.*, 1988; Nemli, 1990; Horiuchi, 1991; Sainamol, 1992). However, most of the information on nematode response to solarization was restricted to endoparasitic phytonematodes.

According to Stapleton and DeVay (1983), the extent of reduction on the population of nematodes by solarization depend on many factors including (a) degree of solar heating (b) crop and cropping history (c) nematode taxa involved (d) nematode distribution in the soil and (e) soil depth. Population reductions, varying from 42-100.0 per cent were achieved by soil solarization for species of plant parasitic nematodes in at least 10 genera including *Meloidogyne, Heterodera, Globodera, Pratylenchus, Ditylenchus, Paratrichodorus, Criconemella, Xiphenema, Helicotylenchus* and *Paratylenchus* (Hadar *et al.*, 1983; Stapleton and DeVay, 1983; Katan, 1984; LaMondia and Brodie, 1984). However, soil solarization has not been consistent in controlling root galling caused by *M. incognita* (Overman, 1981). Reductions in nematode populations and subsequent increased plant growth were often greater following solarization plus fumigant than with solarization alone.

Solarization was found to inhibit the population of *Criconemella* sp. (Stapleton and DeVay, 1983), *Ditylenchus* sp. (LaMondia and Brodie, 1984; Chandran, 1989); *Heterodera* sp. (Stapleton and DeVay, 1983); *Meloidogyne* spp. (Katan, 1984; Cartia *et al.*, 1991); *M. javanica* (Porter and Merriman, 1983; Cartia *et al.*, 1989; Abu-Gharbieh *et al.*, 1991); *M. incognita* (Stapleton *et al.*, 1987; Stapleton and Heald, 1992); *Paratylenchus* sp. (LaMondia and Brodie, 1984; Davis and Sorensen, 1986); *Tylenchulus semipenetrans* (Porter and Merriman, 1983; 1985) and *Xiphenema* sp. (Hadar *et al.*, 1983; Katan, 1984; Chandran, 1989).

Effect of solarization on weeds

The presence of dormant weed seeds in agricultural soils provides a source for persistent weed problems that often require repeated control measures. Control of a wide spectrum of weeds is one of the visible results of solarization. Annual weeds are usually more sensitive than perennials.

The possible mechanisms of weed control suggested by Katan (1981) are

(1) Thermal killing of weed seeds

(2) Thermal killing of seeds induced to germinate

(3) Breaking of seed dormancy and consequent killing of the germinating seed

(4) Biological control through weakening or other mechanisms

Solarization results in effective weed control lasted for a whole year or even longer (Horowitz, 1980; Bell and Laemmlen, 1991; Borges and Sequiera, 1992;

Sainamol, 1992). Successful control of the following weeds through solarization were reported.

Response of representative weeds to soil solarization

Weeds controlled	References
1	2
Ageratum conyzoides	Chandran (1989)
Alysicarpus sp.	Sainamol (1992)
Alternanthera sessilis	Chandran (1989)
Amaranthus sp.	Katan (1981), Elmore (1983), Horowitz *et al.* (1983), Rubin and Benjamin (1984), Stapleton and DeVay (1985), Villapudua and Munnecke (1987), Abdel-Rahim *et al.* (1988), Satour *et al.* (1991)
A. virdis	Sainamol (1992)
Brachiaria ramosa	Chandran (1989)
Cassia sp.	Sainamol (1992)
Centrosema sp.	Sainamol (1992)
Curculigo orchioides	Chandran (1989), Sainamol (1992)
Cynodon dactylon	Rubin and Benjamin (1984)
Cyperus rotundus	Katan *et al.* (1976)
Desmodium tridentata	Chandran (1989)
Digitaria sanguinalis	Elmore (1983), Porter and Merriman (1983), Daelemans (1989)
Euphorbia hirta	Sainamol (1992)
Hemidesmus indicus	Chandran (1989)
Hyptis suaveolens	Sainamol (1992)
Isachne miliacea	Chandran (1989)
Knoxia sp.	Sainamol (1992)

Contd.

1	2
Lindernia crustacea	Chandran (1989)
Merrimea tridentata	Chandran (1989)
Mimosa pudica	Sainamol (1992)
Oldenlandia corymbosa	Chandran (1989)
Phyllanthus niruri	Sainamol (1992)
Phyllanthus sp.	Sainamol (1992)
Portulaca oleracea	Horowitz *et al.* (1983), Abdel-Rahim *et al.*. (1988), Satour *et al.* (1991), Sainamol (1992)
Scoparia dulcis	Sainamol (1992)
Sida rhombifolia	Sainamol (1992)
Solanum nigrum	Elmore (1983), Porter and Merriman (1983)
Stachytarpheta indica	Sainamol (1992)
Vernonia sp.	Milevoj (1989)
Vernonia cineria	Sainamol (1992)
Weeds partly or not controlled	
Cynodon dactylon	Rubin and Benjamin (1983, 1984), Fahim *et al.* (1987), Prakash and Mani (1991)
Cyperus esculentum	Elmore (1983)
Cyperus rotundus	Egley (1983), Rubin and Benjamin (1983 , 1984), Fahim *et al.* (1987), Satour *et al.* (1991), Prakash and Mani (1991)
Malva niceaensis	Katan *et al.* (1980), Horowitz *et al.* (1983), Rubin and Benjamin (1983), Satour *et al.* (1991)
Orobanche	Horowitz *et al.* (1983), Prakash and Mani (1991)

Effect of solarization on Mycorrhizal and Rhizobial colonisation

The effect of solarization on mycorrhizal fungi has not been thoroughly explored. However, roots of annual and perennial crops growing in recently solarized soil were well colonised by vesicular-arbuscular mycorrhizae (VAM). Menge *et al.* (1979) observed the thermal death point of *Glomus fasiculatus* was 10 minutes at 51.5°C.

Mycorrhizal fungus, *Glomus fasiculatus* survived solarization and was able to colonise cotton roots (Pullman *et al.*, 1981b). However, no visible differences in the extent of root infection by VAM (*Glomus* spp.) between solarized and non-solarized roots of almond trees were noticed by Stapleton and DeVay (1984). Similar results were reported by Triolo *et al.* (1988) in lettuce plants.

Solarization for 30 days was found to increase mycorrhizal infection by 20.0 per cent in cowpea (Nair *et al.* 1990). Sainamol (1992) observed that colonization by VA mycorrhizae was more in roots of chilly plants grown in solarized soil (25.6%) than in control (7.2%). According to Afek *et al.* (1991), VAM colonization of roots of cotton, onion and pepper was maximum (65.0, 59.0 and 63.0 per cent respectively) in non-fumigated solarized fields. They also suggested that VAM combined with solarization can be one of the best approach to replace or at least reduce the use of chemicals in Agriculture.

Solarization caused a four fold reduction in the native *Rhizobium* population (ICRISAT, 1985). Similar results were also recorded by Abdel-Rahim *et al.* (1988) and Choughan *et al.* (1988). While, Nair *et al.* (1990) recorded a 104.7 per cent increase in root nodule count in cowpea grown in solarized fields.

Effect of solarization on soil properties and mineral nutrients

Plastic mulched and steamed soils usually contain higher levels of soluable mineral nutrients than untreated soils (Baker and Cook, 1974; Jones *et al.*, 1977). Significant increases in ammoniacal nitrogen, nitrate nitrogen, calcium, magnesium and electrical conductivity were consistently found. Phosphorus, potassium and chlorine increased in some soils, while other micronutrients (iron, manganese, zinc and copper) were not increased. Wet soil which was covered with polyethylene film but protected from solar heating did not differ in chemical properties from untreated control soil (Stapleton *et al.*, 1985) indicating that heating released soluable mineral nutrients from organic material and heat killed soil biota.

Studies of Kaewruang *et al.* (1989a & b) clearly showed that solarized soils had significantly higher levels of nitrate nitrogen (66.2%) and ammoniacal nitrogen (108.3%) at 0-10 cm depth in comparison with control. However, Hori *et al.* (1979) showed a decline in both nitrate nitrogen and ammoniacal nitrogen in solarized soil. Daelemans (1989) and Sainamol (1992) reported that solarization had no significant influence on the total nitrogen, N-nitrate, N-ammonium content of the top soil.

Availability of phosphorus was significantly increased by solarization (Stapleton *et al.* 1985). Kaewruang *et al.* (1989a) observed an increase in the phosphorus content by 157.9 per cent in the solarized soils. Similar results were obtained by Chandran (1989). Whereas, a significantly lower phosphate concentration in the solarized soil was reported by Kaewruang *et al.* (1989b), while Sainamol (1992) found no change on the available phosphorus content in solarized soil.

Kaewruang *et al.* (1989a), Chandran (1989) and Sainamol (1992) observed increased potassium content in the solarized soil.

Solarization exerted marked influence on the exchangeable cations. Availability of calcium, magnesium (Chen and Katan, 1980; Katan, 1980, 1981; Stapleton *et al.*, 1985; Sainamol, 1992), sodium (Sainamol, 1992) and chlorine (Chen and Katan, 1980) were found to be increased in solarized plots. Stapleton *et al.* (1985) observed that solarization did not consistently affect the availability of iron, manganese, zinc, copper and chlorine in the soil. According to Davis and Sorensen (1986) and Kaewruang *et al.* (1989a), solarization did not change the iron content in the soil.

According to Stapleton *et al.* (1989), solarization did not consistently affect the total organic matter content in the soil. While contradictory results were reported by Alkayassi *et al.* (1989) and Sainamol (1992).

The soil pH has not significantly influenced by solarization (Chen and Katan, 1980; Kaewruang *et al.*, 1989a and b).

Electrical conductivity, which is a function of total soluable salt concentration, increased (Chen and Katan, 1980; Sainamol, 1992) or did not alter (Kaewruang *et al.*, 1989a; Chandran, 1989) in solarized soil.

Increased plant growth response

Increased plant growth response is frequently observed in plants grown in solarized soil. Many theories have been put forward to explain the increased growth response of plants grown in solarized soil. Upon soil solarization, minerals are released and the nutritional status in soil is improved which results in increased yield. Other mechanisms for stimulation of plant growth are stimulation of beneficial organisms (Nair *et al.*, 1990), destruction of pathogens and nullification of toxins in soil (Katan, 1981) and production of beneficial chemicals like fulvic acid (Davis and Sorensen, 1986).

Increased plant growth and yield in carrot (Cartia *et al.*, 1987), cowpea (Chandran, 1989; Nair *et al.*, 1990), chillies (Cartia *et al.*, 1989; Sainamol, 1992), egg plant (Katan *et al.*, 1976), cotton (Katan *et al.*, 1983), onion (Satour *et al.*, 1989; Hartz *et al.*, 1989), potato (Davis, 1991) sugar beet (Stapleton and DeVay, 1984), tomato (Katan *et al.*, 1976), peach (Stapleton and DeVay, 1982) have been reported in plants grown in solarized soil.

Effect of solarization on insects and mites

Population of soil mite *Rhizoglyphus robini* which causes heavy damage to certain crops were drastically reduced by solar heating (Gerson *et al.*, 1981). Lazarovits *et al.* (1991a) observed that the numbers of arthropods extracted by Tullgreen funnels were low and there was no significant difference among plots or between upper and lower depths in pretreatment samples. They also found that there were no significant differences among non-solarized plots with the exception of astigmatid mites, which were significantly more in solarized plots following tarp removal. It was also observed that there were no significant difference in the counts of free living nematodes or soil borne arthropods and they found that the arthropods got re-colonized in solarized soils within a few months following the removal of the tarp.

Cost effectiveness of solarization

About 250-500 kg/ha of polyethylene, depending on its thickness (25-40 μm) and mode of application, are needed for soil mulching (Katan, 1981). The additional income obtained through solarization exeeds, with many vegetable crops, the cost of polyethylene and labour, but with the less expensive field crops the situation might be different.

The cost of pre-plant row coverage solarization in California was estimated at US $ 200-250/acre (4050 m^2) and solid coverage at US $ 350/acre (Pullman *et al.*, 1984). Thus solarization falls into the medium price range of soil disinfestation treatments. As solarization technology advances, eg. development of thinner but stronger films, use of photodegradable or biodegradable films (Everett and McLaughlin, 1975; Gilead, 1979) or more efficient film laying machinery (Hetzroni *et al.*, 1983) the overall cost of application should decrease. Moreover, the use of solarization may lower the requirement and expense of fertilizers (Stapleton *et al.*, 1985).

According to Martyn and Hartz (1985), the cost of solarization would be approximately $ 116/acre. This figure is based on typical watermelon production on 12 inch centers and stripping with four inch wide plastic in the center of the row. The probable benefits offered by solarization in the form of increased seed germination and stand establishment, increased plant growth, disease and weed control and water conservation, coupled with the decreasing availability and increased cost of virgin land, would well outweigh the extra $ 26/acre cost. The plastic after solarization could serve as a mulch for the following spring is an additional benefit.

Long term effect of solarization

The long term effect of solarization on disease control and yield increase extending for a second or even a third crop was observed in various regions with a variety of pathogens and crops (Katan, 1987). The requisites for a long term effect by solarization are a drastic reduction of pathogens inoculum to considerable soil suppressiveness to retard reinfestation from various sources. The long term effect possibly indicates that as a rule, solarization does not create a biological vaccum (Katan, 1987).

Solarization treatments for four weeks or more resulted in control of *Verticillium* wilt in cotton in two successive crops (Pullman *et al.*, 1981b). The incidence of *Fusarium* wilt of cotton in the third year after solarization was significantly lower, eventhough, the solarized plots were exposed to heavy reinfestation from surrounding soil (Katan *et al.*, 1983)

Tjamos and Paplomatas (1987) reported that beneficial effect of solarization in artichokes and olive trees lasted for two to three years. Soil solarization either singly or in combination with a reduced dosage of methyl bromide (34 g/m^2) was effective in controlling *Verticillium* wilt of globe artichokes for three successive cropping season (Tjamos and Paplomatas, 1988). This long term effect could at least partially be attributed to the activity of *T. flavus* in inhibiting the germination of microsclerotia or causing their death (Tjamos and Paplomatas, 1987, 1988). Long term effect of solarization in reducing corky root disease and broom rape in tomato was reported by Abdel-Rahim *et al.* (1988).

Materials and Methods

MATERIALS AND METHODS

Location of field experiment

The investigation on "Effectiveness of soil solarization for the control of soft rot disease in ginger" was undertaken at the College of Horticulture, Vellanikkara during March 1992 to December 1993. The field trials were conducted at the experimental plots of the College of Horticulture, Vellanikkara located at an altitude of 22.5 m above MSL, between 70° 32' N latitude and 76° 16' E longitude. The area has a typical warm humid tropical climate. The soil of the experimental field is of loamy laterite type of moderate fertility with a pH of 5.30.

Field experiment

Field experiments were carried out to study the effectiveness of soil solarization for the control of soft rot disease in ginger. The land used for the trial was left fallow for one year before the commencement of the field experiment. The land was then dug to a fine tilth. Clods and root bits were crushed or removed and the land was levelled properly. Raised beds of height 25 cm and size of 2 x 1 m were formed. The experimental plot was fenced all around to avoid trampling of mulch by stray animals. The field experiment was laid out during March 1992. The details of the experiment were as follows.

Crop	: Ginger, variety - Rio-de-janeiro
Design	: Factorial RBD
Spacing	: 25 x 25 cm
Number of plants per plot	: 32
Replications	: 3

The treatments

T_1 - Control

T_2 - Solarization for 30 days

T_3 - Solarization for 45 days

T_4 - Neem cake (500 g/sqm) amendment

T_5 - Neem cake + solarization for 30 days

T_6 - Neem cake + solarization for 45 days

T_7 - Neem leaves (1 kg/sqm) amendement

T_8 - Neem leaves + solarization for 30 days

T_9 - Neem leaves + solarization for 45 days

T_{10} - *Trichoderma harzianum* Rifai. (125 g/sqm)

T_{11} - *Trichoderma* + solarization for 30 days

T_{12} - *Trichoderma* + solarization for 45 days

T_{13} - *Trichoderma* + Neem cake

T_{14} - *Trichoderma* + Neem cake + solarization for 30 days

T_{15} - *Trichoderma* + Neem cake + solarization for 45 days

T_{16} - *Trichoderma* + Neem leaves

T_{17} - *Trichoderma* + Neem leaves + solarization for 30 days

T_{18} - *Trichoderma* + Neem leaves + solarization for 45 days

T_{19} - Bordeaux mixture drenching (2.5 l/sqm)

T_{20} - Bordeaux mixture + solarization for 30 days

T_{21} - Bordeaux mixture + solarization for 45 days

Isolation and purification of the pathogen

The pathogen causing soft rot disease of ginger, used for the study was isolated from the naturally diseased rhizomes using standard isolation techniques

(Riker and Riker, 1936). The pathogen was identified as *Pythium aphanidermatum* by comparing the characters of the isolate with the type culture available at the Department of Plant Pathology, College of Horticulture, Vellanikkara. The pure culture of the fungus was maintained in potato dextrose agar medium. Koch's postulates were established using the isolate on Rio-de-janeiro, variety of ginger.

Mass multiplication of *P. aphanidermatum*

The pathogen *P. aphanidermatum* was mass multiplied on sand oats medium, sterilized paddy seeds, sterilized red rice, ginger rhizome bits and potato dextrose agar medium.

Sand oats medium

Sand oats medium was prepared by mixing washed white sand with oat meal in the ratio 19:1. This mixture was taken in 1000 ml conical flasks moistened with water and sterilized by autoclaving at 1.02 kg/cm^2 pressure for 20 minutes. Actively growing culture bits were aseptically introduced into the flasks containing sterilized sand oats medium and were incubated for two weeks at room temperature before incorporating in the field.

Paddy seeds and red rice

Fifty gram of paddy (with 25 ml water) or red rice (with 50 ml water) were taken in 250 ml conical flasks and sterilized by autoclaving at 1.02 kg/cm^2 pressure for 20 minutes. They were inoculated with *P. aphanidermatum* and incubated at room temperature for two weeks and used for soil inoculation.

Ginger rhizome bits

Healthy surface sterilized ginger rhizomes (variety - Rio-de-janeiro) were cut into small bits and inoculated with seven day old culture of *P. aphanidermatum* and were kept in aseptic moist chambers and incubated at room temperature till complete rotting of the rhizomes bits took place. The rotted rhizome bits were mixed with soil (1 kg rhizome bits/2 kg of soil) and used for field inoculation.

Potato dextrose agar

Fifteen day old culture of *P. aphanidermatum* grown on potato dextrose agar was also used to inoculate soil at the rate of 10 culture plates (9 cm diameter) per kg of soil. The soil after mixing with the fungal growth was sieved twice in order to get a uniform distribution of the pathogen.

Mass multiplication of *Trichoderma harzianum* Rifai.

T. harzianum available in the Department of Plant Pathology, College of Horticulture, Vellanikkara was used for the present investigation. *T. harzianum* was found to suppress *P. aphanidermatum* under laboratory conditions. The fungus was mass multiplied on sterilized rice bran (Henis *et al.*, 1979).

Soil inoculation with *Pythium aphanidermatum*

For soil inoculation, the fungus (*P. aphanidermatum*) grown on sand oats medium, paddy seeds, red rice, ginger bits and potato dextrose agar were used. All the five types of inocula were mixed well and uniformly applied in every plot to a depth of 5 cm. After incorporating, the plots were watered daily. Soil inoculation was carried out five days before mulching with polyethylene sheets in solarized as well as non-solarized plots.

Soil inoculation with *T. harzianum* Rifai.

Two hundred and fifty grams of *T. harzianum* grown on rice bran was incorporated uniformly into beds requiring its inoculation, just before mulching with polyethylene sheets in solarized as well as in non-solarized plots.

Soil application of neem cake, neem leaves and Bordeaux mixture

In plots requiring incorporation of neem cake, powdered neem cake was applied at the rate of 500 g/m^2. While fresh neem leaves were incorporated at the rate of 1 kg/m^2, Bordeaux mixture was drenched at the rate of 2.5 l/m^2 in plots requiring this treatment. All these treatments were applied just before mulching with polyethylene sheets in solarized plots and in non-solarized plots on the same day.

Mulching with polyethylene sheets

Five days after inoculation of *P. aphanidermatum* in soil, the beds requiring solarization were mulched with transparent 150 gauge polyethylene sheets. The beds for solarization were levelled and the pebbles present on the surface were removed. The levelled beds were irrigated at the rate of 5 l/m^2 and mulched with polyethylene sheets manually as shown in Plate 1. The edges of the sheet were covered with soil to keep the sheets in position. Adequate care was taken to keep the sheets in close contact with the soil and to prevent the formation of air pockets between the soil and the sheets. The polyethylene sheets were removed 30 or 45 days after mulching depending on the treatment.

Soil temperature

Soil temperatures at depths of 5, 10 and 15 cm from solarized and non-solarized soil were recorded. For this, soil thermometers were installed in the centre of the bed at depths of 5, 10 and 15 cm. In solarized plots, the hole made for inserting the thermometer was neatly covered with cellophane tape. Soil temperatures were recorded daily at 8.30 am and 2.30 pm. Soil temperature in solarized soil was recorded only 24 h after mulching in order to stabilize the temperature under the mulch.

Planting

Seed ginger (variety, Rio-de-Janeiro) obtained from Regional Agricultural Research Station, Ambalavayal was used for the study. The seed rhizomes were soaked in water containing 0.3 per cent Indofil M-45 and 0.05 per cent Quinalphos for 30 minutes as a prophylactic measure to check the seed borne fungal and scale infection. The soaked rhizomes were spread in shade to drain off the excess water and were stored in paddy chaff till sowing. Seed rhizomes were also treated similarly with fungicide and insecticide mixture just before planting. Seed rhizomes having one or two viable healthy buds and weighing approximately 15.0 g were used for planting. Polyethylene sheets were removed from all the plots on 5-5-92 and planting was done on the same day. All the agricultural operations were conducted as per the Package of Practices Recommendations (Kerala Agricultural University, 1989).

Germination

The number of rhizomes germinated in each plot were counted up to 45 days to work out the germination per cent.

Disease incidence

Pre-emergence rotting

The non-germinated rhizomes were removed and the identity of the pathogenic organism was established by isolating the causal organism.

Post-emergence rotting

The number of plants showing rotting symptoms were counted and uprooted at fortnightly interval. The identity of the causal agent was established by isolating the pathogen from the diseased plants.

Incidence of *Phyllosticta* leaf spot

The intensity of *Phyllosticta zingiberi* infection was recorded by using a score card having nine grades from 0-8 and the disease index was calculated by the method of Premanathan *et al.* (1980).

Biometric observations

Five plants at random were tagged in each plot for studying the biometric observations. Observations from these plants were taken one, two and three months after planting.

Height of the plant

Distance from base of the main pseudostem to tip of the top most leaf was taken as height of the plant.

Number of tillers per plant

The number of tillers was determined by counting the number of aerial shoots.

Number of leaves per plant

The number of leaves was determined by counting number of leaves of all the aerial shoots.

Length and breadth of leaf

Length and breadth of the last fully opened leaf of the main tiller was measured. Length was taken from base to tip of the leaf while, breadth was measured from the centre of the leaf.

Length of petiole

The bottom most leaf was used for measuring length of petiole. Length was measured from top of the rhizome to base of the leaf.

Harvesting

The crop was harvested 230 days after planting, when the aerial parts of the plants were dried up completely. Five plants/plot selected at random were uprooted individually for taking the post harvest observations. The rest of the plants were harvested for recording the total yield per plot.

Post harvest observations

Number of roots, length of roots, fresh weight of shoot and fresh weight of rhizomes were recorded by uprooting one plant from each plot after one, two and three months after planting.

Number and length of roots

The total number of roots produced by the plants were recorded separately and their mean was calculated. Five roots were selected at random from each plant for measuring the length.

Number of fingers

The number of rhizomes originating from the seed rhizomes and those originating from the primary rhizomes were counted and recorded at the time of harvest as the number of fingers.

Yield of rhizome

Five plants, selected at random from each plot, were harvested separately and the weights of their rhizomes were recorded. From this, the individual plant yield was calculated by taking the average weight of the rhizomes obtained from those five selected plants.

The plot yield was recorded by taking the weight of the entire rhizomes harvested from each plot of size 2 x 1 m^2.

Laboratory studies

Collection of soil samples

From each bed, soil samples were collected randomly from four different locations at a depth of 0-10 cm and mixed. This was used for estimating microbial population and also for chemical analysis. Soil samples were collected before mulching, immediately after removing the polyethylene sheets, one, two, three and six months after planting and at the time of harvest.

Estimation of *Pythium* population

Fifty mg of soil collected from the bed was sprinkled uniformly in a petriplate and approximately 20 ml of the cooled selective medium (Peethambaran and Singh, 1977) was poured over it. The plates were rotated before solidification of the medium in order to get a uniform distribution of the soil particles. The plates were incubated at 25-30°C for three days and the colonies were counted.

Estimation of microbial population

Population of fungi, bacteria and actinomycetes from the soil samples was estimated by Serial Dilution Plate Technique (Johnson and Curl, 1972). Martin's rosebengal streptomycin agar, Thornton's standardisation medium and Kenknight's agar were used for estimating fungi, bacteria and actinomycetes respectively.

The population of *Pseudomonas* sp. from the soil samples was estimated by serial dilution plate technique using triphenyl tetrazolium chloride agar-TZC (Kelman, 1954).

Estimation of VA Mycorrhizae association

The VAM index was estimated by observing 100 root bits at random, of approximately one cm length from each treatment. The root bits were stained with 0.5 per cent trypan blue following the procedure of Phillips and Hayman (1970) and the percentage infection was recorded.

Estimation of *Azospirillum* association

Azospirillum was isolated from the root samples using nitrogen free bromothymol blue (NFb) semi solid malate medium (Dobereiner *et al.*, 1976).

Estimation of nematode population

Nematode population was estimated by modified Baerman's Funnel Technique of Christie and Perry (1951).

Weed population

Weeds present in the field before solarization were identified before preparation of the land in each of the beds. All the weeds were removed while preparing the land. The weed population in each bed, immediately after removing the polyethylene mulch, one, two, three and six months after planting and on the day of the harvest were recorded. In all cases once the count was made, all the weeds present in the beds were removed. Weeds on the top and sides of the beds were counted separately. Fresh weight of the weeds were recorded two, three and six months after planting and on the day of the harvest.

Chemical analysis of soil samples

In order to find out the effect of solarization on the nutrient status of the soil, different plant nutrients before solarization, after solarization, three months after planting and at the time of harvest were estimated.

Nitrogen

Available nitrogen was determined by alkaline permangnate method (Subbiah and Asija, 1956).

Phosphorus

Available phosphorus in the soil was extracted in Bray No. 1 dilute acid fluoride solution (Bray and Kurtz, 1945) and estimated by ascorbic acid blue colour method (Watnabe and Oleson, 1965). The intensity of the colour was measured in Klett Summerson photo electric colorimeter.

Potassium

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

Organic carbon

Organic carbon was determined by the Walkley and Black's rapid titration method as described by Hesse (1971).

Electrical conductivity

Electrical conductivity was measured by extraction in distilled water (1:2.5) using Elico conductivity bridge.

pH

The pH of the soil was read in a 1:2.5 soil water suspension using Elico digital pH meter.

Cost effectiveness of solarization

The benefit/cost ratio for solarizing one hectare of ginger field was calculated.

Meteorological data

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

Long term effect of solarization

The long term effect of soil solarization against soft rot of ginger was evaluated during 1993 crop season. For this, the beds used for growing ginger during 1992 season were replanted with ginger during 1993 cropping season without any additional treatment. Fresh ginger seed material of variety Rio-de-janeiro obtained from the Regional Agricultural Research Station, Ambalavayal was used for planting during 1993 season also. Details on incidence of pre-emergence rotting and post-emergence rotting (soft rot) were recorded from these beds. The crop was harvested, 223rd day after planting.

Results

RESULTS

Isolation and purification of pathogen

The pathogen causing soft rot of ginger was isolated from naturally infected ginger rhizomes. The isolate was purified by hyphal tip method and maintained on potato dextrose agar slants by periodic subculturing. Koch's postulates were confirmed on ginger variety Rio-de-Janeiro. Based on the characters, the fungus causing soft rot of ginger was identified as *Pythium aphanidermatum* (Edson) Fitzpatrick.

Soil temperature

Temperatures of the solarized and non-solarized soil were recorded during the entire period of solarization by installing soil thermometers at 5, 10 and 15 cm depths.

Soil temperatures at 8.30 am and 2.30 pm at depths of 5, 10 and 15 cm; atmospheric temperature; rainfall and sunshine hours from 21-3-92 (the date of mulching) to 5-5-92 (the date of removal of polyethylene sheets) are presented in Table 1.

The atmospheric temperature during the period (21-3-92 to 4-5-92) ranged from 23.0°C to 39.4°C and the soil temperature at 5 cm depth in non-solarized soil ranged from 27.50°C to 49.50°C. The corresponding values for solarized soil were 30.0°C to 63.0°C, respectively (Table 1).

The variation in temperature in non-solarized soil at 5 cm depth during the period under observation was 22.0°C, while, in solarized soil it was 33.0°C. The

Table 1. Maximum and Minimum atmospheric temperature, soil temperature, rainfall and sunshine during the solarization period (21-3-92 to 4-5-92)

Date	Atmospheric temperature °C		Soil temperature of solarized soil °C						Neem leaves amended solarized soil		Soil temperature of Non-solarized soil °C						Rainfall (mm)	Sunshine (h)
	Min.	Max.	5 cm		10 cm		15 cm		5 cm		5 cm		10 cm		15 cm			
			8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
21-3-92	23.5	39.2	32.0	56.0	32.0	46.0	33.0	40.0	26.0	51.0	29.0	45.5	30.0	39.5	32.0	35.0		8.1
22-3-92	23.8	39.1	32.0	57.0	37.0	50.0	34.0	41.0	32.0	52.0	29.5	46.0	30.5	40.0	32.5	35.5		9.5
23-3-92	23.0	38.0	30.0	56.0	37.0	50.0	34.5	41.5	30.0	52.0	30.0	45.0	31.0	39.0	32.5	35.5		8.1
24-3-92	24.0	37.0	30.0	59.0	38.0	50.0	34.0	42.0	30.0	54.0	30.0	46.0	31.0	39.5	32.0	35.5		7.0
25-3-92	23.2	35.2	35.0	54.0	37.0	49.0	34.5	40.5	34.0	50.0	30.0	43.0	31.0	37.0	32.5	35.0		5.2
26-3-92	23.6	38.1	35.0	59.0	36.0	55.0	34.0	42.0	34.0	51.0	30.5	46.5	31.0	40.0	32.0	35.5		9.5
27-3-92	23.4	36.9	35.0	60.0	37.0	52.0	35.0	43.0	35.0	54.0	30.5	40.7	31.0	40.0	32.5	36.0		9.8
28-3-92	23.5	35.4	35.0	59.0	38.0	54.0	35.5	43.0	35.0	51.0	31.0	46.0	31.5	39.5	32.0	36.0		9.2
29-3-92	24.4	36.0	36.0	60.0	39.0	53.0	36.0	44.0	36.0	56.0	31.0	47.0	32.0	40.5	33.0	36.5		9.9
30-3-92	24.4	36.4	38.0	60.0	39.0	54.0	36.5	44.5	38.0	56.0	31.5	47.5	32.5	41.0	33.5	37.0		9.8
31-3-92	24.0	36.5	38.0	61.0	38.0	54.0	36.5	45.0	38.0	57.0	30.5	48.0	32.5	41.5	33.5	37.0		10.0
1-4-92	24.2	36.5	38.0	60.0	40.0	54.0	37.0	44.0	38.0	55.0	31.0	45.5	32.5	41.0	34.0	36.5		8.7
2-4-92	23.6	39.4	38.0	61.0	40.0	55.0	36.5	45.0	38.0	57.0	31.5	47.0	32.0	40.5	33.5	36.5		10.0
3-4-92	24.2	36.5	36.0	61.0	40.0	55.0	37.0	45.5	39.0	57.0	31.0	48.5	32.5	41.5	34.0	37.0		10.4
4-4-92	24.2	35.5	37.0	60.0	40.0	53.0	37.0	44.0	38.0	55.0	31.5	46.5	33.0	40.5	34.0	37.0		8.1
5-4-92	23.0	34.8	37.0	60.0	40.0	54.0	36.5	45.0	37.0	58.0	31.0	48.0	32.0	41.0	33.5	37.0		10.0
6-4-92	23.4	35.0	38.0	61.0	40.0	54.0	37.0	45.0	38.0	57.0	31.5	48.0	32.5	41.0	34.0	37.0		9.2
7-4-92	24.6	35.0	38.0	54.0	40.0	50.0	37.0	42.5	38.0	47.0	32.0	44.5	33.0	39.5	34.0	36.5		7.7
8-4-92	25.0	35.5	38.0	55.0	40.0	50.0	36.5	42.0	37.0	52.0	32.0	44.0	32.5	39.0	33.5	36.0		7.4
9-4-92	25.5	35.9	39.0	59.0	40.0	54.0	36.5	44.0	39.0	55.0	33.0	47.0	33.0	40.5	34.0	37.0		9.1

Contd.

Table 1. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
10-4-92	25.2	36.0	38.0	55.0	40.0	54.0	37.0	43.5	38.0	52.0	32.5	46.5	33.5	40.5	34.5	37.0		8.6
11-4-92	25.0	36.2	38.0	60.0	40.0	53.0	37.0	43.5	38.0	56.0	32.5	47.0	33.5	40.5	34.5	36.5		9.6
12-4-92	24.0	37.2	36.0	60.0	40.0	53.0	37.0	44.0	37.5	55.5	32.5	47.0	33.0	41.0	34.0	38.0		9.9
13-4-92	24.0	35.8	39.0	59.0	41.0	54.0	37.5	44.5	39.0	55.0	32.0	47.0	33.0	41.0	34.5	37.0		8.9
14-4-92	24.5	36.2	38.0	60.0	39.0	56.0	37.0	46.0	39.0	57.0	32.5	48.0	33.0	42.0	34.0	38.0		9.9
15-4-92	25.0	36.1	39.0	60.0	39.0	55.0	38.0	45.0	40.0	58.0	33.5	48.0	33.5	41.5	34.5	37.5		9.6
16-4-92	24.6	37.6	39.0	63.0	38.0	59.0	37.5	46.5	39.0	60.0	32.5	49.5	33.5	42.5	34.5	38.0		10.7
17-4-92	25.3	37.2	39.0	58.0	41.0	54.0	38.5	46.0	39.0	55.0	33.5	46.0	34.0	41.0	35.5	38.0		5.6
18-4-92	23.9	36.6	35.0	51.0	35.2	49.0	35.5	40.5	33.0	50.0	30.0	42.0	35.0	38.0	35.0	36.0		4.9
19-4-92	24.0	35.9	38.0	60.0	40.0	55.0	36.0	45.5	40.0	56.0	32.0	48.0	32.5	41.5	34.0	38.0		9.2
20-4-92	24.4	36.5	39.0	58.0	42.0	53.0	37.5	43.0	40.0	55.0	32.5	46.0	33.0	40.0	34.5	37.0		9.0
21-4-92	25.1	36.8	39.0	60.0	40.0	55.0	38.0	45.0	39.0	58.0	33.0	48.5	33.5	41.5	35.0	38.0		7.8
22-4-92	25.0	36.4	39.0	59.0	41.0	54.0	38.0	44.5	40.0	56.0	33.0	48.5	33.5	41.0	35.0	37.5		9.5
23-4-92	25.0	36.5	40.0	61.0	41.0	57.0	38.0	45.5	40.0	59.0	33.5	49.0	33.5	42.0	35.0	38.0		10.1
24-4-92	25.4	37.4	39.0	59.0	41.0	55.0	38.5	45.0	40.0	55.0	33.5	48.0	34.0	41.5	35.5	38.0		7.4
25-4-92	24.0	37.8	38.0	60.0	40.0	56.0	37.0	46.0	38.0	59.0	29.0	46.5	30.5	42.5	33.0	37.5	8.2	7.6
26-4-92	23.0	35.5	34.0	54.0	32.0	50.0	35.5	40.5	32.0	55.0	27.5	37.0	28.5	34.5	30.5	33.0	35.4	3.8
27-4-92	23.5	34.2	36.0	60.0	39.0	53.0	35.0	43.0	37.0	58.0	28.5	39.0	28.5	36.5	29.5	34.0	5.0	9.5
28-4-92	24.0	35.3	38.0	60.0	40.0	55.0	36.5	44.5	38.0	59.0	29.0	45.0	28.0	40.5	30.5	36.5		11.5
29-4-92	25.0	36.4	39.0	60.0	40.0	55.0	37.0	45.0	39.0	58.0	31.0	46.0	30.5	41.5	32.0	38.0		10.1
30-4-95	25.6	35.5	39.0	60.0	42.0	54.0	38.0	45.5	40.0	58.0	32.5	46.0	31.5	42.0	33.0	39.0		10.7
1-5-92	24.5	35.5	39.0	60.0	40.0	54.0	37.5	45.5	40.0	57.0	32.0	46.0	31.5	42.0	33.5	39.0		10.0
2-5-92	25.5	36.0	40.0	60.0	41.0	53.0	38.0	45.0	40.0	57.0	33.0	45.5	32.0	41.5	34.0	39.0		10.2
3-5-92	25.6	36.5	40.0	62.0	41.0	56.0	38.0	45.0	40.0	58.0	34.0	47.0	32.0	43.0	34.0	40.0		10.8
4-5-92	26.5	35.5	41.0	54.0	51.0	39.0	39.0	45.0	41.0	52.0	34.5	43.0	33.5	40.5	35.0	39.0		5.8

corresponding variation in atmospheric temperature was only 16.4°C. Maximum temperature variation observed during a day in non-solarized soil was 17.5°C (on 31-3-92 and 3-4-92), while, in solarized soil it was 29.0°C (24-3-92) and the minimum temperature variation in solarized and non-solarized soils were 13.0°C and 8.5°C respectively (4-5-92) (Table 1). In general, the average daily variation in the soil temperature in non-solarized plots during the period was 14.47°C compared to 21.58°C in solarized soil.

The maximum temperature (2.30 pm) at 5 cm depth in non-solarized soil ranged from 37.0°C to 49.5°C compared to 51.0°C to 63.0°C in solarized soil. Similarly, the temperature at 8.30 am ranged from 27.5°C to 34.5°C in non-solarized soil compared to 30.0°C to 41.0°C in solarized soil (Table 1).

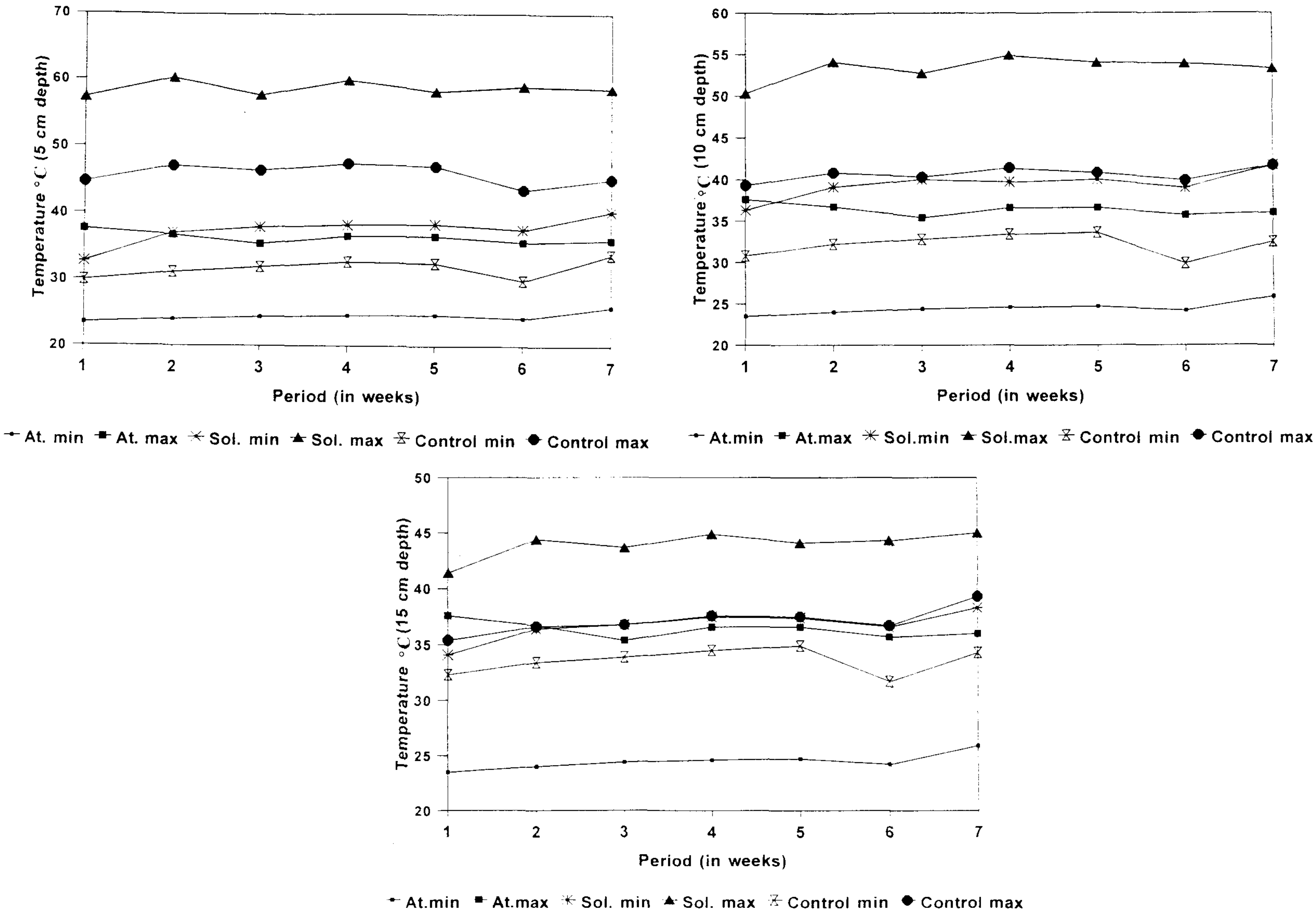
When the weekly average temperature of the solarized soil and non-solarized soil at 5 cm depth was taken into consideration, it was observed that the weekly average maximum temperature (2.30 pm) in solarized soil ranged from 57.3°C to 60.3°C with a mean of 58.8°C. The corresponding figures in non-solarized soil were 44.7°C to 47.5°C and 45.9°C, respectively (Table 2, Fig.1). The mean minimum temperature of the solarized soil ranged from 32.7°C to 40.3°C with an average of 37.5°C compared to 29.9°C to 33.8°C and 31.7°C, respectively in non-solarized soil. In the solarized soil, the average weekly mean temperature difference was 21.3°C (37.5-58.8°C) and 14.2°C (31.7-45.9°C) in non-solarized soil.

Temperature at 10 cm depth ranged from 32.0-59.0°C in solarized soil and 28.0-43.0°C in non-solarized soil. The variation in temperature during the entire period of observation in solarized soil at 10 cm depth was 27.0°C compared to 15.0°C in non-solarized soil. The temperature recorded at 2.30 pm at 10 cm depth in

Table 2. Atmospheric and soil temperatures during the period of solarization (21.3.92 to 4.5.92) Weekly mean

Week	Atmospheric temperature		Soil temperature °C														
	Minimum	Maximum	Solarized soil						Neem leaves amended solarized soil		Non-solarized soil					
			5 cm		10 cm		15 cm		5 cm		5 cm		10 cm		15 cm	
			8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm	8.30 am	2.30 pm
1	23.5	37.6	32.7	57.3	36.3	50.3	34.1	41.4	31.6	52.0	29.9	44.7	30.8	39.3	32.3	35.4
2	24.0	36.7	37.0	60.3	39.1	54.1	36.4	44.4	37.4	55.6	31.1	47.1	32.2	40.8	33.4	36.6
3	24.4	35.4	37.9	57.7	40.0	52.7	36.8	43.7	37.9	53.7	31.9	46.4	32.8	40.3	33.9	36.8
4	24.6	36.6	38.3	60.0	39.7	54.9	37.5	44.9	38.8	56.6	32.7	47.5	33.4	41.4	34.5	37.6
5	24.7	36.6	38.4	58.3	40.0	54.0	37.4	44.1	38.9	55.6	32.5	47.1	33.6	40.8	34.9	37.5
6.	24.2	35.7	37.6	59.1	39.0	53.9	36.6	44.3	37.7	57.7	29.9	43.6	29.9	39.9	31.7	36.7
7	25.9	36.0	40.3	58.7	41.7	53.3	38.3	45.0	40.3	55.7	33.8	45.2	32.5	41.7	34.3	39.3
Average	24.5	36.4	37.5	58.8	39.4	53.3	36.7	44.0	37.5	55.3	31.7	45.9	32.2	40.6	33.6	37.1

Fig.1. Atmospheric and soil temperature (weekly mean) during the soil solarization period (21/3/92 to 4/5/92)



solarized soil ranged from 49.0°C to 59.0°C, while the maximum temperature in non-solarized soil (43.0°C) was less than the least temperature recorded in solarized soil at 2.30 pm (Table 1). At this depth, the average maximum temperature ranged from 50.3°C to 54.9°C with a mean of 53.3°C in solarized soil compared to 39.3°C to 41.7°C and 40.6°C in non-solarized soil (Table 2, Fig.1). In solarized soil, the weekly average mean temperature difference was 13.9°C (39.4-53.3°C), while it was only 8.4°C (32.2-40.6°C) in non-solarized soil.

Soil temperature at 15 cm depth ranged from 34.0°-46.5°C in solarized soil compared to 29.5°-40.0°C in non-solarized soil. The variation in temperature in solarized and non-solarized soil was 12.5°C and 10.5°C respectively. The maximum temperature variation attained during a day was 9.5°C (on 19-4-92) in solarized soil as against 6.0°C in non-solarized soil (Table 1). The weekly average maximum temperature at this depth ranged from 41.4°C-45.0°C with an average of 44.0°C in solarized soil. While, the corresponding values were 35.4°C-39.3°C and 37.1°C in non-solarized soil (Table 2, Fig.1).

In solarized soil, the soil temperatures were 7.0°-23.6°C, 9.0°-19.6°C and 11.0°-7.1°C above atmospheric temperature respectively at 5, 10 and 15 cm depth, while, the corresponding values in non-solarized soil were 4.5°-10.1°C, 5.0°-3.6°C and 6.5°-0.6°C respectively.

At 10 cm depth, the variation in the temperature in solarized soil was 6.0°C less than that observed at 5 cm. But at 15 cm depth, the variation was 20.5 and 14.5°C lesser than that observed at 5 and 10 cm depths. Whereas, the non-solarized soil at 15 cm depth showed only 11.5 and 4.5°C lesser variation at 5 and 10 cm depths respectively.

In solarized soil at 5 cm depth, soil temperature was above 50.0°C for the entire period of solarization and above 55.0°C for 38 out of 45 days of solarization. While at 10 cm depth, soil temperature was above 50.0°C for 35 days and above 55.0°C for 5 days. At 15 cm depth, the maximum temperature recorded was 46.5°C and the soil temperature above 40.0°C was observed for 44 days (Table 1).

The weekly average maximum temperature recorded in solarized soil at 15 cm depth was 14.8°C and 9.3°C less than that recorded at 5 and 10 cm depths. Unlike the variations in maximum temperature, the variation in the minimum temperature in solarized soil at 15 cm depth was only less than 2.7°C and 0.8°C at 10 and 5 cm depths. Whereas the minimum temperature variation in the non-solarized soil at 15 cm depth was 1.9°C and 1.4°C more than that of 5 and 10 cm depths.

Soil temperature in neem leaves amended solarized soil at 5 cm depth ranged from 30.0°-60.0°C and it was 7.0°-20.6°C above the atmospheric temperature (Table 1). The variation in maximum and minimum temperature (30.0°C) in this treatment was 3.0°C lower than that observed in solarized soil. The maximum temperature variation of 24.0°C observed during a day (on 24-3-92) in neem leaves amended soil was 5.0°C less than the temperature in solarized soil recorded on the same day. The maximum temperature in this treatment was above 50.0°C for 42 days and above 55.0°C for 24 out of 45 days of solarization. The weekly average maximum temperature in neem leaves amended solarized soil ranged from 52.0°-57.7°C with a mean of 55.3°C (Table 2, Fig.1). The corresponding figures in solarized soil were 57.3°C-60.3°C with a mean of 58.8°C.

After mulching, heat build up occurred within 24-48 hours. Whenever a heavy rain was obtained, the soil temperature in solarized soil as well as non-solarized soil dropped down. However, in solarized soils, within 24 hours, the heat build up occurred and normal temperature was regained. On 25-4-92, there was 8.2 mm rain and the maximum temperature in solarized soil dropped from 60°C to 54.0°C at 5 cm depth on 26-4-92. The temperature under the mulch regained within 24 hours and on 27-4-92, the temperature was again 60.0°C at 5 cm depth.

The sunshine hours during the solarization period ranged from 3.8-11.5 h (Table 1).

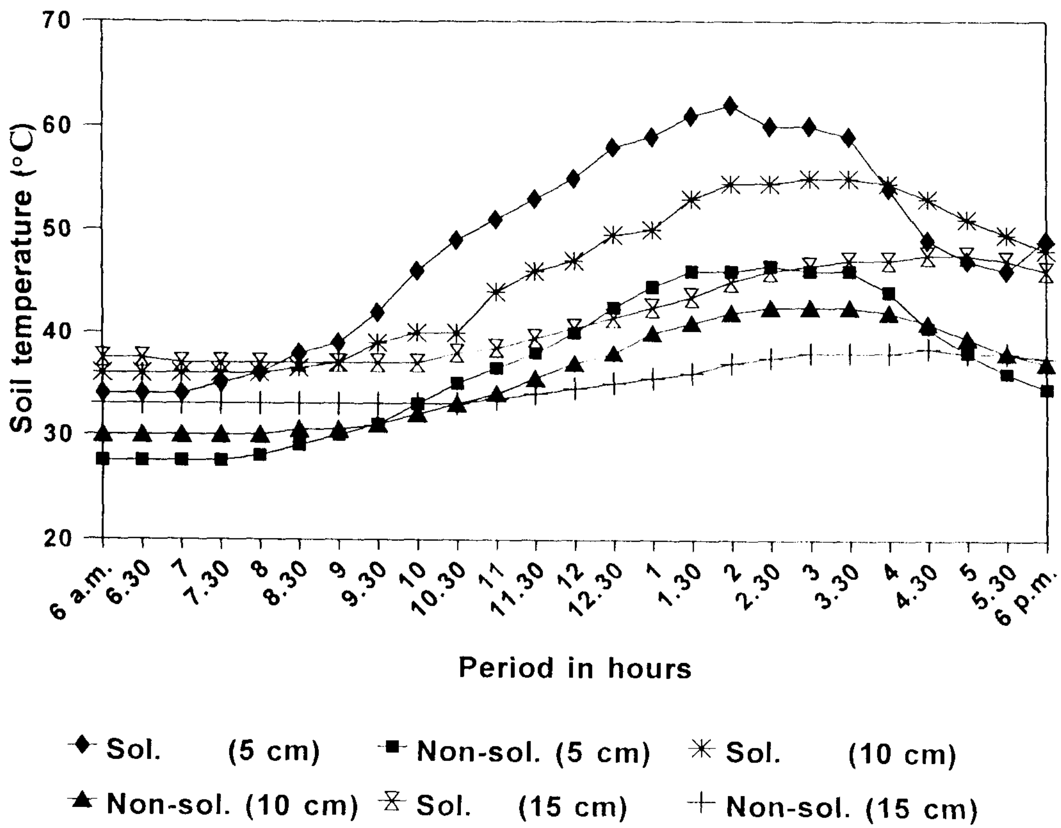
Fluctuations in soil temperature at 30 minutes interval for a period of 12 hours from 6 am to 6 pm was recorded on 25-4-92 at depths of 5, 10 and 15 cm in solarized and non-solarized soil (Table 3, Fig.2). In general. there was a gradual increase in temperature from 6 am to 3.30 pm. The maximum heat build up was at 2.00 to 3.00 pm. This trend was common for solarized and non-solarized soils. Maximum increase in temperature was noticed at a depth of 5 cm in solarized soil. Maximum temperatures of 62.0°C, 55.0°C and 47.5°C recorded in solarized soil on that day at depths of 5, 10 and 15 cm were 15.5°C, 12.5°C and 9.0°C more than that recorded in non-solarized soils.

The fluctuations in temperature on 25-4-92 narrowed down at lower levels. The fluctuations in solarized and non-solarized were 28°C (34.0-62.0°C) and 19.5°C (27.5-46.5°C) at 5 cm depth and 19°C (36.0-55.0°C), 12.5°C (30.0-42.5°C) at 10 cm depths (Table 3).

Table 3. Temperature of soil at different depths in solarized and non-solarized on 25-4-92 at 30 minutes interval from 6 am to 6 pm

Time	Soil temperature °C					
	5cm		10 cm		15 cm	
	Solarized soil	Non-solarized soil	Solarized soil	Non-solarized soil	Solarized soil	Non-solarized soil
6am	34.0	27.5	36.0	30.0	37.5	33.0
6.30	34.0	27.5	36.0	30.0	37.5	33.0
7.00	34.0	27.5	36.0	30.0	37.0	33.0
7.30	35.0	27.5	36.0	30.0	37.0	33.0
8.00	36.0	28.0	36.0	30.0	37.0	33.0
8.30	38.0	29.0	36.5	30.5	37.0	33.0
9.00	39.0	30.0	37.0	30.5	37.0	33.0
9.30	42.0	31.0	39.0	31.0	37.0	33.0
10.00	46.0	33.0	40.0	32.0	37.0	33.0
10.30	49.0	35.0	40.0	33.0	38.0	33.0
11.00	51.0	36.5	44.0	34.0	38.5	33.5
11.30	53.0	38.0	46.0	35.5	39.5	34.0
12.00	55.0	40.0	47.0	37.0	40.5	34.5
12.30	58.0	42.5	49.5	38.0	41.5	35.0
1 pm	59.0	44.5	50.0	40.0	42.5	35.5
1.30	61.0	46.0	53.0	41.0	43.5	36.0
2.00	62.0	46.0	54.5	42.0	45.0	37.0
2.30	60.0	46.5	54.5	42.5	46.0	37.5
3.00	60.0	46.0	55.0	42.5	46.5	38.0
3.30	59.0	46.0	55.0	42.5	47.0	38.0
4.00	54.0	44.0	54.5	42.0	47.0	38.0
4.30	49.0	40.5	53.0	41.0	47.5	38.5
5.00	47.0	38.0	51.0	39.5	47.5	38.0
5.30	46.0	36.0	49.5	38.0	47.0	38.0
6 pm	49.0	34.5	48.0	37.0	46.0	37.5

Fig. 2 Temperature of soil at different depths in solarized and non-solarized soil on 25/4/92 at 30 min interval from 6 a.m. to 6.p.m.



On this day (25-4-92), the solarized plots at 5 cm and 10 cm depths had a temperature greater than 45.0°C for eight hours and 6.5 hours and 40°C for 8.5 hours and eight hours, respectively. In untarped plots soil temperature reached 45.0°C only at 5 cm depth and it lasted for two hours only.

Based on soil and air temperatures, simple and multiple regressions were calculated with a view to predict the soil temperature under the mulch.

The regressions of maximum soil temperature under polyethylene cover (Y) against maximum soil temperature (NST) in non-solarized soil at 5, 10 and 15 cm depths were

$$Y = 0.5765\ NST + 32.408$$

$$Y = 0.9307\ NST + 15.958$$

$$Y = 0.8482\ NST + 12.704$$

The coefficient of determination for the above equations was 34.0, 54.1 and 56.5 per cent respectively.

A simple regression equation calculated based on the maximum soil temperature under polyethylene cover (Y) against maximum atmospheric temperature (X) for 5 and 10 cm depths was expressed as below

$$Y = 0.7037\ X + 33.461$$

$$Y = 0.89\ X + 21.483$$

The coefficient of determination for these equations was only 4.8 and 15.7 per cent respectively for 5 and 10 cm depths. The regression value at 15 cm depth was not significant.

A multiple regression equation using maximum soil temperature under non-solarized soil (NST) and maximum atmospheric temperature (X) at 10 cm depth was calculated to find out the maximum temperature under polyethylene mulch (Y) at 10 cm depth (Fig.3).

$$Y = 0.37365 X + 0.851 NST + 5.6614$$

The coefficient of determination for this multiple regression equation was 58.0 per cent.

Germination

Solarization, in general increased the rate of germination of ginger. There was more than 95.0 per cent germination in all the plots solarized for 45 days except in the plot which received *Trichoderma* and neem leaves along with solarization (Table 4). A similar trend was also observed in the plots solarized for 30 days. There was no significant difference between the germination percentage of ginger in plots solarized for 30 and 45 days. The highest germination percentage of 98.96 was observed in *Trichoderma* incorporated plot solarized for 45 days.

In the non-solarized plots, the germination was less than 90.0 per cent in all treatments except in the one which received Bordeaux mixture drenching. While the least germination was noticed in the plot incorporated with *Trichoderma* (79.17%). In general, the plots which received *Trichoderma* and neem leaves, both solarized (90.63%) as well as non-solarized (81.25%) had the least germination.

Fig. 3 Observed and predicted solarized soil temperature (10 cm depth in the afternoon) - year 1992

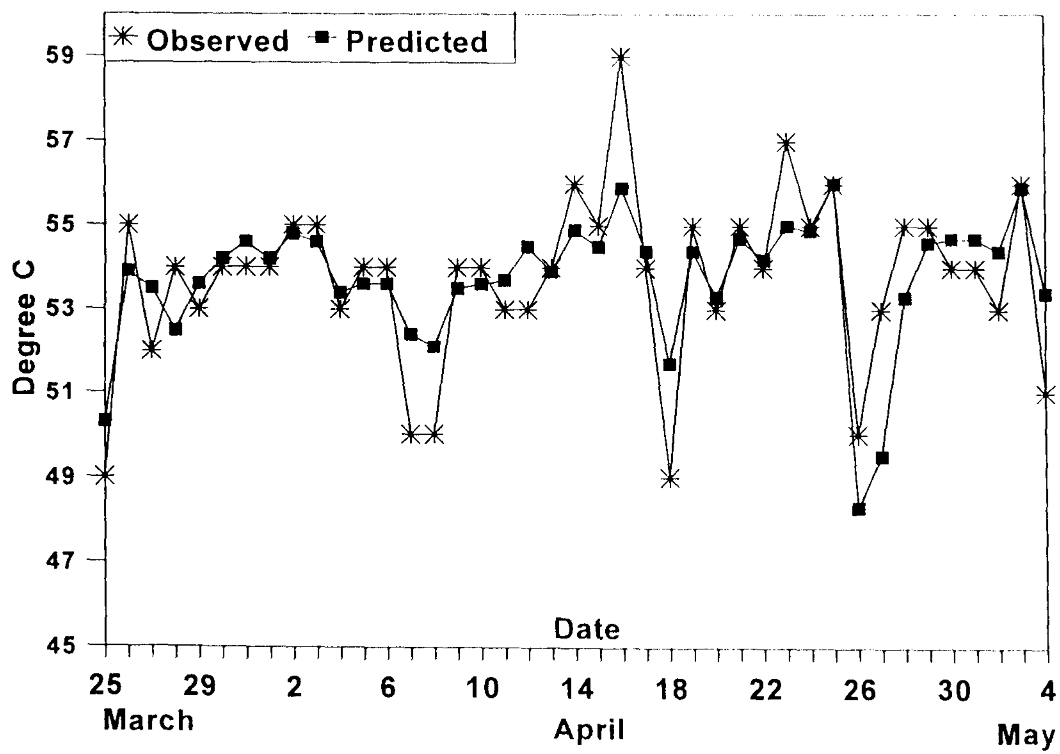


Table 4. Influence of soil solarization on germination of ginger

Treatment	Per cent germination		
	Non-solarization	Solarization	
		30 days	45 days
Control	85.42 def	95.84 abc	95.84 abc
Neem cake	86.46 def	97.92 ab	95.84 abc
Neem leaves	84.38 def	95.84 abc	96.88 abc
Trichoderma	79.17 f	97.92 ab	98.96 a
Trichoderma + Neem cake	82.29 ef	96.88 abc	95.83 abc
Trichoderma + Neem leaves	81.25 f	90.63 cde	90.63 cde
Bordeaux mixture	92.71 bcd	94.80 abc	97.92 ab

Means followed by the same letter are not significantly different at 5% level

Effect of solarization on the incidence of disease

Pre-emergence rotting

The effect of solarization on pre-emergence rotting in ginger was estimated by counting the number of non-germinated rhizomes at the end of 45 days after planting. The non-germinated rhizome bits were dug out and examined for the presence of *P. aphanidermatum*. Considerable variations in the pre-emergence rotting was noticed between the solarized and non-solarized plots.

In the non-solarized treatments, the damping off percentage ranged from 7.29 to 20.83 (Table 5). In all the treatments, except Bordeaux mixture (7.29%), the pre-emergence rotting was more than 13.0 per cent. The highest per cent rotting of 20.83 was recorded in *Trichoderma* incorporated plot. Except in neem cake and Bordeaux mixture treated soils, all the treatments had higher percentage of rotting compared to absolute control (14.58%).

Solarization for both 30 and 45 days was effective in reducing the pre-emergence rotting compared to control. In all the solarized treatments, pre-emergence rotting was less than 10.0 per cent. In plots solarized for 30 days, highest incidence of 9.38 per cent was noticed in *Trichoderma* + neem leaves incorporated soil. All the other treatments did not differ significantly from one another and ranged from 2.09 to 5.21 per cent.

There was no difference in the control of pre-emergence rotting in plots solarized for 45 days compared to those solarized for 30 days. Even in this, as in 30 days solarized plots, the highest rotting of 9.38 per cent was observed in *Trichoderma*

Table 5. Influence of solarization on pre-emergence rotting in ginger

Treatments	Per cent rotting		
	Non-solarization	Solarization	
		30 days	45 days
Control	14.58 abc	4.17 def	4.17 def
Neem cake	13.55 abc	2.09 ef	4.17 def
Neem leaves	15.63 abc	4.17 def	3.13 def
Trichoderma	20.83 a	2.09 ef	1.04 f
Trichoderma + Neem cake	17.71 ab	3.13 def	4.17 def
Trichoderma + Neem leaves	18.75 a	9.38 bcd	9.38 bcd
Bordeaux mixture	7.29 cde	5.21 def	2.09 ef

Means followed by the same letter are not significantly different at 5% level

+ neem leaves amended soil. All treatments except *Trichoderma* + neem leaves did not differ significantly from one another.

Post-emergence rotting (soft rot)

Solarization had a profound influence on the control of soft rot of ginger. Soft rot incidence was minimum in plots solarized for 30 days followed by those solarized for 45 days. The effect of solarization was more pronounced during the initial stages of the growth (Table 6). Soft rot was first noticed at the end of fourth fortnight and it continued up to 13th fortnight after planting (Plate 2). In all the treatments disease incidence was severe during eighth to 10th fortnight after planting.

In non-solarized control plots, 9.36 per cent of the plants were infected by soft rot at the end of the fourth fortnight. This gradually increased to 31.35, 78.92 and 80.31 per cent during sixth, nineth and 11th fortnight, there was no further incidence afterwards (Table 6, Fig.4). A similar trend was observed for all other treatments except in neem cake and *Trichoderma* + neem cake amended plots, where the soft rot incidence was 2.78 and 1.67 per cent during the fourth and 13.73 and 9.14 per cent at the end of sixth fortnight respectively. After the sixth fortnight, all the non-solarized treatments did not differ significantly. During the 13th fortnight after planting, 75.85 (Bordeaux mixture drenched) to 90.50 per cent (neem cake amended plots) of the plants were infected by the disease.

In 30 days solarized control plot, soft rot incidence was first noticed during the eighth fortnight (4.0%) and at the time of harvest 75.0 per cent of the plants were free from infection, which was significantly superior to non-solarized control (Table 6, Fig.4). In neem cake and neem leaves amended plots, the disease was first

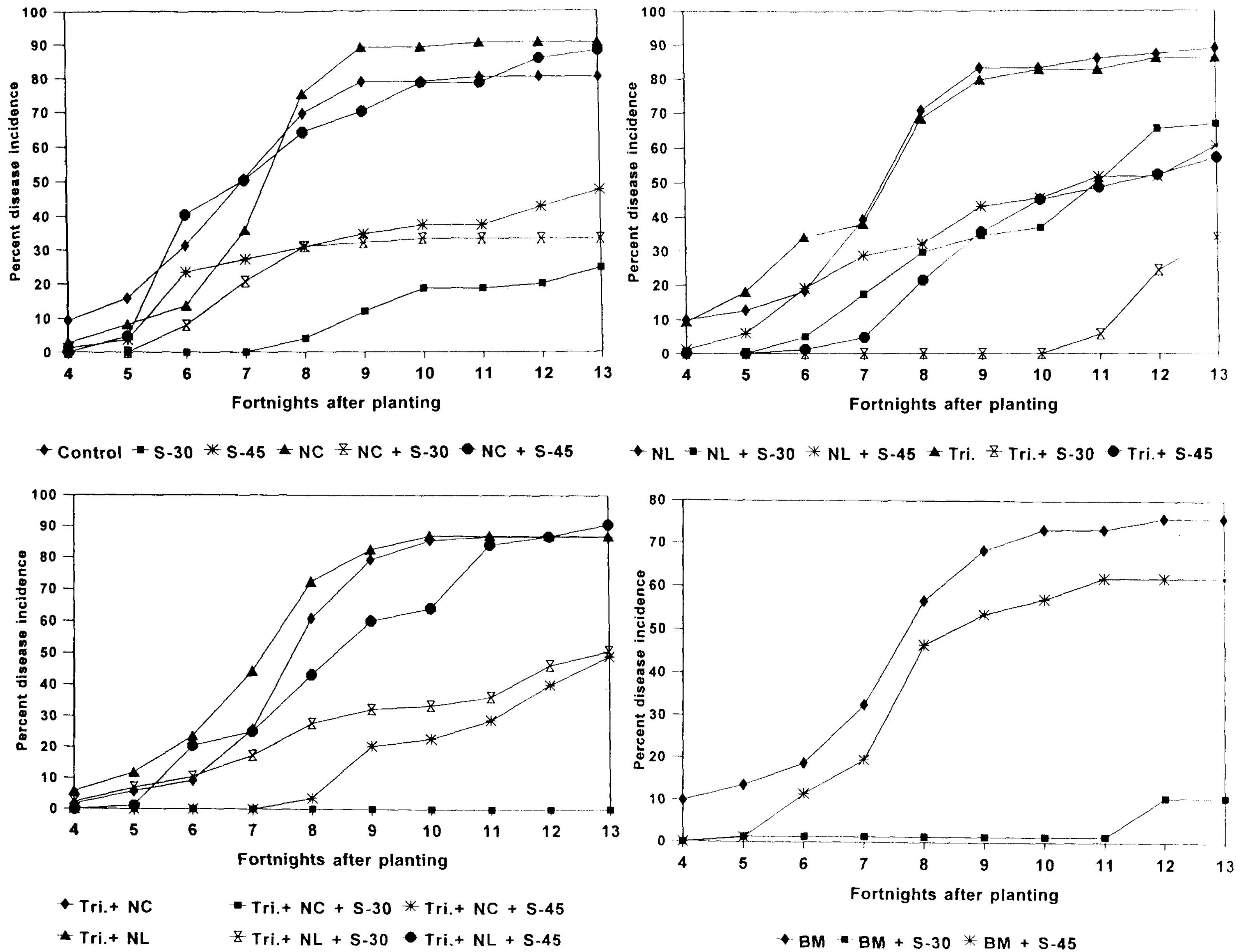
Table 6. Effect of solarization on incidence of soft rot disease in ginger
(Fortnightly disease incidence)

Treatments	Per cent incidence														
	4th fortnight			5th fortnight			6th fortnight			7th fortnight			8th fortnight		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	9.36 ab	0.00 c	1.23 c	15.83 ab	0.00 e	3.70 de	31.35 abc	0.00 c	23.46 abc	50.75 a	0.00 b	27.16 ab	69.62 a	4.00 b	30.87 ab
Neem cake	2.78 abc	0.00 c	0.00 c	8.23 bcde	0.00 e	4.76 cde	13.73 abc	8.05 bc	40.48 a	35.78 ab	20.69 ab	50.37 a	75.39 a	31.03 ab	64.19 a
Neem leaves	9.93 a	0.00 c	1.19 c	12.68 abcd	0.00 e	5.95 cde	18.23 abc	4.94 bc	19.05 abc	39.30 ab	17.29 ab	28.57 ab	70.64 a	29.63 ab	32.14 ab
Trichoderma	9.33 ab	0.00 c	0.00 c	18.00 a	0.00 e	0.00 e	34.00 ab	0.00 c	1.19 c	38.00 ab	0.00 b	4.76 b	68.33 a	0.00 b	21.43 ab
Trichoderma + Neem cake	1.67 bc	0.00 c	0.00 c	5.80 cde	0.00 e	0.00 e	9.14 bc	0.00 c	0.00 c	25.59 ab	0.00 b	0.00 b	60.71 ab	0.00 b	3.57 b
Trichoderma + Neem leaves	5.80 abc	2.30 abc	0.00 c	11.72 abcd	6.90 bcde	1.19 e	23.51 abc	10.35 bc	20.24 abc	44.19 ab	17.24 ab	25.00 ab	72.26 a	27.59 ab	43.10 ab
Bordeaux mixture	9.88 a	0.00 c	0.00 c	13.58 abc	1.33 e	1.15 e	18.71 abc	1.33 c	11.49 bc	32.59 ab	1.33 b	19.58 ab	56.62 ab	1.33 b	46.47 ab

Treatments	Per cent incidence														
	9th fortnight			10th fortnight			11th fortnight			12th fortnight			13th fortnight		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	78.92 abc	12.00 cd	34.77 abcd	78.92 abc	18.67 cd	37.43 abcd	80.31 abc	18.67 cde	37.34 abcde	80.31 ab	20.00 bcd	42.77 abcd	80.31 abc	24.76 cde	47.67 abcde
Neem cake	89.11 a	32.18 abcd	70.24 ab	89.11 a	33.33 abcd	78.57 a	90.50 a	33.33 abcde	78.57 ab	90.50 a	33.33 abcd	85.72 a	90.50 a	33.33 bcde	88.10 a
Neem leaves	83.14 a	34.57 abcd	43.21 abcd	83.14 abc	37.04 abcd	45.68 abcd	85.99 ab	50.62 abc	51.85 abcde	87.20 a	65.43 a	51.85 abcd	88.83 a	66.66 abcd	60.49 abcd
Trichoderma	79.67 ab	0.00 d	35.71 abcd	82.67 abc	0.00 d	45.24 abcd	82.67 ab	5.75 de	48.81 abcde	86.00 a	24.39 bcd	52.38 abcd	86.00 ab	33.93 bcde	57.14 abcd
Trichoderma + Neem cake	79.18 ab	0.00 d	20.27 bcd	85.39 ab	0.00 d	22.65 bcd	86.60 ab	0.00 e	28.77 bcde	86.60 a	0.00 d	40.11 abcd	86.60 ab	0.00 e	49.08 abcde
Trichoderma + Neem leaves	82.47 ab	32.18 abcd	60.00 abcd	86.88 a	33.33 abcd	64.00 abc	86.88 ab	36.23 abcde	84.00 a	86.88 a	46.38 abcd	86.67 a	86.88 ab	50.72 abcde	90.67 a
Bordeaux mixture	68.24 abcd	1.33 d	53.57 abcd	73.18 abc	1.33 d	57.14 abcd	73.18 abc	1.33 e	61.90 abcd	75.85 abc	10.67 cd	61.90 abc	75.85 abc	10.67 de	61.90 abcd

Means followed by the same letters are not significantly different at 5% level

Fig.4. Influence of soil solarization on incidence of soft rot disease in ginger



observed during the sixth fortnight after planting. From then onwards the disease increased gradually and at the time of harvest 33.33 per cent plants were succumbed to disease in neem cake and 66.66 per cent in neem leaves amended soil. *Trichoderma* inoculation was highly effective in reducing soft rot. The first incidence of the disease in this treatment was noticed only during the 11th fortnight after planting (5.75%) but during 12th and 13th fortnight disease suddenly increased and at the end of 13th fortnight 33.93 per cent of the plants were infected by soft rot. There was no significant difference between *Trichoderma* amended plots and neem cake amended plots solarized for 30 days.

The efficacy of neem cake was increased when *Trichoderma* was used along with it and all the plants were free from infection till harvest. But this inhibitory effect of *Trichoderma* was not observed when it was incorporated with neem leaves. In this treatment, disease was observed even during the fourth fortnight (2.3%) and 50.0 per cent of the plants were infected at the time of harvest. Only less than 2.0 per cent of the plants got infected in plots treated with Bordeaux mixture till the end of 11th fortnight after planting. Even at the time of harvest about 90.0 per cent of the plants were free from infection.

Increasing the period of solarization from 30 to 45 days did not correspondingly decrease the disease incidence. However, it was better than non-solarized treatments. *Trichoderma*, eventhough, prevented the infection till the end of fifth fortnight in plots solarized for 45 days, there was an increase in the disease incidence from eighth fortnight onwards and at the time of harvest only 42.80 per cent of the plants survived infection (Table 6). *Trichoderma* + neem cake treatment inhibited the disease till the seventh fortnight after planting. However, nearly

50.0 per cent of the plants in this treatment got infected from eighth to 13th fortnights. Over 80.0 per cent of the plants were diseased at the end of 13th fortnight in treatments where *Trichoderma* was incorporated along with neem leaves. At the time of the harvest, all the treatments in plots solarized for 45 days did not differ significantly from one another.

Effect of solarization on *Phyllosticta* leaf spot of ginger

The intensity of the leaf spot disease of ginger caused by *Phyllosticta zingiberi* was graded during the 12th fortnight after planting when the plants were in the advanced stage of rhizome formation and maturity. Highest incidence of *Phyllosticta* leaf spot (65.42 per cent) was recorded in *Trichoderma* + neem leaves amended soil solarized for 45 days and the lowest in non-solarized control and Bordeaux mixture drenched plots (Table 7). Significant differences were not recorded among the various treatments with 30 and 45 days of solarization.

Effect of solarization on *Pythium* population

Mass multiplied *P. aphanidermatum* propagules were uniformly incorporated in all the experimental plots five days before solarization. Initial population of *Pythium* in the soil was 321.96 c.f.u./g of soil on the day of mulching. A marked reduction in the population of *Pythium* was observed in solarized as well as non-solarized plots immediately after removing the mulch. The reduction was more pronounced in solarized compared to non-solarized treatments (Table 8, Fig.5).

In the non-solarized control, 47.48 per cent reduction in the propagules over the initial count was recorded, compared to 98.0 and 93.0 per cent respectively in 30 and 45 days solarized plots, immediately after removing the mulch. Maximum

Table 7. Effect of soil solarization on *Phyllosticta* leaf spot disease of ginger

Treatments	Per cent incidence		
	Non-solarization	Solarization	
		30 days	45 days
Control	38.68 c	49.05 abc	55.56 abc
Neem cake	47.57 bc	42.15 bc	53.93 abc
Neem leaves	44.00 bc	46.79 bc	47.02 bc
Trichoderma	50.77 abc	49.01 abc	55.18 abc
Trichoderma + Neem cake	45.88 bc	56.60 ab	45.90 bc
Trichoderma + Neem leaves	42.54 bc	50.69 abc	65.42 a
Bordeaux mixture	38.04 c	55.87 abc	52.68 abc

Means followed by the same letter are not significantly different at 5% level

Table 8. Influence of soil solarization on *Pythium* population in soil (c.f.u./g of soil)

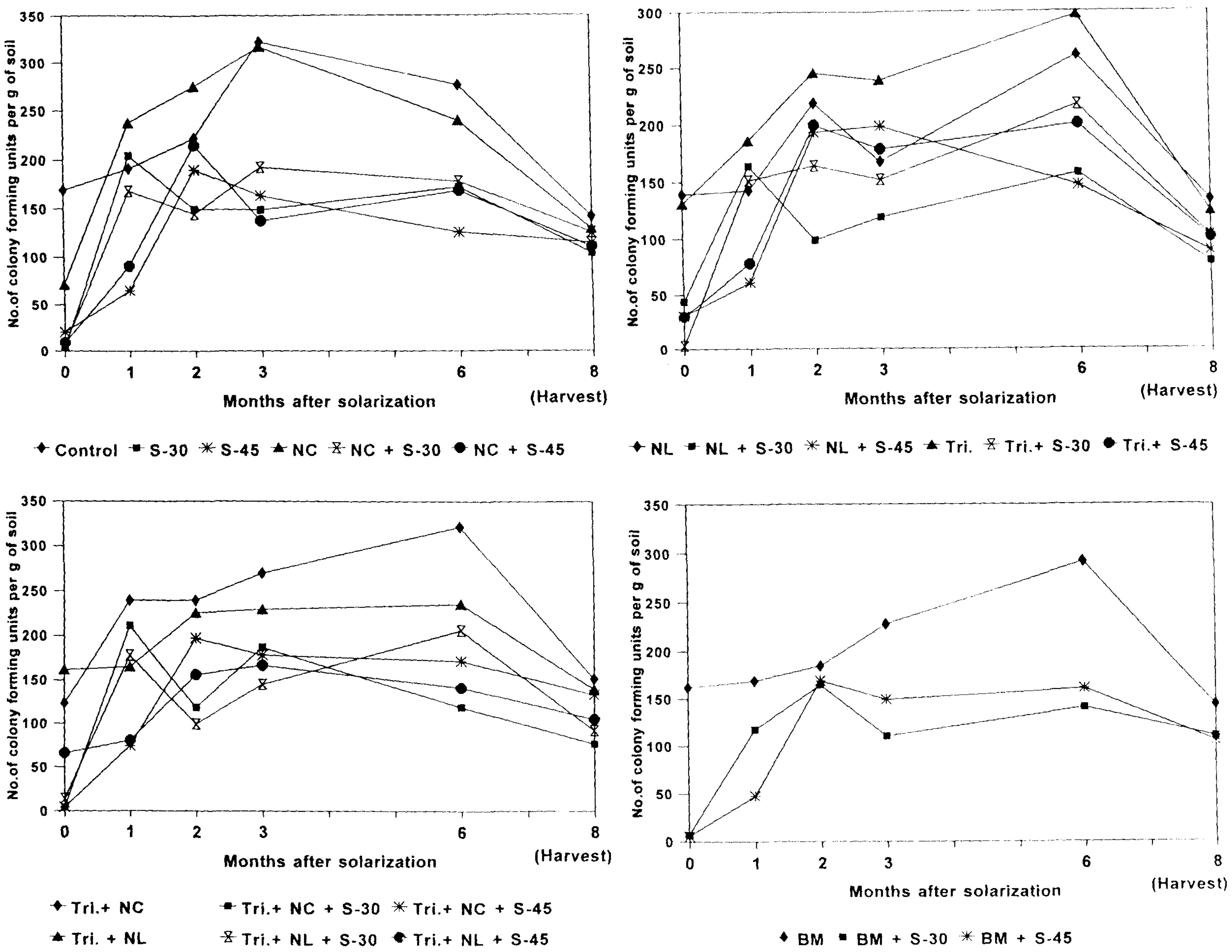
Treatments	AS			1 MAP			2 MAP		
	Non-solarization	Solarization		Non-solari-zation	Solarization		Non-solari-zation	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	169.08 a	4.35 gh	20.29 defg	191.47 abcd	204.91 abc	65.09 gh	222.74 abcde	149.70 defg	190.18 abcdef
Neem cake	71.02 b	7.41 fgh	8.79 efgh	237.98 a	168.48 bcd	90.87 fg	275.19 a	144.70 efg	215.50 abcde
Neem leaves	139.45 a	43.80 bcd	30.60 cde	142.63 de	164.08 bcde	61.19 gh	218.35 abcde	98.45 g	193.28 abcde
Trichoderma	130.76 a	2.89 h	29.63 cdef	186.05 abcd	151.42 cde	78.26 g	244.96 ab	164.08 cdefg	199.48 abcde
Trichoderma + Neem cake	123.35 a	4.03 gh	4.35 gh	239.54 a	211.37 ab	74.39 gh	239.78 abc	118.35 fg	197.42 abcde
Trichoderma + Neem leaves	161.99 a	13.69 efgh	66.02 bc	165.37 bcde	178.29 bcd	80.68 fg	225.58 abcd	99.46 g	156.33 defg
Bordeaux mixture	162.32 a	6.76 fgh	5.64 fgh	169.25 bcd	117.57 ef	47.82 h	185.00 bcdef	164.86 bcdef	169.51 bcdef

Treatments	3 MAP			6 MAP			Harvest		
	Non-solarization	Solarization		Non-solari-zation	Solarization		Non-solari-zation	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	321.96 a	148.77 efg	163.31 defg	276.74 abc	172.87 defgh	126.36 h	142.38 ab	104.39 abc	114.88 abc
Neem cake	316.54 ab	192.51 cdef	137.47 fg	240.30 abcd	178.68 defgh	169.32 defgh	129.46 abc	125.84 abc	110.85 abc
Neem leaves	267.70 abc	118.86 g	198.45 cdef	260.46 abc	157.69 efgh	146.95 gh	133.59 abc	78.81 c	88.37 abc
Trichoderma	238.50 abcd	151.94 efg	178.81 defg	296.64 ab	216.79 bcde	200.26 cdefg	123.26 abc	101.80 abc	100.52 abc
Trichoderma + Neem cake	270.03 abc	187.34 cdef	178.55 defg	321.45 a	118.86 h	172.09 defgh	152.19 a	76.74 c	133.60 abc
Trichoderma + Neem leaves	229.49 abcde	145.25 fg	166.93 defg	235.40 bcd	206.20 cdef	141.34 fgh	140.05 ab	92.51 bc	105.43 abc
Bordeaux mixture	227.91 bcde	110.85 g	149.61 efg	291.98 ab	141.34 gh	161.51 efgh	144.19 ab	110.85 abc	105.94 abc

Means followed by the same letter are not significantly different at 5% level

Initial population - 321.96 cfu/g

Fig.5. Influence of soil solarization on *Pythium* population in soil



reduction in *Pythium* population among non-solarized treatments was recorded in plots amended with neem cake (77.94%). In *Trichoderma* incorporated soil, the reduction in the population was only 59.38 per cent. However, when *Trichoderma* was incorporated along with neem cake or neem leaves, the reduction in *Pythium* population was less when these two amendments were applied separately. Among the different treatments in non-solarized plots, the least inhibition was observed in Bordeaux mixture drenched plot (49.58%).

More than, 95.0 per cent reduction in the population of *Pythium* was noticed in all the plots solarized for 30 days except in plots amended with neem leaves (86.4%) when the population was assessed immediately after removing the mulch (Table 8). In plots solarized for 45 days also more than 90.0 per cent reduction in population over the initial count was noticed in all the treatments except in plot amended with neem leaves and *Trichoderma* (79.49%).

The population of *Pythium* showed an increasing trend during the first month after planting ginger. However, the population count at this time was less than the original count recorded on the day of solarization (321.96 c.f.u./g of soil). The increase was more pronounced in plots solarized for 30 days. In the non solarized treatments, increase in population ranged from 2.1 (*Trichoderma* incorporated neem leaves amended non-solarized) to 235.1 per cent (Neem cake) over those observed immediately after removing the polyethylene sheets (Table 8). *Pythium* population in 45 days solarized plots was significantly lesser than that of 30 days solarized plots and non-solarized plots at the end of one month after planting. Lowest population of 47.82 c.f.u./g of soil was recorded in plots drenched with Bordeaux mixture and the highest of 90.87 was in neem cake amended plots. Even the maximum population of *Pythium* in 45 days solarized plots was less than the lowest population recorded in 30 days solarized plots (117.57) and the non-solarized plots (142.63).

Compared to the population of *Pythium* at the end of one month after planting, there was an increase in the population at the end of two months after planting in non-solarized and plots solarized for 45 days (Table 8, Fig.5). Among the non-solarized, the increase ranged from 0.1 per cent (*Trichoderma* + neem cake) to 53.09 per cent (neem leaves). But, even at this stage, the population of *Pythium* recorded in all the treatments was less than that observed on the day of solarization. In plots solarized for 45 days, the increase in population of *Pythium* ranged from 93.76 (*Trichoderma* + neem leaves) to 254.48 per cent (Bordeaux mixture). The maximum count of 215.50 c.f.u./g of soil observed in neem cake amended 45 days solarized plot was less than the count observed in all the control plots except that drenched with Bordeaux mixture (185.00 c. f.u./g of soil). Unlike in control and 45 days solarized plots, *Pythium* population in all the treatments (except Bordeaux mixture and *Trichoderma*) in 30 days solarized plots showed a decrease ranging from 14.14 (neem cake amended) to 44.21 per cent (*Trichoderma* + neem leaves). The highest count of 164.86 c.f.u./g of soil observed in Bordeaux mixture drenched 30 days solarized plot was on par with the lowest count of 156.33 c.f.u./g recorded in 45 days solarized plot incorporated with *Trichoderma* and neem leaves.

The population of *Pythium* in non-solarized plots increased during the third month after solarization compared to the previous month in all the treatment except in *Trichoderma*, where 2.64 per cent reduction was observed (Table 8). Among the various treatments in non-solarized plots, Bordeaux mixture drenched plot with 227.91 c.f. u./g of soil was superior to the control (321.96 c.f.u./g of soil). All other treatments were not significantly different from one another. During this period, the population of *Pythium* in 30 days solarized plots were significantly lower than that observed in control. However, there was no significant difference among the various treatments except in plot where neem cake was applied alone or mixed with *Trichoderma*. During this period, the population of *Pythium* in 45 days solarized treatments did not differ significantly from one another and from the corresponding treatments in 30 days solarized plots.

At the end of six months after planting, population of *Pythium* in *Trichoderma* mixed neem cake amended non-solarized plot (321.45 c.f.u./g of soil) was the same as that of the initial count (321.96 c.f.u./g of soil) and which in turn was not significantly different from almost all other non-solarized treatments. Similarly, the population of *Pythium* in 30 and 45 days solarized treatments did not differ significantly from one another, but they were lower than in control.

From the sixth month onwards till harvest, a general reduction in the population of *Pythium* was noticed in all the treatments (Table 8). At the time of harvest, the solarized plots had less number of *Pythium* propagules compared to the non-solarized plots. Further, there was no significant difference in the propagules in different treatments in 30 and 45 days solarized plots.

Effect of solarization on soil microflora

The effect of solarization on the population of fungi, bacteria, actinomycetes and *Pseudomonas* sp. in soil were studied. The population counts were estimated before solarization, on the day of removal of polyethylene sheets, one, three and six months after planting and at the time of harvest.

Fungi

Variation in the fungal population in different non-solarized treatments on the day of removal of the polyethylene mulch, ranged from 30.39 (Bordeaux mixture drenched) to 48.85 c.f.u./g of soil (*Trichoderma* + neem leaves amended plot) which was not significantly different from the population recorded before the solarization (Table 9). However, significant reduction in the fungal count was recorded in solarized treatments compared to pre-solarization count. The population count in solarized plots ranged from 0.88 (neem cake amended 30 days solarized treatment) to 14.32 c.f.u./g of soil (neem leaves amended) in 30 days solarized and 1.54 to 11.02 in 45 days solarized plots. In both 30 and 45 days solarized plots maximum fungal population was in plots amended with neem leaves.

When the population of fungi was recorded one month after planting, increase in the count over the count on the day of removal of polyethylene mulch, was recorded only in control and Bordeaux mixture drenched plots among the non-solarized treatments. All the other treatments showed a reduction. However, in all the treatments, both in 30 and 45 days solarization, a marked increase in the count of fungi was noticed over those recorded in the previous month. In 30 days solarized plots, highest population of fungi was in plot amended with neem leaves alone or in combination with *Trichoderma*, while, the least count was in 30 days solarized control (24.50 c.f.u./g of soil). In 45 days solarized plots also the lowest count was in the control (21.87 c.f.u./g of soil) (Table 9, Fig.6). The population fluctuation among the various treatments in non-solarized and solarized plots were not marked except in neem leaves amended soils solarized for 30 days, which showed a significant increase.

Table 9. Influence of soil solarization on total fungal population in soil (c.f.u./g of soil)

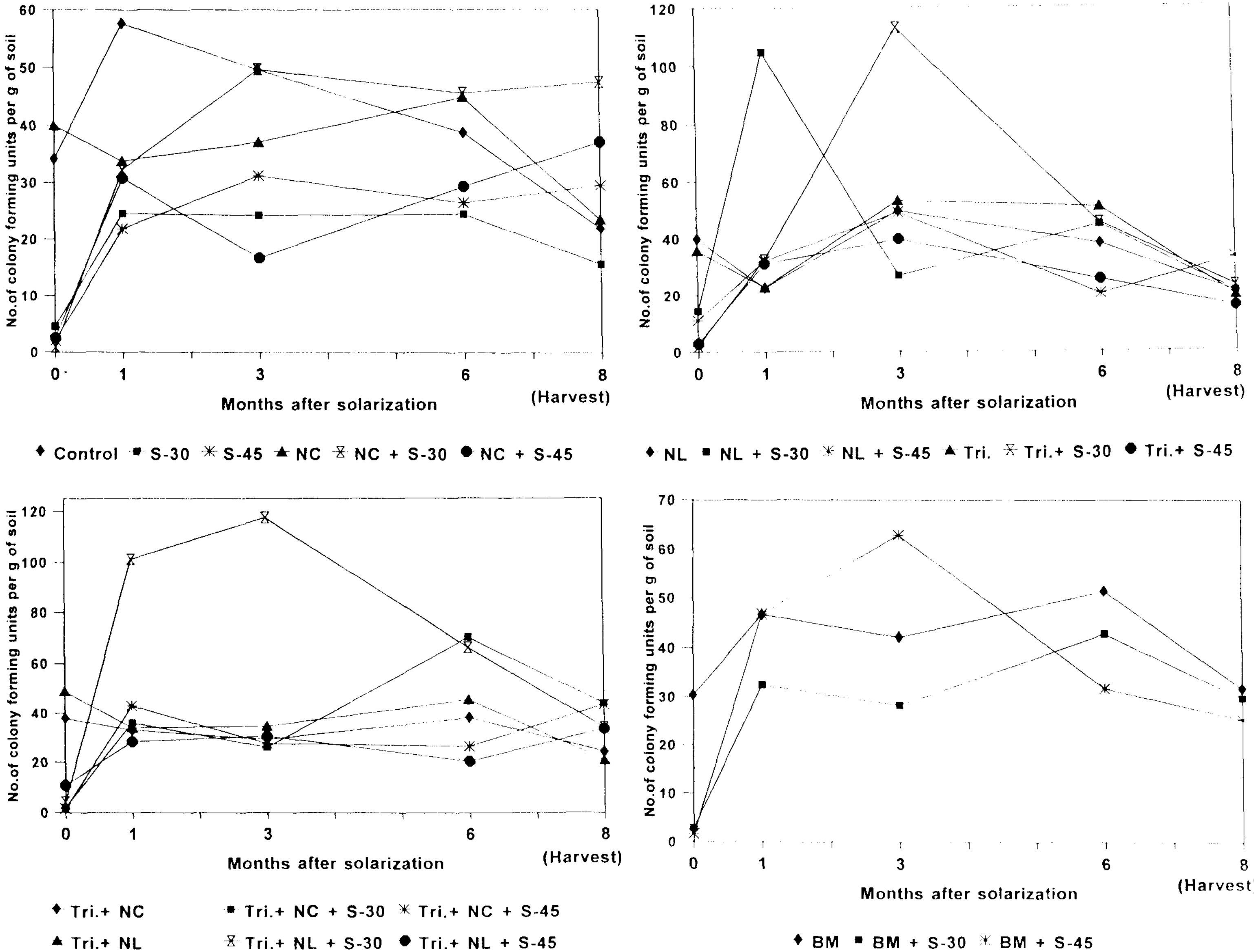
Treatments	AS			1 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	34.19 b	4.53 de	1.99 ef	57.66 b	24.59 f	21.87 f	49.61 bcde	24.28 fg	31.28 defg
Neem cake	39.97 ab	0.88 f	2.46 ef	33.89 cdef	32.38 bcde	30.90 cdef	37.15 bcdef	49.67 bcd	16.74 g
Neem leaves	39.83 ab	14.32 c	11.02 cd	22.58 f	104.69 a	32.05 def	49.63 bcd	26.80 defg	49.09 bcd
Trichoderma	35.62 ab	2.02 ef	2.77 ef	22.78 def	32.51 def	31.08 cdef	53.22 bc	112.94 a	39.62 bcdef
Trichoderma + Neem cake	37.93 ab	1.93 ef	1.54 ef	33.16 cdef	36.16 cdef	43.06 bcde	29.31 cdefg	26.13 efg	27.69 defg
Trichoderma + Neem leaves	48.85 a	4.25 e	10.80 c	34.16 cdef	101.26 a	28.42 ef	34.79 cdefg	117.61 a	30.66 cdefg
Bordeaux mixture	30.39 b	2.85 ef	1.68 ef	46.72 bc	32.52 cdef	46.85 bcd	42.15 bcdef	28.32 defg	62.94 b

Treatments	6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	38.82 cdef	24.50 fg	26.51 fg	22.04 cdef	15.68 f	26.93 bcdef
Neem cake	44.93 cd	45.63 bcd	29.44 defg	23.55 cdef	47.52 a	37.19 abc
Neem leaves	37.90 cdef	44.67 bcd	20.14 g	20.73 cdef	20.97 cdef	32.82 abcd
Trichoderma	50.90 abc	45.31 bcd	25.33 fg	19.46 def	22.93 cdef	15.60 ef
Trichoderma + Neem cake	38.33 cdef	70.38 a	26.66 efg	24.56 bcdef	44.16 ab	43.59 ab
Trichoderma + Neem leaves	45.56 bcd	66.36 ab	20.54 g	21.12 cdef	34.48 abcd	33.79 abcde
Bordeaux mixture	51.36 abc	42.84 cde	31.79 defg	31.71 abcdef	29.70 abcdef	25.29 bcdef

Means followed by the same letter are not significantly different at 5% level

Initial population - 34.4

Fig.6. Influence of soil solarization on total fungal population in soil



From third month onwards, the population of total fungi in solarized plots showed a gradual increase, while, in the solarized control plots, there was no significant difference in the population of fungi. Whereas, the population increased from 21.67 to 31.28 c.f.u./g of soil in 45 days solarized control. Significant difference in the fungal population in the various non-solarized treatments was not noticed at the end of three months after planting. A similar trend was observed till harvest. However, at the time of harvest, a reduction in the population count over the previous month's was noticed in all the non-solarized treatments.

Compared to the observation at the end of one month after planting, significant population fluctuations in 30 days solarized control was not observed during third month and this was on par with neem leaves, *Trichoderma* + neem cake and Bordeaux mixture. The highest population count of 117.61 c.f.u./g of soil was noticed in *Trichoderma* + neem leaves amended 30 days solarized soil (Table 9). During this period, the highest and least population in 45 days solarized treatments were recorded in Bordeaux mixture drenched (62.94 c.f.u./g of soil) and neem cake amended (16.74 c.f.u./g of soil) plots respectively.

During six months after planting, in all the 45 days solarized treatments except neem cake amended soil, the population of total fungi showed a decrease and all the treatments did not differ significantly from one another. In general, higher fungal population was observed in 30 days solarized treatments compared to 45 days solarization. The maximum population of 70.38 c.f.u./g of soil was recorded in 30 days solarized soil amended with neem cake and *Trichoderma*. At the time of harvest, all the treatments except neem cake amended solarized treatments (both 30 and 45 days) showed a decrease in population of fungi over the initial count of 34.4 c.f.u./g of soil.

Bacteria

The bacterial population in non-solarized and solarized plots decreased over the initial population on the day of removal of the mulch (Table 10). The decrease was maximum in 45 days solarized plots followed by 30 days. In non-solarized plots, the reduction was maximum in neem leaves and minimum in neem cake amended plots. In 30 days solarized plots, the population in various treatments ranged from 7.25 (neem cake) to 14.95 c.f.u./g of soil (*Trichoderma* + neem leaves). The bacterial population in all the treatments did not differ significantly from one another. In 45 days solarized plots, the population ranged from 1.10 (45 days solarized control) to 3.19 c.f.u./g of soil (neem leaves amended). The neem leaves amended treatment alone or in combination with *Trichoderma* were significantly superior to the 45 days solarized control.

One month after planting, the population in solarized plots (both 30 and 45 days) showed an increase. While, a reduction was noticed in neem cake, *Trichoderma* + neem leaves and Bordeaux mixture drenched plots among non-solarized treatments. During the period, however, the population of bacteria in 30 days solarized plot was more than that of non-solarized plots except in *Trichoderma* and *Trichoderma* + neem cake amended soils. In 45 days solarized plots, eventhough there was an increase in population over the previous month, the count was less than that of 30 days solarized and non-solarized plots. The population did not differ significantly except in *Trichoderma* + neem cake amended plot solarized for 45 days

Table 10. Influence of soil solarization on bacterial population in soil (c.f.u./g of soil)

Treatments	AS			1 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	19.04 ab	11.46 cdef	1.10 h	21.08 cdefg	55.76 a	7.38 kl	12.65 abcd	11.03 cd	15.77 abcd
Neem cake	24.27 a	7.25 f	1.58 gh	22.77 cdef	35.44 b	9.24 jkl	20.25 a	12.54 bcd	13.04 abcd
Neem leaves	10.39 cdef	10.40 cdef	3.19 g	11.99 hijkl	23.17 cde	10.99 ijkl	18.02 abc	10.69 cd	14.23 abcd
Trichoderma	10.42 cdef	7.95 ef	1.89 gh	18.87 defghi	13.30 fghijkl	6.60 l	11.73 abcd	14.22 abcd	11.21 bcd
Trichoderma + Neem cake	12.07 cde	7.75 ef	2.50 gh	26.72 bcd	18.36 defghi	17.25 defghij	11.30 bcd	9.10 d	15.57 abcd
Trichoderma + Neem leaves	13.19 cd	14.95 bc	3.15 g	12.85 ghijkl	29.79 bc	10.35 ijkl	11.93 abcd	20.18 ab	17.13 abc
Bordeaux mixture	14.82 bc	9.20 def	2.95 gh	14.80 efghijk	20.31 cdefgh	9.49 jkl	11.04 bcd	14.60 abcd	16.96 abc

Treatments	6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	25.61 abc	11.97 ef	10.67 f	8.30 a	10.30 a	10.76 a
Neem cake	30.08 a	13.38 def	12.77 ef	10.89 a	10.72 a	9.80 a
Neem leaves	21.91 abcd	17.00 cdef	10.36 f	10.66 a	7.52 a	8.65 a
Trichoderma	28.56 ab	20.09 abcde	12.08 ef	8.52 a	8.08 a	9.71 a
Trichoderma + Neem cake	20.49 abcde	27.25 abc	13.18 def	8.57 a	7.13 a	8.69 a
Trichoderma + Neem leaves	18.02 bcdef	18.51 bcdef	10.50 f	10.92 a	9.18 a	10.41 a
Bordeaux mixture	24.03 abc	16.67 cdef	12.14 ef	9.72 a	7.91 a	7.36 a

Means followed by the same letter are not significantly different at 5% level

Initial population - 29.30

which recorded the maximum (17.25 c.f.u./g of soil), all were on par (Table 10, Fig.7).

During the third month after planting, there was a stabilization in the population of bacteria in most of the treatments. The population did not differ significantly among the 45 days solarized plots. The variation in population during this period ranged from 20.25 (neem cake) to 9.10 c.f.u./g of soil (30 days solarized *Trichoderma* + neem cake amended plot).

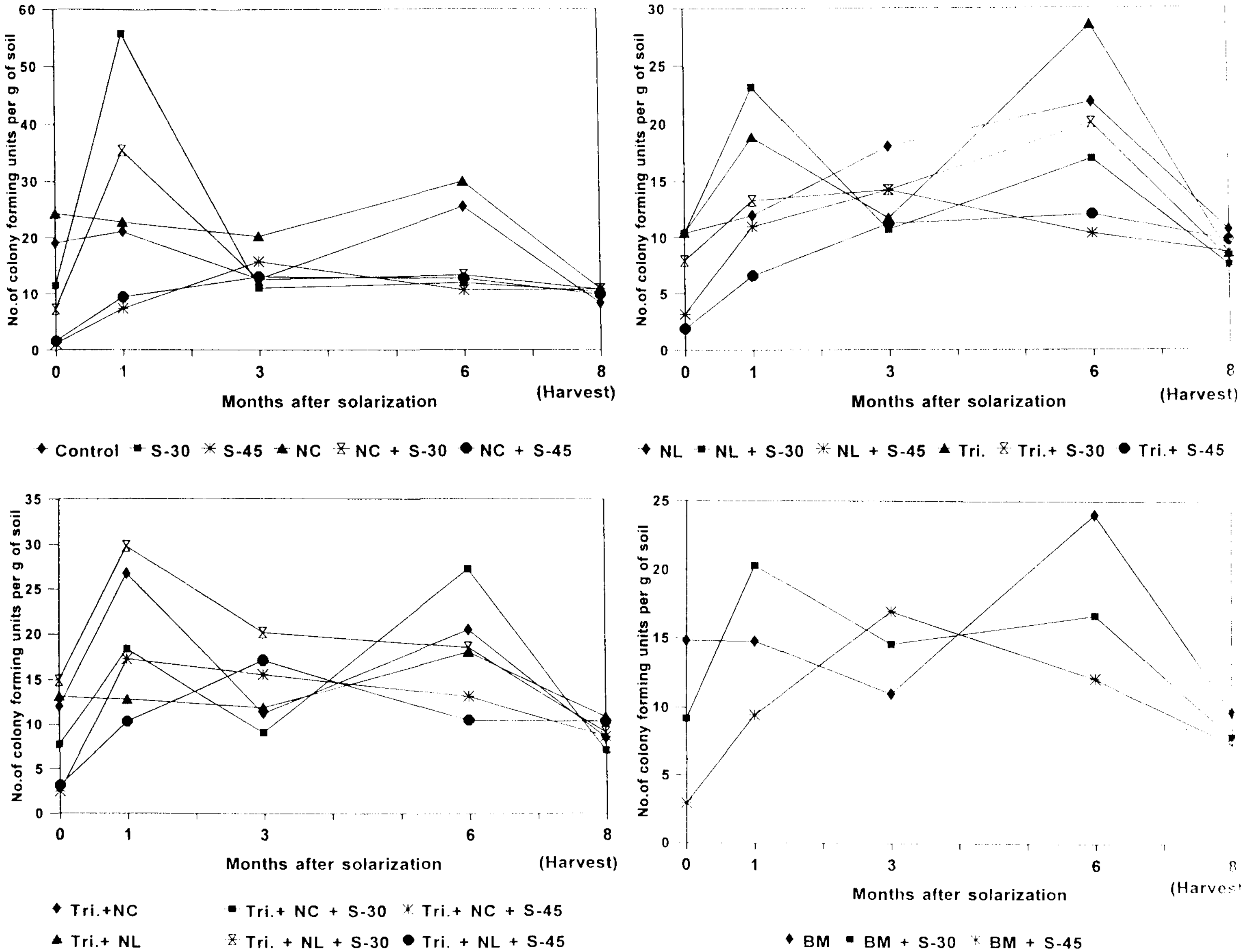
A general increase in the population of bacteria in the non-solarized and 30 days solarized treatments over the previous observation was noticed during six month after planting. This increase was more pronounced in the non-solarized plots. However, in 45 days solarized plots, a general reduction in the population was recorded. Eventhough, the population of bacteria in all the 45 days solarized treatments was less than that of 30 days solarized and non-solarized plots, there was no significant variation in the population among the different treatments.

At the time of harvest, a general reduction in the population of bacteria was noticed in all the treatments. Further, there was no significant difference among the different treatments in non-solarized and solarized plots.

Actinomycetes

Solarization had a profound inhibitory effect on the population of actinomycetes in the soil. Population reduction in 45 days solarized treatments was more pronounced than 30 days except in *Trichoderma* + neem leaves amended soil. Population of actinomycetes did not differ significantly among non-solarized treatments. Compared to 33.47 in the control plot, the 30 days solarized control recorded

Fig.7. Influence of soil solarization on bacterial population in soil



only 4.10 c.f.u./g of soil. The corresponding value for 45 days solarized control was 1.52 c.f.u./g of soil (Table 11, Fig.8). A similar trend was noticed in all other treatments also. However, in *Trichoderma* incorporated neem leaves amended and Bordeaux mixture drenched 45 days solarized plots, the population count of actinomycetes was more than that of 30 days solarized plots.

One month after planting, the actinomycetal population in the non-solarized treatments decreased from 20.0 per cent (*Trichoderma* + neem cake) to 42.2 per cent (Bordeaux mixture) over the population recorded immediately after removing the mulch. In contrast, in 30 and 45 days solarized plots, there was an increase in the population except in neem leaves amended 30 days and 45 days solarized plot amended with neem leaves in combination with *Trichoderma*.

When the population was estimated at the end of third month after planting, the population of actinomycetes in non-solarized plots again showed a decrease over that recorded during one month after planting. But this reduction was least (9.3%) in the control (Table 11). The population of actinomycetes in the non-solarized treatments except in control did not differ significantly. Population reduction was also observed in both 30 and 45 days solarized plots.

In general, the population of actinomycetes in all the treatments increased during six month after planting compared to the previous observation. *Trichoderma* + neem leaves amended soil recorded the highest increase of 74.9 per cent among the non-solarized treatments. In 30 days solarized plots, the maximum increase was in neem cake amended plot (158.3%) compared to 317.3 per cent supported by neem leaves amended 45 days solarized treatment. The variations among the non-solarized treatments were not significant.

Table 11. Influence of soil solarization on actinomycetal population in soil (c.f.u./g of soil)

Treatments	AS			1 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	33.47 a	4.10 efg	1.52 g	23.58 a	12.19 cd	13.24 bcd	21.39 a	7.60 cdefg	5.97 efg
Neem cake	30.78 ab	2.19 g	1.89 g	18.76 abc	15.14 abc	11.49 cd	11.95 bcd	5.47 fg	6.26 efg
Neem leaves	25.79 ab	11.68 cde	5.87 efg	17.51 abc	10.71 cd	11.32 cd	12.18 bc	4.74 g	4.05 g
Trichoderma	23.67 abc	3.81 efg	1.24 g	18.19 abc	15.08 abc	11.21 cd	12.05 bcd	7.22 defg	5.30 fg
Trichoderma + Neem cake	19.65 abcd	2.52 g	2.39 g	15.72 abc	18.18 abc	15.26 abc	13.53 b	6.34 efg	6.34 efg
Trichoderma + Neem leaves	26.01 ab	11.00 def	23.08 bcd	17.76 abc	14.41 abc	15.91 abc	9.39 bcdef	9.53 bcdef	4.38 g
Bordeaux mixture	28.79 ab	1.94 g	3.10 fg	16.64 abc	21.68 ab	6.73 d	10.34 bcde	6.20 efg	4.41 g

Treatments	6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	18.73 ab	8.17 ef	9.13 def	17.14 a	9.46 bcde	10.64 bcde
Neem cake	20.54 ab	14.13 bcde	13.48 bcdef	13.44 abc	9.07 cde	10.63 bcde
Neem leaves	16.27 abc	7.37 f	16.90 abc	11.65 abcde	9.47 bcde	9.70 cde
Trichoderma	22.22 a	9.10 def	11.29 cdef	14.21 abc	13.35 abcd	11.04 bcde
Trichoderma + Neem cake	16.11 abc	13.03 bcdef	14.54 bcde	10.54 bcde	8.84 de	9.28 bcde
Trichoderma + Neem leaves	16.43 abc	10.58 cdef	13.38 bcdef	10.14 bcde	7.53 e	13.52 abcd
Bordeaux mixture	15.13 abcd	8.52 ef	14.07 bcde	16.62 a	14.46 ab	9.57 bcde

Means followed by the same letter are not significantly different at 5% level

Initial population - 58.97

At the time of harvest, the population of actinomycetes was reduced in all the non-solarized treatments over the previous as well as the initial count (58.97 c.f.u./g of soil). The population ranged from 10.14 (*Trichoderma* + neem leaves) to 17.14 (control) c.f.u./g of soil (Table 11). In 30 days solarized plots, the population count of actinomycetes in *Trichoderma* + neem leaves were on par with control, neem cake, neem leaves and *Trichoderma* + neem cake (7.53 to 9.47). Except in *Trichoderma* and Bordeaux mixture treated plots solarized for 45 days, the population of actinomycetes in all the other treatments was more than that of 30 days solarization. The highest count of 13.52 c.f.u./g of soil was in *Trichoderma* + neem leaves amended 45 days solarized plot.

Pseudomonas sp.

Pseudomonas sp. is a common bacterium observed in Kerala causing bacterial wilt of ginger. The experimental plot had an initial population of 18.08 c.f.u./g of soil. Like with *Pythium*, the artificial inoculation of the soil with the bacterium was not done. The population count of the bacterium was estimated from one month after planting till harvest. Maximum reduction in the population was noticed in 45 days solarized plots at the end of one month after planting where the population fluctuations ranged from 2.30 to 7.02 c.f.u./g of soil (Table 12). However, the treatments were not significantly different.

In 30 days solarized plots, significant reduction in the population of the bacterium compared to the initial count was not noticed in the neem leaves amended and Bordeaux mixture drenched plots, while, the other treatments showed a marginal reduction. Almost a similar pattern was recorded in the control plots also. However,

Table 12. Influence of soil solarization on *Pseudomonas* sp. population in soil (c.f.u./g of soil)

Treatments	1 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	4.32 def	8.92 abcde	2.80 ef	0.59 fg	0.49 fg	1.01 defg
Neem cake	11.56 abcd	10.32 abcd	2.62 ef	1.34 bcdef	0.65 efg	2.21 abcd
Neem leaves	4.73 def	17.18 a	4.85 cdef	0.64 efg	1.03 cdefg	3.95 a
Trichoderma	4.75 def	6.50 cdef	2.30 f	0.80 efg	0.38 g	1.39 bcdef
Trichoderma + Neem cake	18.08 a	9.75 abcd	4.68 def	1.27 bcdef	0.88 efg	1.66 bcde
Trichoderma + Neem leaves	3.85 def	13.22 abc	7.02 bcdef	2.60 ab	1.30 bcdefg	3.38 a
Bordeaux mixture	17.18 a	15.61 ab	5.66 cdef	1.15 bcdefg	0.94 efg	2.22 abc

Treatments	6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	1.66 ab	1.44 ab	1.05 b	0.67 bcdefg	1.46 abcde	0.44 efg
Neem cake	1.84 ab	3.85 a	2.31 ab	0.69 bcdefg	1.85 a	1.99 a
Neem leaves	0.81 b	2.16 ab	1.73 ab	0.45 defg	0.78 bcdefg	1.62 abc
Trichoderma	0.99 b	1.14 ab	1.83 ab	0.52 cdefg	1.64 abc	1.33 abcdef
Trichoderma + Neem cake	2.31 ab	1.16 ab	1.93 ab	0.30 fg	1.24 abcdefg	0.47 efg
Trichoderma + Neem leaves	1.09 b	2.56 ab	1.13 b	0.68 bcdefg	0.48 defg	1.65 ab
Bordeaux mixture	1.87 ab	1.11 b	2.26 ab	1.54 abcde	0.26 g	0.41 efg

Means followed by the same letter are not significantly different at 5% level

Initial population - 18.08

in control plots, the neem cake amended treatments and Bordeaux mixture drenched treatments did not inhibit the bacterial population. At the time of harvest, the bacterial population in all the treatments reduced considerably over the initial count and it ranged from 0.26 (Bordeaux mixture drenched 30 days solarized) to 1.99 c.f.u./g of soil (neem cake amended 45 days solarized).

Effect of solarization on VA Mycorrhizal colonization

The general colonization pattern of VAM in all the treatments was similar *viz.*, an increase in VAM numbers upto six months after planting followed by a reduction till the harvest. In the non-solarized control plot, 20.0 per cent of the roots were infested with VAM one month after planting and it increased to 80.0 per cent by six months and then reduced to 39.0 per cent at the time of harvest (Table 13).

In plot solarized for 30 days also, the maximum colonization (98.0%) was recorded six months after planting. However, during the first and second months after planting, the colonization level (5.0 and 17.0%) was less than that noticed in the control. A similar trend was noticed in plots solarized for 45 days also. In plots amended with neem leaves, colonization by VAM was low upto six months after planting compared to the control. A similar trend was noticed when plots amended with neem cake or neem leaves were solarized for 30 or 45 days.

In *Trichoderma* incorporated non-solarized soils, a marked reduction (24.0%) in the colonization by VAM was noticed six months after planting compared to control (80.0%). The inhibitory effect of neem cake and *Trichoderma* on VAM colonization was clearly observed when they were applied together in solarized

Table 13. Influence of soil solarization on association by mycorrhizal fungi in ginger

Treatments	Per cent association														
	1 MAP			2 MAP			3 MAP			6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	20.00	5.00	8.00	29.00	17.00	26.00	44.44	52.00	42.00	80.00	98.00	57.00	39.00	63.00	80.00
Neem cake	35.00	19.00	8.00	32.00	27.00	12.00	20.00	57.00	22.00	76.00	93.00	71.00	88.00	35.00	85.70
Neem leaves	10.00	1.00	1.00	12.00	8.00	7.00	26.00	68.00	40.00	51.11	77.00	55.00	57.00	32.94	48.00
Trichoderma	18.00	16.00	21.00	32.00	12.00	5.00	39.00	39.00	30.00	24.00	81.05	92.00	60.00	61.00	45.00
Tricoderma + Neem cake	25.00	23.00	6.00	20.00	40.00	1.00	30.00	57.78	14.00	54.00	38.00	84.00	16.92	56.00	36.00
Tricoderma + Neem leaves	42.22	4.00	13.00	16.00	26.00	17.00	32.00	33.00	32.00	86.00	61.00	76.00	61.00	59.00	20.00
Bordeaux mixture	12.00	2.00	1.00	24.00	8.00	33.00	40.00	57.00	27.00	66.67	87.00	93.00	65.00	51.00	52.00

as well as in non-solarized plots. Among 30 days solarized plots, the per cent colonization of VAM was only 38.0 in *Trichoderma* incorporated and neem cake amended plots compared to 98.0 per cent in solarized control six months after planting. While, the per cent colonization by VAM in this 45 days solarized treatment was 1.0, 14.0 and 36.0 per cent compared to 26.0, 42.0 and 80.0 per cent in the solarized control second and third months after planting and at the time of harvest respectively.

Reduction in the VAM colonization was also noticed when *Trichoderma* in combination with neem leaves was added and this inhibition was more pronounced in solarized plots. In general, plants grown in Bordeaux mixture drenched soil, both solarized as well as non-solarized, supported less colonization of roots by VAM compared to control.

Effect of solarization on *Azospirillum*

Azospirillum was isolated from the roots of ginger plants grown in all the treatment plots. The formation of thin, white sub surface pellicular growth in nitrogen free bromothymol blue (NFb) medium indicated the presence of *Azospirillum*.

An increase in the *Azospirillum* association with ginger roots was observed three months after planting in all the treatments (Table 14). This increase was more pronounced in 45 days solarized plots. In *Trichoderma* incorporated non-solarized as well as 30 days solarized soil, a marked reduction of 50.0 per cent and 20.0 per cent in the association of *Azospirillum* was noticed six months after planting over those observed at the end of three months of growth. In *Trichoderma* incorporated and neem cake amended plot solarized for 30 days, the per

Table 14. Influence of soil solarization on association by *Azospirillum* in ginger

Treatments	Per cent association														
	1 MAP			2 MAP			3 MAP			6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
Control	0.00	0.00	0.00	0.00	0.00	0.00	60.00	100.00	60.00	60.00	40.00	80.00	80.00	100.00	100.00
Neem cake	0.00	20.00	40.00	20.00	0.00	0.00	40.00	40.00	100.00	40.00	100.00	100.00	80.00	100.00	100.00
Neem leaves	20.00	0.00	60.00	0.00	40.00	20.00	80.00	80.00	100.00	100.00	80.00	80.00	80.00	100.00	80.00
Trichoderma	0.00	40.00	0.00	20.00	0.00	0.00	80.00	100.00	80.00	40.00	80.00	100.00	100.00	100.00	100.00
Trichoderma + Neem cake	60.00	20.00	20.00	0.00	20.00	20.00	80.00	60.00	100.00	100.00	80.00	100.00	100.00	60.00	100.00
Trichoderma + Neem leaves	0.00	0.00	0.00	20.00	80.00	0.00	100.00	100.00	100.00	60.00	100.00	60.00	100.00	100.00	80.00
Bordeaux mixture	20.00	0.00	20.00	20.00	40.00	20.00	80.00	100.00	100.00	60.00	100.00	100.00	80.00	100.00	100.00

cent association of *Azospirillum* was only 60.0 compared to 100.0 per cent in this treatment solarized for 45 days and non-solarized plot at the time of harvest.

Eventhough the Bordeaux mixture drenched non-solarized plots supported comparatively lower association during the early stages of growth 100.0 per cent association was noticed from three months onwards.

Effect of solarization on plant characters

Plant characters like, height, number of leaves, number of tillers, leaf length and breadth, petiole length, number of roots and root length were recorded at monthly intervals for three months. Considerable variation in the plant characters were noticed when the ginger plants were grown in solarized and non-solarized plots (Plate 3 and 4).

Plants grown in soil solarized for 30 days were significantly taller (29.03 cm) than the non-solarized and 45 days solarized plots (Table 15). However, there was no considerable variation in the plant height among the treatments receiving 30 days of solarization. In general, the plant height in the various treatments in soil solarized for 30 days were maximum followed by non-solarized treatments. A similar trend was noticed during the second month also. During this period, all the treatments receiving 30 days solarization did not differ significantly. Neem leaves amended plot solarized for 45 days showed a reduction in plant height (38.84 cm) compared to 30 days solarization.

Among the non-solarized plots plants grown in absolute control plots had the least growth of 37.83 cm (Table 15), while all other treatments were on par. After three months of growth, there was marked difference in the plant height in

Plate 3. Plant characters as influenced by solarization (3 MAP)

Plate 4. Plant characters as influenced by solarization (6 MAP)


B.M.
CONTROL


B.M.
CONTROL

Table 15. Influence of soil solarization on plant characters in ginger

Treatments	Height (cm)								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	23.71 cdef	29.03 a	20.16 fghi	37.83 g	48.87 ab	42.93 defg	39.16 g	65.21 ab	60.30 abc
Neem cake	24.33 bcde	26.47 abc	16.65 i	42.02 defg	46.40 abcd	42.06 defg	45.77 efg	61.64 abc	55.87 bcde
Neem leaves	22.37 defg	27.71 ab	21.12 efgh	44.04 bcde	49.81 a	38.84 fg	40.30 g	62.05 ab	55.57 bcde
Trichoderma	25.88 abcd	27.38 abc	19.29 ghi	43.98 bcde	48.13 abc	42.56 defg	48.27 defg	69.13 a	63.17 ab
Trichoderma + Neem cake	25.24 abcd	24.94 bcde	18.73 ghi	44.02 bcde	46.15 abcd	44.70 abcde	47.29 efg	66.73 a	62.48 ab
Trichoderma + Neem leaves	23.57 cdef	25.32 abcd	18.08 hi	41.34 defg	46.41 abcd	40.60 efg	43.18 fg	67.87 a	58.65 abcd
Bordeaux mixture	24.78 bcde	24.05 bcde	17.78 hi	43.15 cdef	45.35 abcde	41.89 defg	51.22 cdef	64.05 ab	61.42 abc

Treatments	No. of tillers/plant								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	2.27 bc	2.13 bc	2.73 ab	5.87 abc	5.73 bc	5.53 bc	8.60 f	16.73 abcd	17.00 abcd
Neem cake	2.13 bc	2.53 bc	2.27 bc	5.53 bc	6.53 abc	5.87 abc	14.12 cdef	15.93 abcde	17.33 abcd
Neem leaves	2.27 bc	2.13 bc	2.53 bc	5.60 bc	5.33 c	5.33 c	8.33 f	12.73 def	15.51 abcde
Trichoderma	2.53 bc	2.60 bc	2.53 bc	6.07 abc	7.07 ab	6.07 abc	18.19 abcd	19.87 abc	16.40 abcde
Trichoderma + Neem cake	2.53 bc	2.07 bc	3.27 a	6.07 abc	5.53 bc	6.13 abc	21.31 a	18.13 abcd	18.00 abcd
Trichoderma + Neem leaves	2.60 bc	2.47 bc	2.74 ab	7.40 a	6.87 abc	5.47 bc	10.63 ef	21.00 ab	17.53 abcd
Bordeaux mixture	2.60 bc	2.73 ab	2.60 bc	5.40 c	6.67 abc	6.60 abc	15.23 bcde	18.13 abcd	16.20 abcde

Means followed by the same letter are not significantly different at 5% level

different treatments. During this period also, plants grown in 30 days solarized plots exhibited maximum growth. Plants grown in soil solarized for 45 days exhibited significantly better growth than the non-solarized control. Least growth of plants (39.16 cm) was recorded in the absolute control, while, Bordeaux mixture drenched non-solarized plot was superior to all other non-solarized treatments in plant height (51.22 cm).

Number of tillers per plant

Solarization did not significantly increase the tiller numbers in most of the treatments upto one month after planting (Table 15). During the second month also, considerable variation in the different treatments was not observed. During the third month, tiller number in the non-solarized control was only 8.60 compared to 16.73 and 17.00 in plots solarized for 30 and 45 days respectively. However, there was no significant difference among all the different treatments after 30 and 45 days of solarization.

Number of leaves per plant

Leaf production by the plants was influenced by solarization. During the first month, maximum number of leaves per plant (7.73) was produced by the plants grown in the *Trichoderma* incorporated plots solarized for 30 days and the least (4.47) was in neem leaves amended non-solarized treatments (Table 16). In general, it was observed that during the first month, more number of leaves was noticed in 30 days solarized plots followed by non-solarized and 45 days solarized treatments. However, no significant difference was observed among all the treatments in 30 or 45 days solarized plots. Significant difference in the number of leaves produced by the

Table 16. Influence of soil solarization on plant characters in ginger

Treatments	No. of leaves/plant								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	5.20 def	6.20 abcde	5.80 cdef	39.80 ab	33.00 b	35.20 ab	68.13 fg	134.20 abcd	117.00 cdef
Neem cake	5.20 def	7.33 abc	4.80 ef	36.93 ab	44.07 a	33.27 b	105.18 cdefg	136.67 abcd	128.60 bcde
Neem leaves	4.47 f	6.60 abcd	5.80 cdef	37.13 ab	32.80 b	31.93 b	65.78 g	101.40 defg	117.93 cdef
Trichoderma	6.60 abcd	7.73 a	6.67 abcd	37.33 ab	44.00 a	35.53 ab	118.11 cdef	173.73 ab	119.93 cde
Trichoderma + Neem cake	6.13 bcde	5.40 def	5.53 def	41.13 ab	32.20 b	36.20 ab	138.56 abcd	146.80 abcd	145.80 abcd
Trichoderma + Neem leaves	6.67 abcd	7.20 abc	5.40 def	36.73 ab	38.47 ab	33.40 b	82.05 efg	179.40 a	127.27 bcde
Bordeaux mixture	6.13 bcde	7.60 ab	5.40 def	33.20 b	38.80 ab	38.87 ab	116.65 cdef	152.47 abc	126.80 bcde

Treatments	Leaf length (cm)								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	12.69 abcde	14.70 a	10.40 fgh	16.34 h	20.96 ab	19.28 bcdefg	14.89 c	22.65 a	23.06 a
Neem cake	12.56 abcdef	13.71 ab	8.51 h	18.69 cdefg	20.70 abc	18.64 cdefg	16.11 c	21.19 a	20.93 ab
Neem leaves	11.22 cdefg	13.49 abc	10.88 defg	18.93 bcdefg	21.45 a	17.52 gh	15.78 c	21.72 a	21.48 a
Trichoderma	13.04 abcd	14.03 ab	10.49 efgh	19.07 bcdefg	19.82 abcdef	18.51 defg	17.37 c	21.73 a	23.68 a
Trichoderma + Neem cake	12.19 bcdef	12.80 abcd	9.16 gh	18.17 efgh	20.57 abcd	20.03 abcde	17.20 c	23.44 a	23.63 a
Trichoderma + Neem leaves	12.74 abcde	13.49 abc	9.67 gh	17.75 fgh	20.29 abcde	18.20 efgh	16.02 c	22.29 a	22.92 a
Bordeaux mixture	12.24 bcdef	12.57 abcdef	9.45 gh	18.29 efgh	19.18 bcdefg	19.43 abcdefg	17.75 bc	21.45 a	22.93 a

Means followed by the same letter are not significantly different at 5% level

plants was not observed after two months of growth in different treatments. At the end of three months after planting, solarized treatments showed significant increase in the leaf production. At this stage, 30 days solarized treatments were significantly superior to others. But difference among the treatments receiving solarization for 30 days was not significant. A similar trend was noticed in treatments with 45 days of solarization also. Maximum leaf production (179.40) was observed in 30 days solarized plot receiving *Trichoderma* and neem leaves, while, the minimum leaf production (65.78) was recorded in the neem leaves amended non-solarized treatments.

Leaf length

There was marked difference in the length of leaves of plants grown in non-solarized and solarized plots (Table 16). During the first month, maximum leaf length was recorded in plants grown in 30 days solarized plots followed by non-solarized and 45 days solarized plots. But length difference of leaves was not significantly different among different treatments both in non-solarized and solarized plots. Plants in 30 days solarized plots showed maximum length during the second month also. But during this period, 45 days solarized plants had a better leaf length compared to control. During the third month, leaf length was significantly better in all the treatments receiving 45 days solarization and was on par with 30 days solarization. At this stage, the non-solarized treatments were inferior to solarized treatments. Maximum length of 23.68 cm was noticed in 45 days solarized plot incorporated with *Trichoderma*. However, this was on par with all the treatments receiving solarization. All the treatments in control did not differ significantly from one another.

Leaf breadth

Thirty days of solarization had significant effect in maximising the breadth of ginger leaves. At the end of one month of planting, plots solarized for 30 days recorded the maximum (2.75 cm) leaf breadth (Table 17). This was significantly better than all the treatments receiving 45 days of solarization, which in turn, was inferior to the control. In general, during the second month, 30 days solarized treatments were better than 45 days which in turn were better than the non-solarized control. However, at the end of three months of growth, the leaf breadth in 30 days and 45 days solarized plants was on par and was significantly superior to control.

Petiole length

Solarization had no significant effect on the length of the petiole during the first month of planting. However, during the third month, soil solarized for 30 days and drenched with Bordeaux mixture supported the maximum length (13.65 cm) of petiole (Table 17). In general, petiole of plants grown in plots solarized for 30 days was longer than those of non-solarized and plants grown in plots solarized for 45 days.

Fresh weight of shoots

Shoot development in ginger was influenced by solarization. Thirty days solarization was significantly superior in influencing the shoot development compared to other treatments. Maximum fresh weight of shoots (5.88 g) was observed in neem cake amended plot solarized for 30 days one month after planting which was

Table 17. Influence of soil solarization on plant characters in ginger

Treatments	Leaf breadth (cm)								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	2.46 ab	2.75 a	1.95 cde	2.30 f	2.64 ab	2.52 bcde	1.89 c	2.64 a	2.52 a
Neem cake	2.42 ab	2.43 ab	1.83 e	2.47 bcdef	2.51 bcde	2.51 bcde	2.04 c	2.52 a	2.40 ab
Neem leaves	2.31 bc	2.41 ab	1.95 de	2.41 cdef	2.73 a	2.46 bcdef	1.84 c	2.50 a	2.44 ab
Trichoderma	2.60 ab	2.47 ab	1.97 cde	2.41 cdef	2.39 cdef	2.45 bcdef	2.16 bc	2.47 ab	2.60 a
Trichoderma + Neem cake	2.31 bc	2.46 ab	1.81 e	2.33 ef	2.57 abc	2.49 bcdef	2.16 bc	2.61 a	2.47 ab
Trichoderma + Neem leaves	2.46 ab	2.55 ab	1.83 e	2.36 def	2.57 abc	2.50 bcdef	1.99 c	2.64 a	2.56 a
Bordeaux mixture	2.36 b	2.27 bcd	1.79 e	2.45 bcdef	2.42 cdef	2.47 bcdef	2.40 ab	2.47 ab	2.55 a

Treatments	Petiole length (cm)								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	9.59 b	10.06 a	8.89 abc	7.77 d	8.26 cd	10.05 a	9.71 cde	12.43 abcd	7.93 e
Neem cake	9.60 ab	9.05 abc	7.63 c	8.48 bcd	8.84 abcd	10.01 a	10.20 abcde	11.38 abcde	8.50 e
Neem leaves	8.36 abc	9.59 ab	8.72 abc	8.10 cd	8.76 abcd	9.35 abc	8.02 e	12.75 abcd	10.02 bcde
Trichoderma	9.84 ab	9.81 ab	8.38 abc	8.73 abcd	8.43 bcd	9.67 ab	10.81 abcde	13.25 abc	9.93 bcde
Trichoderma + Neem cake	9.39 abc	9.34 abc	8.15 bc	8.75 abcd	7.70 d	9.97 a	9.80 bcde	12.59 abcd	9.67 de
Trichoderma + Neem leaves	8.79 abc	8.49 abc	8.31 abc	7.49 d	8.49 bcd	9.22 abc	8.43 e	13.31 ab	8.49 e
Bordeaux mixture	9.13 abc	8.41 abc	8.41 abc	8.43 bcd	8.19 cd	9.71 ab	10.94 abcde	13.65 a	9.30 de

Means followed by the same letter are not significantly different at 5% level

however on par with other treatments receiving 30 days solarization (Table 18). Fresh weight of shoots observed in control plots with different treatments did not differ significantly from one another and with treatments in which the soil was solarized for 45 days. During the second month after planting, neem cake amended plots solarized for 30 days supported maximum fresh weight (27.93 g), while, plants grown in the *Trichoderma* incorporated control plot had the least fresh weight of shoots (6.97 g). Fresh weight of shoots at the end of three months after planting was nearly six times more in 30 days solarized plots (121.94 g) when compared to control. Different treatments in the control did not differ significantly from one another.

Fresh weight of rhizomes

No significant difference in the fresh weight of rhizome was observed for the first two months of growth with different treatments. Solarization enhanced the rhizome development from the third month onwards (Table 18). Significant difference was noticed in solarized treatments compared to non-solarized treatments. At the end of third month after planting, maximum rhizome development (125.02 g) was recorded in neem leaves amended plots solarized for 45 days followed by the plants grown (101.61 g) in 30 days solarized plot, while the minimum fresh weight (27.68 g) was recorded in non-solarized control plot.

Number of roots

Significant difference in the root development of plants in the different treatments was not observed up two months after planting. Three month old plants grown in 45 days solarized plots incorporated with *Trichoderma* and neem leaves produced maximum number of roots (62.67) followed by plants grown in

Trichoderma incorporated with neem cake amended plot (59.33) solarized for 30 days (Table 19).

Average length of roots

Significant difference in the root length of ginger plants was not observed among the different treatments upto the end of one month of growth (Table 19). Thirty days solarized treatments were significantly superior after attaining three months of growth. Maximum root length (19.76 cm) was observed in plants grown in the *Trichoderma* incorporated plot amended with neem cake and solarized for 30 days, while plants grown in the neem cake amended non-solarized treatments (10.87 cm) produced the shortest roots.

Average number of fingers/plant

Significant effect of 30 days solarization was also observed in the number of fingers produced per plant. However, 45 days of solarization was on par with the non-solarized treatments (Table 20). There was no significant difference among the various treatments in 30 days solarized plots. Plants grown in the Bordeaux mixture drenched plot (62.83) followed by *Trichoderma* incorporated with neem cake (57.75) solarized for 30 days produced maximum numbers of fingers.

Yield

A significant increase in the yield of ginger was observed when plants were grown in solarized plots. This was more evident in plots solarized for 30 days (Table 21, Fig.9). *Trichoderma* + neem cake amended plot solarized for 30 days gave the maximum yield of 10,159.59 g/plot and was significantly superior to all the

Table 19. Influence of soil solarization on plant characters in ginger

Treatments	No. of roots								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-soarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	7.00 e	15.00 bcde	10.00 de	23.00 bcde	25.33 bcde	23.00 bcde	25.00 defgh	39.00 bcdefg	23.33 efgh
Neem cake	20.00 abcd	30.33 a	10.33 de	17.33 de	39.00 bc	25.67 bcde	13.33 h	23.67 efgh	25.67 defgh
Neem leaves	12.00 cde	14.67 bcde	15.33 bcde	29.00 bcde	18.00 cde	40.67 b	20.67 gh	25.67 defgh	46.33 abc
Trichoderma	11.00 de	14.67 bcde	23.67 abc	22.33 bcde	14.67 de	23.67 bcde	16.67 h	49.67 abc	44.67 abcd
Trichoderma + Neem cake	16.67 bcde	23.67 abc	19.67 abcd	20.33 bcde	27.67 bcde	79.00 a	21.00 fgh	59.33 ab	20.00 gh
Trichoderma + Neem leaves	18.67 abcde	14.00 bcde	20.67 abcd	34.00 bcd	26.67 bcde	24.67 bcde	23.33 efgh	33.33 cdefgh	62.67 a
Bordeaux mixture	24.67 ab	19.33 abcd	10.00 de	24.67 bcde	19.33 bcde	10.00 e	33.67 cdefgh	41.33 bcdef	43.00 abcde

Treatments	Average root length (cm)								
	1 MAP			2 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	10.15 a	10.23 a	7.84 a	15.16 abc	14.25 abcde	12.07 bcde	12.49 bc	19.75 a	13.04 bc
Neem cake	9.17 a	10.86 a	8.61 a	13.51 abcde	17.56 a	11.87 bcde	10.87 c	15.17 abc	17.60 ab
Neem leaves	10.92 a	10.35 a	8.64 a	13.97 abcde	9.67 de	14.75 abcd	12.90 bc	17.25 abc	18.48 ab
Trichoderma	9.09 a	9.91 a	7.97 a	12.97 abcde	12.18 bcde	14.66 abcd	10.88 c	17.41 abc	13.91 abc
Trichoderma + Neem cake	8.71 a	8.75 a	9.35 a	9.13 e	15.34 ab	16.46 ab	14.29 abc	19.76 a	12.83 bc
Trichoderma + Neem leaves	9.15 a	9.62 a	11.01 a	15.13 abc	17.03 ab	13.27 abcde	14.00 abc	18.87 ab	16.07 abc
Bordeaux mixture	8.73 a	10.31 a	9.06 a	10.09 cde	13.59 abcde	14.88 abc	17.28 abc	18.51 ab	16.21 abc

Means followed by the same letter are not significantly different at 5% level

Table 20. Influence of soil solarization on average number of fingers per plant

Treatments	Non-solarization	Solarization	
		30 days	45 days
Control	8.89 cde	54.36 abc	36.45 abcde
Neem cake	9.50 cde	57.58 abcd	10.67 de
Neem leaves	10.17 bcde	22.58 abcde	29.30 abcde
Trichoderma	13.05 abcde	57.19 ab	43.92 abcde
Trichoderma + Neem cake	9.67 bcde	57.75 a	41.92 abcd
Trichoderma + Neem leaves	12.17 abcde	41.42 abcde	6.84 e
Bordeaux mixture	10.32 bcde	62.83 a	33.58 abcde

Means followed by the same letter are not significantly different at 5% level

Table 21. Influence of soil solarization on yield in ginger

Yield/plot (g)

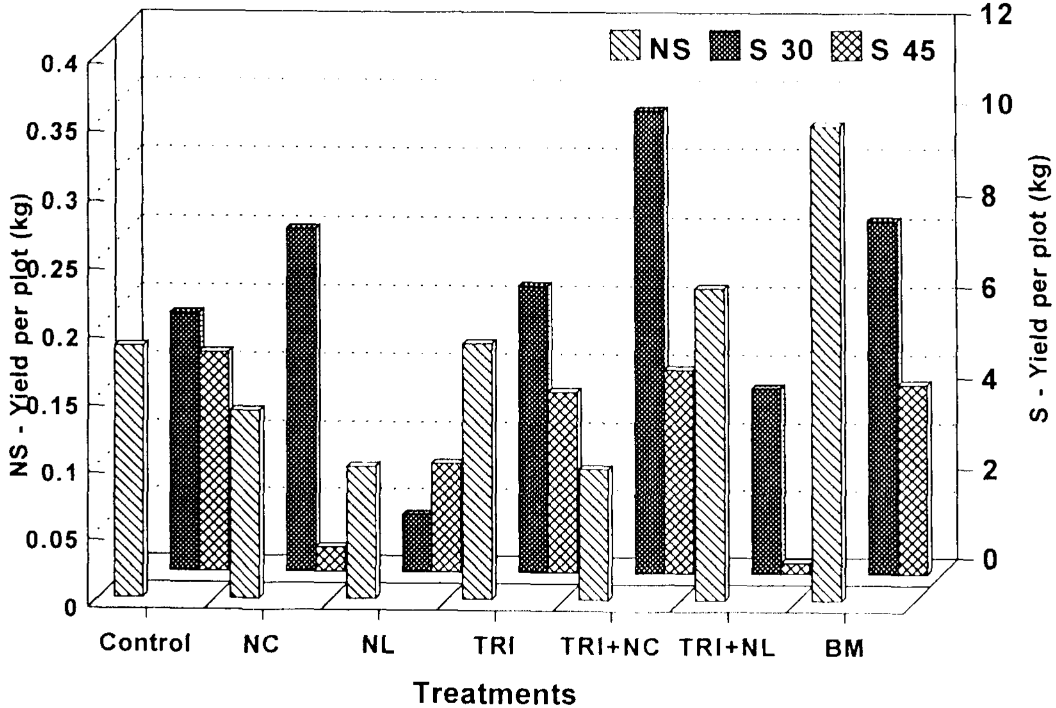
Treatments	Non-solarization	Solarization	
		30 days	45 days
Control	186.03 cd	5715.57 abcd	4851.53 abcd
Neem cake	138.50 cd	7576.83 ab	535.27 cd
Neem leaves	98.13 d	1266.57 cd	2426.27 bcd
Trichoderma	189.23 cd	6344.40 abc	4013.43 abcd
Trichoderma + Neem cake	97.93 d	10159.57 a	4513.03 abcd
Trichoderma + Neem leaves	230.33 cd	4121.13 abcd	241.63 cd
Bordeaux mixture	347.63 cd	7792.17 ab	4202.33 abcd

Average yield per plant (g)

Treatments	Non-solarization	Solarization	
		30 days	45 days
Control	56.02 d	462.65 ab	540.27 a
Neem cake	49.63 d	454.63 abc	92.63 cd
Neem leaves	45.18 d	176.29 bcd	342.85 abcd
Trichoderma	75.33 d	464.09 ab	371.02 abcd
Trichoderma + Neem cake	50.53 d	623.23 a	391.27 abcd
Trichoderma + Neem leaves	82.23 d	380.28 abcd	79.15 d
Bordeaux mixture	62.34 d	552.21 a	277.21 abcd

Means followed by the same letter are not significantly different at 5% level

Fig. 9 influence of soil solarization on yield of ginger

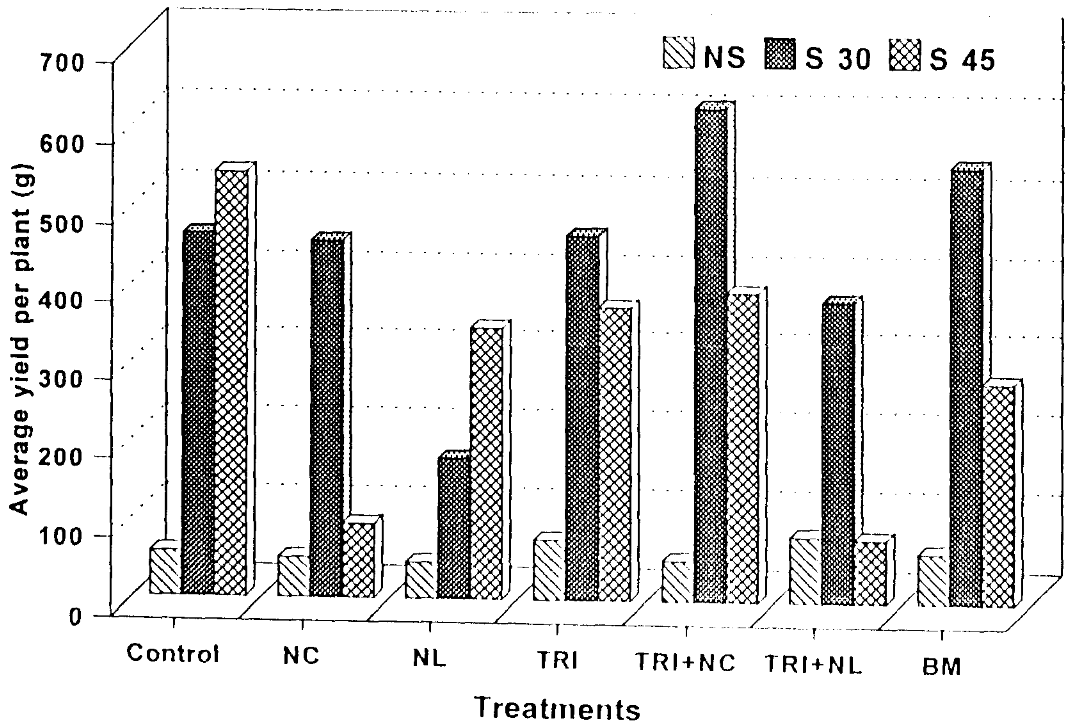


other treatments. Among the 30 days solarized treatments, neem leaves amended plot (1266.57 g) recorded the lowest yield. In general, the yield in 45 days solarized plots was inferior to those observed in 30 days solarized treatments. Among this, the maximum yield of 4851.53 g was obtained in 45 days solarized control plot which in turn was on par with the treatments receiving *Trichoderma*, *Trichoderma* with neem cake and Bordeaux mixture.

In the non-solarized treatments, yield difference was not significant among the treatments and it ranged from 98.13 g/plot (neem leaves) to 347.63 g/plot (Bordeaux mixture). The percentage increase in the yield of ginger in 30 days solarized plot over the non-solarized plots ranged from 1190 to 10274 per cent and that of 45 days of solarized plots from 17.81 to 1605.0 per cent. However, yield increase observed in 45 days solarized plots over non-solarized plots ranged only from 4.9 to 4508.0 per cent (Table 21).

The influence of solarization was more evident when yield per plant was compared. The yield per plant in the various treatments ranged from 45.18 g (neem leaves amended non-solarized plot) to 623.23 g (*Trichoderma* incorporated and neem cake amended plot solarized for 30 days) (Table 21, Fig.10). Thus, 1279.0 per cent increase in the yield was noticed between the lowest and highest yield. In general, the yield per plant was minimum in non-solarized plots. The yield difference among the various treatments in the non-solarized plots was not significant. Thirty days solarization was significantly superior to other treatments. The maximum yield per plant (623.23 g) was recorded in *Trichoderma* incorporated and neem cake amended 30 days solarized plot and was significantly superior to others but was on par with Bordeaux mixture drenched 30 days solarized plot (552.21 g) and control plot

Fig. 10 Influence of soil solarization on average yield of ginger (per plant)



solarized for 45 days (540.27 g). Plants grown in neem leaves amended non-solarized plot recorded the lowest yield per plant (45.18 g).

Effect of solarization on nematodes

The nematode population was decreased significantly as a result of solarization. In this study, no attempt was made to differentiate the parasitic and non-parasitic nematodes. The nematode count prior to solarization was 95.98 numbers/ 200 g of soil. Immediately after solarization, the population reduction was 99.65 to 100.0 per cent in all the solarized treatments except in neem leaves amended 30 days solarized plot, where the reduction was 95.13 per cent (Table 22). In non-solarized plots, marked increase in the population count over the initial was observed except in Bordeaux mixture, where there was a decrease of 36.79 per cent.

One month after planting, a gradual increase in the population of nematodes was noticed in the solarized treatments. However, this increase was less in 45 days solarized treatments compared to 30 days. The highest population count of 143.33 numbers/200 g of soil was noticed in 30 days solarized control. While the lowest of 10.0 numbers/200 g of soil was observed in the plot solarized for 45 days amended with *Trichoderma* and neem leaves. The population count in the control plots was significantly higher than the solarized plots except in absolute control which was par with 30 days solarized control.

At the end of three months after planting, the population count in solarized plots was more than that observed during one month after planting except in 30 days solarized, *Trichoderma* incorporated plot where it showed a marginal decrease (Table 22). The increase in population in 45 days solarized plots was highly

Table 22. Influence of soil solarization on population of soil borne nematodes
(No. of nematodes/200 g soil)

Treatments	AS			1 MAP			3 MAP		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	198.33 bc	0.00 e	0.00 e	103.33 abcdef	143.33 abcdef	18.33 ef	57.67 abc	120.67 abc	125.00 abc
Neem cake	99.67 cd	0.00 e	0.00 e	190.33 ab	36.67 cdef	21.67 def	67.33 abc	51.67 bc	90.00 abc
Neem leaves	167.00 bc	4.67 e	0.00 e	285.00 a	53.67 bcdef	116.33 bcdef	55.00 abc	114.67 abc	120.33 abc
Trichoderma	275.33 ab	0.00 e	0.00 e	113.00 abcde	85.00 bcdef	10.67 f	63.00 abc	43.67 bc	107.33 abc
Trichoderma + Neem cake	169.67 bc	0.00 e	0.00 e	153.33 abc	53.67 bcdef	10.00 f	45.33 bc	60.00 abc	156.33 ab
Trichoderma + Neem leaves	358.33 a	0.33 e	0.67 e	146.00 abc	59.33 bcdef	49.67 cdef	47.67 bc	166.33 a	55.67 bc
Bordeaux mixture	60.67 d	0.00 e	0.33 e	128.00 abcd	24.00 def	13.33 f	91.67 abc	35.33 c	77.00 abc

Treatments	6 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days
Control	44.00 efg	401.33 a	73.00 defg	10.33 fg	93.62 abc	83.33 abc
Neem cake	74.33 defg	238.33 abc	142.00 bcdefg	12.67 fg	100.00 a	26.00 defg
Neem leaves	37.00 fg	131.67 bcdefg	81.67 defg	19.33 defg	80.00 abcde	68.00 abcd
Trichoderma	34.33 g	238.33 abc	150.67 bcde	7.67 g	91.00 ab	60.33 abcde
Trichoderma + Neem cake	43.00 efg	283.33 ab	96.00 cdefg	9.67 g	96.33 ab	37.33 bcdefg
Trichoderma + Neem leaves	41.67 efg	50.33 efg	168.00 bcdef	25.33 defg	87.67 abc	64.67 abcdef
Bordeaux mixture	46.67 efg	192.33 bcd	110.00 bcdefg	19.33 efg	58.33 abcde	30.33 cdefg

Means followed by the same letter are not significantly different at 5% level

Initial population - 95.98

significant. However, in the non-solarized treatments, a marked reduction in the population was observed over the initial count as well as the population one month after planting. At the end of six months after planting, the population of nematodes in the non-solarized treatments did not differ significantly from the values observed at the end of three months and there was no significant difference among the various treatments. However, in 30 days solarized plots all the treatments except *Trichoderma* + neem leaves exhibited an increase in the population of nematodes. The increase ranged from 14.83 to 445.8 per cent (Table 22). The population count of nematodes in 45 days solarized treatments was less than that observed in 30 days solarized plots except in *Trichoderma* incorporated plots amended with neem leaves.

At the time of harvest, in general, there was a significant reduction in the nematode population in almost all the treatments compared to the population observed at the time of six months after planting. This reduction was maximum in non-solarized plots. In the solarized plots, the nematode count in the various treatments was less in 45 days compared to 30 days. The least population of 30.33 numbers/ 200 g of soil was recorded in 45 days solarized plot treated with Bordeaux mixture and the highest count of 100.0 numbers/200 g of soil was in neem cake amended 30 days solarized plot.

Effect of solarization on weed population

In the experimental field, 48 different types of weeds were observed, out of which seven were monocots and the remaining dicots. At the time of land preparation, the field was completely covered with dried *Cynodon dactylon, Mimosa pudica, Scoparia dulcis, Lantana camara, Stachytarpheta indica* and *Clitoria ternatea*. All the weeds were removed at the time of bed preparation. Weed counts were taken separately from the top and sides of the bed. For the purpose of taking the total weed count 21 plots were counted as one unit and the total count of the weeds from this was made. Thus, there were 21 plots each under non-solarized, 30 days solarized and 45 days solarized treatments. No attempt was made to study the effect of different amendments on weed population.

Weeds on top of the bed

On the day of removal of the mulch, there were no weeds on the top portion of the solarized beds (Table 23). While, the non-solarized beds were covered with 652 numbers of monocots comprising of three species, *viz.*, *C. dactylon* (618), *Cyperus rotundus* (10) and *Digitaria ciliaris* (24) and 1418 numbers of dicots - consisting of *Crotalaria mucronata* (374), *Indigofera hirsuta* (463), *Knoxia* sp. (116) and *Merrimea* sp. (165).

When the weed population was counted one month after removing the mulch, a total of 1008 weeds were observed in non-solarized plots (Table 23, Plate 5 and 6), of which 363 were monocots and the remaining dicots. *C. dactylon* (245) and *Knoxia* sp. (431) were the major monocot and dicot weeds respectively during this period. Among the solarized plots, better control of both dicots and monocots was noticed in 45 days solarized plots. Compared to 433 weeds in 30 days solarized plots, there were only 111 in 45 days solarized plots. In both the cases *C. dactylon* was the major monocot, while, *Knoxia* sp. and *Amaranthus viridis* were the major dicots respectively in 30 and 45 days solarized plots.

Maximum weed population was noticed in all the treatments during the second month after planting (Table 23). Non-solarized plots had 1646 numbers of

Table 23. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
7 *Cleome viscosa*	31	-	-	31	4	4	20	6	6	5	-	-	11	-	17	-	-	-
8 *Clitoria terntea*	11	-	-	6	11	-	-	-	-	-	-	-	-	-	-	-	-	-
9 *Centrosema pubescens*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 *Crotalaria mucronata*	374	-	-	3	16	7	1	4	6	-	-	-	1	3	-	-	-	2
11 *Desmodium trifolium*	1	-	-	-	-	-	1	6	2	1	-	1	-	-	-	-	-	-
12 *Emilia sonchifolia*	-	-	-	6	-	-	37	5	2	4	-	-	9	-	8	3	3	15
13 *Euphorbia hirta*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14 *Hemidesmus indicus*	21	-	-	2	-	-	13	1	1	-	-	-	8	-	-	2	-	-
15 *Hyptis suaveolens*	10	-	-	3	-	-	1	-	-	-	-	-	-	-	-	-	-	-
16 *Ichinocarpus frutiscens*	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17 *Indigofera hirsuta*	463	-	-	24	2	-	-	-	-	-	-	-	-	-	-	-	-	-
18 *Knoxia* sp.	116	-	-	431	63	2	914	156	107	55	14	74	198	63	307	8	2	46
19 *Lindernia parviflora*	2	-	-	-	-	-	992	214	-	321	123	44	208	50	181	2	-	-
20 *Lantana camara*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21 *Lucas aspera*	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
22 *Ludwigia parviflora*	-	-	-	-	-	-	429	181	4	85	21	10	65	9	103	2	-	-
23 *Merrimea* sp.	165	-	-	2	2	2	-	1	2	-	-	-	-	-	-	-	-	-
24 *Mimosa pudica*	97	-	-	83	11	4	3	3	1	-	-	4	2	2	-	2	-	13
25 *Mullugo disticha*	-	-	-	27	10	11	1807	393	248	7	6	24	-	-	29	-	1	2
26 *Oldenlandia affinis*	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-
27 *Passiflora edulis* var. *foetida*	1	-	-	1	-	-	-	1	3	-	-	-	-	-	-	-	-	-

Contd.

Table 23. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
28 *Peuraria phaseoloides*	-	-	-	-	-	-	4	3	5	-	-	-	2	2	1	-	1	2
29 *Phylanthus niruri*	7	-	-	4	-	-	50	13	7	-	-	-	8	3	-	1	-	2
30 *Physalis minima*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31 *Portulacca oleracea*	-	-	-	-	-	-	4	6	-	-	-	-	-	-	-	-	-	-
32 *Peperomia pellucida*	-	-	-	-	-	-	-	-	-	3	-	-	-	3	23	-	-	-
33 *Ricinus communis*	-	-	-	3	2	-	-	-	-	-	-	-	-	-	-	-	-	-
34 *Scoparia dulcis*	46	-	-	1	-	-	8	5	-	47	12	5	136	90	47	58	4	26
35 *Sesbania* sp.	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36 *Sida rhombifolia*	27	-	-	2	-	-	2	1	4	-	-	-	1	-	-	-	-	-
37 *Stachytarpheta indica*	9	-	-	2	-	-	10	-	1	-	1	-	18	-	2	-	-	-
38 *Synedrella nodiflora*	1	-	-	10	1	-	98	62	21	21	7	8	83	11	69	7	3	17
39 *Urena lobata*	-	-	-	-	-	-	-	1	3	-	-	-	-	-	-	-	-	-
40 *Vernonia cineria*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-
41 *Vicoa indica*	-	-	-	-	-	-	2	-	-	4	1	-	7	-	-	-	-	-
Total	1418	-	-	645	128	46	4432	1090	423	553	185	173	764	244	791	88	15	165
Grand total	2070	-	-	1008	433	111	6078	1887	1061	828	285	293	1164	283	916	250	30	279

Plate 5. Weed population in solarized ginger bed

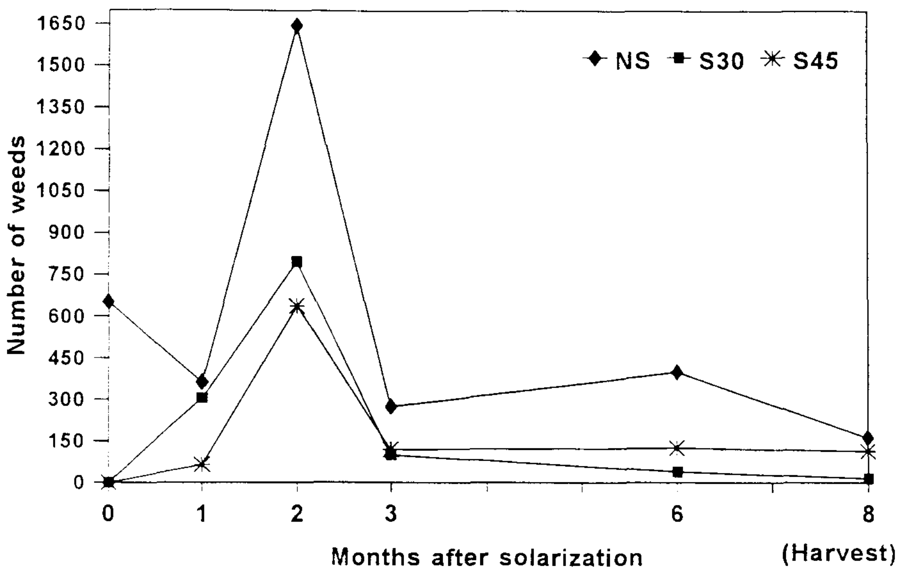
Plate 6. Weed population in non-solarized ginger bed

monocots weeds. More than 95.0 per cent of the weeds belonged to *Bulbostylis barbata, C. dactylon, C. rotundus* and *Dactyloctenium aegyptium*. A similar pattern with reduced numbers was observed in 30 and 45 days solarized plots. During this period, 4432 dicots weeds were noticed in non-solarized plots of which 1807 were *Mullugo disticha*, 992 *Lindernia parviflora*, 914 *Knoxia* sp. and 429 *Ludwigia parviflora*. In 30 days solarized plots a similar pattern with reduced population count (1090) was noticed. In 45 days solarized plots, population of weeds were less than in 30 days solarized plots (423). In this treatment, compared to 30 days solarized plots, population of *Lindernia parviflora* and *Ludwigia parviflora* were reduced and that of *A. viridis* increased.

From third month onwards, population of weeds showed a decreasing trend. During the sixth month, higher numbers of weeds were observed in 45 days solarized plots compared to 30 days, eventhough both these treatments were better than the control. The 45 days solarized plots had comparatively more numbers of dicots especially with *Knoxia* sp. (307), *Lindernia parviflora* (181) and *Ludwigia parviflora* (103). The corresponding values in 30 days were 63.0, 50.0 and 9.0. At the time of harvest, *Biophytum sensitivum* which was not observed before, was noticed in 45 days solarized plots. The total weed population per plot over the entire period was 542.76, 138.95 and 126.66 respectively for non-solarized, 30 and 45 days solarized treatments of which 376.19, 79.14 and 76.09 were dicots. Thus, 30 days solarization reduced weed population by 74.5 per cent while, for 45 days the reduction was 76.7 per cent over the control. The per cent reduction of monocots over control was 64.5 and 69.9 for 30 and 45 days solarization respectively (Fig.11), whereas, the reduction in dicots over the control was 78.98 and 79.8 per cent for 30 and 45 days (Fig.12).

Fig.11. Influence of soil solarization on population of monocot weeds

(a) Top of beds



(b) Slope of beds

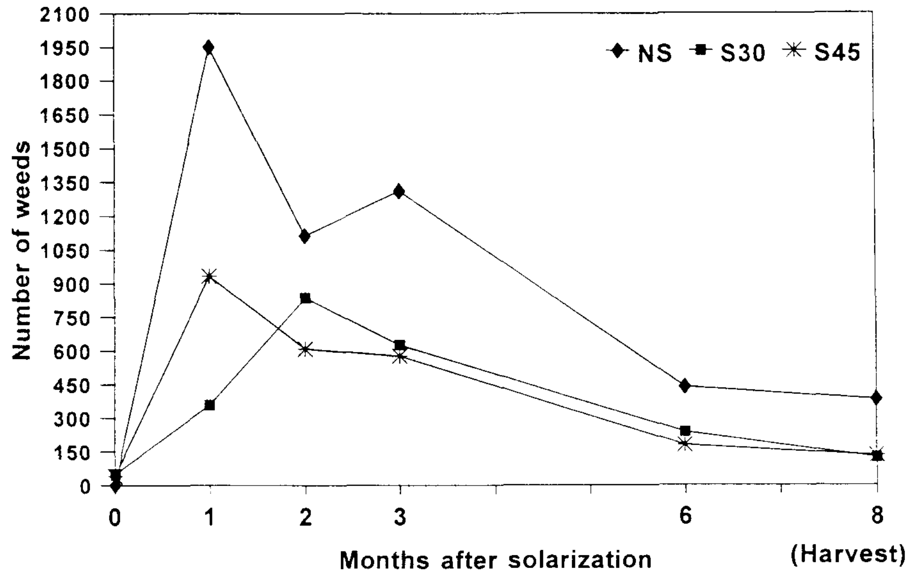
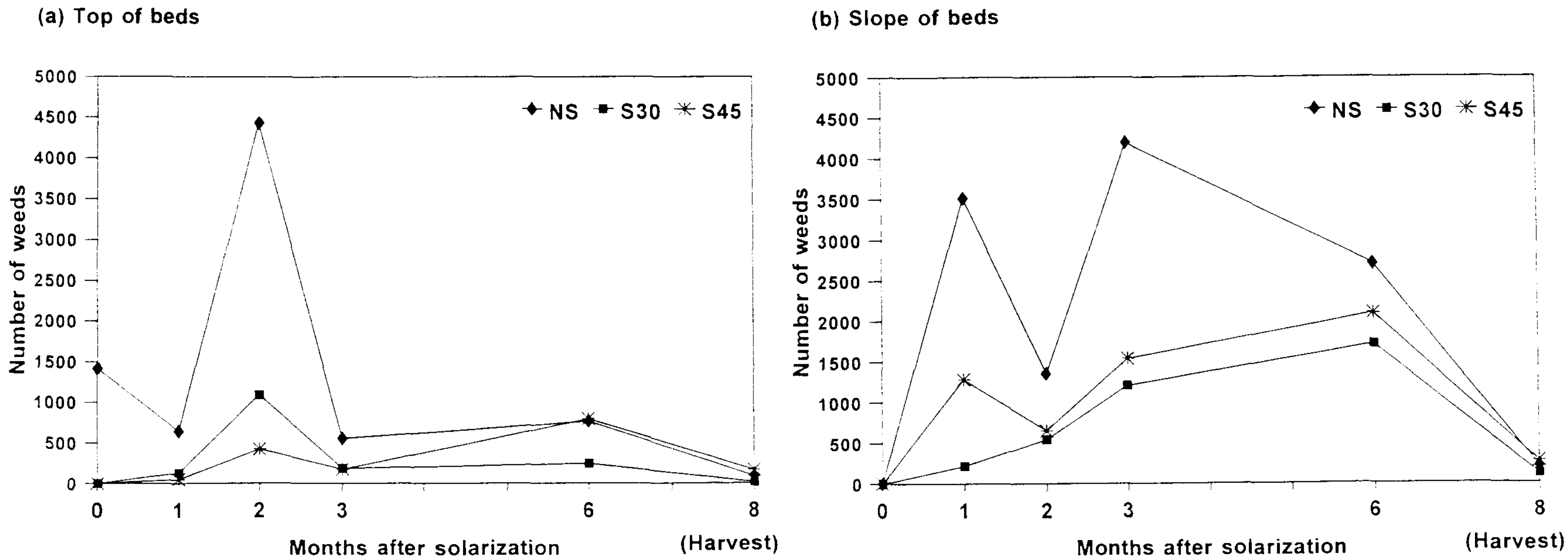


Fig.12. Influence of soil solarization on population of dicot weeds



Weeds on the sides of the bed

The weed population seen on the sides of the ginger bedswas recorded at regular intervals. After every observation, the weeds were removed. In general, the weed population was more in the sides of the beds compared to the top. Thirty days solarization was more effective in reducing the weed population than 45 days. Dicot population was maximum in the sides of the beds compared to monocots. *Knoxia* sp., *Ludiwigia parviflora, Lindernia parviflora, Mullugo disticha, S. dulcis* and *Synedrella nodiflora* were the predominant dicots observed in the sides of the beds. *B. barbata, C. dactylon, C. rotundus, D. aegyptium, D. ciliaris* and *Pennisetum* sp. were the common weeds among monocots (Table 24).

On the day of removal of the polyethylene sheets, there were no weeds on the sides of the non-solarized beds (Table 24) while, only three types of monocots, viz., *B. barbata, C. dactylon* and *C. rotundus* were present in the sides of the solarized beds. Out of a total of 90 weeds, 50 were in 30 days solarized and the remaining in 45 days solarized beds. Dicot weeds were not observed at this stage.

When the weed population was taken one month after removing the mulch, a total of 5465 numbers of weeds were observed in non-solarized plots of which 1950 were monocots and the remaining dicots (3515) (Table 24). At this stage six types of monocots and 20 types of dicots were noticed among which, *B. barbata* (904), *C. dactylon* (974) were the major monocot species and *Knoxia* sp. (1461) was the dominant dicot species. A similar pattern with reduced numbers were observed in solarized plots. Among the solarized plots, better control of monocot and dicot weeds

Table 24. Influence of soil solarization on weed population

Side of the bed

	Number of weeds																	
	AS			1 MAP			2 MAP			3 MAP			6 MAP			Harvest		
	NS	S		NS	S		NS	S		NS	S		NS	S		NS	S	
		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days		30 days	45 days
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Monocots																		
1 *Alloteropsis cimicina*	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-
2 *Bulbostylis barbata*	-	4	14	904	157	780	461	485	369	846	507	432	-	-	-	-	-	-
3 *Cynodon dactylon*	-	39	27	974	162	108	294	120	178	339	85	112	237	70	28	358	66	65
4 *Cyperus rotundus*	-	7	-	28	36	27	350	225	54	112	30	33	91	136	134	15	20	21
5 *Dactyloctenium aegyptium*	-	-	-	21	1	-	-	-	4	2	4	-	28	9	16	10	36	44
6 *Digitaria ciliaris*	-	-	-	-	-	18	-	-	-	-	-	-	72	18	-	-	-	-
7 *Pennisetum* sp.	-	-	-	23	2	-	7	7	3	13	-	-	13	6	2	-	2	3
Total	-	50	41	1950	358	933	1113	837	609	1312	626	577	441	239	180	383	124	133
Dicots																		
1 *Achyranthus aspera*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 *Aerva lanata*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 *Amaranthus viridis*	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	4	-	15
4 *Biophytum sensitivum*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17	7	38
5 *Cassia tora*	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
6 *Chromolaena odorata*	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
7 *Cleome viscosa*	-	-	-	45	-	-	2	-	1	14	-	-	21	13	1	-	-	2

NS - Non-solarization; S - Solarization

Contd.

Table 24. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
8 *Centrosema pubiscens*	-	-	-	6	-	3	24	-	-	-	-	-	5	4	-	2	1	3
9 *Clitoria ternatea*	-	-	-	-	-	-	-	-	-	3	-	-	6	4	-	-	-	1
10 *Crotalaria mucronata*	-	-	-	81	2	65	-	3	3	-	-	-	-	-	-	-	-	-
11 *Desmodium trifolium*	-	-	-	2	-	-	-	2	-	-	3	-	4	4	-	-	-	-
12 *Emilia sanchifolia*	-	-	-	27	-	-	18	1	-	38	-	-	18	22	-	-	2	9
13 *Euphorbia hirta*	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-
14 *Hemidesmus indicus*	-	-	-	15	12	5	8	11	5	20	7	2	5	6	-	13	-	1
15 *Hyptis suaveolens*	-	-	-	10	-	2	-	-	1	-	-	-	11	-	1	1	-	-
16 *Ichinocarpus frutiscens*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17 *Indigofera hirsuta*	-	-	-	44	-	-	-	-	-	-	-	-	1	-	-	-	-	-
18 *Knoxia* sp.	-	-		1461	115	538	466	265	262	878	146	423	688	439	428	37	38	93
19 *Lindernia parviflora*	-	-	-	-	-	-	310	132	20	2665	877	716	324	200	283	1	-	-
20 *Lantana camara*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-
21 *Lucas aspera*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22 *Ludwigia parviflora*	-	-	-	-	-	-	270	-	32	117	49	136	161	119	159	-	-	-
23 *Merrimea* sp.	-	-	-	12	1	2	-	-	-	-	-	-	-	-	-	-	-	-
24 *Mimosa pudica*	-	-	-	604	11	5	11	1	5	-	6	-	6	1	1	-	3	10
25 *Mullugo disticha*	-	-	-	956	72	638	231	125	298	81	69	206	-	-	1	-	-	-
26 *Oldenlandia affinis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27 *Passiflora edulis* var. *foetida*	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
28 *Peruraria phaseoloides*	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	1	1

Contd.

Table 24. Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
29 *Phyllanthus niruri*	-	-	-	44	-	6	4	-	1	9	-	1	18	-	-	-	-	1
30 *Physalis minima*	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-
31 *Portulacca oleracea*	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
32 *Peperomia pellucida*	-	-	-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	-
33 *Ricinus communis*	-	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-
34 *Scoparia dulcis*	-	-	-	10	1	-	-	-	17	142	49	38	1006	786	970	107	47	89
35 *Sesbania* sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36*Sida rhombifolia*	-	-	-	61	1	3	-	1	2	3	2	-	-	-	-	-	-	-
37 *Stachyturpheta indica*	-	-	-	60	1	16	-	-	2	2	-	-	50	15	25	-	-	-
38 *Synedrella nodiflora*	-	-	-	69	-	-	14	-	-	205	-	20	273	69	211	27	16	6
39 *Urena lobata*	-	-	-	6	-	-	-	-	-	-	-	-	1	3	-	-	-	-
40 *Vernonia cineria*	-	-	-	-	-	-	-	-	-	2	-	-	13	3	-	-	-	-
41 *Vicoa indica*	-	-	-	-	-	-	-	-	-	-	1	-	84	31	12	-	-	-
Total	-	-	-	3515	217	1284	1358	541	649	4197	1209	1542	2710	1722	2101	210	115	269
Grand Total	-	50	41	5465	575	2217	2471	1378	1258	5509	1835	2119	3151	1961	2281	593	239	402

were noticed in 30 days solarized plots. Compared to 2217 numbers of weeds in 45 days solarized plots, there were only 575 weeds in 30 days solarized plots.

In solarized beds compared to the weed population observed during the end of one month after planting, a reduction in the population of weeds was noticed during the second month after planting (Table 24). During this period, *D. aegyptium, S. indica* and *S. dulcis* were only noticed in 45 days solarized plots. Non-solarized plots had 2471 number of weeds of which 1113 were monocots. More than 99.0 per cent of the monocots consists of *B. barbata, C. dactylon* and *C. rotundus*. A similar pattern was observed in solarized beds. Altogether, 2471 dicots were observed in non-solarized plots, of which *Knoxia* sp. (466), *Lindernia parviflora* (310), *Ludwigia parviflora* (270) and *M. disticha* (231) were the major ones. The same pattern was observed in 45 days solarized beds also. *Ludwigia parviflora* was not observed in 30 days solarized treatments.

Maximum weed population was noticed during the third month after planting (Table 24). During this period 5509 numbers of weeds were present in the non-solarized plots, while only 1835 and 2119 numbers of weeds were recorded in 30 and 45 days solarized plots, respectively. Forty five days solarized plots had comparitively more numbers of dicots especially *Lindernia parviflora* (716) and *Knoxia* sp. (423). The corresponding figures in 30 days were 877 and 146 with the same species, respectively.

A reduction in the weed population was observed in non-solarized plots during the sixth month, whereas the solarized treatments showed an increase in the population. *S. dulcis* was the most prominent dicot weed in all the treatments at this time. At the time of harvest, a marked reduction of weed population was observed in all the treatments. During this period, 593 weeds were observed in non-solarized plots compared to 237 and 402 weeds respectively in 30 and 45 days solarized plots. The total weed population per plot on the sides of the beds over the entire period was 818.52, 287.52 and 396.09 respectively for non-solarized, 30 and 45 days solarized beds. Thus, 30 days solarization reduced weed population by 65.0 per cent while, for 45 days solarization, the reduction was only 52.0 per cent over the non-solarized beds. The per cent reduction of monocots over the control was 57.03 and 52.43 respectively, for 30 and 45 days solarization (Fig.11), while, corresponding values for dicots were 68.27 and 51.25 per cent, respectively (Fig.12).

Effect of solarization on the fresh weight of weeds

Weeds on top of the bed

Fresh weight of the weeds were taken at four intervals viz., two, three and six months after planting and at the time of harvest. Weeds present in the beds and on the sides of the beds were collected separately and the fresh weights recorded.

At the end of the second month after planting, the total weight of the weeds per plot in non-solarized treatments was 99.32 g as compared to 45.19 g and 28.62 g in 30 and 45 days solarized plots, respectively (Table 25). A similar trend was also noticed during the third month after planting. However, during the sixth month after planting maximum fresh weight of 830.33 g/plot was observed in 45 days solarized plots as compared to 496.03 g and 284.13 g respectively in control and 30 days solarized plots. At the time of harvest, the minimum weight of 0.88 g per plot was recorded in 30 days solarized plots followed by 45 days solarization and control with 9.17 g and 13.01 g, respectively.

Table 25. Influence of soil solarization on fresh weight of weeds
(Weight (g)/plot size of 2 x 1 m)

Treatments	2 MAP	3 MAP	6 MAP	Harvest
a) Top of the bed				
Non-solarization	99.32	55.36	496.03	13.01
30 days solarization	45.19	15.91	284.13	0.88
45 days solarization	28.62	7.82	830.33	9.17
b) Side of the bed				
Non-solarization	26.18	105.59	1293.65	23.91
30 days solarization	12.38	40.34	236.51	9.68
45 days solarization	30.62	33.91	363.76	12.06

Weeds on the sides of the bed

The fresh weight of the weeds present in the sides of the plot followed a definite pattern. The maximum weight was recorded in non-solarized and followed by 45 and 30 days solarized beds (Table 25). The total weight of the weeds during the entire period of observation was 1.45 kg/plot in non-solarized and followed by 0.44 kg and 0.30 kg/plot in 45 and 30 days solarized plots, respectively.

Effect of solarization on nutrient status, pH and Electrical Conductivity of the soil

Available nitrogen

Soil solarization has been found to influence the availability of nutrients. The available nitrogen content of the experimental plot on the day of solarization was 454.95 kg ha^{-1}. Except in absolute control and neem leaves amended non-solarized treatment, all other treatments showed an increase in the available nitrogen content of the soil on the day of removal of the mulch (Table 26). The increase was more pronounced in 45 days solarized plots. The least available nitrogen content among 30 and 45 days solarized plots was recorded in soil amended with neem leaves (489.22 kg ha^{-1}), while, the highest was in neem cake incorporated solarized plots (917.28 kg ha^{-1}).

Three months after solarization, a reduction in the available nitrogen content was noticed in all the treatments (both solarized and non-solarized) except in absolute control and neem leaves amended non-solarized plots. At the time of harvest, the available nitrogen content of the non-solarized soil increased except in Bordeaux mixture and *Trichoderma* + neem cake amended plots over the value recorded during three months after planting. In general, the available nitrogen content of 45 days

Table 26. Effect of soil solarization on nutrient status of soil

Available nitrogen (kg ha^{-1})

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	400.89 lm	604.73 fghijk	584.34 ghijk	462.04 abcd	434.86 bcd	387.30 d	509.60 ab	496.01 abc	502.81 ab
Neem cake	516.39 ijkl	794.98 bc	917.28 a	434.86 bcd	434.86 bcd	523.19 ab	570.75 a	455.24 bcd	502.81 ab
Neem leaves	380.50 m	489.22 klm	523.19 hijk	455.24 abcd	441.65 abcd	400.89 cd	475.63 bcd	441.65 bcde	468.83 bcd
Trichoderma	496.01 jklm	611.52 fghij	761.00 cd	387.30 d	482.42 abcd	482.42 abcd	407.68 cde	396.70 de	408.20 cde
Trichoderma + Neem cake	529.98 hijk	747.41 cde	803.69 ab	462.04 abcd	462.04 abcd	489.22 abcd	428.06 bcde	428.06 bcde	434.86 bcde
Trichoderma + Neem leaves	523.19 hijk	625.11 fghi	720.24 cdef	441.65 abcd	394.09 d	302.81 abc	502.81 ab	399.32 de	385.21 de
Bordeaux mixture	509.60 ijkl	638.70 efgh	659.08 defg	462.04 abcd	468.83 abcd	543.57 a	408.20 cde	362.21 e	390.96 de

Means followed by the same letter are not significantly different at 5% level

Initial nitrogen content - 454.95 kg ha^{-1}

solarized plots was higher than that observed in 30 days. But among the solarized treatments a reduction in the available nitrogen content over the initial level was noticed in various treatments except in solarized controls and neem cake amended solarized plots.

Available phosphorus

Available phosphorus content of the soil on the day of solarization was 28.44 kg ha^{-1}. In all the treatments except in Bordeaux mixture drenched plots (solarized as well as non-solarized) an increase in the available phosphorus content immediately after the removal of the polyethylene sheets was noticed (Table 27). The highest available phosphorus content of the soil was recorded in neem cake amended 45 days solarized plot (47.16 kg ha^{-1}), while the least was in Bordeaux mixture drenched non-solarized treatment (18.58 kg ha^{-1}). Marked increase in the available phosphorus content was observed in all the treatments three months after solarization. Forty five days solarized treatments were significantly superior to others. Absolute control recorded the highest available phosphorus content (135.04 kg ha^{-1}) at this stage. At the time of harvest, the available phosphorus content of the soil was decreased over the third months value in all treatments except in *Trichoderma* added and *Trichoderma* + neem leaves amended non-solarized plots. However, all the treatments (both solarized and non-solarized) recorded increased phosphorus content than the initial level.

Available potassium

The available potassium content of the experimental plot on the day of solarization was 359.0 kg ha^{-1}. In general, the available potassium content of the soil

Table 27. Effect of soil solarization on nutrient status of soil

Available phosphorus (kg ha^{-1})

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	31.80 cdefg	38.59 abcde	31.44 cdefg	135.04 a	62.16 cde	100.03 abc	106.10 ab	59.66 def	65.74 cdef
Neem cake	46.80 a	34.30 abcdef	47.16 a	79.31 bcde	59.66 cde	101.46 abc	64.91 def	51.80 f	88.96 abcdef
Neem leaves	32.54 bcdef	34.30 abcdef	38.58 abcde	92.53 abcd	78.24 bcde	92.17 abcde	92.53 abcd	92.88 abcd	86.46 abcdef
Trichoderma	39.30 abcde	29.30 defg	33.94 abcdef	86.46 bcde	52.87 de	130.76 a	103.25 abc	80.38 abcdef	65.74 cdef
Trichoderma + Neem cake	46.09 ab	39.65 abcde	42.51 abcd	115.39 ab	78.96 bcde	132.90 a	90.03 abcde	70.74 bcdef	117.90 a
Trichoderma + Neem leaves	30.48 cdefg	43.94 abc	43.94 abc	98.53 abc	96.82 abc	97.18 abc	104.68 ab	83.60 abcdef	80.03 abcdef
Bordeaux mixture	18.58 g	24.65 fg	28.58 efg	78.95 bcde	70.02 cde	48.94 e	57.17 def	57.88 def	53.99 f

Means followed by the same letter are not significantly different at 5% level

Initial phosphorus content - 28.44 kg ha^{-1}

was increased after the removal of polyethylene sheets (Table 28). This increase was more pronounced in 45 days solarized treatment and was significantly superior to other treatments. Among the solarized treatments, *Trichoderma* added and Bordeaux mixture drenched plots showed a decrease in the available potassium content at this stage. Neem cake amended 45 days solarized treatment supported the highest value of 681.33 kg ha^{-1} while, Bordeaux mixture drenched solarized plot (both 30 and 45) recorded the least available potassium content of 284.67 kg ha^{-1}. During the third month after solarization, a reduction in the available potassium content was noticed over the day of removal of mulch in all the solarized treatments except in Bordeaux mixture drenched 45 days solarized plot. Forty five days solarized treatments were significantly superior than others, while all the 45 days solarized treatments were on par.

At the time of harvest, the available potassium content of the non-solarized soil decreased over the initial level. The non-solarized treatments did not differ significantly. In general, at this stage, the 30 days solarized treatments showed an increase in the available potassium content, whereas the 45 days solarized treatments showed a reduction except in *Trichoderma* added neem cake and neem leaves amended plots.

Organic carbon

Organic carbon content of the experimental field was 0.92 per cent on the day of solarization. The organic carbon content did not show marked variations in the non-solarized control plots immediately after the removal of the mulch (Table 29). A similar trend was noticed in solarized plots also. The organic carbon content showed an increase in all the plots when it was estimated three months after

Table 28. Effect of soil solarization on nutrient status of soil

Available potassium (kg ha^{-1})

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	336.00 fg	326.67 fg	364.00 defg	373.33 abcde	224.00 h	382.67 abcde	294.00 bc	382.67 bc	317.33 bc
Neem cake	653.33 ab	560.00 bc	681.33 a	252.00 fgh	373.33 abcde	452.67 ab	303.33 bc	266.00 c	317.33 bc
Neem leaves	326.67 fg	457.33 cde	616.00 ab	396.67 abcd	270.67 efgh	392.00 abcd	308.00 bc	560.00 a	378.00 bc
Trichoderma	396.67 defg	336.00 fg	344.67 efg	284.67 defgh	308.00 defgh	396.67 abcd	294.00 bc	406.00 abc	350.00 bc
Trichoderma + Neem cake	597.33 ab	466.67 cd	658.00 ab	312.67 defgh	247.33 gh	438.67 abc	270.67 c	294.00 bc	448.00 ab
Trichoderma + Neem leaves	382.67 defg	420.00 def	672.00 ab	326.67 cdefgh	364.00 abcdef	378.00 abcde	322.00 bc	373.33 bc	424.67 abc
Bordeaux mixture	298.67 g	284.67 g	284.67 g	382.67 abcde	340.67 bcdefg	457.33 a	308.00 bc	340.67 bc	322.00 bc

Means followed by the same letter are not significantly different at 5% level

Initial potassium content - 359.00 kg ha^{-1}

Table 29. Effect of soil solarization on nutrient status of soil

Organic carbon (per cent)

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	0.92 cd	0.92 cd	0.90 cde	1.15 abc	1.02 bcd	1.00 bcd	1.27 ab	1.19 abcd	1.05 cd
Neem cake	1.09 a	0.98 bc	1.04 ab	1.09 abcd	0.99 bcd	1.20 ab	1.17 abcd	0.99 d	1.09 bcd
Neem leaves	0.83 de	0.90 cde	0.92 cd	1.05 bcd	0.99 bcd	1.33 a	1.22 abc	1.12 bcd	1.12 bcd
Trichoderma	0.82 e	0.88 cde	0.98 bc	1.16 abc	0.89 cd	1.03 bcd	1.12 bcd	0.99 d	1.13 bcd
Trichoderma + Neem cake	1.11 a	0.97 bc	0.96 bc	1.21 ab	1.05 bcd	1.15 abc	1.16 abcd	1.04 cd	1.13 bcd
Trichoderma + Neem leaves	0.93 cd	0.84 de	0.88 cde	1.08 abcd	1.07 abcd	1.09 abcd	1.35 a	1.12 bcd	1.05 cd
Bordeaux mixter	0.88 cde	0.87 cde	0.89 cde	1.00 bcd	0.87 d	1.01 bcd	1.08 bcd	1.05 cd	1.08 bcd

Means followed by the same letter are not significantly different at 5% level

Initial organic carbon content - 0.92%

solarization. The increase was more pronounced in neem leaves amended plots. The organic carbon increased from 0.83 to 1.05 per cent (neem leaves amended non-solarized plots), while the corresponding values for 30 days solarized neem leaves amended plots were 0.9 to 0.99 and 0.92 to 1.33 per cent in 45 days solarized plot. At the time of harvest, the organic carbon content of the various solarized plots did not differ significantly and the values ranged from 0.99 (30 days solarized neem cake) to 1.35 per cent (*Trichoderma* + neem leaves amended non-solarized).

pH

The initial pH of the experimental plot was 5.30. On the day of removal of the mulch, all the non-solarized plots except *Trichoderma* + neem cake amended plot showed a reduction in the pH over the initial value (Table 30). However, solarized plots (both 30 and 45 days) showed an increasing trend over the initial. This increase was more pronounced in 45 days solarized plots. The highest pH value of 6.26 was recorded in *Trichoderma* + neem leaves amended 45 days solarized plot. The difference in the pH in the various treatments narrowed down during the third month after planting and the fluctuations in pH was only from 5.10 (control) to 5.62 (neem leaves amended 30 days solarized). A similar trend was also observed during harvest.

Electrical conductivity

Electrical conductivity is a function of total soluble salt concentration in soil. The initial electrical conductivity of the test plot was 0.23 dS/m. A reduction in the electrical conductivity was noticed in solarized as well as non-solarized plots on the day of the removal of the plastic sheets (Table 31). Three months after

Table 30. Effect of soil solarization on pH of the soil

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	4.83 ghi	5.33 cdefgh	5.43 cdefg	5.10 g	5.14 efg	5.53 abcd	5.59 defg	5.65 cdef	5.68 bcdef
Neem cake	5.22 defgh	5.62 abcdef	5.87 abcd	5.26 cdefg	5.26 cdefg	5.44 abcde	5.56 efg	5.79 abcde	5.71 bcdef
Neem leaves	4.80 ghi	4.87 ghi	5.83 abcd	5.22 defg	5.62 a	5.44 abcde	5.61 defg	5.82 abcd	5.37 gh
Trichoderma	4.70 hi	5.57 bcdef	5.81 abcd	5.27 cdefg	5.27 cdefg	5.49 abcd	5.24 h	5.89 abc	5.82 abcd
Trichoderma + Neem cake	5.90 abc	5.98 abc	6.20 ab	5.12 fg	5.41 abcdef	5.54 abc	5.18 h	5.99 a	5.67 bcdef
Trichoderma + Neem leaves	5.07 efgh	4.35 i	6.26 a	5.15 efg	5.41 abcdef	5.43 abcde	5.53 fg	5.83 abcd	5.91 ab
Bordeaux mixture	4.96 fghi	5.70 abcde	6.13 ab	5.43 abcde	5.60 ab	5.30 bcdefg	5.74 bcdef	5.67 bcdef	5.80 abcde

Means followed by the same letter are not significantly different at 5% level

Initial pH - 5.30

Table 31. Effect of soil solarization on electrical conductivity of soil (dS/m)

Treatments	AS			3 MAP			Harvest		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	0.16 bc	0.14 bc	0.12 c	0.21 abc	0.14 bcd	0.14 bcd	0.10 a	0.09 abc	0.07 efg
Neem cake	0.22 abc	0.18 abc	0.21 abc	0.16 abcd	0.10 d	0.22 abc	0.08 bcde	0.06 g	0.07 efg
Neem leaves	0.12 c	0.24 ab	0.20 abc	0.17 abcd	0.12 cd	0.24 ab	0.09 bcd	0.10 a	0.08 cdef
Trichoderma	0.17 abc	0.23 ab	0.20 abc	0.15 abcd	0.10 d	0.17 abcd	0.07 defg	0.08 cdef	0.07 efg
Trichoderma + Neem cake	0.19 abc	0.16 bc	0.21 abc	0.25 a	0.08 d	0.22 abc	0.07 defg	0.08 cdef	0.08 cdef
Trichoderma + Neem leaves	0.23 ab	0.18 abc	0.21 abc	0.16 abcd	0.19 abcd	0.17 abcd	0.09 abc	0.08 cdef	0.07 efg
Bordeaux mixture	0.20 abc	0.18 abc	0.27 a	0.14 bcd	0.12 cd	0.14 bcd	0.08 cdef	0.07 efg	0.07 efg

Means followed by the same letter are not significantly different at 5% level

Initial EC - 0.23 dS/m

solarization, electrical conductivity values were lower in 30 days solarized plots. The difference between solarized and non-solarized plots were not significant. The lowest value of 0.08 dS/m was recorded in *Trichoderma* + neem cake amended 30 days solarized plot. A marked reduction in the electrical conductivity was observed at the time of harvest. The electrical conductivity ranged from 0.07 to 0.10 dS/m at this stage.

Cost effectiveness of soil solarization

The benefit/cost ratio of solarization was worked out to find out the feasibility of large scale adoption of this technique in farmers field. The cost of cultivation of ginger during 1992 season in control plot was Rs.54,040/ha, of which Rs.26,200/- was utilized towards the cost of inputs like seed, manures and fertilizers etc. and Rs.29,840/- was spent towards labour charges (Table 32). For solarizing the plots an additional expenditure of Rs.52,500/ha was incurred being the cost of 875 kg of 150 guage transparent plastic sheets (Rs.60/kg). One hectare of ginger field usually has 3500 beds of 2 x 1 m size and 0.25 kg of plastic sheet of width 150 cm was required for covering one bed. Additional 25 men and 10 women were required for laying the plastic and removing it after solarization. This involved an additional expenditure of Rs.2450/ha. Thus, the total expenditure incurred for cultivating one hectare of land with solarization came to Rs.1,19,900/-, while, it was Rs.54,040/- for control. The yield obtained per hectare in 30 days solarized plot was 20,004.5 kg, while, it was 17,080.4 kg for 45 days solarized and 651.0 kg for control plots. The yield obtained from control plot was far below the normal yield, because the field was inoculated with high inoculum of soft rot pathogen. The total return obtained from 30 days solarized plot was Rs.1,60,036/ha, Rs.1,36,642/ha for 45 days and Rs.5208/ha

Table 32. Cost of cultivation of ginger (per ha)

Items of work	Non-solarization			30 days solarization			45 days solarization		
	Men @ Rs.70/-	Women	Total	Men @ Rs.70/-	Women	Total	Men @ Rs.70/-	Women	Total
1	2	3	4	5	6	7	8	9	10
1. Preparing the land by ploughing with tractor	6	2	560.00	6	2	560.00	6	2	560.00
2. Making beds	100	-	7000.00	100	-	7000.00	100	-	7000.00
3. Polythene mulching	-	-	-	20	10	2100.00	20	10	2100.00
4. Applying FYM and fertilizer	50	50	7000.00	50	50	7000.00	50	50	7000.00
5. Removal of polyethylene sheets	-	-	-	5	-	350.00	5	-	350.00
6. Preparation of seed rhizomes and planting	-	50	3500.00	-	50	3500.00	-	50	3500.00
7. Collecting mulch material and mulching	15	30	3150.00	15	30	3150.00	15	30	3150.00
8. Weeding, Ist fertilizer application, earthing up and mulching	30	40	4900.00	30	35	4550.00	30	35	4550.00
9. Weeding, IInd fertilizer application, earthing up and mulching	12	15	1890.00	30	35	4550.00	20	25	3150.00
10. Plant protection	2	2	280.00	6	6	840.00	6	6	840.00
11. Harvesting and cleaning	5	3	560.00	35	70	7350.00	30	65	6650.00
Total			29840.00			40950.00			38850.00

Contd.

Table 32. Continued

1	4	7	10
12. Cost of seed material 1500 kg @ Rs.10/-	15000.00	15000.00	15000.00
13. Farm yard manure 30 tonnes @ Rs.300/ton	9000.00	9000.00	9000.00
14. Urea 160 kg @ Rs.3.50/kg	560.00	560.00	560.00
15. Superphosphate 225 kg @ Rs.2/kg	550.00	550.00	550.00
16. Muriate of Potash 85 kg @ Rs.4/kg	340.00	340.00	340.00
17. Cost of Plant protection chemicals	250.00	1000.00	1000.00
18. Cost of polyethylene sheets 875 kg @ Rs.60/kg	-	52500.00	52500.00
Total	26200.00	78950.00	78950.00
Grand total	54040.00	1,19900.00	1,17800.00
Yield	651 kg @ Rs.8/kg	20,004.5 kg	17,080.4 kg
	Rs.5208.00	Rs.1,60036.00	Rs.1,36643.2
	Loss Rs.48,832.00	Profit Rs.40,136.00	Profit Rs.18,843.00
Benefit/cost ratio	0.1	1.33	1.15

for control. The net profit in 30 days solarization was Rs.40,136/ha and Rs.18,843/ha for 45 days. While, a loss of Rs.48,832/ha was incurred in the control, when fresh ginger was sold at the rate of Rs.8/kg. The benefit/cost ratio was 1.33 and 1.15 respectively for 30 and 45 days solarization.

Long term effect of solarization

Pre-emergence rotting

For studying the long term effect of solarization against soft rot of ginger, beds solarized during 1992 crop season were replanted during 1993 without any additional treatment. Pre-emergence rotting in the various plots ranged from 0-3.22 per cent (Table 33).

Post-emergence rotting (soft rot)

Soft rot was first noticed during the third fortnight after planting and continued up to 13th fortnights in all the treatments except in Bordeaux mixture drenched 30 days solarized plots where the disease was not noticed till harvest.

In the non-solarized plots, soft rot was observed only in neem cake amended plot during the third fortnight, while from sixth fortnight onwards the disease was noticed in all the treatments. The disease intensity gradually increased and at the end of 13th fortnight, it ranged from 37.10 (*Trichoderma* + neem leaves) to 83.87 (neem leaves amended) per cent (Table 34). However, there was no significant difference among the treatments.

In 30 days solarized plots, soft rot was not observed in neem cake amended, *Trichoderma* + neem leaves amended and Bordeaux mixture drenched plots

Table 33. Long term effect of soil solarization on pre-emergence rotting in ginger

Treatments	Per cent rotting		
	Non-solari-zation	Solarization	
		30 days	45 days
Control	1.61 ab	3.22 a	0.00 b
Neem cake	0.00 b	0.00 b	1.61 ab
Neem leaves	0.00 b	0.00 b	1.61 ab
Trichoderma	0.00 b	1.61 ab	0.00 b
Trichoderma + Neem cake	0.00 b	1.61 ab	0.00 b
Trichoderma + Neem leaves	0.00 b	1.61 ab	0.00 b
Bordeaux mixture	0.00 b	0.00 b	0.00 b

Means followed by the same letter are not significantly different at 5% level

Table 34. Continued

Treatments	Per cent incidence								
	11th			12th			13th		
	Non-solarization	Solarization		Non-solarization	Solarization		Non-solarization	Solarization	
		30 days	45 days		30 days	45 days		30 days	45 days
Control	57.74 a	88.34 a	80.65 a	65.81 a	88.34 a	80.65 a	80.43 a	93.33 a	85.49 a
Neem cake	74.20 a	40.33 ab	85.27 a	82.26 a	45.16 ab	85.27 a	82.26 a	46.77 ab	85.27 a
Neem leaves	53.23 a	93.55 a	96.67 a	67.74 a	93.55 a	[illegible]7 a	83.87 a	93.55 a	96.67 a
Trichoderma	54.84 a	40.00 ab	66.14 a	59.68 a	40.00 ab	79.03 a	72.58 a	40.00 ab	90.33 a
Trichoderma + Neem cake	67.75 a	48.39 ab	67.74 a	74.20 a	48.39 ab	75.81 a	80.65 a	48.39 ab	87.10 a
Trichoderma + Neem leaves	32.26 ab	75.75 a	87.10 a	35.50 ab	85.38 a	90.33 a	37.10 ab	93.44 a	90.33 a
Bordeaux mixture	59.68 a	0.00 b	90.33 a	64.52 a	0.00 b	96.78 a	67.74 a	0.00 b	96.78 a

Means followed by the same letter are not significantly different at 5% level

till the end of third fortnight after planting. Bordeaux mixture drenched plots were free from disease till the harvest. At the end of eighth fortnight, the percentage infection was less than 40.0 in neem cake amended, *Trichoderma* incorporated, *Trichoderma* + neem leaves amended and Bordeaux mixture drenched plots. While, at the time of harvest, control, neem leaves amended and *Trichoderma* + neem leaves amended treatments had more than 90.0 per cent infection and the other treatments (excepting Bordeaux mixture) had 40.50 per cent infection (Table 34).

In 45 days solarized plots, disease was observed only in neem cake, neem leaves amended and Bordeaux mixture drenched plots at the end of third fortnight after planting. At the end of eighth fortnight, 93.39 per cent of the neem leaves amended plants were succumbed to infection and the disease intensity ranged from 38.71 (*Trichoderma*) to 67.74 (*Trichoderma* + neem leaves) per cent in other treatments. The intensity of infection increased gradually and at the time of harvest, only 4-15 per cent plants were free from infection.

Discussion

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DISCUSSION

The term solarization refers to a chemical change in glass, caused by sunlight or other ultraviolet radiation, which causes a photochemical reaction resulting in a decrease in ultraviolet transmission in addition to a noticeable colour change (Koller, 1965). In agricultural research, the term solarization is applied to include the thermal, chemical and biological changes in soil caused by exposure to solar radiation covered by transparent plastic film, especially when the soil has a high moisture content (Stapleton and DeVay, 1986).

Covering moist soil during hot season increases soil temperature and thereby kills the pathogens and weeds and improves plant growth (Katan *et al.*, 1976; Katan, 1981a). In the present experiments, maximum temperature of 63.0°C obtained at 5 cm depth under tarp was 13.5°C more than that in the non-solarized soil. Such a significant difference in temperature under mulched and non-mulched soils was also reported by many workers (Katan, 1981a; Pullman *et al.*, 1981b; Mihail and Alcorn, 1984; Tu *et al.*, 1991 and Dwivedi, 1993).

The difference in temperature under solarized and non-solarized soils in the present study was higher than that reported by Katan *et al.* (1976); Meron *et al.* (1989); Triolo *et al.* (1989); Dwivedi (1991) and Dubey (1992). However, it was lower than that reported (69.0°C) by Lodha *et al.* (1991).

Soil temperature fluctuations in solarized and non-solarized soil depend on several factors like atmospheric temperature, thickness of polyethylene film, moisture content of the soil, soil type, colour etc. (Katan, 1981). The maximum temperatures recorded in the solarized soil at 5, 10 and 15 cm depths were 63.0°C, 59.0°C and 46.5°C, respectively, as compared to 49.5°, 43.0° and 40.0°C in non-solarized plots. Thus, with an increase in soil depth there was a corresponding decrease in the soil temperature. High thermal capacity and poor conductivity of the soil may be the main causes for the reduction in temperature at deeper layers of soil. Similar observations were also recorded by Katan (1981).

When hourly temperature fluctuations of the soil for a day under the polyethylene mulch was recorded, it was found that the temperature in the tarped plot was more than 50.0°C for six and 4.5 h at a depth of 5 and 10 cm, respectively. While it was below 50.0°C at a depth of 15 cm in solarized as well as non-solarized soils. Increase in soil temperature in mulched soil has been reported to be due to the greenhouse effect caused by polyethylene and has been correlated with air temperature, humidity, radiation, wind velocity and soil characteristics (Mahrer, 1979; Katan, 1981). Thus, in deeper soil, the soil temperature fluctuations are much less compared to top soil, both in solarized and non-solarized soils.

Mahrer (1979), Chandran (1989) and Sainamol (1992) developed simple regression equations for predicting temperature under the mulch using air temperature. In the present investigation also, two simple regression equations based on soil and air temperatures at 10 cm depth were developed, viz.

$$Y = 0.9307 \, NST + 15.958$$

where Y = Maximum soil temperature under polyethylene mulch

NST = Maximum soil temperature in non-solarized soil

Using the regression equation it is possible to predict the maximum soil temperature under plastic mulch based on the maximum temperature in the non-solarized soil.

$$Y = 0.89\,X + 21.483$$

where Y = Maximum soil temperature under polyethylene mulch

X = Maximum atmospheric temperature

The coefficient of determinations of these models were 54.1 and 15.7 per cent respectively.

A multiple regression equation based on soil and air temperature at 10 cm depth was also derived.

$$Y = 0.37365\,X + 0.851\,NST + 5.6614$$

where Y = Maximum soil temperature under polyethylene mulch

X = Maximum atmospheric temperature

NST = Maximum soil temperature under non-solarized soil

The coefficient of determination for the multiple regression equation was the highest (58.0 per cent). Thermal death points of different pathogenic microorganisms, nematodes and weeds have been worked out. Thus, using this model, it is possible to find out the period of solarization required for obtaining satisfactory control of the diseases and weeds by knowing the air temperature or soil temperature of the non-solarized soil. These models can replace the work of temperature measurement under the mulch and enable us to choose the most appropriate time of the year for solarization.

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Solarization was highly effective in reducing the pre-emergence rotting in ginger caused by *Pythium aphanidermatum*. Better germination of ginger rhizomes were observed in solarized plots compared to non-solarized plots. The pre-emergence rotting in solarized treatments ranged from 1.04 to 9.38 per cent compared to 7.29 to 20.83 in non-solarized treatments. The various treatments in solarized plots did not differ significantly from one another. There was no significant reduction of the pre-emergence rotting in the non-solarized treatments except in plots received Bordeaux mixture. Studies on thermal death point of various microorganisms have shown that at or above 50.0°C, a temperature often exceeded in the upper soil layers during solarization, survival is limited to a maximum of a few hours. At temperatures of 37-50.0°C, eradication or marked reductions in populations occur within 2-5 weeks (Pullman *et al.*, 1981a and b).

The thermal death point of plant pathogens vary from organism to organism depending upon the stage of the organism, nutrient status of the growing media, etc. Pullman *et al.* (1979) showed that the number of oospores of *Pythium* sp. per gram of soil upto 15 cm depth was reduced from 369.7 to 0.3 following nine weeks of solarization. The maximum temperature recorded at 15 cm depth was 50.0°C. Pullman *et al.* (1981a) observed that 90.0 per cent of *P. ultimum* propagules could be destroyed on exposing the fungus grown on PDA at 47.0°C for 180 minutes or 37.0°C for 20 days. This clearly indicates that the inhibition of microorganisms is not only controlled by temperature but also by other factors.

In the present study, the average maximum temperatures in solarized soil at 5 and 10 cm depths were 58.8 and 53.5°C, respectively, while they were 45.9 and 40.6°C, in the non-solarized soil. This high temperature in solarized soil could have inactivated or killed large numbers of *Pythium* propagules resulting in reduced incidence of pre-emergence rotting in solarized soil. Similar observations were recorded by Kulkarni *et al.* (1992), Sainamol (1992) and Gamliel and Stapleton (1993a and b). Nearly 80.0 per cent control of the pre-emergence rotting in non-solarized soil may be due to a comparatively high temperature recorded in non-solarized soil.

Apart from high temperature, pre-disposition of pathogen propagules to damage from anaerobes by exposing the propagules to low redox potential also may be one of the reasons for their accelerated death rate in soil tarped with polyethylene sheets (Cook and Baker, 1983). Polyethylene mulch increases soil temperature and soil respiration and serves as a barrier to oxygen diffusion into the soil and carbondioxide diffusion out of it. Solarization process in moist soils without the heating component may mimic the effects of soil flooding to reduce the population of soil microflora. The treatment becomes more effective as temperature of moist soil is increased (Stapleton and DeVay, 1986).

In addition to thermal death, the effects of sublethal heating result in delayed propagule germination, reduced growth rates, greater sensitivity to soil fumigants and possible induced biological control of several phytopathogenic fungi (Lifshitz *et al.*, 1983). The greatest reduction in soil biota during solarization occurs near the soil surface as the temperature in this region is the highest. Even in the non-solarized plots the soil temperature at 5 cm depth ranged from 37.0° to 49.5°C. This high temperature might have caused a reduction in the population of *P. aphanidermatum*. However, the temperature at lower levels in non-solarized soil was less than 40.0°C which might not have caused appreciable decimation of the pathogens and hence resulting in reinfestation of the upper area where the conditions became favourable for the multiplication of the pathogen.

Increasing the period of solarization from 30 to 45 days did not result in a corresponding reduction in the pre-emergence rotting. In both these treatments, the reduction in the disease incidence ranged from 1.04 to 9.38 per cent. One of the possible reasons for this might be the fact that the propagules of *Pythium* present in the upper strata might have been eradicated by solarization for 30 days and the remaining might have escaped the longer period of exposure for 45 days.

On perusal of the data on disease incidence, it is clear that the percentage of diseased plants in solarized treatments are low in the initial periods (upto seventh fortnight). While, in non-solarized plots it is observed even from the fourth fortnight. However, the number of infected plants increased during the later stages of the growth of the ginger plants. Soil temperature under polyethylene mulch was more than 50.0°C upto a depth of 10.0 cm which resulted in marked reductions of the pathogen propagules. During the later stages of the plant growth whatever propagules remained in the lower level might have multiplied and caused infection. Anandaraj and Sarma (1993) observed that *P. aphanidermatum* propagules placed even at a depth of 30.0 cm could cause infection of ginger plants through their roots towards the later stages of plant development. Once the pathogen starts causing infection, its multiplication rate increases under a semi sterilized condition in solarized soil. As the infection in solarized treatment plots started only late in the season, it did not affect the yield significantly. In non-solarized control, the disease started during fourth fortnight onwards resulting in higher yield loss.

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The increase in the disease during the eighth to 11th fortnight was more pronounced because, this period coincides with the south west monsoon. A partially viable propagule may recover and resume its course of development if provided with normal conditions and sufficient time (Pullman *et al.*, 1981a). The build up of inoculum from survived propagules of *P. aphanidermatum* takes time to reach a level to initiate disease. Increase in the incidence of disease in solarized plots during the later periods in this study may be due to this reason. Similar effects of heat under laboratory conditions were observed on *Armillaria mellea* (Munnecke *et al.*, 1976). *Verticillium dahliae, Thielaviopsis basicola, Pythium ultimum* and *Rhizoctonia solani* (Pullman *et al.*, 1981a; Chandran, 1989).

The plant mortalities occurred in solarized treatments can also be explicable as caused by reinfestation due to soil movement in rain water which passed through the non-solarized plots. This possibly led to an increased disease in certain solarized plots. This results are in agreement with the findings of Kulkarni *et al.* (1992) in periwinkle for the control of dieback and collar rot disease.

Survival of microorganisms under the mulch is related with time, species, soil depth and soil characters. *Phytophthora cinnomomi* could be completely inactivated within two weeks of solarization at 15 and 30 cm depth. While, *P. megasperma* survived solarization for four weeks (Juarez-Palacios *et al.*, 1991). Thermal sensitivity of *P. aphanidermatum* under various temperature conditions at different depths has to be studied to find out the exact period of solarization for eradication of the pathogen.

The results of the analysis of population of *P. aphanidermatum* in soil were highly variable. This problem was compounded by the lack of information on the relative proportion of pathogenic and non-pathogenic isolates.

Anandaraj and Sarma (1993) have shown that by merely placing the inoculum away from the root zone, the incidence of rhizome rot of ginger could be delayed. The types of infection in rhizome rot appears to be a moving infection court with a fixed inoculum (Baker, 1970). This suggests that in solarized soil, disease incidence from the *P. aphanidermatum* in the upper strata of the soil will be less. But, those present in the lower layers could come in contact with the roots of ginger only when the roots come in contact with the pathogen. This may be one of the reason for late development of disease in solarized soil.

The incorporation of neem leaves, neem cake, *Trichoderma* and Bordeaux mixture did not appreciably reduce the incidence compared to that in the non-solarized condition. Studies conducted by Sainamol (1992) with *P. aphanidermatum* in chillies, had shown that neem cake application was not effective in reducing damping off disease. Superimposition of solarization on the various amendments did not enhance disease management.

It is possible that pre-solarization compost amendment decomposed slowly in solarized soil because of reduction of microflora during the solarization. This is evident from the fact that amended neem leaves under the mulch remained undecomposed till the removal of the polyethylene sheets. Even after the removal of the mulch, the leaves remained in a dried state for a long period of time. The combination of neem leaves and solarization was not effective in reducing the incidence of disease. Further, the temperature in neem leaves amended solarized soil was $3.0^{\circ}C$ less than the non-amended solarized plot at 5.0 cm depth.

Eventhough, *Trichoderma* sp. caused inhibition of *Pythium* under laboratory conditions, this inhibitory effect was not discernible under field conditions. Inactivation of the propagules of *Trichoderma* sp. under high soil temperature in solarized soil might have been a possible reason for this. The involvement of heat resistant antagonists like *Talaromyces flavus* and *Aspergillus terreus* of *V. dahliae* in the longer range effect of soil solarization on globe artichoke has been postulated by Tjamos and Paplomatas (1988). However, the heat sensitivity of *T. harzianum* culture used in the present investigation has not been worked out. The inability of *T. harzianum* to control the pathogen under solarized condition indicates that the strain used is a heat sensitive one.

The disease incidence in 45 days solarized plots was more compared to 30 days solarized treatments. The reduction in the population of *P. aphanidermatum* immediately after solarization in 45 days solarized control was 93.82 per cent compared to 98.65 per cent in 30 days solarized control. Eventhough the reduction in the *Pythium* propagules immediately after solarization between 30 and 45 days was only 5.0 per cent, the per cent variation in the disease development was 22.9. Apart from decreasing the viability of propagules, solarization may also reduce the capacity of the propagule to cause disease. This is clear from the observation that even if the same number of viable propagules taken from solarized and non-solarized treatments are allowed to infect same number of plants, the infection per cent may vary. The probability that solarized viable propagules causing the disease is less compared to viable propagules from non-solarized treatments.

Organic amendments can either increase or decrease incidence and severity of plant diseases (Chen *et al.*, 1988). Some of the organic amendments like decomposing cruciferous plants have high concentration of sulphur containing compounds which can generate toxic volatile compounds resulting in inhibition of diseases (Villapudua and Munnecke, 1987, 1988). In the present investigation neem cake incorporated solarized treatments gave better control than non-solarized treatments. This may be due to the inhibitory effect of volatiles accumulated under the mulch from decomposing neem cake. Whatever volatiles produced in non-mulched plots escaped without acting on the pathogen. Neem leaves compared to neem cake was less inhibitory. This may be due to the fact that the neem leaves under the mulch dried up rather than decomposing and releasing the volatiles.

The ability of *Trichoderma* to inhibit the disease under solarization increased when it was incorporated with neem cake. There was 100.0 per cent control of the disease in this treatment solarized for 30 days. This may be due to the combined action of the volatiles and *Trichoderma* on *P. aphanidermatum*. However, the effect of this combined treatment was reduced when solarized for 45 days probably because in longer periods of exposure, the volatiles might have inhibited the growth of *Trichoderma* also. The effectiveness of solarization may thus be increased by incorporating an amendment capable of releasing volatiles which are toxic to the pathogenic microflora.

The population of bacteria and actinomycetes were less in 45 days solarized plots compared to 30 days. However, difference in the fungal population was not marked. The possibility of antagonistic activity of bacteria and actinomycetes on *P. aphanidermatum* cannot be ruled out. Thus, a lower population of these microorganisms indicates a lower population of antagonistic flora resulting in higher population of pathogenic fungi. A decrease in the population of bacteria and actinomycetes in 45 days compared to 30 days may be partially responsible for increased disease incidence in 45 days solarized plots. Increase in antagonistic organisms has been found to be directly proportional in controlling *Verticillium* wilt of globe artichoke by Tjamos and Paplomatas (1988).

Baker (1962) opined that solarization may create a shift in the microbial population in soil in favour of heat resistant saprophytes. In general, pathogens are less resistant to heat than saprophytes. Hence, the total microbial count in solarized soil need not necessarily give an actual picture of its ability to inhibit the pathogenic fungi.

Under normal conditions, free exchange of gases takes place in soil and whatever volatiles produced escape to the atmosphere. Permeability of polyethylene to gases is low. The lethal effect of increased quantities of soil volatiles is more on parasitic fungi than on saprophytes in soil (Peethambaran, 1975; Gamliel and Stapleton, 1993b). Thus, accumulation of volatiles under polyethylene mulch might have also helped in inactivating or killing *P. aphanidermatum* and there by reducing the disease incidence.

Solarization reduced the population of free living nematodes by almost 100.0 per cent. The studies by Lazarovits *et al.* (1991b) have shown differences in the mortality rate of nematodes under different temperatures. Porter and Merriman (1983) found that 70.0, 80.0 and 90.0 per cent reductions in *Pratylenchus penetrans* populations after exposure to 35.0, 40.0 and 45.0 °C, respectively for six hours daily over two weeks. However, under solarization conditions in a field study, Davis and

Sorensen (1986) found that after seven weeks, the population of *Pratylenchus* declined by 65.0 per cent at 15.0 cm depth at a mean temperature of 41.0°C.

In the present experiment, the very high inhibition of nematodes may be due to a high temperature (63.0°C) recorded at 5.0 cm depth under the mulch. The recolonization of nematodes in the solarized plots was observed from fourth week onwards. Recolonization may be from the near by untreated plots or by migration of nematodes from the lower horizons in solarized plots. The volatiles produced by decomposing organic matter have been found to increase/decrease the nematode population. The higher rate of inhibition observed in the neem amended solarized plots may also be due to the volatiles produced from decomposing amendments. The role of neem cake as a nematicide is a well established fact.

Solarization had pronounced suppressive effect on weeds. There were no weeds in the top portion of solarized beds on the day of removing the mulch and weed population remained low till harvest of ginger. Excellent weed control with solarization was reported by Horowitz (1980); Rubin and Benjamin (1981); Egley (1983); Chandran (1989) and Hartz *et al.* (1993). Solarization has two complimentary effects: (1) inducing the emergence of dormant propagules and foliar scorching of emerged plants under plastic cover and (2) decreased weed emergence after removal of the polyethylene sheets (Horowitz *et al.*, 1983). Induction of secondary dormancy by relatively high temperature has been reported by Koller (1972); Mayer and Polyakoff Mayber (1975). Heating seeds to temperature above optimum for germination (42.0°C) resulted in a reduction of the germination rate, possibly due to denaturation of functional protein (Taylorson and Hendricks, 1977; Levitt, 1980). The average maximum temperature recorded in the upper layer of the solarized soil was 12.9°C higher than that of unmulched soil and this caused a reduction of germination rate. Hendricks and Taylorson (1976) reported that heating weed seeds from 30.0-35.0°C modified the membrane permeability which resulted in the leakage of endogenous amino acids. This attracts soil microflora which in turn reduce the germination rate.

Dry seeds of many weed plants are resistant to temperature as high as 120.0°C, while, hydrated seeds are killed at 50.0°C (Levitt, 1980). In presence of water, less energy is required to damage the peptide chain configuration of protein resulting in decreased heat resistance (Katan, 1981). The average temperature of soil during the entire solarization period was above 50.0°C in the upper 5 cm layer, the soil zone from which the most annual weeds emerge, and soil under the mulch was also wet throughout the period of solarization which reduced heat resistance of hydrated seeds. These may be the possible reasons for reduction in weed count under the mulch. Similar results were observed by Horowitz *et al.* (1983) and Hartz *et al.* (1993).

Soil oxygen concentration under plastic sheets do not differ appreciably from uncovered control, while, the concentration of carbondioxide increases upto 30 times or more (Rubin and Benjamin, 1981) which can induce seed germination (Koller, 1972). The changes in carbondioxide/oxygen levels in the mulched soil may cause partial or complete breaking of seed dormancy, thus enhancing the germination. Such germinated seeds are killed as a result of high temperature under the polyethylene mulches.

The reduction in weed population noticed in solarized plot may be due to a combination of factors like thermal killing of seeds, inducing seed dormancy, breaking of seed dormancy through production of carbondioxide and other gases in soil, altering seed metabolism or action of soil microflora on the weakened seeds, may all be responsible for the destruction of weeds under the mulch (Hendricks and Taylorson, 1976; Pavlica *et al.*, 1978; Rubin and Benjamin, 1984).

Weeds like *Cynodon dactylon, Cyperus rotundus* propagate mainly by vegetative parts/rhizomes, were not effectively controlled by solarization. Similar results were observed by Egley (1983); Fahim *et al.* (1987) and Sainamol (1992). Relative high tolerance of *C. dactylon* and *C. rotundus* to solarization may be due to the fact that at least a part of their subterranean vegetation is located in a relatively deep layer which is not markedly affected by solarization. The vegetative parts/seeds present in the upper layers of the soil were killed by the excess heat, but rhizomes/tubers/seeds located in deeper layers survived solar heating and were able to grow after the removal of the mulch. The fresh weed emergence observed one month after solarization may be from those weed seeds/vegetative parts which were buried deeper in the soil escaped the effect of solarization.

Effect of solarization on weeds was lesser in the sides of the beds compared to the top. *Bulbostylis barbata, C. dactylon* and *C. rotundus* were present in the sides of the solarized beds even on the day of removal of the polyethylene sheets. Temperature at the edges of the polyethylene cover is usually 2-4.0°C lower than that at the centre. Further, solar heating efficiency is also reduced especially at the edges of the mulch (Mahrer and Katan, 1981). This leads to the conclusion that because of the lower temperature at the edges of mulch should be reflected in reduced killing of weeds existing in this area.

The results from the nutrient assays following solarization revealed an increase in the status of available nitrogen, phosphorus and potassium. Amounts of soluble and organic minerals in the soil generally increased with solarization. Chandran (1989) and Kaewruang *et al.* (1989a and b) observed increase in the available nitrogen content in the solarized soil. Significant increase in the phosphorus and potassium found in the solarized soil was almost similar to those reported by Chen and Katan (1980).

The increase in nitrogen and phosphorus levels in solarized soils might be due to an increase in soil temperature under the mulch. During day time more evaporation takes place in solarized soil and these vapours are not lost but blocked by polyethylene sheet. During night time these vapours condense and drip down to the soil. This process is repeated throughout the period of solarization and this might have helped in a greater mineralisation leading to an increase in the status of available nitrogen and phosphorus. The increased carbondioxide content in solarized soil also might have influenced the availability of nutrients by making the soil reaction more acidic which in turn helps in a greater solubilisation, especially of phosphorus (Rubin and Benjamin, 1984). The increase in temperature is known to catalyse the chemical and biological process that takes place in a soil which may further lead to the increase in the status of available nutrients.

Present study showed that solarization did not consistently increase the organic carbon content in the soil. Similar results were observed by Stapleton *et al.* (1985) and Kaewruang *et al.* (1989a & b). Organic carbon content generally decreases with increase in temperature (Chandran, 1989).

The response of ginger plants to solarization in this study is evident mainly as increase in the height of plants, number of leaves per plant, leaf length, development of root system and yield. These are the typical responses of plants to improved fertility of the soil. Increase in the plant growth parameters as a result of solarization was reported in chillies (Sainamol, 1992), wheat (Cook *et al.*, 1987) and peach seedlings (Stapleton and DeVay, 1982).

In this study, plants grown in solarized soil had a better level of mycorrhizal association during the active growth stage of the plants. Indigenous VAM fungi are very important for growth response and yield of plants (Nair *et al.*, 1990; Afek *et al.*, 1991). Plants raised in solarized soil had better levels of VAM association indicating that solarization did not greatly affect the survival activity of mycorrhizal fungi in the soil. Many reports have already published on the effect of solarization in reducing the population of potential soil borne plant pathogens and other heat sensitive organisms besides causing shift in microbial population in favour of beneficial organisms especially when plants are cultivated shortly after solarization (Nair *et al.*, 1990). Such effects of solarization might have favoured better colonization by VAM fungi. Ferguson (1981) and Graham and Leonard (1982) also reported that high temperature can also enhance colonization by VAM. The present study thus demonstrates that VAM combined with solarization can be one of the best approaches to replace or at least reduce the use of chemicals in plant disease control. It is possible that better plant growth response obtained in this investigation might have resulted from the effects of better VAM colonization of ginger roots and increased availability of nutrients.

In general, the incidence of *Phyllosticta* leaf spot was more in solarized compared to non-solarized treatments. Studies conducted by Premanathan (1981) on the infection and development of leaf spot of ginger revealed that if sufficient inoculum potential is available, the availability of sufficient number of matured leaves is the most important condition for development of the disease, recording a significant positive correlation between the number of matured leaves/plant and intensity of disease. Plants grown in solarized plots had increased number of leaves compared to control and this helped in increasing the infection by *Phyllostica zingiberi*. However, the infection usually does not cause appreciable yield reduction in ginger.

The long term effect of solarization in reducing the pre and post emergence rotting in ginger was not observed in the present study. The pre-requisites for a long term effect by solarization (or any disinfestation method) are drastic reduction of pathogen inoculum to considerable soil depths and the induction of soil suppressiveness to retard reinfestation from various sources (Abdel-Rahim *et al.*, 1988). The population of *Pythium* at the time of harvest of first crop ranged from 76.74 (*Trichoderma* + Neem cake + 30 days solarization) to 142.38 (control) c.f.u/g of soil. This population was high enough to incite infection during the second cropping season. Further, there was considerable movement of water from the control plots to the solarized plots during the rainy season resulting in reinfestation of the solarized plots. Basallote-Ureba and Melero-Vara (1993) failed to get good control of white rot of garlic caused by *Sclerotium cepivorum* for two consecutive years because inoculum densities in the soil increased during the first year to levels that brought about uneconomic disease incidence and yield loss.

The effectiveness of any agricultural operation apart from increasing the yield, quality of the produce and reducing the incidence of pest and diseases depends on the additional income generated over the increased expenditure involved in adopting the new technique. Solarization under the present condition involves a high cost of Rs.52,500/- per ha. The additional profit generated from this technique was Rs.40,136/ha and Rs.18,843/ha respectively for 30 and 45 days solarized plots. The yield obtained in the control plot of the present study was too low as the incidence of soft rot was high because of artificial inoculation.

The initial expenditure involved in solarization is comparatively high with the present cost of polyethylene sheets. However, with the advancement of solarization technology eg. production of thinner and durable polyethylene sheets may reduce the overall cost of solarization.

Thus, the present study clearly indicates that solarizing the land for 30 days before planting is a cost effective and viable technology not only for decreasing the disease incidence but also for increasing the yield of ginger. While practising solarization, it is essential that the seed material of ginger must be free off pest and pathogens. Otherwise, the organisms present in them may multiply in the solarized soil also and cause severe incidence of pest and diseases. So, as a precautionary measure disinfest the seed material with appropriate fungicides and insecticides before planting, which will avoid over use of pesticides. Solarization has a definite advantage in the framework of non-chemical cropping systems like organic and biological farming and stands out as an exceptionally and prospective alternate method to chemical control. The produces from solarized land brings forth a net marketing advantage in the light of public preference for natural farm produces over chemically protected ones.

Summary

SUMMARY

The investigation on "Effectiveness of soil solarization for the control of soft rot disease in ginger" was conducted at the experimental plot of the College of Horticulture, Vellanikkara during March 1992 to December 1993. Five days before mulching with polyethylene sheets, the plots were inoculated with *Pythium aphanidermatum* (Edson) Fitz.

Two hundred and fifty grams of *Trichoderma harzianum* Rifai. grown on rice bran was incorporated uniformly in plots requiring its application just before mulching with polyethylene sheets.

In plots requiring the incorporation of neem cake and neem leaves, powdered neem cake @ 500 g/m^2 and fresh neem leaves @ 1 kg/m^2 were applied at the time of mulching.

Bordeaux mixture was drenched at the rate of 2.5 l/m^2 in required plots just before solarization.

The beds requiring solarization were mulched with 150 guage transparent polyethylene sheets during March to May 1992. Two durations of solarization, viz., 30 and 45 days were tried. Soil temperature was recorded daily at 8.30 a.m. and 2.30 p.m. at depths of 5, 10 and 15 cm during the entire period of solarization.

The atmospheric temperature of the experimental area during the period of solarization ranged from 23.0°C to 39.4°C. Soil temperature at 5 cm depth ranged from 27.5°C to 49.5°C and 30.0°C to 63.0°C, respectively, in non-solarized and solarized soils.

The maximum temperature (at 2.30 pm) at 5 cm depth in non-solarized soil ranged from 37.0°C to 49.5°C compared to 51.0°C to 63.0°C in solarized soil.

Soil temperature variations at 5 cm depth in solarized soil was 33.0°C as against 22.0°C and 16.4°C in non-solarized soil and atmospheric temperature.

Maximum temperature variation during a day in solarized soil at 5 cm depth was 29.0°C (24-3-92), while, in non-solarized soil it was 17.5°C (on 31-3-92 and 3-4-92).

The weekly average maximum temperature at 5 cm depth in solarized soil ranged from 57.3°C to 60.3°C with a mean of 58.8°C compared to 44.7°C - 47.5°C and 45.9°C, respectively, in non-solarized soil.

The weekly average mean temperature differences were 21.3°C and 14.2°C, respectively, in solarized and non-solarized soils at 5 cm depth.

Soil temperature at 10 cm depth ranged from 32.0°C - 59.0°C in solarized soil and 28.0°C - 43.0°C in non-solarized soil. The variation in temperature was 27.0°C in solarized soil compared to 15.0°C in non-solarized soil at 10 cm depth.

The average maximum temperature at 10 cm depth ranged from 50.3°C to 54.9°C with a mean of 53.3°C in solarized soil compared to 39.3° - 41.7°C and 40.6°C in non-solarized soil.

The difference in weekly average mean temperature was 13.9°C in solarized soil as against 8.3°C in non-solarized soil at 10 cm depth.

Maximum soil temperature at 15 cm depth was 46.5°C in solarized soil as compared to 40.0°C in non-solarized soil. The variation in temperature in solarized and non-solarized soil was 12.5°C and 10.5°C, respectively.

The weekly mean temperature at 15 cm depth ranged from 41.4°C to 45.0°C with a mean of 44.0°C in solarized soil, while, it was 35.4°C - 39.3°C and 37.1°C in non-solarized soil.

Soil temperatures in solarized soil were 7.0°C - 23.0°C, 9.0°C - 19.6°C and 11.0°C - 7.1°C above atmospheric temperature respectively at 5, 10 and 15 cm depths.

The temperature variation in solarized soil at 10 cm depth was 6.0°C less than that at 5 cm, while, at 15 cm depth it was 20.5 and 14.5°C lower than that at 5 and 10 cm depths. Non-solarized soil at 15 cm depth showed only 11.5 and 4.5°C lesser variation than that at 5 and 10 cm depths.

Soil temperature in solarized soil at 5 cm depth was above 50.0°C for the entire solarization period and above 55.0°C for 38 days (out of 45 days of solarization). Soil temperature was above 50.0°C for 35 days and above 55.0°C for 5 days at 10 cm depth. At 15 cm depth, the soil temperature was above 40°C for 44 days.

The variation in weekly average maximum temperature in solarized soil at 15 cm depth was 14.8°C and 9.3°C less than that at 5 and 10 cm depths.

The variation in temperature in neem leaves amended solarized soil at 5 cm depth (30.0°C) was 3.0°C lower that of solarized soil. The maximum temperature variation of 24.0°C (24-3-92) during a day was 5.0°C less than that of solarized soil recorded on that day.

Fluctuations in temperature at 30 minutes interval for a period of 12 h from 6 a.m. to 6 p.m. was recorded on 25-4-92.

Diurnal temperature increased from 6 am to 3.30 pm and the maximum heat build up occurred at 2.00 - 3.00 pm. Maximum temperatures of 62.0°C, 55.0°C and 47.5°C recorded in solarized soil on 25-4-92 at depths of 5, 10 and 15 cm and were 15.5°C, 12.5°C and 9.0°C more than those of non-solarized soil.

Temperature in the tarped plot was more than 50.0°C for six and 4.5 h at depths of 5 and 10 cm respectively, while, it was below 50.0°C in solarized soil at a depth of 15 cm. Thus, with an increase in soil depth there was a corresponding decrease in soil temperature.

Based on the soil and air temperatures recorded, two simple regression equations at 5 and 10 cm depths, a simple regression equation at 15 cm depth and a multiple regression equation at 10 cm depth were developed. By these, it was possible to predict the soil temperature under polyethylene mulch at known atmospheric temperature/non-solarized soil temperature. These models can replace the work of temperature measurement under the mulch and enable to choose the most appropriate time of the year for solarization.

Better germination of ginger rhizomes was observed in solarized plots. Solarization was highly effective in reducing the pre-emergence rotting in ginger caused by *P. aphanidermatum*. The incidence of the disease ranged from 1.04 to 5.21 per cent compared to 7.29 to 20.83 per cent in control plots. Increasing the period of solarization from 30 to 45 days did not result in a corresponding reduction in the pre-emergence rotting.

Soft rot occurred both in solarized and non-solarized fields at the end of fourth fortnight and continued upto 13th fortnight after planting. During eighth to 10th fortnights, the increase in the disease was more pronounced. Marked reduction in the soft rot incidence was observed in solarized treatments. *Trichoderma* incorporated neem cake amended 30 days solarized treatment was highly effective and there was 100.0 per cent control of the disease. Maximum disease incidence (90.67%) among solarized plots was recorded in *Trichoderma* incorporated neem leaves amended plot solarized for 45 days.

No effect of solarization was observed in the incidence of *Phyllosticta* leaf spot in ginger.

Solarization reduced population of *Pythium* in the soil. The reduction, which was more pronounced in solarized plots immediately after removing the mulch, ranged from 79.49 to 99.1 per cent compared to 47.19 to 77.94 per cent in non-solarized plots.

Reduction in fungal, bacterial, actinomycetal and *Pseudomonas* sp. populations were recorded as a result of solarization. The population of bacteria and actinomycetes was less in 45 days solarized plot compared to 30 days. However, the difference in fungal populations was not marked.

Colonization of VA Mycorrhizae was more in the roots of ginger grown in solarized plot during the active stage of the crop growth (six months after planting). The present study demonstrates that VAM combined with solarization can be one of the best approaches to replace or at least reduce the use of chemicals in plant disease control.

Better association of *Azospirillum* with ginger roots was observed in solarized plots during third month after planting till harvest.

Solarization reduced the population of free living nematodes by almost 100.0 per cent. Recolonization by nematodes in the solarized plots was observed from fourth week onwards. The higher rate of inhibition in the population of nematodes was observed in neem amended solarized plots.

Solarization had pronounced suppressive effect on weeds. There were no weeds in the top portion of the beds at the time of removal of polyethylene sheets and weed population remained low till harvest of ginger. Weeds like *Cynodon dactylon, Cyperus rotundus* were not effectively controlled by solarization. The percent reduction of monocots over control was 64.5 and, 69.9 respectively for 30 and 45 days of solarization, while, it was 78.93 and 79.8 per cent in dicots for 30 and 45 days solarization, respectively.

Effect of solarization on weeds was lesser in the sides of the beds compared to the top. *Bulbostylis barbata, C. dactylon* and *C. rotundus* survived solarization effect in the edges during the period of solarization. The per cent

References

reduction over control was 57.03 and 52.43 in monocots and 69.27 and 51.25 in dicots, respectively, for 30 and 45 days solarization.

The total fresh weight of the weeds during the entire period of observation was 1.45 kg/plot in non-solarized plot followed by 0.44 kg and 0.30 kg in 45 and 30 days solarized plots.

Increased growth response of ginger plants was observed as a result of solarization. This response is mainly evident as increase in the height of plants, number of leaves per plant, leaf length, development of root system and yield. Significant increase in yield of ginger was obtained as a result of solarization. Yield increase was more in 30 days solarized plots. *Trichoderma* incorporated neem cake amended 30 days solarized plot gave maximum yield of 10159.57 g/plot, which was 5361 per cent more over that of control.

The influence of solarization, which was more evident on per plant yield, ranged from 79.15 to 623.23 g compared to 45.18 to 82.23 in non-solarized plots. Maximum yield per plant was in *Trichoderma* incorporated neem cake amended 30 days solarized plot (623.23 g/plant), which was 1279.0 per cent increase over the lowest yield.

Solarization influenced the availability of soil nutrients like available nitrogen, phosphorus and potassium. However, the organic carbon content in the soil did not consistently increase by solarization. Electrical conductivity of the soil was not altered by solarization, while, solarization increased the pH of the soil.

The initial expenditure involved in solarization is comparatively high with the present cost of polyethylene, i.e., Rs.52,500/- per hectare. The additional profit generated from this technique was Rs.40,136/- per hectare for 30 days solarization. The benefit/cost ratio was 1.33 and 1.15 respectively for 30 and 45 days of solarization.

The long term effect of solarization in reducing the pre and post-emergence rotting in ginger was not observed in this study.

Solarizing the land for 30 days before planting is a cost effective and viable technology not only for decreasing the disease incidence but also for increasing yield of ginger.

REFERENCES

Abdel-Rahim, M.F., Satour, M.M., Mickail, K.Y., El-Eraki, S.A., Grinstein, A., Chen, Y. and Katan, J. 1988. Effectiveness of soil solarization in furrow-irrigated Egyptian soil. *Pl. Dis.* **72**:143-146

Abu-Gharbieh, W.I., Saleh, H. and Abu-Blan, H. 1991. Use of black plastic for soil solarization and post plant mulching. *FAO Pl. Prod. Prot. Pap.* **109**:229-242

Afek, U., Menge, J.A. and Johnson, E.L.V. 1991. Interaction among mycorrhizae, soil solarization, metalaxyl and plants in the field. *Pl. Dis.* **75**:665-671

Al-Kayssi, A.W., Ahmed, S., Hussain, R. 1989. Influence of soil solarization on salts movement and distribution. *Plasticulture* **84**:47-53

Al-Khafuji, H.M., Jarjees, M.M. and Al-Kassan, K.K. 1988. Chemical physical and biological control of *Pythium aphanidermatum* (Edson) Fitz. *Arab J. Pl. Prot.* 2:94-96

Al-Raddad, A.M.M. 1979. Soil disinfestation by tarping. M.Sc. thesis, Univ. Jordan. pp.95

Al-Sammaria, F.H., El-Bahadil, A.H. and Al-Ravi, F.A. 1988. Comparison between effects of soil disinfestation methods on some pathogens of cucumber. *Arab Pl. Prot.* **6**:106-112

Anandaraj, M. and Sarma, Y.R. 1993. Role of root infection in rhizome rot of ginger (*Zingiber officinale* Rose.). *J. Plantn. Crops.* **21**:140-143

Arora, D.K. and Pandey, A.K. 1989. Effects of soil solarization on *Fusarium* wilt of chickpea. *J. Phytopath.* **124**:13-22

Arya, A. and Mathew, D.S. 1993. Studies on rhizosphere microflora of pigeonpea; qualitiative and quantitative incidence of micro organisms after solarization. *Indian Phytopath.* **46**:151-154

Ashworth, L.J. and Gaona, S.A. 1982. Evaluation of clear polyethylene mulch for controlling *Verticillium* wilt in established pistachio nut groves. *Phytopathology* 72:243-246

Baker, K.F. 1962. Thermotherapy of planting material. *Phytopathology* 52:1244-1255

Baker, K.F. 1970. Selected killing of soil micro organisms by aerated steam. *Root Diseases and Soil Borne Pathogens* (Eds.) Tousson, T.A., Bega, R.V., Nelson, R.E., University of California Press, Berkeley, London, p.234-239

Baker, R. 1970. Use of population studies in research on plant pathogens in soil. *Root Diseases and Soil Borne Pathogens* (Eds.) Toussoun, T.A., Robert, U. and Nelson, R.E., University of California Press, Berkeley, London, p.11-15

Baker, K.F. and Cook, R.J. 1974. *Biological control of plant pathogens*. Freeman, San Francisco. pp.433

Basallote-Ureba, M.J. and Melero-Vara, J.M. 1993. Control of garlic white rot by soil solarization. *Crop Prot.* 12:219-223

Bell, C.E. and Laemmlen, F.F. 1991. Soil solarization in the Imperial valley of California. *Soil Solarization* (Eds.) Katan, J. and DeVay, J.E. CRC Press, Florida, p.245-255

Ben-Yephet, Y., Stapleton, J.J., Wakeman, R.J. and DeVay, J.E. 1987. Comparative effects of soil solarization with single and double layer of polyethylene film on surival of *F. oxysporum f. sp. vasinfectum*. *Phytoparasitica* 15:181-185

Besri. M. 1991. Solarization of soil and agricultural materials in Morrocco for control of *Verticillium* wilt and *Didymella* stem canker in tomato. *Soil Solarization*. (Eds.) Katan, J. and DeVay, J.E. CRC Press, Florida. p.237-243

* Bicici, M. and Erkilic, A. 1986. Integrated control of black scurf and stem cancer caused by *Rhizoctonia solani* Kuhn on potatoes. *Yoga Tarinix Ormancilik* 10:149-173

Borges, M.L. and Sequeira, J.C. 1992. Soil solarization and plant viruses. *Recent Advances in Vegetable Virus Research*. 7th Conference ISHS Vegetable Virus Working Group Athens, Greece. July 12-16

Cook, R.J., Sitton, J.W. and Haglund, W.A. 1987. Influence of soil treatments of growth and yield of wheat and implication for control of Pythium root rot. *Phytopathology* 77:1192-1198

Daelemans, A. 1989. Soil solarization in West Cameroon: Effect on weed control, some chemical properties and pathogens of the soil. *Acta Hort.* 255:169-173

Davis, J.R. 1991. Soil solarization: Pathogen and disease control and increases in crop yield and quality; short and long term effects and integrated control. *Soil solarization* (Eds) Katan, J. and DeVay, J.E. CRC Press, Florida. p.39-50

Davis, J.R. and Sorensen L.H. 1986. Influence of soil solarization at moderate temperatures on potato genotypes with differing resistances to *V. dahliae*. *Phytopathology*. 76:1021-1026

Deshpande, A.L. and Tiwari, R.K.S. 1991. Effect of solarization on sclerotia of *Sclerotium rolfsii* causing collar rot in betelvine. *Indian Phytopath.* 44:353-355

DeVay, J.E. 1991. Use of soil solarization for the control of fungal and bacterial plant pathogens including biocontrol. *FAO Pl. Prod. Prot. Pap.* 109:79-93

Dobereiner, J., Marriel, J.E. and Nery, M. 1976. Ecological distribution of *Spirillum* Beijerinck. *Can. J. Microbiol.* 22:1464-1473

Dubey, R.C. 1992. Effect of soil solarization on the survival of *Macrophomina phaseolina* in fungicide amended and unamended soils. *Trop. Sci.* 32:275-279

Duff, J.D. and Barnart, A. 1992. Solarization controls soil borne fungal pathogens in nursery potting mixes. *Aust. Pl. Path.* 21:20-23

Duff, J.D. and Connelly, M.I. 1993. Effect of solarization using single and double layers of plastic mulch on *Pythium*, *Phytophthora* and *Sclerotium* species in a nursery potting mixture. *Aust. Pl. Path.* 22:28-35

Dwivedi, S.K. 1991. Studies on population dynamics of *F. oxysporum* f. sp. *lycopersici* in solar heated soil. *Natn. Acad. Sci. Lett.* 14:235-237

Dwivedi, S.K. 1993. Soil solarization adversely affects some fungal pathogens causing wilt disease of guava (*Psidium guajava* L.). *Soil Biol. Biochem.* **25**:1635-1636

Dwivedi, R.S. and Dubey, R.C. 1987. Effect of soil solarization on the population dynamics of *Macrophomina phaseolina* Goid and general soil mycoflora. *J. Trop. Pl. Dis.* **5**:67-73

Egley, G. 1983. Weed seed and seedling reductions by soil solarization with transparent polythene sheets. *Weed Sci.* **31**:404-409

Elad, Y., Katan, J. and Chet, I. 1980. Physical, biological and chemical control integrated for soil borne diseases in potatoes. *Phytopathology* **70**:418-422

Elmore,C.L. 1983. Solarization for weed control in vegetable crops. *Abstr. Weed. Sci. Soc. Am.* 32

Everett, P.H. and Mc Laughlin, C.J. 1975. Biodegradable liquid polymers as soil mulches for tomatoes. *Proc. Fla. St. Hort. Soc.* **88**:233-237

Fahim, M.M., Osman, A.R., El-Attar, A.H. and Mabrouk, M.S.M. 1987. Root rot of common bean and its control by chemical and physical means. *Egypt. J. Phytopath.* **19**:71-83

Ferguson, J.J. 1981. Inoculum production and field application of vesicular - arbuscular mycorrhizal fungi. Ph.D. dissertation, University of California, Riverside. pp.117

Freeman, S., Sztenjnberg, A., Shabi, E. and Katan, J. 1990. Long term effect of soil solarization for the control of *Rosellinia necatrix* in apple. *Crop Prot.* **9**:312-316

Gamliel, A. and Katan, J. 1991. Involvement of fluorescent pseudomonads and other microorganisms in increased growth response of plants in solarized soils. *Phytopathology* **81**:494-502

Gamliel, A. and Katan, J. 1992a. Influence of seed and root exudates on fluorescent pseudomonads and fungi in solarized soil. *Phytopathology* **82**:320-327

Gamliel, A. and Katan, J. 1992b. Chemotaxis of fluorescent pseudomonads towards seed exudates and germinating seeds in solarized soil. *Phytopathology* **82**:328-332

Gamliel, A. and Stapleton, J.J. 1993a. Effect of chicken compost or ammonium phosphate and solarization on pathogen control, rhizosphere micro organisms and lettuce growth. *Pl. Dis.* **77**:886-891

Gamliel, A. and Stapleton, J.J. 1993b. Characterisation of antifungal volatile compounds evolved from solarized soil amended with cabbage residues. *Phytopathology* **83**:899-905

Gamliel, A., Hadar, E. and Katan, J. 1989. Soil solarization to improve yield of gypsophilla in monoculture systems. *Acta Hort.* **255**:131-138

Gamliel, A., Hadar, M. and Katan, J. 1993. Improvement of growth and yield of *Gypsophila paniculata* by solarization or fumigation of soil or container medium in continuous cropping systems. *Pl. Dis.* **77**:933-938

* Garibaldi, A. 1987. The use of plastic materials for solar heating of soil. *Colture Protette* **16**:25-28

Garibaldi, A. and Tamietti, G. 1989. Solar heating, recent results obtained in northern Italy. *Acta Hort.* **255**:125-130

Gerson, U., Yathom, S. and Katan, J. 1981. A demonstration of bulb mite control by solar heating of the soil. *Phytoparasitica* **9**:153-155

Ghaffar, A. 1984. Integrated control of sclerotial fungi. *Final Res. Rep.* 1st Nov.-31st January 1984. Karachi, Pakistan. pp.124

Ghini, R. 1993. A solar collecter for soil disinfestation. *Neth. J. Pl. Path.*. **99**:45-50

Gilead, D. 1979. The use of photodegradable polyethylene films in the cultivation of field crops in Israel. *Plasticulture* **43**:31-37

* Gil-Ortega, R., Barriuso Vargas, J., Palazon Espanol, C. and Zaragoza-Larios, C. 1990. The effect of soil solarization in an open air pepper culture. *ITEA, Production Vegetale* **86**:142-154

Graham, J.H. and Leonard, R.T. 1982. Interaction of light intensity and soil temperature with phosphorus inhibition of vesicular-arbuscular mycorrhizae formation. *New Phytol.* **91**:683-690

Greenberger, A., Yogev, A. and Katan, J. 1985. Induced suppressiveness in solarized soils. *Phytopathology* **75**:1291

Greenberger, A., Yogev, A. and Katan, J. 1987. Induced suppressiveness in solarized soils. *Phytopathology* **77**:1663-1667

Grinstein, A., Orions, D., Greenberger, A. and Katan, J. 1979. Solar heating of the soil for the control of *V. dahliae* and *Pratylenchus thornei* in potatoes. *Soil borne plant pathogens.* (Eds.) Schippers, B. and Gams, W. Academic Press, New York. p.431-438

* Hadar, E., Sofer, S., Brosh, S., Mordechai, M., Cohn, E. and Katan, J. 1983. Control of clover cyst nematode on carnation. *Hadasseh* **63**:1698-1700

* Harper, J.L. 1974. Soil sterilization and disinfestation, the pertubation of ecosystems. *Agro ecosystems* **1**:105-106

Hartz, T.K., Bogle, C.R., Bender, D.A. and Avila, F.A. 1989. Control of pink root disease in onion using solarization and fumigation. *J. Am. Soc. hort. Sci.* **114**:587-590

Hartz, T.K., DeVay, J.E. and Elmore, C.L. 1993. Solarization is an effective soil disinfestation technique for strawberry production. *Hort. Sci.* **28**:104-106

Hasan, M.S. 1989. Soil solarization by solar heating, in Iraq. *Arab J. Pl. Prot.* **7**:122-125

Hendricks, S.B. and Taylorson, R.B. 1976. Variation in germination and amino acid leakage of seeds with temperature related to membrane phase change. *Pl. Physiol.* **58**:7-11

Henis, Y. and Papavizas, G.C. 1983. Factors affecting germinability and susceptibility to attack sclerotia of *Sclerotium rolfsii* by *Trichoderma harzianum* in field soil. *Phytopathology* **73**:1469-1474

Henis, Y., Elad, Y., Chet, I. and Hadar, Y. 1979. Control of soil borne plant pathogenic fungi in carnation, strawberry and tomato by *Trichoderma harzianum*. *Phytopathology* **69**:1031

Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis*. William Clowes and Sons Ltd., London. pp.66

Hetzroni, A., Grinstein, A., Alper, Y. and Frankel, H. 1983. A continuous plastic film covering and welding machine for soil solarization. *Acta Hort.* **152**:259-265

* Hori, K. Morita, H., Namura, H., Suzuki, T., Muramatsu, Y. and Kawamori, T. 1979. Control of wilting symptoms of tomato plants grown semi forcingly x Influence of solar heating in summer microbial flora in soil. *Bull. Shizhoka Agric. Exp. Stn.* **24**:48-53

Horiuchi, S. 1984. Soil solarization for suppressing soil borne diseases in Japan. *Soil borne Crop Diseases in Asia* (FFTC Book series No.26) Jan-Bay-Peterson. Taiwan, pp.27

Horiuchi, S. 1991. Solarization for green house crops on Japan. *FAO Pl. Prod. Prot. Pap.* **109**:16-27

* Horiuchi, S., Hori, M., Takashi, S. and Shimizu, K. 1983. Factors responsible for the development of club root - suppressing effect in soil solarization. *Bull. Chugoku Natn. agric. Expt. Stn.* **20**:25-48

Horowitz, M. 1980. Weed research in Israel. *Weed Sci.* **28**:457-460

Horowitz, M. Regev, Y. and Herzlinger, G. 1983. Solarization for weed control. *Weed Sci.* **31**:170-179

ICRISAT. 1985. Effects of soil solarization. *A. Rep.* 183-184

ICRISAT. 1986. Effect of soil solarization. *A. Rep.* 177-178

Ioannou, N. and Poullis, C.A. 1990. Evaluation of soil solarization for control of *Fusarium* wilt of watermelon. *Trop. Bull. - Cyprus Agric. Res. Inst.* **121**: pp.8

Jackson, M.S. 1958. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi. 2nd (ed). pp.498

JimenezDiaz, R.M., Bejarano, J., Blanco, M.A., Gomez, J., Gonzalez, R. and Melero, J.M. 1991. Control of *Verticillium* wilt and *Fusarium* wilt by soil solarization in Southern Japan. *FAO Pl. Prod. Prot.* Pap. **109**:94-107

Johnson, L.F. and Curl, E.A. 1972. Isolation of groups micro organisms from soil. *Methods for Research on the Ecology of Soil Borne Plant Pthogens.* Burgees Publishing Company. New York. p.6-33

Jones, J.P., Overman, A.J. and Geralsons, C.H. 1966. Effect of fumigants and plastic film on the control of several soil borne pathogens of tomato. *Phytopathology*. **56**:929-932

Jones, T.L., Jones, U.S. and Ezell, D.O. 1977. Effect of nitrogen and plastic mulch on properties of Troup loamy sand and on yield of 'Walter' tomatoes. *J. Am. Hort. Sci.* **102**:273-275

Juarez-Palacios, C., Felix-gastelum, R., Wakeman, R.J., Paplomatas, E.J. and DeVay, J.E. 1991. Thermal sensitivity of three sps. of *Phytophthora* and the effect of soil solarization on their survival. *Pl. Dis.* **75**:1160-1164

Kaewruang, W., Sivasithamparam, K. and Hardy, G.E. 1989a. Effect of solarization on soil within plastic bags on root rot of gerbera (*Gerbera jamesonii* L.) *Pl. Soil.* **120**:303-306

Kaewruang, W., Sivasithamparam, K. and Hardy, G.E. 1989b. Use of soil solarization to control root rots in gerberas (*Gerbera jamesonii*). *Biol. Fertil. Soils.* **8**:38-47

Katan, J. 1980. Solar pasteurisation of soils for disease control: Status and prospectus. *Pl. Dis.* **64**:450-454

Katan, J. 1981. Solar heating (Solarization) of soil for control of soil borne pests. *A. Rev. Phytopathol.* **19**:211-236

Katan, J. 1981a. Solar heating of soil and other economically safe methods of controlling soil borne pests for increasing food production. *Proc. Sym. IX Int. Con. Pl. Prot.* Washington D.C., USA. p.26-30

Katan, J. 1984. Soil solarization. *Acta Hort.* **152**:227

Katan, J. 1987. Soil solarization. *Innovative Approaches to Plant Disease Control* (Ed.) Chet, I. John Wiley & Sons, New York. p.77-105

Katan, J., Greenberger, A., Alon, H. and Grinstein, A. 1976. Solar heating by polyethylene mulching for the control of disease by soil borne pathogens. *Phytopathology* **66**: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 soil borne diseases in onions. *Phytoparasitica* **8**:39-50

Katan, J., Fishler, G. and Grinstein, A. 1983. Short and long term effect of soil solarization and crop sequence on *Fusarium* wilt and yield of cotton in Israel. *Phytopathology* **73**:1215-1219

Kelman, A. 1954. The relationship of pathogenicity of *Pseudomonas solanacearum* to colony appearance on a tetrazolium medium. *Phytopathology* **44**:693-695

Kerala Agricultural University. 1989. *Package of. Practices Recommendations 'Crops'*. Directorate of Extension, Mannuthy, Thrissur, Kerala, India. p.180-183

* Kodama, T. and Fukui, T. 1979. Solar heating sterilization in the closed vinyl house against soil borne diseases. *Bull. Nara. Prof. Agric. Expt. Stn.* **10**:71-72

Koller, L.R. 1965. *Ultraviolet Radiation*. John Wiley & Sons, Inc. New York.

Koller, D. 1972. Environmental control of seed germination. *Seed Biology*. (Ed) Kozlowski, T.T. Academic Press, London. p. 2-101

Kulkarni, R.B., Kalra, A. and Ravindra, N.S. 1992. Integration of soil solarization with host resistance in the control of die back and collar rot disease of periwinkle. *Trop. Agric.* **69**:217-221

* Kye, U.K. and Kim, K.C. 1985. Possibility of soil solarization in Korea. *Korean J. Pl. Prot.* **24**:107-114

LaMondia, J.A. and Brodie, B.B. 1984. Control of *Globodera rostochiensis* by solar heat. *Pl. Dis.* **68**:474-476

Lazarovits, G., Hawke, M.A., Olthof Th. H. A., Coutu Sundy, J. 1991a. Influence of temperature on survival of *Pratylenchus penetrans* and of microsclerotia of *Verticillium dahliae* in soil. *Can. J. Pl. Path.* **13**:106-111

Lazarovits, G., Hawke, M.A., Tomlin, A.T., Olthof Th. H. A. and Squire, S. 1991b. Soil solarization to control *V. dahliae* and *Pratylenchus penetrans* on potatoes in Central Ontario. *Can. J. Pl. Path.* **13**:116-123

Levitt, J. 1980. *Response of Plants to Environmental Stresses* Vol.I. Academic Press, New York. pp.64

Lewis, J.A. and Papavizas, G.C. 1974. Effect of volatiles from decomposing plant tissues on pigmentation, growth and survival of *Rhizoctonia solani*. *Soil Sci.* **118**:156-163

Lifshitz, R.M., Tabachnik, J., Katan, J. and Chet, I. 1983. The effect of sublethal heating on sclerotia of *Sclerotium rolfsii*. *Can. J. Microbiol.* **29**:1607-1610

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

Lodha, S., Singh, M. and Sharma, B.M. 1991. Solarization brings down soil-borne pathogens in arid lands. *Indian Fmg.* **41**:12-13

Mahrer, Y. 1979. Prediction of Soil temperature of a soil mulched with transparent polyethylene. *J. Appl. Metereol.* **18**:263-267

Mahrer, Y. and Katan, J. 1981. Spatial soil temperature regime under transparent polyethylene mulch: numerical and experimental studies. *Soil Sci.* **131**:82-87

Malathrakis, N.E. and Kambourakis-Tzagaroulakis, E. 1989. Control of tomato corky root rot by soil solarization in combination with soil fumigation. *Acta Hort.* **255**:205-211

Malathrakis, N.E. and Loulakis, M.D. 1989. Effectiveness of the type of polyethylene sheet on soil solarization. *Acta Hort.* **255**:235-241

Martyn, R.D. and Hartz, T.K. 1985. Soil solarization for the control of *Fusarium* wilt of watermelon. *TAES* Leafl. pp.13

Matrod, L., Faddoul, J., Elmemar, A. and Al-Chaabi, S. 1991. The use of solar energy for controlling white rot disease of garlic. *FAO Pl. Prod. Prot. Pap.* **109**:118-128

Mayer, A.M. and Polyakoft-Mayber, 1975. *The Germination of Seeds* 2nd (ed). Pergamon Press, Oxford. pp.192

Mc-Cain, A.H., Bege, R.V. and Jenkinson, J.C. 1986. Effect of fallow sowing and solar heating of soil on two conifer seedling diseases. *Tree Planter's notes* **37**:17-20

Mc Lean, G.D., Burt, J.R., Thomas, D.W. and Sproul, A.N. 1982. The use of reflective mulch to reduce the incidence of watermelon mosaic virus in Western Australia. *Crop. Prot.* **1**:491-496

Menge, J.A., Johnson, E.L.V. and Minassian, V. 1979. Effect of heat treatment and three pesticides upon the growth and reproduction of the mycorrhizal fungus *Glomus fasciculatus. New Phytol.* **82**:473-480

Meron, M., Filler, Y., Cohen, Y., Grinstein, A., Gamliel, A., Chen, Y. and Katan, J. 1989. Solarization and fumigation for reclamation of organic soils. *Acta Hort.* **255**:117-122

Mihail, J.D. and Alcorn, S.M. 1984. Effects of soil solarization on *Macrophomina phaseolina* and *Sclerotium rolfsii. Pl. Dis.* **68**:156-159

* Milevoj, L. 1989. Trials on the solarization of the soil in the lower Alps. *Zastita Bilja* **40**:223-226

Moens, M. and Ben-aicha, B. 1990. Control of Pepper wilt in Tuniasia. *Parasitica* **46**:103-109

Morgan, D.P., Leibman, J.A., Epstein, L. and Jimenz, M.L. 1991. Solarizing soil planted with cherry tomatoes vs. solarizing fallow ground for control of *Verticillium* wilt. *Pl. Dis.* **75**:148-151

Munnecke, D.E., Wilbur, W., Darley, E.F. 1976. Effect of heating or drying on *Armillaria mellea* or *Trichoderma viride* and the relation to survival of *A. mellea* in soil. *Phytopathology* **66**:1363-1368

Myers, D.F., Campbell, R.N. and Greathead, A.S. 1983. Thermal inactivation of *Plasmodiophora brassicae* Woron and its attempted control by solarization in the Salinas Valley of California. *Crop Prot.* 2:325-333

Nair, S.K., Peethambaran, C.K., Geetha, D., Kamala Nayar and Wilson, K.I. 1990. Effect of soil solarization on nodulation, infection by mycorrhizal fungi and yield of cowpea. *Pl. Soil* **125**:153-154

*Nemli, T. 1990. The use and spectrum of soil solarization. *Ege Universitiesi Ziraat Fakuiltesi Dergisi* 27:299-308

Ogbuji, R.O. 1989. Views on soil solarization: The nigerian situation. *Acta Hort.* **255**:177-179

Olsen, C.M. and Baker, K.F. 1968. Selective heat treatment of soil and its effect on the inhibition of *Rhizoctonia solani* by *Bacillus substilis*. *Phytopathology* **58**:79-87

Osman, A.R., Fahim, M.M., Sahab, A.F. and Abdel-Elkader, M.M. 1986. Soil solarization for the control of Lupin wilt. *Egypt. J. Phytopathol.* **18**:75-88

Overman, A.J. 1981. Off season land management and soil fumigation for tomato on sandy soil. *J. Nemat.* 13:455

Papavizas, G.C. and Lumsden, R.D. 1980. Biological control of soil borne fungal propagules. *A. Rev. Phytopathol.* **18**:389-413

Pavlica, D.A., Hora, T.S., Bradshaw, J.J., Skogerboe, R.K. and Baker, R. 1978. Volatiles from soil influencing activities of soil fungi. *Phytopathology* **68**:758-765

Peethambaran, C.K. 1975. Studies on the comparative survival of *Pythium* spp. in the soil. Ph.D. thesis, G.B. Pant University, Pant Nagar. pp.140

Peethambaran, C.K. and Singh, R.S. 1977. Survival of different structures of *Pythium* spp. in soil. *Indian Phytopath.* 30:347-352

Phillips, J.M. and Hayman, D.S. 1970. Improved procedures for clearing root and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Br. Mycol. Soc.* 55;158-160

Porter, I.J. and Merriman, L.R. 1983. Effect of solarization of soil on nematode and fungal pathogens at two sites in Victoria. *Soil Biol. Biochem.* 15:39-44

Porter, I.J. and Merriman, L.R. 1985. Evaluation of soil solarization for control of root diseases of row crops in Victoria. *Pl. Path.* 34:108-118

Prakash, K.S. and Mani, A. 1991. Solarization in crop production. *The Hindu* Daily, 22 May, Wednesday.

Premanathan, T. 1981. Studies on the *Phyllosticta* leaf spot of ginger. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur, pp.97

Premanathan, T., Peethambaran, C.K. and Abi Cheeran. 1980. Screening of ginger varieties against *Phyllosticta* leaf spot. *Proc. Nat. Sem. on Ginger and Turmeric* held at Calicut on 8-9-1980. p.127-128

Pullman, G.S., DeVay, J.E., Garber, R.H. and Weinhold, A.R. 1979. Control of soil borne fungal pathogens by plastic tarping of soil. *Soil Borne Plant Pathogens* (Eds) Schippers, B. and Gams, W. Academic Press, New York. p.439-446

Pullman, G.S., DeVay, J.E. and Garber, R.H. 1981a. Soil solarization and thermal death. A logarathmic relationship between time and temperature for four soil borne pathogens. *Phytopathology* 71:959-964

Pullman, G.S., DeVay, J.E., Garber, R.H. and Weinhold, A.R. 1981b. Effects on *Verticillium* wilt of cotton and soil borne populations of *Verticillium dahliae, Pythium* spp., *Rhizoctonia solani* and *Thielaviopsis basicola. Phytopathology* 71:954-959

Pullman, G.S., DeVay, J.E., Elmore, C.L. and Hart, W.H. 1984. Soil solarization - a non-chemical method for controlling disease and pests. *Co-operative Extension, Division of Agriculture and Natural Resources*, Leaflet 21377: University of California, Davis, C.A. pp.7

Riker, A.J. and Riker, R.S. 1936. *Introduction to research on plant diseases*. John Swift Co., St.Louis, Chicago. pp.117

Ristaino, J.B., Perry, K.B. and Lumsden, R.D. 1991. Effect of solarization and *Gliocladium virens* on sclerotia of *Sclerotium rolfsii*, soil microbiota and the incidence of Southern blight of tomato. *Phytopathology* **81**:1117-1124

Rubin, B. and Benjamin, A. 1981. Solar sterilization as a tool for weed control. *Abstr. Weed Sci.* **29**:135

Rubin, B. and Benjamin, A. 1983. Solar heating of the soil. Effect on weed control and on soil incorporated herbicides. *Weed Sci.* **31**:819-825

Rubin, B. and Benjamin, A. 1984. Solar heating of the soil. Involvement of Environmental factors in the weed control process. *Weed Sci.* **32**;138-142

Russel, R.S. 1977. *Plant Root Systems: Their Function and Interaction with the soil.* Mc Graw-Hill, London, pp.198

Sainamol Kurian, P. 1992. Effect of solarization on damping off diseases of vegetables. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur. pp.136

Sainamol Kurian, P. and Peethambaran, C.K. 1994. Solarization and plant growth stimulation in chillies. *Hort. Natn.* KHDP Seminar held at Trivandrum on 24-1-1995.

Satour, M.M., Abdel-Rahim, M.F., El-Yamani, T., Radwan, A., Grinstein, A., Rabinowitch, H.D. and Katan, J. 1989. Soil solarization in onion fields in Egypt and Israel; short and long term effects. *Acta Hort.* **255**:151-159

Satour, M.N., El-Sherif, E.M., El Ghareeb, L., El-hazdad, A. and El-wakil, H.R. 1991. Achievements of soil solarization in Egypt. *FAO Pl. Prod. Prot.* Pap. **109**:200-212

Singh, D.V., Srivastava, K.D. and Aggarwal, R. 1991. Mulching as a means of karnal bunt management. *Pl. Dis. Res.* **6**:115-116

Siti, E., Cohn, E., Katan, J. and Mordechai, M. 1982. Control of *Ditylenchus dispaci* in garlic by bulb and soil treatments. *Phytoparasitica* **10**:93-100

* Skoudridakis, M.T. and Bourbos, V.A. 1989. Soil solarization by mulching with films of transparent polyethylene for control of *Verticillium* wilt of olive. *Rivista di Patologia vegetale* **25**:46-49

Stapleton, J.J. 1991. Soil solarization in tropical agriculture for pre- and post plant application. *FAO Pl. Prod. Prot. Pap.* **109**:220-228

Stapleton, J.J. and DeVay, J.E. 1982. Effect of soil solarization on populations of selected soil borne micro organisms and growth of deciduous fruit tree seedlings. *Phytopathology* **72**:323-326

Stapleton, J.J. and DeVay, J.E. 1983. Response of phytoparasitic and free living nematodes to soil solarization and 1, 3 dichloropropene in California. *Phytopathology* **73**:1429-1436

Stapleton, J.J. and DeVay, J.E. 1984. Thermal component 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

Stapleton, J.J. and DeVay, J.E. 1986. Soil solarization, a non-chemical approach for management of plant pathogens and pests. *Crop Prot.* **5**:190-198

Stapleton, J.J. and Garzalopez, J.G. 1988. Mulching of soil with transparent (solarization) and black polythene films to increase growth of annual and perennial crops in South Western Mexico. *Trop. Agric.* **65**:29-33

Stapleton, J.J. and Heald, C.M. 1992. Management of phytopathogenic nematodes by soil solarization. *Soil Solarization* (Eds) Katan, J. and DeVay, J.E. CRC Press, Florida. p.51-60

Stapleton, J.J., Quick, J. and DeVay, J.E. 1985. Soil solarization: Effects on soil properties, crop fertilization and plant growth. *Soil Biol. Biochem.* 7:369-373

Stapleton, J.J., Lear, B. and DeVay, J.E. 1987. Effect of combining soil solarization with certain nematicides on target and nontarget organisms and plant growth. *Ann. appl. Nemat.* **1**:107-112

Stapleton, J.J., Asai, W.K. and DeVay, J.E. 1989. Polymer mulches in the integrated pest management programmes for establishment of perennial fruit crops. *Acta Hort.* **255**:161-168

Stapleton, J.J., DeVay, J.E. and Lear, B. 1991. Soil solarization and field experiments of ammonia based fertilizers and soil solarization on pathogen survival, soil fertility and crop growth. *FAO Pl. Prod. Prot. Pap.* **109**:331-342

Stapleton, J.J., Paplomatas, E.J. Wakeman, R.J. and DeVay, J.E. 1993. Establishment of apricot and almand trees using soil mulching with transparent (solarization) and black polyethylene film: effects on *Verticillium* wilt and tree health. *Pl. Path.* **42**:333-338

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* **25**:259-260

Sztenjnberg, A., Freeman, S. Chet, I. and Katan, J. 1987. Control of *Rosellinia necatrix* in soil and in apple orchard by solarization and *Trichoderma harzianum*. *Pl. Dis.* **71**:365-369

* Tamietti, G. and Garibaldi, A. 1981. Control of corky root in tomato by solar heating of the soil in green house on Riviera Ligure. *La Difesa delle Piente.* **3**:143-150

* Tamietti, G. and Garibaldi, A. 1989. The use of solarization against *Rhizoctonia solani* under green house conditions in Liguria. *Informatore Fitopathologico* **39**:43-45

Taylorson, R.B. and Hendricks, S.B. 1977. Dormancy in seeds. *A. Rev. Pl. Physiol.* **28**:331-354

Tjamos, E.C. 1991. Post plant application of soil solarization for tree crops. *FAO Pl. Prod. Prot. Pap.* **109**:243-252

* Tjamos, E.C. and Paplomatas, E.J. 1987. Effect of solarization on survival of fungal antagonists of *V. dahliae*. *Bull. OEPP* **17**:645-653

Tjamos, E.C. and Paplomatas, E.J. 1988. Long term effect of soil solarization in controlling *Verticillium* wilt of globe artichokes in Greece. *Pl. Path.* 37:507-515

Tjamos, E.C., Biris, D.A. and Paplomatas, E.J. 1991. Recovery of olive trees with *Verticillium* wilt after individual application of soil solarization in established olive orchards. *Pl. Dis.* **75**:557-562

* Triolo, E., Vannacci, G., Materazzi, A. 1988. Solar heating of soil in vegetable production. Part 2. Studies on possible mechanisms of the effect. *Colture Protette* **17**:59-62

* Triolo, E., Vannacci, G. and Materazzi, A. 1989. Soil solarization in vegetable crop production. 3. Control of *R. solani* Kuhn. *Difesa delle Piente* 12:289-296

Tu, C.C., Cheng, Y.H. and Hwang, S.C. 1987. Effects of solar energy and green manures on the control of southern blight of tomato. *Res. Bull.*, Tainan District Agricultural Improvement Station, Taiwan, 32-41

Tu, C.C., Cheng, Y.H. and Hwang, S.C. 1991. Effect of solar energy and green manures on the control of southern blight of tomato. *Pl. Prot. Bull.*. 33;95-102

* Ursad, M. 1977. Weed control in drip irrigated soil strips by raising soil temperatures and by fumigation with methylbromide. *Hassadeh* **47**:1347-1350

Usmani, S.M.H. and Ghaffer, A. 1982. Polythene mulching of soil to reduce viability of sclerotia of *Sclerotium oryzae. Soil Biol. Biochem.* **14**:203-206

Villapudua, J. and Munnecke, D.E. 1986. Solar heating and amendments control cabbage yellows. *Calif. Agric.* **546**:11-13

Villapudua, J. and Munnecke, D.E. 1987. Control of cabbage yellows (*Fusarium oxysporum f. sp. conglutinans*) by solar heating of field soils amended with dry cabbage residues. *Pl. Dis.* **71**:217-221

Villapudua, R.J., Munnecke, D.E. 1988. Effect of solar heating and soil amendments of cruciferous residues on *Fusarium oxysporum* f. sp. *conglutinans* and other organisms. *Phytopathology* **78**:289-295

Watnabe, F.S. and Oleson, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and sodium bicarbonate extracts from soil. *Proc. Soil Sci. Soc. Am.* **29**:677-678

White, J.G. and Buczacki, S.T. 1979. Observations on suppression of club root by artificial or natural heating of soil. *Trans. Br. Mycol. Soc.* **73**:271-275

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

* Originals not seen

EFFECTIVENESS OF SOIL SOLARIZATION FOR THE CONTROL OF SOFT ROT DISEASE IN GINGER

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ABSTRACT OF THE THESIS

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ABSTRACT

The effectiveness of soil solarization for the control of soft rot disease in ginger was studied at the College of Horticulture, Vellanikkara, Thrissur during March 1992 to December 1993. The beds were inoculated with *Pythium aphanidermatum*, five days before the solarization. Transparent, 150 guage polyethylene sheets were used for solarizing the beds.

Maximum soil temperatures recorded were 63.0°, 59.0° and 46.5° at 5, 10 and 15 cm depths in solarized soil, while, that in non-solarized soils were 49.5°, 43.0°C and 40.0°C, respectively, at 5, 10 and 15 cm depths.

Temperature in the solarized soil at 5 cm depth was above 50.0°C for the entire solarization period and above 55.0°C for 38 days, while, at 10 cm depth the temperature was above 50.0°C for 35 days and above 55.0° for five days. The soil temperature at 15 cm depth never reached 50.0°C during the solarization period.

Based on the soil and air temperature recorded, two simple regression equations at 5 and 10 cm depths, one simple equation at 15 cm depth and one multiple regression equation at 10 cm depth were developed for predicting soil temperature under polyethylene mulch.

Rate of germination in ginger was enhanced by solarization. Significant effect of solarization was observed in controlling the pre and post-emergence rotting in ginger. Increasing the period of solarization from 30 to 45 days did not result in a corresponding reduction in the pre-emergence rotting.

Trichoderma incorporated neem cake amended 30 day solarized treatment was highly effective and recorded cent percent control of the soft rot disease, while, maximum disease incidence (90.67%) was in *Trichoderma* incorporated neem leaves amended 45 days solarized plots.

Reduction in *Pythium* population ranging from 79.49 to 99.1 per cent was observed in solarized plots immediately after the removal of polyethylene sheets.

Solarization reduced the total fungal, bacterial, actinomycetal and *Pseudomonas* sp. population in the field. Plants grown in solarized plots showed better colonization of VAM and *Azospirillum*.

Significant reduction in the nematode population was recorded by solarization.

Solarization had a profound suppressive effect on the weed population and it lasted till harvest. Solarization effect was more pronounced in dicots. Eventhough, solarization substantially reduced weed population, its effect was less in the edges. *Bulbostylis barbata, Cynodon dactylon* and *Cyperus rotundus* survived the solarization effect.

Increased growth response of ginger plants was observed as a result of solarization. Growth parameters like height, number of leaves/plant, number of tillers, number of roots, leaf length, leaf breadth, fresh weight of shoots and rhizomes were influenced by solarization.

Significant increase in the yield was obtained through solarization. *Trichoderma* incorporated and neem cake amended 30 days solarized treatment gave the maximum yield/plant (623.23 g) and also per plot yield (10159.57 g), which was 5361 per cent more than that of control.

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

The initial cost of solarization is comparitively high, an amount of Rs.52,500/- is required for solarizing one hectare of ginger field. An additional profit generated from this technique was Rs.40,136/ha for 30 days solarization.