SOIL SOLARIZATION : EFFECT ON SOIL'S NUTRIENTS, MICROORGANISMS AND PLANT GROWTH RESPONSE

THESIS

Submitted to the
G.B. Pant University of Agriculture & Technology
Pantnagar-263 145, U.P., INDIA

by

Deepa Khulbe

IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Doctor of Philosophy
(Plant Pathology)

September, 2000

Dedicated

to

My Beloved Parents

ACKNOWLEDGEMENT

I take this great opportunity to express extreme reverence and profound sense of gratitude to Dr. H.S. Chaube, Professor, Department of Plant Pathology, chairman of my Advisory Committee, for his genuine and thoughtful guidance, untiring supervision, invaluable suggestions and painstaking efforts throughout the course of investigation and in the preparation of the manuscript.

Profound indebtedness are to the reverend members of my advisory committee, Dr. K.P. Singh, Professor, Department of Plant Pathology, Dr. U.S. Singh, Associate Professor, Department of Plant Pathology and Dr. Rita Goel, Associate Professor, Department of Microbiology, whose critical scrutiny made it possible to represent the work in a lofty manner.

Thanks are due to Dr. Y.P.S. Rathi, Professor and Head, Department of Plant Pathology, Dean, College of Agriculture and Dean, College of Post Graduate Studies for providing necessaries facilities.

I am also grateful to Dr. S.N. Vishwakarma, Senior Research Officer, Department of Plant Pathology for his kind co-operation and guidance. I humbly acknowledge Dr. Kewlanand, Junior Research Officer, Department of Agronomy, Dr. B.S. Mahapatra, Associate Professor, Department of Agronomy and Dr. P.C. Srivastava, Associate Professor, Department of Soil Science, for their kind support and rendering necessary facilities for chemical analytical work.

I sincerely acknowledge Basanth Kandpal Sir, Navneet Sir, Prashant, Rajesh, Ajay and Dinkar for their unselfish and valuable help in the time of need. Sincere thanks are due to Jyotsna ma'am and Sri Prakesh for their genuine co-operation.

I wish to express my heartfelt gratitude to my friends Shachi, Deepti, Swati, Shalini, Arvinder and Geeta for their joyful company. I sincerely thank my friends and batchmates Shaheen, Shekhar, Deo Sharan, Deepak and Sangeeta and also my labmates Vishal, Meenakshee, Lalit, Shivalingham and Jameel. I thank Mr. Prabhakar Joshi for his invaluable help.

Appreciation is extended to all the office staff of Plant Pathology Department, Sri J.C. Papnai, Sri J.S. Sharma, Sri. A.K. Saxena and Sri A.B. Joshi for their help and co-operation.

The University Fellowship provided by this university during Ph.D. programme is also duly acknowledged.

I am sincerely thankful to Jijaji for his valuable suggestion. I would not like to add any adjective to my grandparents, parents, sister and brother for their affection and inspiration have always been with me.

September, 2000
Pantnagar

(Deepa Khulbe)

Dr. H.S. Chaube
Professor

Department of Plant Pathology
College of Agriculture
G.B.Pant Univ. of Agric. & Tech.
Pantnagar-263 145
Uttar Pradesh (INDIA)

CERTIFICATE

This is to certify that the thesis entitled **"SOIL SOLARIZATION : EFFECT ON SOIL'S NUTRIENTS, MICROORGANISMS AND PLANT GROWTH RESPONSE"**, submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** in Agriculture with major in **Plant Pathology** of the College of Post-Graduate Studies, G.B.Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Ms. Deepa Khulbe**, Id.No. 19484, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and sources of literature have been duly acknowledged.

(H.S. Chaube)
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Ms. Deepa Khulbe**, Id.No. 19484, a candidate for the degree of **Doctor of Philosophy** in Agriculture with major in **Plant Pathology**, agree that the thesis entitled **"SOIL SOLARIZATION : EFFECT ON SOIL'S NUTRIENTS, MICROORGANISMS AND PLANT GROWTH RESPONSE"**, may be submitted by **Ms. Deepa Khulbe** in partial fulfilment of the requirements for the degree.

(H.S. Chaube)
Chairman

(K.P. Singh)
Member

(U.S. Singh)
Member

(Reeta Goel)
Member

(Head of the Department)
Ex-officio Member

CONTENTS

INTRODUCTION

1. INTRODUCTION

Soilborne plant pathogens constitute the first bio-hostile element of the soil ecosystem that plants encounter before emergence and also at various stages of growth and development. After the notable success of "green revolution" in terms of stability in food-grain production, nutritional aspects of the human diet is the potential area awaiting exploitation. Without vegetables the nutritional requirements, taste, flavour and fancy of human dietary system will remain incomplete. It is important to support and strengthen unpredictable and fragile food grain production. Vegetable cultivation must be encouraged to supplement food grain production. As per statistics, availability, production, productivity and consumption of vegetables and fruits at national level is too low **(Chadha, 2000)**.

Most horticultural corps are raised in nurseries and then transplanted. It is well recognized that due to seed rots and seedling death, above 50 per cent plant populations are lost. This affects further production. Thus, the health of nurseries is of immense significance for profitable and sustainable production of vegetables, ornamentals, flowers and fruits etc. through the production of healthy seedlings. But none of the disease control techniques available presently, could bring the level of soil sanitation above critical threshold, where it could reduce seed and seedling diseases

Plate 1. A : Cauliflower seedling parasitized by *Pythium*

B : Post-emergence damping-off of cabbage - fungal growth visible

C : Cauliflower seedling - collar region infected

D : Toppled tomato seedlings

A

B

D

C

(Chaube and Singh, 1991). The routine sanitation approaches, crop-rotation and soil disinfestation with fumigants and other pesticides, have become restricted because of their incompatibility with sustainable agriculture. For example-methyl bromide, the most widely used soil fumigant, which is a potent ozone depletor, is liberated in the environment, mainly from its agricultural use **(Ristaino and Thomas, 1997)** and poses a threat to harmonious ecosystems and environment. Crop rotations have now become untenable because of intensification of agriculture. The claim of some control with chemical and bioagent seed-treatments do exist in literature and the cultural practices such as raised beds, restricted plant densities, manipulated irrigation systems etc. have served only limited purpose and never got universal practical acceptance. An alternative claimed as an innovative approach is **'soil solarization' (Chet, 1987)**. It is very simple and cheap technique which requires no special scientific know-how. Solarization is just to capture the solar radiations/energy to heat up the soil. The moist soil is covered air tight with polyethylene mulches/sheeting during the period of intense solar radiations for a period of 15 days to few months **(Katan *et al.*, 1976; Stapleton *et al.*, 1982)**.

Solarization is effective in subtropical areas where solar radiation is sufficiently intensive to create sublethal soil temperatures **(Blok *et al.*, 2000; Katan, 1987)**. Under suitable climatic conditions, solarization can control a wide spectrum of soil-borne pests including fungi, bacteria, weeds, nematodes and insects **(Gamliel and Stapleton, 1993a)**.

The technique and process involved, suggests that physico-chemical and biological changes do occur during and after solarization, which contribute to the biocidal effect **(Chen and Katan, 1980; Stapleton *et al.*, 1991, 1985; Ristaino *et al.*, 1996)**. Thus, soil solarization is a passive but complex phenomenon, comprised of physical, chemical and biological components. Besides direct hydrothermal inactivation and enhanced antagonism, it often results in improved plant growth response **(Chen and Katan, 1980; Gamliel and Katan, 1991; Stapleton and DeVay, 1984; Stapleton *et al.*, 1985)**. Increased concentrations of certain mineral nutrients have directly been correlated to increased plant growth response in solarized soils **(Gamliel and Katan, 1991; Stapleton *et al.*, 1991)**. Since physics, chemistry and biology- the three major soil components are involved, it is required to be investigated thoroughly, in different agroclimatic and agroecological regions to define and propagate its utility. It is more so important to study, as all the three partners of the "disease triangle" are affected producing positive effects. Soil nutrients are more available; pathogens, pests, weeds and nematodes are suppressed; disease-pest index is reduced; antagonists increased and PGPR are stimulated. Thus, a complex process occurs as a result of processes which occur during and after solarization. It is in this context, effect of soil solarization on health of nurseries of some horticultural crops was studied through field trials, glass-house experiments and *in vitro* studies with the following objectives :

1. Effect of solarization on major physical factors such as temperature, moisture, pH, etc.
2. Effects on availability/concentrations of some nutrients.
3. Impact on pre and post-emergence damping-off.
4. Impact on plant growth i.e. plant growth response (PGR).
5. Effect on population of antagonists, PGPR, pathogens and weeds.
6. Elucidation of mechanism(s).

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

1. Historical Perspective

Soil solarization exploits the basic knowledge of conserving/trapping solar irradiation, drawn from early agriculture where organic or inorganic mulching/covering of soil was done to provide protective barrier against frost or to increase soil temperatures or to conserve soil moisture for proper germination and plant growth. Control of *Thielaviopsis basicola* in tobacco by direct soil exposure to the sun during summer seasons, was the earliest record of using killing action of solar heat against microorganisms **(Grooshevoy, 1939)**. Several workers confirmed the findings subsequently and suggested similar methods for control of soilborne pests and pathogens **(Avidov, 1956; Raghavan, 1964; Waggoner *et al.*, 1960;)**. **Courter and Oebker (1964); Hopen (1965) and Vanderberg and Tiessen (1972)** reported increase in yield and early maturity of vegetables besides disease control in mulched soil.

Jaccov Katan and Co-workers (1976) from Israel, suggested for the first time, the actual technology of soil solarization i.e. use of transparent polyethylene film to increase soil temperatures to the levels lethal to the propagules of *Fusarium oxysporum* f. sp. *vasinfectum* and *Verticillium dahliae* in soil. This pioneer work by **Katan *et al.* (1976)** opened up a new era and approach for non-chemical control of soilborne pests. **Stapleton and DeVay (1982)** advocated covering of moistened soil during summers for effective control of pathogens. Solar heating should be done for several weeks for long lasting effectivity **(Stapleton and Graza-Lopez, 1988)**.

Although various terms have been used to describe this method viz., solar heating, plastic or polyethylene tarping/mulching, solar pasteurization and soil solarization **(Katan, 1981)**, the term 'soil solarization' is considered the most justified one, since it encompasses the physical, chemical and biological changes in the soil subjected to solar heating **(Pullman *et al.*, 1981)**.

After its success in Israel **(Katan *et al.*, 1976, 1981)** the approach is now being studied and adapted globally (Fig. 1). Several aspects such as disease/pathogen suppression, annulment of fungistasis, biological control, increased plant growth responses etc. has been studied **(Esfahani, 1991; Greenberger *et al.*, 1987; Gamliel *et al.*, 1993; Stapleton and DeVay, 1986; Stapleton and Duncan, 1998; Tjamos and Fravel, 1995)**.

2. Principles

Soil solarization involves trapping of solar heat/energy through polyethylene covering, to raise the soil temperature to the levels where it becomes lethal to temperature-sensitive or mesophylic soil microorganisms, to which category, most of the plant pathogenic fungi, bacteria etc. belong. The physical and chemical balance of soil is also altered by the action of trapped solar energy **(Ahmad *et al.*, 1996; Chen and Katan, 1980; Kumar and Yaduraju, 1992; Stapleton *et al.*, 1985)**. Polyethylene covering of soil produce

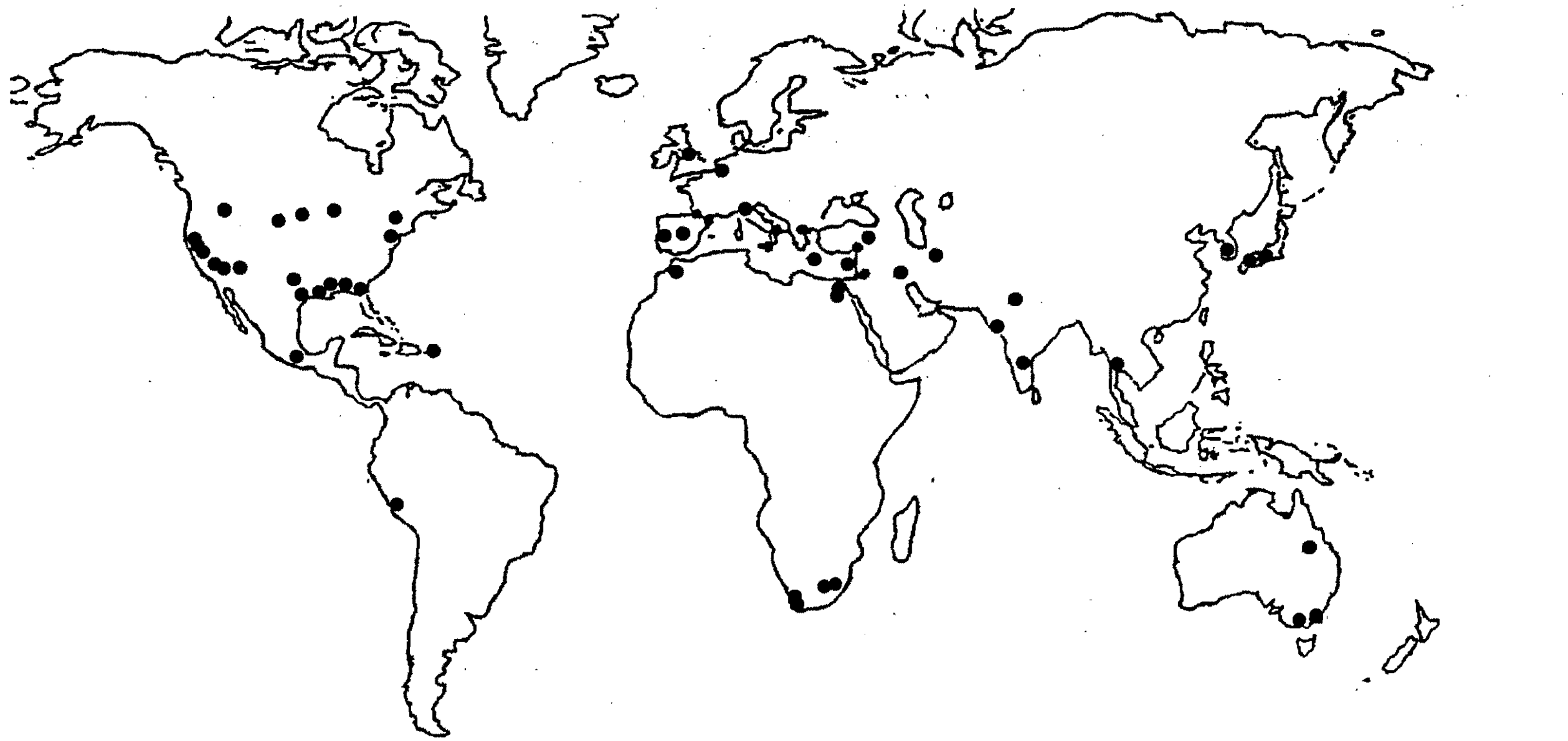


Fig. 1 : World distribution of sites (indicated as black dots) where solarisation has been investigated

greenhouse effect and result in raised soil temperatures commonly to 35-36^{0}C during hot months of the years, as polyethylene reduces heat convection and water evaporation from the soil to the atmosphere **(Silverstein, 1976)**. According to **Katan (1981, 1987)** and several others, for the effectivity and efficacy of soil solarization, following facts must be considered while making recommendations :

i. Transparent polyethylene should be used for solarization since it transmits most of the solar radiation, which heats the soil **(Katan, 1987)**.

ii. The thickness of polyethylene should be thinnest possible because it is cheaper and heats more effectively **(Esfahani, 1991; Horowitz and Regev, 1980; Pullman *et al.*, 1979; Raj and Kapoor, 1993)**. Organic amendments applied before covering the soil, may further aid to solar heating **(Blok *et al.*, 2000; Gamliel and Stapleton, 1993)**.

iii. Adequate soil moisture should be maintained during solarization to increase thermal sensitivity of resting structures of soil microorganisms and to improve heat conductivity **(Grinstein *et al.*, 1979a, b; Katan, 1981, 1987; Mcfayden, 1967)**.

iv. The maximal soil temperatures attained through solarization decrease with increasing soil depths. Therefore, solarization period should be sufficiently extended, usually four weeks or longer, in order to achieve pathogen control at deeper soil depths **(Elad *et al.*, 1980; Katan *et al.*, 1976)**.

v. Biologically and technologically it is different from artificial soil heating as there is no need to transfer heat from source to the field and it is carried out at relatively lower temperatures compared to artificial heating which is usually carried out at 60-100°C. Therefore, negative side-effects associated with steaming, are less likely to occur with solarization **(Baker and Cook, 1974; Dawson *et al.*, 1965; Olsen and Baker, 1968)**.

vi. Success of solarization is based on the fact that most plant pathogen and pests are mesophylic and get killed directly or indirectly. However, thermophylic and thermotolerent microflora survive the process of solarization **(DeVay, 1991; Katan, 1987; Stapleton and DeVay, 1984; Tjamos and Fravel, 1995)**.

vii. Efficacy and effectivity of solarization also depends on colour and texture of the soil. Soil properties like relatively higher thermal capacity than air medium and poor heat conductivity result in slower heat penetration.

3. Mechanisms

Solarization is a complex process as shown in Fig. 2, **(Chaube and Singh, 1991)** involving direct thermal inactivation/destruction of pathogen propagules, shift in microbial balance, populations and activity towards creating soil suppressiveness with simultaneous changes in physico-chemical properties of the soil **(DeVay and Katan, 1991; Esfahani, 1991; Greenberger *et al.*, 1984; 1987; Katan, 1987; Pullman *et al.*, 1981; Stapleton *et al.*, 1982)**.

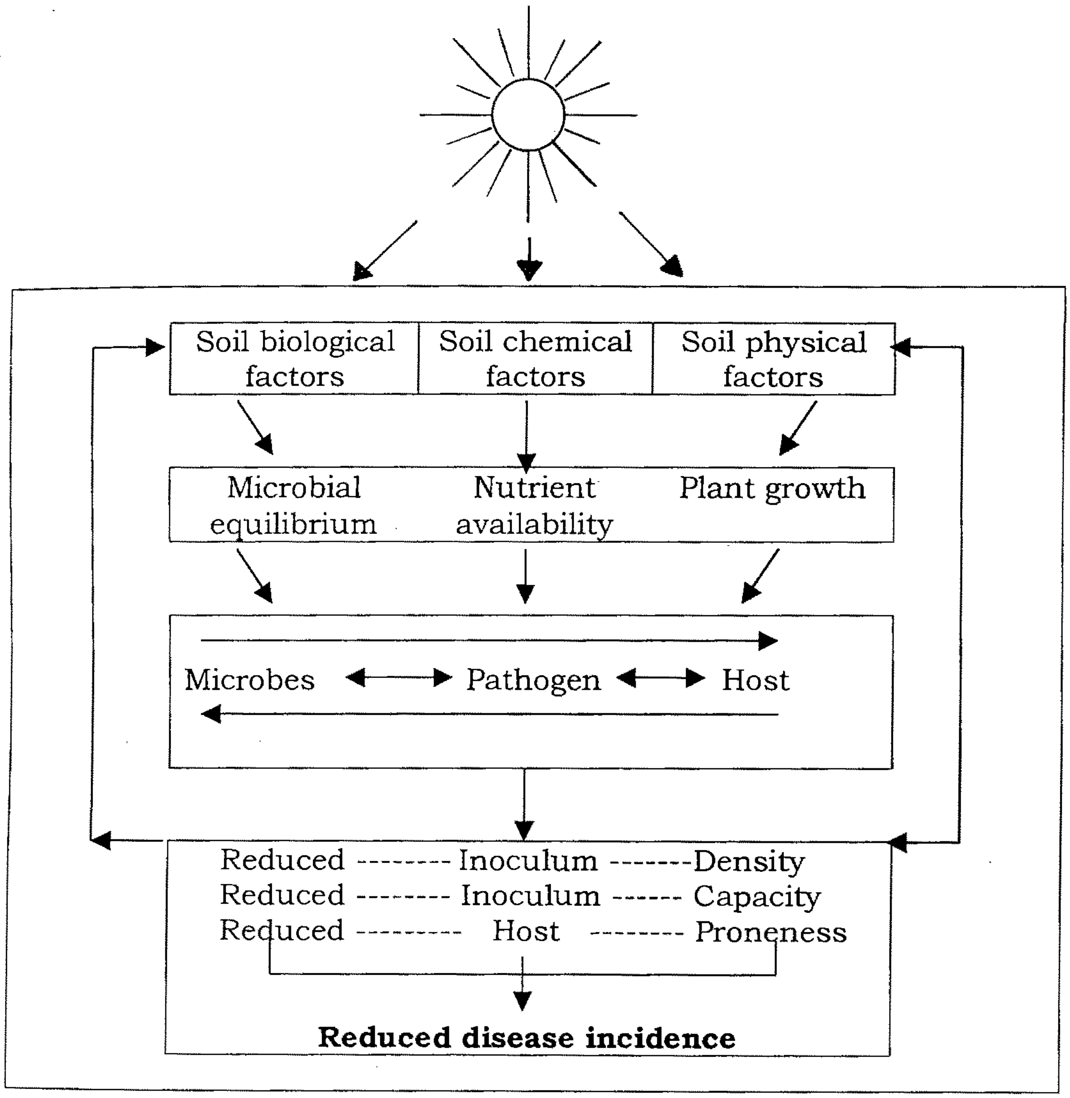


Fig. 2 : **Mechanism of disease control by soil solarization**

Enhanced antagonism and improved plant growth response (IPGR) were other modes of action **(Chen and Katan, 1980; Gamliel and Katan, 1991; Stapleton and DeVay, 1984, 1986; Stapleton *et al.*, 1985)**.

(ii) Thermal inactivation/Physical effect

Direct hydrothermal inactivation of pathogen propagules as a consequence of raised soil temperature has been reported to have most pronounced lethal effects on a broad spectrum of soil organisms **(Freeman and Katan, 1988; Lifshitz *et al.*, 1983; Mahrer, 1979; Pullman *et al.*, 1981; Stapleton and DeVay, 1986)**. Accumulation of heat effect above (a critical temperature threshold for mesophylic organisms is of about 37^{0}C) this temperature over time was lethal. The sensitivity of organisms to high temperatures was related to small differences in macromolecules which lead to increased intramolecular bonding involving slight changes in hydrogen bonds, ionic bonds and disulfide bonds **(Brock, 1978)**,

Pullman *et al.* (1981) showed a logarithmic relationship between time and temperature for thermal death of certain fungal plant pathogens. The thermal death rate of a microbial population depended on the soil temperature level attained and exposure time, which were inversely related **(Katan, 1987; Pullman *et al.*, 1981)**. Reported reduced exposure times for LD 90 at higher soil temperatures have been reported **(Lin-chein Huang, 1995; Munnecke *et al.*, 1976)**. Exposure time reduced to 40, 40 and 20 minutes for LD 90 at 49^{0}C temperature from 120, 150 and 120 minutes, respectively at 45^{0}C for three different strains of *Fusarium oxysporum* f. sp. *apii* **(Lin-chein , 1995)**. *Armellaria mellea* was not viable after 4-7 hrs exposure at 41^{0}C **(Munnecke *et al.*, 1976)**.

Moisture level is crucial factor for soil heating, therefore, proper moistening of soil should be done to facilitate heat conduction in soil layers **(Al-Raddad, 1979; Katan *et al.*, 1987; Pullman, 1979)**.

Reduced/diminished fungistasis was found in heated/solarized soils **(Katan *et al.*, 1976; Greenberger *et al.*, 1987)**. Wet heat was effective in breaking dormancy of *Neurospora tetrasperma* **(Lingappa and Sussman, 1959)**.

The physical effect of solarization is comprised of three processes which may occur simultaneously, viz., reduced propagule viability, increased vulnerability of pathogen propagules to potential antagonists and enhanced activity of antagonistic microflora **(Chaube and Singh, 1991)**. Since heat mortality curves refer only to the first phenomenon reliability of such curves as a tool for predicting the effectiveness of solarization should be evaluated in each and every case **(Henis and Papavizas, 1983; Katan *et al.*, 1987)**.

(ii) Biological control and enhanced antagonism

Thermotolerent and thermophylic soil microflora which survived the sublethal solar heating, became weakened with reduced viability or may be partially damaged and eventually with reduced inoculum potential **(Henis and Papavizas, 1983; Lifshitz *et al.*, 1983; Vannacci *et al.*, 1988)**.

(iii) Disease control

Reduction in disease-incidence in solarized soils results from the effects exerted on each of the three living components involved in disease (host, pathogen and surrounding microorganisms) as well as physico-chemical soil environment, which in turn might be affecting the activities and inter-relationships of the soil organisms. These processes occur during solarization and continue to various extents and in different ways even after the removal of polyethylene sheets and planting **(Chaube and Singh, 1991)**.

There are several reports which advocate the potentiality of soil solarization in reducing inoculum potential and improving plant health. In general soil solarization has been found effective against several soilborne pathogens and diseases under varying conditions (Table 1 and 2).

Several workers have reported decline in total fungal populations in soil after solarization. **Chaube and Singh (1991)** reported that total fungal population in solarized soils after 45 days ranged form 8.22×10^3 to 12.25×10^3 per g of soil as against a total fungal population of 82.25×10^3 per g of soil in non-solarized soil.

Propagules of *Fusaerium solani, Pythium drechsleri and Pythium aphanidermatum* reduced greatly or eliminated between 0 and 25 cm cm depth in solarized soils **(Mansoori and Jaliani, 1996)**. However, population densities of thermotolerent and thermophilic fungal organisms remained relatively higher following

Table 1 : **Selected reports on disease control by soil solatrization**

Disease	Casual organism	Reference(s)
Black shank of tomato	*Phytophthora parasitica*	Wajid *et al.* (1995)
Club root of cabbage	*Plasmodium brassicae*	Porter and Merriman (1985)
Collor rot of tomato	*Sclerotium rolfsii*	Tiwari *et al.* (1997)
Collar rot of tomato	*Pyrenochaeta* spp.	Cartia (1989); Katan (1980); Schor *et al.* (1983); Temieti and Garibaldi (1981); Tjamos (1984); Hartz *et al.* (1989)
Crater disease of wheat	*Bipola ris sorokiniana*	Maura *et al.* (1994)
Crown blight of peper	*Phytopthora capsici*	Yucel (1945)
Damping-off of damping off of tomato cauliflower and onion	*Fusarium* spp.	Mishra (1997); Esfahni (1991)
Damping-off of watermelon	*Phytophthora drechsleri and Fusarium solani* *Pythium aphanidermatum*	Mansooria nad Jaliani (1996)
Damping-off of cucumber	*P. aphanidermatum*	Al-Katagi *et al.* (1991)
Damping-off of vegetable seedlings	*Pythium* spp.	Esfahani (1991); Mishra (1997)
Damping-off of tobacco	*P. aphanidermatum*	Wajid *et al.* (1995)
Damping-off of cereal seedling	*P. graminicola*	Minuto *et al.* (1995)
Damping-off and soft rot of carrot	*Sclerotium* spp.	Cartia *et al.* (1987); Cartia (1989)
Damping-off, wilt and soft rot Lettuce	*S. minor*	Poter and Merriman (1983, 1985),; Vannacci *et al.* (1988)
Pink root of onion	*Pyrenochaeta terrestris*	Katan *et al.* (1980)
Wilt of pepper	*F. solani*	Moesm and Ben-Aicha (1990);
Wilt of bean	*F. oxysporum.* f. sp. *phaseoli*	Mohmed (1990)
Wilt of tomato	*F. oxysporum.* f. sp. *lycopersicae/ V. dahliae*	Raj and Kapoor (1993) Bourbos and Soundridakis (1996)
Wilt of chickpea	*V. ciceri*	Chauhan *et al.* (1988)
Wilt of muskmelon	*V. melonis*	Katan *et al.* (1988)
Wilt of fruit trees	*V. pini, V. dahliae*	McCain *et al.* (1986); Stapleton *et al.* (1993)
Wilt of watermelon	*V. niveum*	Greenbeger *et al.* (1987); Ki and Kin (1985); Martyn and Hertz (1986); Gonzalez *et al.* (1993)
Wilt of pigeonpea	*F. udum*	Singh *et al.* (1993)
Wilt of guava	*R. solani*	Dwivedi (1993)
Wilt of cotton	*F. oxysporum.* f. *sp. vasinfectum*	Katan *et al.* (1983); Ben-Yephet *et al.* (1987); Tjamos and Paplomatas (1986)
Root rot of avocado	*Phytophthora cinnamomi*	Pinkas *et al.* (1984); Barbercheck Von-Brombsen, 1986
White root rot of avocado	*Dematophora necatrix*	Lopez-Herrera *et al.* (1997)

Table 2 : **Selected examples of control of pathogenic fungi by soil solarization**

Pathogen	Control achieved (%)	Reference(s)
Botrytis cinerea	100	Lopez-Herrera *et al.* (1994)
Cortium rolfsii	62/95.4/100	Gamliel and Stapleton (1993); Ristaino *et al.* (1991); Bicici *et al.* (1994); Deshpande and Tiwari (1991)
Colletotrichum coccodes *Pythium debaryanum* *Pyrenochaeta lycopersici* *Rhizoctonia lycopesici* , *Fusarium f.* sp. *radicis lycopesis*	83.5-100	Baurbos and Skoudridakis (1991)
F. oxysporum moniliformi	64.2	Ahmed *et al.* (1996)
F. oxysporum. f. sp. carthemi	100	Sastry and Chattopadhyay (1999)
F. oxysporum f. sp. cumini	60.8	Lodha *et al.* (1991)
F. oxysporum f. sp. leipisi	36.1	Osman *et al.* (1987)
F. oxysporum f. sp. ciceris	80.8	Rao and Krishnappa (1995)
F. oxysporum f. sp. lycopersici	54-100	Katan *et al.* (1979); Ki and Kim (1985); El-Shami *et al.* (1990)
F. oxysporum. f. sp. vasinfectum	58-95	Ben-Yephet *et al.* (1987)
Fusarium spp.	74-94	Skoglund *et al.* (1986); Sivan and Chet (1993)
Pythium ultimum	95	Gamliel and Stapcetor (1993)
P. aphamidermatum	100	Mansori and Jaliani (1996)
P. solani	61-100	Al-Samarria (1988); Fahim *et al.* (1987); Ki and Kim (1985); Tamietti and Garibaldi (1989)
V. dahliae	100	Katan *et al.* (1976)
V. dahliae	35-95	Ben-Yephet *et al.* (1986); Cartia (1989); Danis and Sorenson (1986); Shabi *et al.* (1986); Melero-Vara *et al.* (1995)
Soilborne pathogens	50-80	Gharti (1994); Esfahani (1991); Chaube and Singh (1991)
F. solani	>30	Kamra and Gaur (1998)
Soil bacteria		
Agrobacterium spp.	72	Satapleton and DeVay (1974)
Agerobacterium spp.	92-99	Raio *et al.* (1997)
Clavibacter michigenensis sub sp. *michigenensis*		Antoniou *et al.* (1995)

solarization. Population of *Talaromyces flavus*, *Aspergillus* spp. and *Penicillium* spp. increased in solarized soils **(Dwivedi and Dubey, 1987; Stapleton and DeVay, 1982; Tjamos and Paplomatas, 1988)**.

Similarly, soil bacterial populations and actinomycetes were also reported to be affected by solatization. **Stevens *et al.* (1988)** showed that density of green fluorescent pseudomonads increased in the rhizosphere of sweet potato roots after solarization. *Bacillus* spp. and fluorescent pseudomonads increased in the rhizosphere of lettuce plants in solarized soils **(Gamliel and Stapleton, 1993)**.

Populations of *Clavibacter michiganensis* sub sp. *michiganensis* were reduced drastically by solarization in plastic houses **(Antoniou *et al.*, 1995)**. Population of Agrobacteria in two naturally infested Italian nurseries decreased by 99 per cent and 92 per cent after solarization but no effect on crown gall incidence was observed **(Raio *et al.*, 1997)**. **Stapleton and DeVay (1984)** reported a reduction of 72 per cent in populations of *Agrobacterium* species after solarization.

Populations of actiomycetes reduced by 45 to 58 per cent following solarization **(Stapleton and DeVay, 1984)**, however, **Kaewruang *et al.* (1989)** observed increased populations of actinomycetes antagonistic to *F. oxysporum*, *F. solani* and *R. solani* in solarized soils as compared to non - solarized soil.

Solarization greatly reduced the populations of *Rhizobium* species **(Abdel-Rahim *et al.*, 1988; Katan, 1987)**. However, mycorhizal fungus *Glomus fasiculatus* survived solar heating to the extent that colonization of host roots was not affected **(Pullman *et al.*, 1981; Stapleton *et al.*, 1985)**.

iv. Induction of Suppressiveness

Solarized soil frequently suppressed soilborne pathogens weeds and other pests **(Greenberger *et al.*, 1984; 1987; Rubin and Benjamin, 1983; Stapleton and Garza- Lopez, 1988)**. Suppressiveness was induced especially into 10 cm soil **(Ben-Yephet et al., 1988; Lazarovits *et al.*, 1991)**. Development of disease suppressiveness in solarized soil reflected re-colonization of soil by aggressive and rhizosphere competent mycoparasites/antagonists **(DeVay, 1991)**. Suppressiveness resulted from a shift in microbial populations in favour of heat- tolerant/resistant antagonistic microflora **(Katan *et al.*, 1983)**.

Pathogen suppression in amended solarized soil was attributed to thermal killing and enhanced generation of biotoxic volatile compounds since amended soils had slightly greater temperatures than nonamended soils **(Gamliel and Stapleton, 1997; Blok *et al.*, 2000)**. Pathogen sensitivity to toxic volatiles apparently increased by an increase in soil temperature.

Gamliel and Katan (1992a) observed that solarization changed chemical nature of seed and root exudates. Chemotaxis of *P.*

putida and *P. fluorescens* was more pronounced towards exudates from seeds that were germinated in solarized soils than towards comparable exudates from seeds that were germinated in non solarized soils, which contributed to their rapid establishment in the rhizosphere and roots of plants in solarized soils **(Gamliel and Katan, 1992b)**.

Incidence of *Fusarium, S. rolfsii* and *Verticillium* were lower in solarized and subsequently inoculated soil than in non solarized inoculated soil, while population of lytic and antagonistic microorganisms were higher and chlamydospre formation was also suppressed **(Greenberger *et al.*, 1985)**. A similar phenomenon of induced suppressiveness was observed with *Fusarium* wilt of carnation **(Hardy and Sivasithamparam, 1987)** and *Phytophthora cinnamomi* **(Pinkas *et al.*, 1984)**. Suppressiveness induced by solarization is somewhat similar to the natural one but it should not be regarded as a universal phenomenon. The possibility that in certain soils conduciveness might be induced, should not be excluded **(Katan, 1981)**.

v. Long-term effect

Solarization has been proved to have long-term effect (for 2-3 years) in controlling several diseases **(Greenberger *et al.*, 1987; Katan *et al.*, 1983; 1981)** owing to its ability to induce suppressiveness in the soils. Residual effect of solarization lasted for 1-3 years following a single solarization event, on population of *V.*

dahliae **(Tjamos *et al.*, 1991; Tjamos and Paplomatas, 1987, 1988)**. The long-term effect i.e. effectiveness of solarization for two or even more than two successive crops, may be explained as a combined result of thermal inactivation of pathogenic microflora and enhanced activity of thermotolerant and thermophilic antagonistic mircoflora after solarization. **Mansour and Sultan (1991)** proved economic feasibility of solarization for onion-maize-onion crop rotation. In avocado orchards, following 6-8 weeks of solarization, *P. cinnamomi* could not be detected upto 14 months later **(Lopez-Herrera *et al.*, 1997)**. **Gamliel and Stapleton (1993)** observed that populations of *P. ultimum* and certain other fungi were suppressed in solarized plots during the two successive lettuce crops.

Levels of *Verticillium* wilt in eggplant and tomato and pink root disease in onion remained low for 160-195 days of plant growth though despite continuous re-infestation from surrounding infested non-solarized soil was allowed throughout the growing season **(Katan *et al.*, 1976; Katan *et al.*, 1980)**.

vi. Increased growth response (IGR)

The phenomenon of increased growth of plants in soils that are partially sterilized and free of known pathogen has been observed for decades **(Altman, 1970)**. Numerous similar studies, in fumigated and artificially heated soils have been reported and discussed **(Abu-Gharbich *et al.*, 1991; Bawazir *et al.*, 1995; El-Shami *et al.*, 1990; Gamliel and Katan, 1987; Hasan, 1989)**. Solarization has been observed to frequently results in improved plant growth and yield increase **(Chen *et al.*, 1991; Gamliel *et al.*, 1989; Gamliel and Katan, 1991; Stapleton and DeVay, 1982; Stapleton *et al.*, 1991)**. Reports on increased growth response and yield increase are presented in Table 3.

Increased growth response in solarized soils has been attributed to altered/increased concentrations and availability of macro and micro nutrients in soil environment as a consequence of solarization **(Chen *et al.*, 1991)**. Concentration of NO_3^- -N and NH_4^+ - N increased to various extents in solarized soils **(Ahemad *et al.*, 1996; Daelemans, A. 1989; Kaewruang *et al.*, 1989; Kumar and Yaduraju, 1992; Stapleton *et al.*, 1985)** but no constant effect on the levels of PO_4^{3-}, K^+, Fe^{2+}, Mn^{2+}, Ca^{2+}, Mg^{2+} organic carbon and pH was observed **(Kaewruang *et al.*, 1989; Stapleton *et al.*, 1985)**. **Grunzweig (1998)** further emphasized that solarization affected nutrient status of the soil and played an important role in increasing the growth response.

Complex changes in physico-chemical and properties of the soil which occur during and after solarization, were correlated to improved plant growth response in solarized soil. Amongst physical properties, soil temperature is the fundamental factor affected. Maximum temperatures at a soil depth of 10 cm were 8 degrees higher compared to non-solarized. Depending upon the soil depth, maximum temperature of solarized soil commonly ranged between

Table 3 : **Selected examples of IGR/Yield increase by soil solarization**

Crop	Pathogen/pest affected	Increase (%)	Reference(s)
Cauliflower	Soilborne plant pathogens	75-35	Esfahani (1991); Chaube and Singh (1991)
Chalk plant	Soilborne plant pathogen	17-658	Gamliel *et al.* (1993)
Cotton	*Fusarium oxysporum f. sp. vasinfectum*	40-70	Katan *et al.* (1980)
Cotton	*V. dahliae*	60	Pullman *et al.* (1987)
Eggplant	*V. dahliae*	215	Katan *et al.* (1976)
Lupin	*Pythium spp.*	85	Osman *et al.* (1987)
Onion	*Pythium spp.*	47.5	Bawazir *et al.* (1980)
	Pysenochaeta spp.	60-125/29	Katan *et al.* (1980); Rabinowitch *et al.* (1981)
Potato	*V. dahliae and Pratylenches*	35	Grinstein *et al.* (1979 a, b)
Seed cotton	*V. dahliae*	11.3-130.9	Melero-Vara *et al.* (1995)
Sunflower	*V. dahliae*	113	Pullman (1979)
Tomato	*Pyrenchaeta lycopersici*	30-300	Tjamos and Faridis (1980); Tamietti and Garibaldi (1981); Feume and Tarisi (1995)
Tomato	*P. lycopersici*	26	Moura *et al.* (1987)
	Soilborne plant pathogen	91	Streck *et al.* (1995)
	V. dahliae	112	Bourbos and Skoundridakis (1996)
	Weeds	65-383	Abu-Irmaileh (1991)
Wheat	*Gaumanomyces graminis*	19	Cook *et al.* (1987)
Tomato Cabbage Lettuce	Weeds and *M. incognita*	48-552	Tacconi and Santi (1994)
Potato Cauliflower Cucumber, onion	*Sclerotinia sclerotiorum and R. solani*	10-80	Abu-Gharbieh *et al.* (1994); Adetunji (1994)

42^{0}C to 55^{0}C at the 5 cm depth and from 32^{0} to 36^{0}C at the depth of 45 cm **(Cenis, 1987; Horiuchi, 1984)**. Radiation fluxes, soil flux, sensible heat fluxes, evaporation and condensation are other properties affected by solarization **(Mahrer *et al.*, 1984)**.

Heating efficacy of solarization is dependent on several factors such as intensity of solar radiation, air temperature, thickness and transparency of polyethylene film to solar radiation and terrestrial radiations **(DeVay, 1991)**. Soil colour is also an important factor. **Mahrer *et al.* (1984)** reported that effectivness was affected by size of mulch (thickness), nature of mulch (whether aged or not), and soil piercing prior mulching. **Alkayssi and Alkaraghouli (1991)** evaluated the photometirc properties viz., absorbance, transmittance and reflectance in the light of different radiation-spectrum and showed that these properties changed with change in colour of polyethylene mulch. Transmittance to solar radiation was highest in transparent and red mulch but absorbance of red mulch was greater than that of transparent one. Increase in soil temperature was observed higher under glass house condition or under double layers of PE film compared with soil under single layer of film in the field **(Cenis, 1987; Horiuchi, 1984)**. **Avissar *et al.* (1986b)** found that used PE heats even more efficiently than new one and attributed the fact to change in photometric properties of the mulch with againg **(Avissar *et al.*, 1986a, b)**.

Stapleton *et al.* (1985) reported increase in EC after solarization on some soils but no consistent effect on pH of the soil was observed. **Kaewruang *et al.* (1989)** and **Kumar and Yaduraju (1992)** also observed no change in pH after solarization. However, **Kumar and Yaduraju (1992)** and **Ahmad *et al.* (1996)** observed reduction in electrical conductivity. According to **Chen *et al.* (1991)** effects of solarization on physical properties are limited. Integration of solarization with rabbing with bajra husk (@ 7kg/m^2) and green manuring, significantly increased soil porosity, WHC, organic matter, total N, available N, P and K over control. EC in solarized plots rabbed with bajra husk, increased significantly **(Patel and Patel, 1997)**. **El-Shami (1990)** observed no effect on soil texture and N content but increased in Mn, Mg and Cu contents and decrease in Fe, Zn and P contents after solarization.

vii. Weed and nematode control

Besides controlling soilborne plant pathogens, solarization frequently results in an effective control of weeds lasting, in some cases, for the whole year or even longer and nematodes. **(Ahmad *et al.*,1996; Esfahani,1991; Horowitz and Regev,1980; Katan *et al.*, 1980; Rubin and Benzamin,1981)**. Selected reports on weed and nematode control by solarization are listed in Table 4 and 5. Variable and exceptional control is likely to occur with weeds than plant disease, since a great diversity exists in weed populations occuring naturally in the fields **(Katan, 1981)**. Possible mechanisms of weed

Table 4 : **Selected reports on weed control by solarization**

Weeds species	**Remark(s)**	**References(s)**
Amaranthus, Anagallis, Avena, Capsella, Chenopodium, Convovulus, Cynodon, Eleucine, Fumaria, Lactuca, Lamium, Mercurialis, Molucella, Montia, Notobasis, Phalaris, Poa, Portulaca, Solanum, Sorghum, Xanthium		Bell (1984); Katan *et al.* (1980); Satour *et al.* (1991)
Amaranthus, Digitaria, Datura, Echinocola, Portulaca	Integration with dazomet application	Tacconi and Santi (1994)
Onobanche spp.		Horowitz (1980), Jackson *et al.* (1980); Satour *et al.* (1991); Lodha *et al.* (1991); Hejara *et al.* (1979)
Emperata cylendrica		Daelemans (1989)
Chenopodium, Eupuorbia, Canabis sativa, Melilous alba, Parthenium, Anagallis, Circium spp, Cynodon spp.	Except *Cyperus rotundus* all the prevailing weeds were controlled	Esfahani (1991); Mishra (1997)
Anthemis palestima and *Phalaris*	41-100% reduction in weed population	Abu-Irmaileh (1991)
C. rotundus	In combination with glyphosate @ 0.72 kg/ha	Gonzalez *et al.* (1992)
Trianthema spp., Euphorbia spp., Panicum spp., C. dectylon, Tribulus spp. and C. rotundus (paratially controlled)	Solarization alone or in combination with organic amendments was effective	Kamra and Gaur (1998)

Table 5 : **Selected reports on control of nematodes soil solarization**

Nematode species	Common name	Reference(s)
Criconemella xenoplax	Ring nematodes	Stapleton and DeVay (1993)
Ditylenchus dipsaci	Bulb and Stem nematode	Siti *et al.* (1982); Greco (1985)
Globodera rostochinensis	Cyst nematode	LaMondia and Brodie (1984); Stevens *et al.* (1986)
Helicotylenchus spp.	Spiral nematode	Stapleton and DeVay (1983); Rao *et al.* (1996)
Heterodera trifolli	Cyst nematode	Hader *et al.* (1983); Stapleton and DeVay (1983)
H. sacchari	Cyst nematodes	Coyne and Plowright (1998)
Hoplolaimus indicus		Kamra and Gaur (1998)
Meloidogyne spp.	Root-knot nematodes	McSorley and Parrado (1986); Gaur and Raymundo *et al.* (1988)
M. incognita	Root-knot nematode	Tacconi and Santi (1994); Ravindra *et al.* (1997)
M. hapla	Root-knot nematode	Stapleton and DeVay (1983); Cenis (1984, 1986)
M. javanica	Root-knot nematode	Porter and Merriman (1983); Cenis (1984, 1986); Patel and Makwana (1995)
Pratylenchus	Root lesion nematode	Stapleton and DeVay (1983); Rao *et al.* (1996)
Rotylenchus	Reniform nematodes	Stepleton and DeVay (1983); Abdel-Rahim *et al.* (1989)
Xiphinema	Daggar nematodes	Robinson (1986); Stapleton and DeVay (1983)
Tylenchulus semipenetrans	Citrus nematode	Rao *et al.* (1996)
Tylenchorhynchus vulgaris	-	Kamra and Gaur (1998)

control are (I) direct thermal/hydrothermal killing of weed seeds, (ii) indirect microbial parasitisation of weed seeds weakened by sublethal heating.

iii. Killing of seeds stimulated to germinate in moistened mulched soil after breakdown of dormancy as a consequence of intermittent heating and cooling cycles during solarization and (iv) killing of germinating seeds by the biotoxic volatiles produced in solarized soil environment **(Horowitz, 1980; Rubin and Benzamin, 1981)**.

In general, most of the annual and many perennial weeds have been effectively controlled with solarization (Table 4). But certain weed species like *Melilotus* spp. remained unaffected and purple nutsedge (*Cyperus rotundus* L.) was partially controlled **(Rubin and Benjamin, 1981)**. Response to soilarization expressed by the length of time required for obtaining an effective control varied for different weed species **(Horowitz *et al.*, 1983)**, and other parameters affecting heating **(Standifer *et al.*, 1984)**.

Affectivity of solarization against nematodes (plant parasitic) was first demonstrated by **Katan *et al.* (1976, 1987)** and later on was proved by various workers **(Barbercheck *et al.*, 1986; Greco *et al.*, 1985; LaMondia and Brodie, 1984; Stapleton and DeVay, 1983)**.

4. Soil solarization in IPM

An IPM system entails simultaneous or sequential use of several methods of controlling diseases and pests. In a sub-tropical country like India, control of soilborne diseases by solarization approach is of particular interest as a component of IPM. Combining solarization with host specific biocontrol agents may exert a strong lethal effect on pathogen(s) population. The integration of biocontrol agent with solarization is most legitimate when pest population is quite high. For example, solarization can impose "heat-stress" on pathogen propagules resulting in loss of viability. The reduced inoculum can further be killed by BCA's. Thus, making the integrated method of disease control effective.

Control of soilborne diseases by soil solarization method has been inadequately studied as a component of IPM system. In fact, this technique embodies all the criteria identified for IPM. Solarization affects soils physico-chemical and microbial properties of soil and brings about reduction in diseases, pathogens, weeds, nematodes, arthropods etc.

This intrinsic property can further be improved and long-term management can be ensured by use of solarization combined with (a) cultural control, (b) pesticides, (c) resistant cultivars and (d) biocontrol agents. The status of knowledge pertaining to integration of solarization for the management of crop pests is summarized in Table 6.

Table 6 : **Selected reports on integration of soil solarization with other methods of disease control**

Parasites/method(s) integrated with solarization	Disease/pathogen/pest controlled	Mechanism (s) involved in control	Reference(s)
Cultural methods (organic/chemical amendments)			
Amendment with dried cabbage	*F. oxysporum f. sp. conglutinans* *P. ultimum* *S. rolfsii, M. incognita*	Production of biotoxic volatile compounds. Thermal inactivation	Ramirez-Villapudua and Munnecke (1987, 1988); Stapleton and Duncan (1988)
Cruciferous residues + irrigation	*Macrophomina phaseolina* and soilborne diseases	Increased (lethal) soil temperature + toxic volatile	Lodha *et al.* (1997) and Gamliel and Stapletom (1997)
Chicken compost ammonium phosphate	*P. ultimum, M. incognita, V. dahliae*		Gamliel and Stapleton (1993 a, 1995)
Cabbage residue and crop rotation	Gummy stem blight of watermelon		Keinath (1996)
Fresh broccoli or grass amendments (@ 3.4-4.0 kg fresh wt/m^2)	*F.oxysporum. f. sp. asparagi, R. solani and V. dahliae*	Production of fungitoxic degradation products under the PE cover	Blok *et al.* (2000)
Broccoli amendment	Verticillium wilt of cauliflower	Production of biological fermentation products	Subbarao *et al.* (1999)
Cruciferous green manure	Aphanomyes root rot of pea	Inactivation of propagules by toxic, volatile products produced during decomposition of amended material	Muelchel *et al.* (1990)
Shreded wheat straw + Calcium cyanamide +	*F. solani f. sp. cucurbitae*		Bourbos *et al.* (1997)
Calotropis leaves applied @ 80t/ha	*Pratylenchus reniformis, Helicotylenchus indicus*		Rao *et al.* (1996)
Inoculations of *Glomus fasciculatum* (@ 12 g/hill) + seed treatment with carbofuran	*F. oxysporum. f. sp. ciceri* and *M. incognita*		Rao and Krishanappa (1995)
Glyphosate (@ 0.72 kg/ha)	*Cyperus rotundus*		Gonzalez *et al.* (1992)

2. Resistant cultivars			
Tolerant cotton cultivars	Verticillium wilt of cotton		Melero-Vara *et al.* (1995)
Resistant varieties	Rhizomania of sugarbeet		Lewellen and Wrona (1997)
3. Biocontrol			
Vermicompost (before solarization), *T. harzianum* and *B. subtilis* (after solarization)	*S. cepivorum*	Propagule (slerotia) viability affected by increased temperature and then colonization by antagonists	Pereira *et al.* (1996)
T. harzianum	*R. solani, V. dahliae* and *S. rolfsii*	Antagonism	Chet *et al.* (1982); Chet (1987)
Talaromyces flavus	*Verticillium* wilt of egg pant	Heat inactivation and antagonism	Fravel (1995)
G. virnes	*Corticium rolfisii*	Sclerotial antagonism	Ristanio *et al.* (1996)
D. Chemical disinfestants/fumigants/ Seed-treatments			
Metham-sodium (Vapam)	*V. dahlia, F. oxysporum* f. sp. *vasinfectum*	Increased effectivity of chemical at higher temperature achieved under the PE covering	Ben-Yephet *et al.* (1988)
MBC + lowered dose of methyl bromide	*Phytophthora crown* blight of pepper		Chellemi *et al.* (1994); Yucel (1995)
Metham-sodium	*Phytopththora cactorum*	Yield increase was equivalent to that achieved with chloropicrin fumigation	Hartz *et al.* (1993)
Metham-sodium or 1, 3-dichloropropene + chloropicrin or methyl Bromide + Chloropicrin		*Corticium rolfsii, Paratrichodorus minor, Helicotylenchus spp.*	Chellemi *et al.* (1997)

5. Practical application

Soil solarization has emerged as an promising alternative to chemical soil disinfestation for the eco-friendly management of soilborne pathogens and pests, in last few decades. With extensive research carried out, this technology has now been established in warm geographical areas for both, agricultural and horticultural applications for effective soil disinfestation and is being applied practically in several countries worldwide. Some examples are cited below :

- It is widely used by the growers for organic markets in the Central and Southern Valleys of California, USA and Israel **(Stapleton, 1997)**.
- It is being adapted in Florida, Georgia and USA in combination with lowered dosage of different chemical disinfectants for integrated management of soilborne pests of tomato **(Chellemi *et al.*, 1997, 1994)**.
- In California, solarization has been used for strawberry production as an effective soil disinfestation technique alone or in combination with sublethal doses of chemicals **(Hartz *et al.*, 1993)**.
- The technique has been applied practically in Japan, Greece, Italy, Spain and France **(Garibaldi and Gullino, 1991)**. Where climates are marginally suitable for solarization.

- *Fusarium* wilt of strawberry has been controlled under greenhouses in Japan. Over 2000 ha of strawberry, eggplant, tomato and cucumber soils have been disinfested by this technique **(Horiuchi, 1990)**.
- In Greece effective reduction in soil infestation by *V. dahliae* has been brought about by solarization in several crops. In tomato crop in plastic houses, it controlled verticillium wilt and increased fruit yield upto 300 per cent **(Tjamos *et al.*, 1989)**.
- Solarization has been proved to be a safe and effective method of soil disinfestation for horticultural production on small farms **(Lopez-Herrera *et al.*, 1998; Stapleton *et al.*, 1993)**.
- Solarization has its utility in production of nursery crops, in increase in propagative material and in disinfestation of soil for research plots **(Chauhan *et al.*, 1988; Ganguli *et al.*, 1996; Patel *et al.*, 1995)**.

6. Status of Research in India

The records of our ancient civilization, fully establish the fact that solar energy was invariably used for disinfestation. It has been pointed out **(Katan, 1985)** that farmers of Deccan Plateau have long exploited a form of solar heating of soil by ploughing the soil so as to expose subsoil prior to hot summer period (April-June), when maximum daily air temperature usually exceed 40^{0}C and leaving it fallow.

Chauhan *et al.* (1988) at ICRISAT (AP) studied the effect of soil solarization on pigeonpea and chickpea (Bull No. 11). The studies were conducted in fields infested with fusarium wilt. Solarization was done by covering the soil with transparent PE sheeting (100 μm thick) for 6-8 weeks during April-May. This increased soil temperature by 6-10^{0}C in 0-20 cm soil profile. Other changes recorded were increased mineralization of soil nitrogen to nitrate forms, a decline in population of *Fusarium* spp. and plant parasitic nematodes and decreased weed infestation. When crops were grown, effective control of fusarium wilt disease in susceptible genotypes of pigeonpea and chickpea was observed along with improved plant growth response and yield. Nodulation and N-fixation were adversely affected because of decline in *Rhizobium* populations. However, plant growth and yield were not adversely affected because of the compensatory effect of increased soil nitrate. There was a considerable residual effect of solarization in the second and third seasons.

Raj *et al.* (1997) reported that transparent polyethylene mulch was effective to control damping off of different vegetables in nurseries. Nurseries of 10 different crops raised in solarized beds, recorded 18.3 to 40.0 per cent higher seed germination, lower incidence of post-emergence damping off and had better seedling vigour. According to **Sudha *et al.* (1998)** a number of weeds were reduced significantly by solarization (*C. rotundus, Cynodon dactylon,* *Commelina benghalensis, Euphorbia hirta, Leucas aspera, Tridox procumbens* and *Bidens pilosa*). Soil population of *F. oxysporum* f. sp. *cartheni* reduced to non-detectable levels and soil actinomycetes and fluorescent pseudomonads increased significantly following solarization for 6 weeks **(Sastry and Chattopadhyay, 1999)**. Solarization increased the availability of soil nutrients but physico-chemical properties remained unchanged **(Rao and Krishnappa, 195)**. Significant increase in concentration of NO_3-N and $NH4_4$- N and available 'P' were observed by **Arora (1998)**, however, K and EC increased only marginally and there was no change in organic carbon and pH.

Rao and Krishnappa (1996) showed that application of carbosulfan or addition of *G. fasciculatum* reduced fungal population by 82 per cent in rhizosphere of chickpea infested with *M. incognita*. However, only 59 per cent reduction was observed by solarization alone. **Pandey *et al.* (1996)** reported that integration with neem oilseed meal reduced *Fusarim oxyspuroum* s. sp. *ciciri* population by 49.2 per cent and caused complete elimination of chickpea wilt and there was a positive correlation between reduction in pathogen population and disease incidence in oilseed meal amended or fungicide treated solarized soils. **Sharma *et al.* (1996)** integrated solarization with carbofuran and neem cake application for the management of nematodes in tomato. **Patel and Makwana (1992)** suggested integration with rabbing of soil with bajra husk (@ 7

kg/m^2) and carbofuran (@ 1.5 kg a.i./ha) for the management of *M. incognita, M. jovanica, Tylenchorhynchus vulagris* and *Pratylenchus reniformis.* Population of *Hoplolaimus inidicus* and *T. vulgaris* in nursery beds decreased by 72.6 and 88.5 per cent, respectively as compared to a respective decrease of 9.5 per cent and 33.5 per cent in control plots **(Kamra and Gaur, 1998)**.

7. Research Status at Pantnagar

In last 10 years, soil solarization has been an important area of research for the management of soilborne pests particularly in horticultural crops raised in nurseries. **Esfahani (1991)** conducted exhaustive field trials and recorded significant reduction in damping off incidence of cabbage, cauliflower, brinjal, tomato and chillies. He also observed significant increase in plant health and reduction in populations of fungal pathogens viz., *Pythium* spp., *Fusarium spp., R. solani* and *S. rolfsii.* Population of total fungi, bacteria, actinomycetes, *Trichoderma* and *B. subtilis* decreased drastically after solarization but recovered fully within 4-5 months after solarization. Population of antagonists dominated general microbial counts. **Singh (1990)** studied the impact of solarization on Karnal bunt of wheat and observed significant reduction in disease incidence and survivability of the pathogen. Increased growth response was also observed.

Malik (1999) studied the effect of solarization on survival of *Alternaria* spp. causing Alternaria blight of crucifers. It was observed that solarization using thin transparent polyethylene sheeting reduced survival of pathogen significantly. **Mishra (1997)** observed significant decrease in the incidence of damping-off of tomato, cauliflower and onion raised in nurseries and except *C. rotundus* all the prevailing weed species were controlled. Integration of solarization with seed treatment with fungicides like Thiram etc. and biocontrol agents further improved control of damping-off of seedling **(Mishra, 1999)**. **Gharti (1994)** studied the effect of solarization integrated with chemical and biological seed treatment on damping-off incidence in true potato seed nurseries and on plant growth. He observed reduction of 86.5 per cent in damping-off incidence over control (57.1 % reduction) by integration of solarization and seed-treatment with Bavaistin (@ 2 g/kg seed) followed by 75.41 per cent control by integration of solarization and seed-treatment with *Trichoderma*.

8. Future projections

Effectiveness of the technique has been proved and is well established now. Nevertheless, there are certain question raised against its effectively in marginally suitable climatic condition, regarding the disposal problem and quality of polyethylene mulches. For the large scale adaptation and propagation of this non-chemical and eco-friendly method of disease management, development and research must be concentrated on following lines.

1. Developing more efficient than existing plastic mulches for better energy trapping and thus making the technique equally economic and adaptable in region with marginally suitable climates **(Katan, 1987; Brown *et al.*, 1991)** and reducing the sole dependence on climate for proper soil heating.
2. Considering the problems of disposal of used film/plastic mulch, the investigation must be focused on the possibility of exploiting bio-photodegradable plastic mulching material, as efforts have already been started towards the possibility of using self-destructive disposal technique of solarization **(Ennis, 1987; Hanras, 1979)**.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

1. Location and climate

The study on the effects of soil solarization and its integration with fungicides and BCA's on physico-chemical and microbiological properties of soil and seedling diseases of some horticultural corps was carried out at V.R.C., Pattharchatta, Floriculture Block and in glasshouse of G.B. Pant University of Agriculture and Technology, Pantnagar, U.P., India, located at 29^{0}N and 73.3^{0}E and an altitude of 243.84m above the mean sea level. Agroclimatically it falls under humid sub-tropical zone at South Shivalik Ranges of the Himalayas with on average annual rainfall of 1400-1500 mm. The inherent physico-chemical properties of the soil of experimental sites are given below :

Properties	Locations	
	VRC, Patharchatta	Floriculture Block
Soil texture	Sandy loam	Clay loam
PH	7.1	6.8
Organic carbon (%)	0.62%	1.175%
Available Phosphorus	54.25 kg ha^{-1}	71.8 kg ha^{-1}
Available Potassium	156.0 kg/ha	196.20 kg/ha
Iron	30.37 kg/ha	50.18 kg/ha
Copper	16.11 kg/ha	17.65 kg/ha
Manganese	24.62 kg/ha	13.66 kg/ha

2. Experimental Design and Solarization Technique

Field trials were conducted in plots (raised beds), heavily infested with pathogens like *Pythium* sp., *Fusarium* sp. *R. solani, S. rolfsii* etc., as the seedlings of different vegetables and flowers have been raised uninterruptedly for the last several years. Entire details (design, replications, treatments) of the field experiments are given in Fig. 3 and 4.

Time given for solarization was 30 days. Before mulching the soil, irrigation was given to ensure enough moisture during solarization. Air tight condition and prevention of any leakage of heated air, gases, moisture etc. from the mulched area was ensured. The crops and varieties of the nursery crops raised were cauliflower (Pant Gobhi-4), cabbage (Pride of India), tomato (Pant T-3) and onion (N-53/Nashik Red). After covering the plots with polyethylene sheeting, the edges of polyethylene were tightly buried in soil (Fig. 5). Precautions were also taken to avoid damage to the polyethylene mulch. The damage if any, was repaired immediately.

3. Determination of Soil Moisture

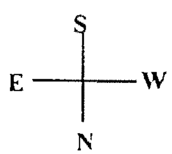
Moisture status of the soil was determined before and after solarization by volumetric method. Soil samples drawn from experimental plots, were weighed and dried at 110^{0}C in oven till constant weight was recorded. Thereafter, percent moisture content was calculated using the following formula :

$$\text{Per cent Soil moisture} = \frac{(\text{Wet soil wt.}) - (\text{oven dried soil wt.})}{\text{Oven dried soil wt.}} \times 100$$

4. Environmental Factors

Environmental parameters like temperature, RH, rainfall and duration of sunshine were recorded daily during the period of

T3	T2	T1	T6	T5	T4 200 B	T2	T1	T6	T5	T4	T3 Check	T1	T6	T5	T4	T3	T2 50 R
T4	T3	T2	T1	T6	T5 200 R	T3	T2	T1	T6	T5	T4 400 R	T2	T1	T6	T5	T4	T3 50 B
T5	T4	T3	T2	T1	T6 200 W	T4	T3	T2	T1	T6	T5 400 W	T3	T2	T1	T6	T5	T4 50 W
T6	T5	T4	T3	T2	T1 50 B	T5	T4	T3	T2	T1	T6 400 B	T4	T3	T2	T1	T6	T5 200 R
T1	T6	T5	T4	T3	T2 50 R	T6	T5	T4	T3	T2	T1 200 W	T5	T4	T3	T2	T1	T6 200B
T2	T1	T6	T5	T4	T3 50 W	T1	T6	T5	T4	T3	T2 200 B	T6	T5	T4	T3	T2	T1 200 W
T3	T2	T1	T6	T5	T4 Check	T2	T1	T6	T5	T4	T3 200 R	T6	T4	T1	T2	T3	T5 400 R
T4	T3	T2	T1	T6	T5 400 B	T3	T2	T1	T6	T5	T4 50 W	T5	T3	T2	T1	T6	T4 400 B
T5	T4	T3	T2	T1	T6 400 R	T4	T3	T2	T1	T5	T6 50 B	T1	T2	T3	T4	T5	T6 400 W
T6	T5	T4	T3	T2	T1 400 W	T6	T5	T4	T3	T2	T1 50 R	T6	T5	T4	T3	T2	T1 Check
R3						R2						R1					



Plot Size 1 m x 1 m

(a) Colour : W - White
R-Red
B- Black

(b) Thickness :
50 gauge
200 gauge
400 gauge

Seed Treatment :
T1 Thiram
T2 Vitavax
T3 Apron
T4 *Trichoderma*
T5 *Pseudomonas*
T5 Check

Fig.3 Lay out of the Experiment at VRC (Pattharchatta)

R1 (plot: 1m × 0.7m)

50 R	T1	T2	T3	T4	T5
50 W	T5	T4	T3	T2	T1
50 B	T4	T1	T2	T3	T5
200 R	T5	T3	T2	T1	T4
200 W	T1	T2	T3	T4	T5
200 B	T5	T1	T2	T3	T4
400 R	T4	T2	T3	T1	T5
400 W	T4	T5	T1	T2	T3
400 B	T3	T4	T5	T1	T2
Check	T2	T3	T4	T5	T1

R3 (1 m)

T1	T2	T3	T4	T5	Check
T5	T1	T2	T3	T4	400 B
T4	T5	T3	T2	T1	400 R
T5	T4	T2	T1	T3	400 W
T4	T3	T1	T2	T5	200 R
T5	T4	T3	T2	T1	200 W
T4	T3	T2	T1	T5	200 B
T5	T2	T1	T3	T4	50 W
T1	T3	T2	T4	T5	50 B
T2	T5	T4	T3	T1	50 R.

50 R	T1	T2	T3	T4	T5
50 W	T5	T1	T2	T3	T4
50 B	T3	T5	T1	T4	T2
200 R	T2	T4	T3	T1	T5
200 W	T4	T2	T5	T3	T1
200 B	T5	T4	T2	T1	T3
400 R	T2	T3	T1	T4	T5
400 W	T3	T1	T5	T4	T2
400 B	T1	T2	T4	T3	T5
Check	T2	T1	T3	T5	T4

R2

Polythene Sheet :

(a) Colour : W - White
R - Red
B - Black

(b) Thickness :
50 gauge
200 gauge
400 gauge

Seed Treatment

T2 Thiram
T2 Vitavax
T3 *Trichoderma*
T4 *Pseudomonas*
T5 Check

E
N S
W

Fig.4 Lay out of the Experiment at Floriculture Block

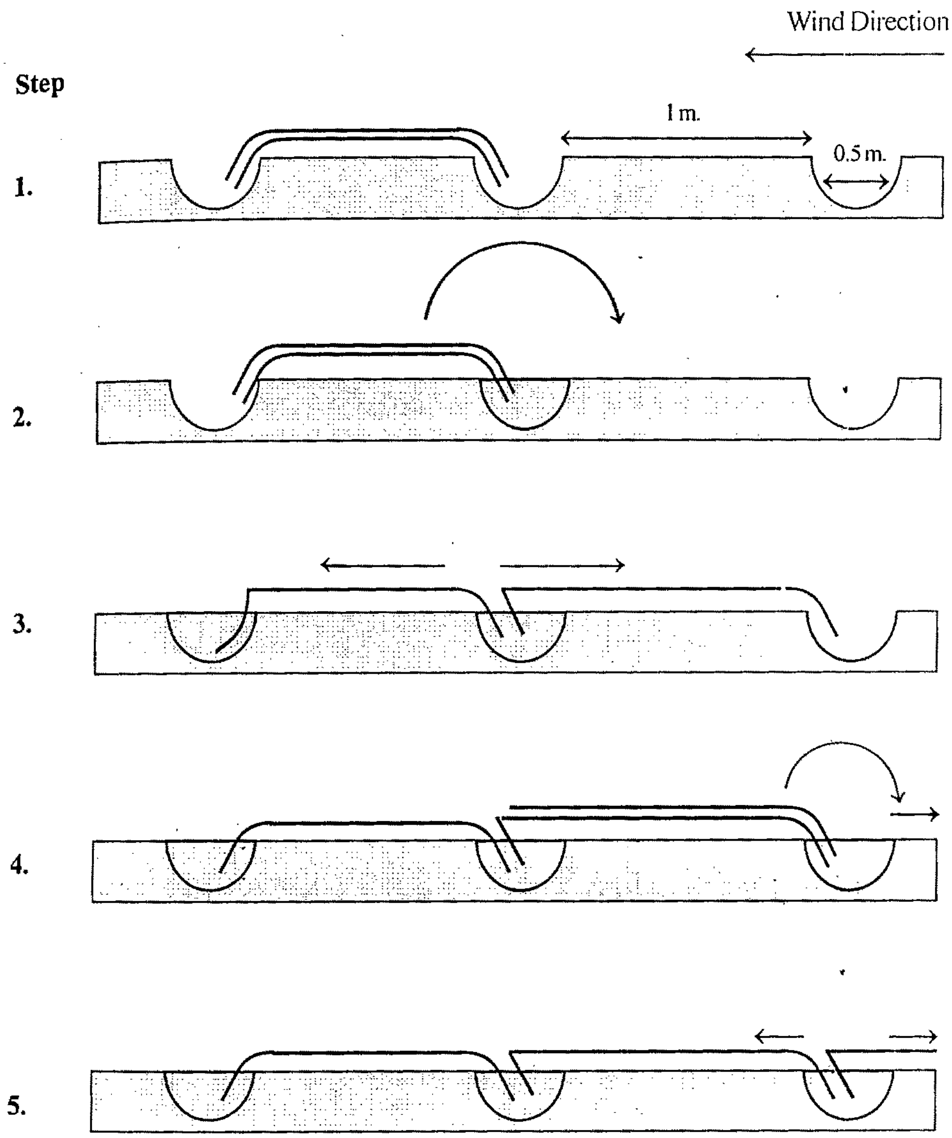
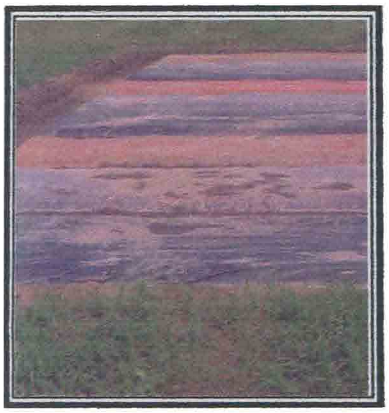


Fig. 5 Method of placing polyethene sheet on nursery bed for soil-solarization

Plate 2. **A-B : Polythene mulching for solarization**

C : Solarization kill weeds - solarized (L) non-solarized (R)



A B

C

solarization from the university Agrometeorological observatory. The data, so obtained are presented in Fig. 6 and 7.

5. Determination of Soil Properties

Solarization is likely to affect physico-chemical and biological properties of the soil. Pertinent work/studies have been reviewed.

5.1. Soil Temperature

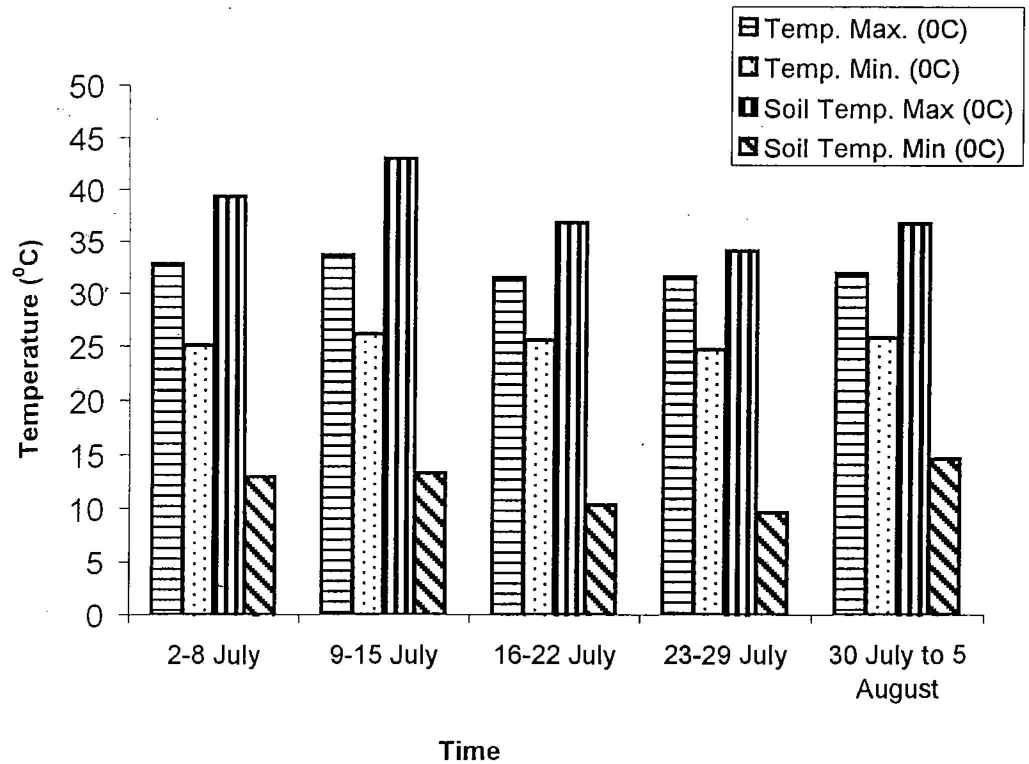
Daily increase and decrease in soil temperature during the period of solarization was recorded by placing soil-thermometers beneath the polyethylene film at a depth upto 10 cm. The temperatures were recorded twice daily at 7.00 A.M. and at 2.30 P.M. Finally weekly average, minimum and maximum temperatures were computed.

5.2. Soil pH

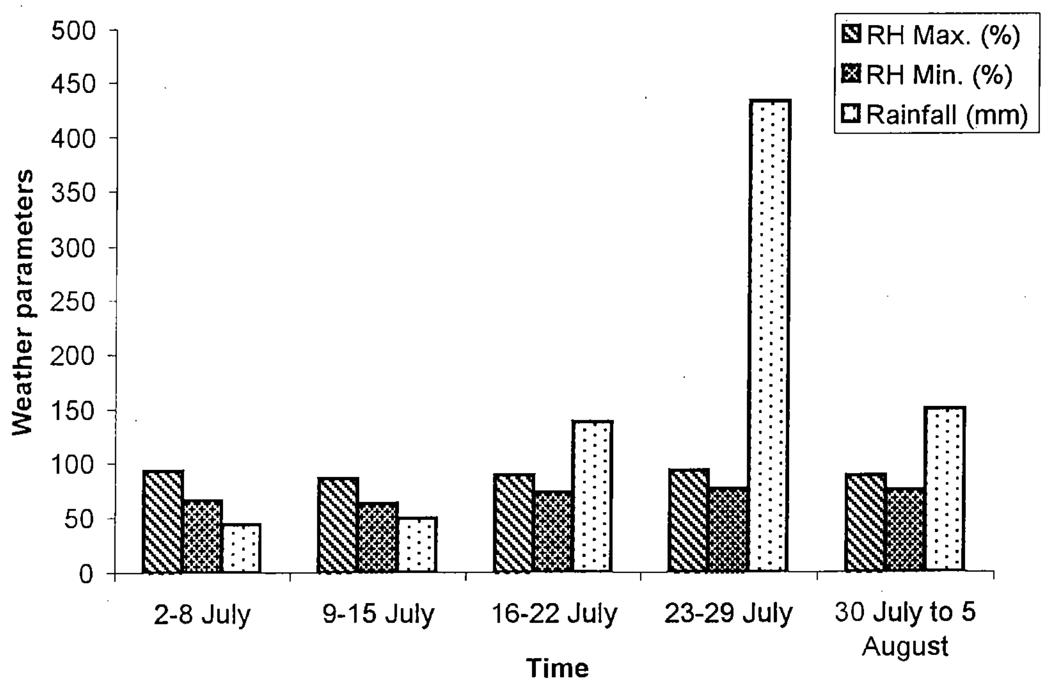
Soil pH was determined in 1 : 2 soil water suspension as described by **Jackson (1956)**. Ten gram soil was taken in a glass beaker of 50 ml capacity and 20 ml distilled water was added to it. The suspension was continuously stirred for 10 minutes and later intermittently. Observations were recorded by dipping the electrode of the digital pH meter into the soil suspension.

5.3. Electrical Conductivity (EC)

After measuring soil pH the same suspensions were used to record EC. The suspensions were allowed to stand for 24 hrs. before taking EC readings.

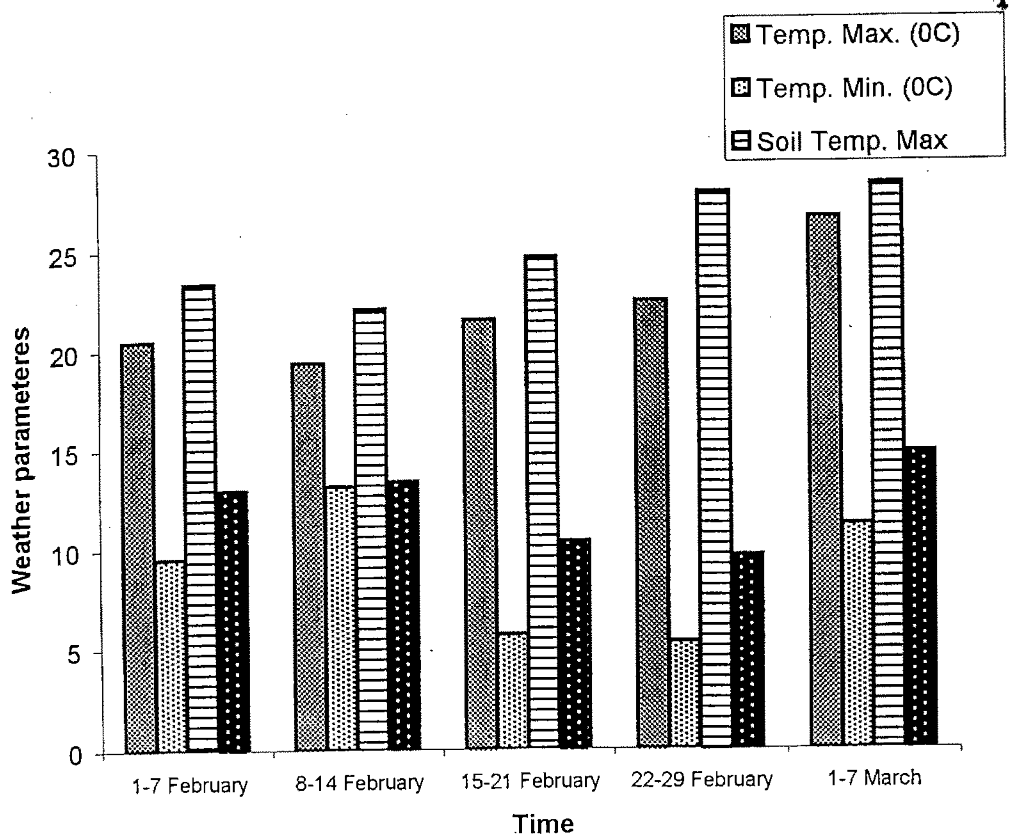


A. Atmospheric and soil temperature (^{0}C)

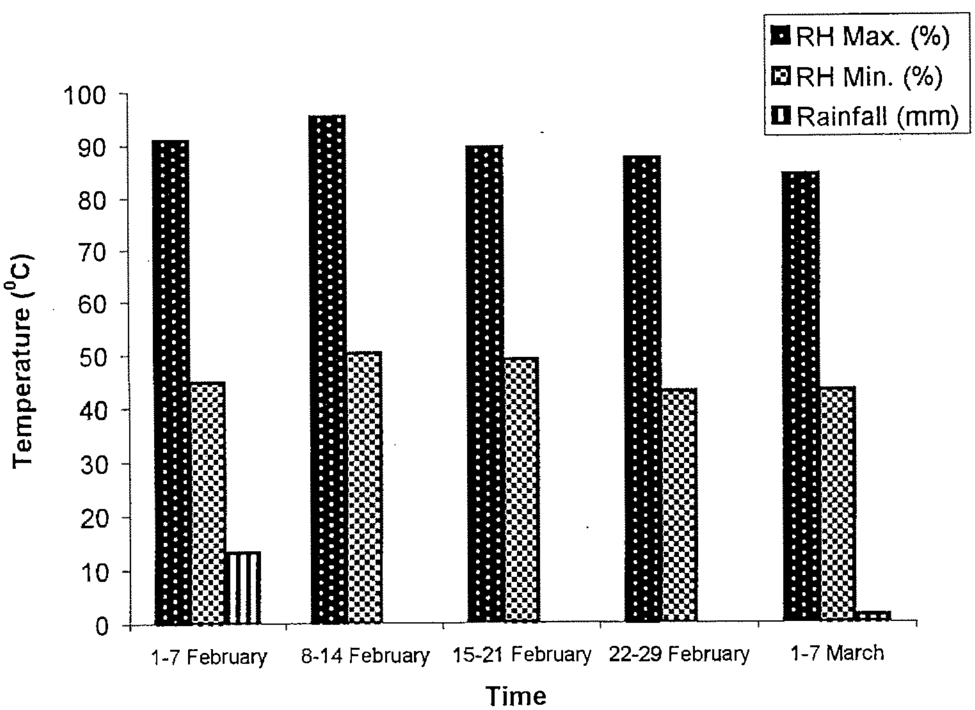


B. Relative humidity (%) and rainfall (mm)

Fig. 6 : Atmospheric weather parameters during the field experimentation (2 July to 5 August, 1999)



A. Atmospheric and soil temperature (^{0}C)



B. Relative humdity and rainfall

Fig. 7: Atmospheric weather parameters during the pot experimentation (1 February to 7 March, 2000)

5.4. Organic Carbon

The amount of organic carbon (nitrogen status) of soil samples was determined by the modified method of **Walkley and Black (1934)** as described by **Jackson (1973)**. Oxidizable matter in a soil sample was oxidized by chromate ions ($Cr_2O_7^{2-}$) and the reaction was facilitated by the heat generated when two volumes of sulfuric acid are mixed with one volume of 1.0N potassium dichromate solution and quantity of substances oxidized was calculated from the amount of $Cr_2O_7^{2-}$ reduced using the formula given below :

$$\text{Organic carbon (per cent)} = \frac{(\text{me oxidized} - \text{me reduced}) \times 0.003}{\text{wt. of soil sample} \times 0.76} \times 100$$

Where,

me oxidized = Volume of potassium dichromate × Normality of Potassium dichromate

me reduced = Volume of ferrous ammonium sulfate × Normality of ferrous ammonium sulfate

0.003 = milliequivalent weight of carbon

0.76 = fraction of organic carbon which was oxidizable to carbon dioxide

5.5. Total Nitrogen

Total nitrogen was determined by the modified Kjeldahl method as described by **Black (1965)**. The samples were digested to convert the nitrogen into ammonium form by heating the samples with conc. H_2SO_4 in the presence of catalyst. After complete digestion, 40 per cent NaOH solution was used for distillation of NH_3. Liberated NH_3 is trapped in Boric acid (4%) solution prepared by dissolving 40 gm of H_3BO_3 (boric acid) in 1 liter of distilled water containing 5 ml of the mixed indicator. About 125 ml of 40 per cent NaOH were poured in the Kjeldahl flask placed on distillation assembly. The colour of boric acid solution changed to greenish blue. Thereafter, the boric acid was back titrated with standard acid (H_2SO_4) of known normality. The per cent nitrogen was calculated as follows :

$$\%\ N\ in\ soil = (T - B) \times N \times \frac{1.4}{s}$$

Where,

T = Sample titration, ml of standard acid

B = Blank titration, ml of standard acid

N = Normality of standard acid solution

s = Sample wt. (g)

5.6. Available Phosphorus

Available Phosphorus was determined by Olsen's method **(Olsen *et al.*, 1954)**, using $NaHCO_3$ as an extractant and ammonium molybdate and ascorbic acid were used to develop blue colour. The intensity of blue colour was recorded on "Spectronic-20" at 730 nm wave length. Intensities of blue colour for standard solutions of 0.1 ppm to 2.0 ppm phosphorus content, prepared by using the 2 ppm stock solution of dihydrogen orthophosphate

(K_2HPO_4), were recorded to plot the standard curve. Then phosphorus contents of soil samples were obtained from the standard curve. Available 'P' (kg/ha) contents were calculated as follows :

Available 'P' (kg/ha) = R × 2.24

Where,

R = µg of P in the aliquot (obtained from standard curve)

5.7. Available Potassium

Available K in soil was determined by extraction with neutral normal ammonium acetate. The extraction was carried out by shaking followed by filtration or centrifugation. The K content was estimated by using flame photometer **(Perur *et al.*, 1973)**. Standard K solutions were prepared using KCl, and were read in flame photometer to obtain standard curve by plotting the readings against different concentrations of K. Available K was calculated as follows :

Available K (Kg/ha) = R × 11.2

Where,

R = ppm of K in the extract (obtained from standard curve)

6. Disease-Incidence

To evaluate the effect of solarization on the incidence of pre, post-emergence and total damping-off, number of seeds expected or likely to germinate (X), number of seeds actually germinated after 7 days of sowing (A) and number of final seedling stand (B) in a row, were counted using telecounter. Damping-off incidences were computed by the following mathematical formulae :

$$\text{(i) Pre-emergence damping-off (\%)} = \frac{X - A}{A} \times 100$$

$$\text{(ii) Post-emergence damping-off (\%)} = \frac{X - B}{X} \times 100$$

$$\text{(iii) Total damping-off (\%)} = \frac{X - A}{A} \times 100$$

In order to identify pathogen causing mortality and also to confirm the associations of pathogens with seedling mortality, isolations were made regularly on Potato Dextrose Agar medium. The cultures, thus obtained were purified, identified and pathogenicity was confirmed.

7. Increased Growth Response

Plant growth parameters used to study IGR were plant height, fresh and dry shoot and root wt. of 30 days old seedlings. For measuring plant height, 20 plants were selected randomly from each plot and measured with the help of scale. After recording plant height, same plants samples were used to record root and shoot weight.

8. Weed Population

To study the effect of solarization on weed populations, the weeds within one square feet from each plot in solarized and non solarized beds, were uprooted, identified and individual weed populations were recorded. Weed populations per square feet were also recorded before preparation of beds.

9. Effect on soil Microbiology

Soil solarization is expected to bring about certain changes in the microbial equilibrium existing in the soil. In order to evaluate and record such changes at different stages, major groups of soil microflora including fungal pathogens and some antagonists, were estimated.

Isolations from soil to assess population dynamics, were done using dilution plate technique **(Walksman and Starkey, 1923)**. In most cases selective/semi-selective media were used. Soil dilution of 1: 10^3 was prepared from 1g air dried soil in sterilized water by employing serial dilution technique. The technique of preparing soil dilution was same for all the microorganisms, except the dilution strength varied accordingly.

One ml of desired dilution was poured in each petriplate and then 20 ml medium was poured, the plates were swirled immediately after pouring until the medium gets solidified, to get uniform distribution of soil suspension in the medium. Plates were incubated at desired temperatures and colony forming units (c.f.u.) were recorded.

9.1. Total fungi

Dextrose Rose Bengal Agar medium (**Martin, 1950**), was used to isolate total fungi. The constituents of the medium were

KH_2PO_4	1.0 g
$MgSO_4 . 7H_2O$	0.5 g
Peptone	5.0 g
Dextrose	10.0 g
Dicrysticine	1.0 g
Rose Bengal	50 ppm
Agar-Agar	20.0 g
Distilled water	1000 ml

Rose Bengal and dicrysticine were suspended in sterilized water and added to the autoclaved and cooled medium before plating. Plates were incubated at 27 ±2°C.

9.2. *Pythium* spp

Isolations were done on selective medium developed initially by **Singh and Mitchell (1977)** with certain modifications as suggested by **Peethamberan and Singh (1978)**. Plates were incubated at 27 ±2°C temperature for 4 days. Colonies, that developed, were counted. Each colony represented one colony forming unit (c.f.u.). Constituents of selective medium were :

KH_2PO_4	1.0 g
$MgSO_4 . 7H_2O$	0.5 g
Peptone	5.0 g
Dextrose	10.0 g
Dicrysticine	500 ppm
Rose Bengal	50 ppm
Benlate	20 ppm
Mycostatin	1000 ppm
Metalaxyl	500 ppm
Agar-Agar	20.0 g
Distilled water	1 liter

Antibiotics, fungicides and Rose Bengal were added after autoclaving and cooling of the medium.

9.3. *Trichoderma* spp.

To estimate populations of *Trichoderma* spp., selective medium described by **Shreshta (1992)** was used with some modifications. Soil dilution of 10^{-3} strength was used. Constituents of the medium were :

$MgSO_4 . 7H_2O$	0.2 g
K_2HPO_4	0.9 g
KCl	0.15 g
NH_4NO_3	1.0 g
Dextrose	3.0 g
Agar-Agar	20.0 g
Water to make up	1 lit.
Dicrysticine	0.05 g
Apron 35 SD	0.05 g
Captan	0.05 g
Vitavax	0.02 g
Rose Bengal	50 ppm

Antibiotic, fungicides and Rose Bengal were added after autoclaving and cooling of the medium. Plates were incubated at 30±1°C for 4 days.

9.4. Total Bacteria

Total bacteria were isolated on soil extract agar medium taking 10^{-6} dilution of soil water suspension **(Lochhead, 1950)**. Composition of medium was as follows :

K_2HPO_4	0.5 g
Soil extract	100 ml
Tap water	900 ml
Glucose	1.0 g
Agar	20 g
pH (adjusted to)	7.0

Soil extract was prepared by 1000 g of garden soil with 1000 ml of tap water in autoclave for 30 minutes at 15 lb pressure. The suspension was filtered though double layer of filter paper.

9.5. *Bacillus* spp.

To isolate *Bacillus* spp. soil dilutions of 10^{-6} strength were prepared and heated at 80^{0}C for 30 minutes prior to plating, to kill all the vegetative cells and get only spore counts. Starch nutrient agar medium **(Ramakrishnan, 1989)** was used for isolation. Composition of medium was :

NaCl	1.0 g
Peptone	5.0 g
Beef Extract	5.0 g
Starch soluble	10.0 g
Agar-Agar	15.0 g
Water to make up	1 lit
pH (adjusted to)	7.0

9.6. Fluorescent pseudomonads

To isolate fluorescent pseudomonads, specific King's B medium **(King *et al.*, 1954)** was taken. Constituents of the medium were :

Protease peptone	20 g
K_2HPO_4	2.5 g
Glycerol	15 ml
$MgSO_4.7H_2O$	6 g
Agar-Agar	15 g
Water to make up	1 lit

10. Seed-treatment

Three different fungicides and two biocontrol agents were taken for seed-treatment to supplement the positive effects of soil solarization against damping-off disease. The seeds were treated by slurry method using CMC. In case of BCA's number of propagules/spores per ml were adjusted:

Fungicides/ bioagent	**Chemical name**	**Rate of application (g/kg seed)**
Thiram	Dithiocarbamate	2.5 (0.25%)
Vitavax	Carboxin	2.0 (0.20%)
Apron 35 SD	Metalaxyl	4.0 (0.4%)
T. harzianum	Commercial formulation of 1.5×10^9 c.f.u.	4.0 (0.4%)
P. fluorescens	Commercial formulation of 1.5×10^9 c.f.u.	4.0 (0.4%)

RESULTS

4. RESULTS

4.1. Soil solarization and physico-chemical properties of the soil

Soil solarization has invariably been implicated to cause substantial and significant changes in several soil factors such as temperature, moisture and macro and micro-nutrients besides perceptible changes in biological properties of the soil. In the following pages/paragraph, such changes that were studied, are described.

4.1.1. Soil moisture

As already discussed, soil solarization is most effective under wet soil conditions. Entire experimental blocks at both the sites were pre-irrigated to saturation point. After stability of moisture content at field capacity, mulching was done. Before mulching, soil samples were drawn randomly from several locations and moisture content was estimated. After solarization for a month, moisture content of solarized and non-solarized soils were re-estimated.

Initial moisture content recorded was taken as 100 per cent for calculation point of view. Moisture contents after solarization were also estimated and per cent loss of moisture over initial moisture content was computed. It clear from the observations (Fig. 8) that loss of moisture from mulched soil was very low. In general, 10-25 per cent moisture lost from mulched soil. But from unmulched soils the loss was above 50-60 per cent.

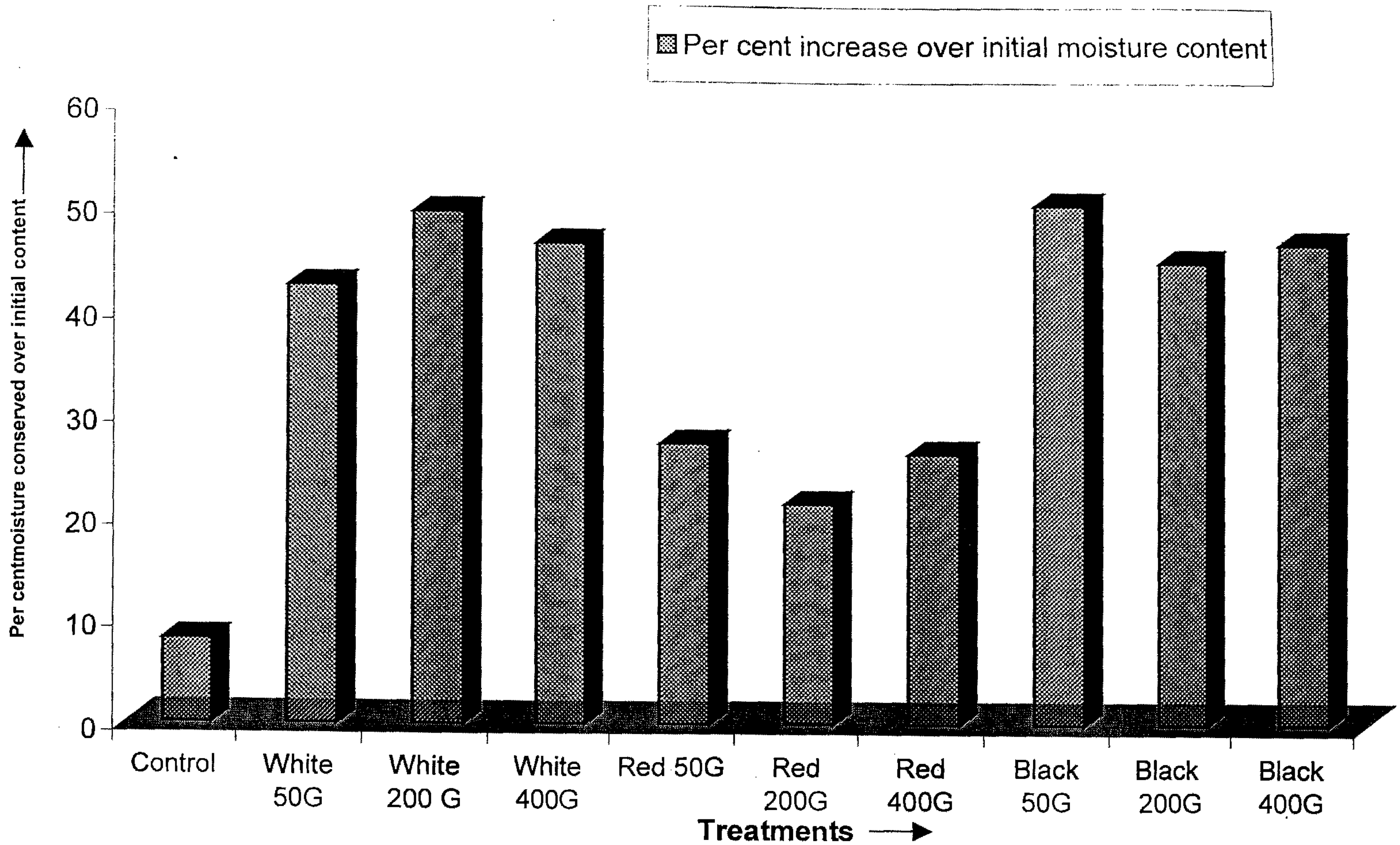


Fig. 8 : Impact of polyethylene covering on soil moisture content

4.1.2. Soil temperature

Hydrothermal heating of soil is the major principle of soil solarization. When wet soil is mulched with polyethylene film, the heat/solar radiations that penetrate the film are not allowed to be dessipated and lost. Covering of the soil with polyethylene, particularly the droplets that appear over the undersurface of the plastic sheeting, ensures conservation of trapped heat. Thus, as per changes in the daily cycles of sunshine and darkness, the temperature status of the solarized soil also changes.

The results of the changes in soil temperature during 4 weeks of solarization are shown in Fig. 9 a. It is clear that the temperature of the solarized soil, on an average, increased every week by about 10-12^{0}C as the soil temperature ranged between 50-52^{0}C in soil mulched with white or red polyethylene sheeting. The increase in soil temperature of the soil mulched with black sheeting did not increase to the extent observed with white and red sheeting. The increase was about 2-4^{0}C over to that of unmulched soil. The thickness of the polyethylene mulches did not cause any change in the soil temperature. Average temperature with all the colours and thickness were almost similar (Fig 9b).

4.1.3. Soil pH

What effect soil solarization will cause to status of soil reaction was studied.. Changes in soil pH of two experimental sites are given in Table 7, 8. Its evident from the data recorded that solarization

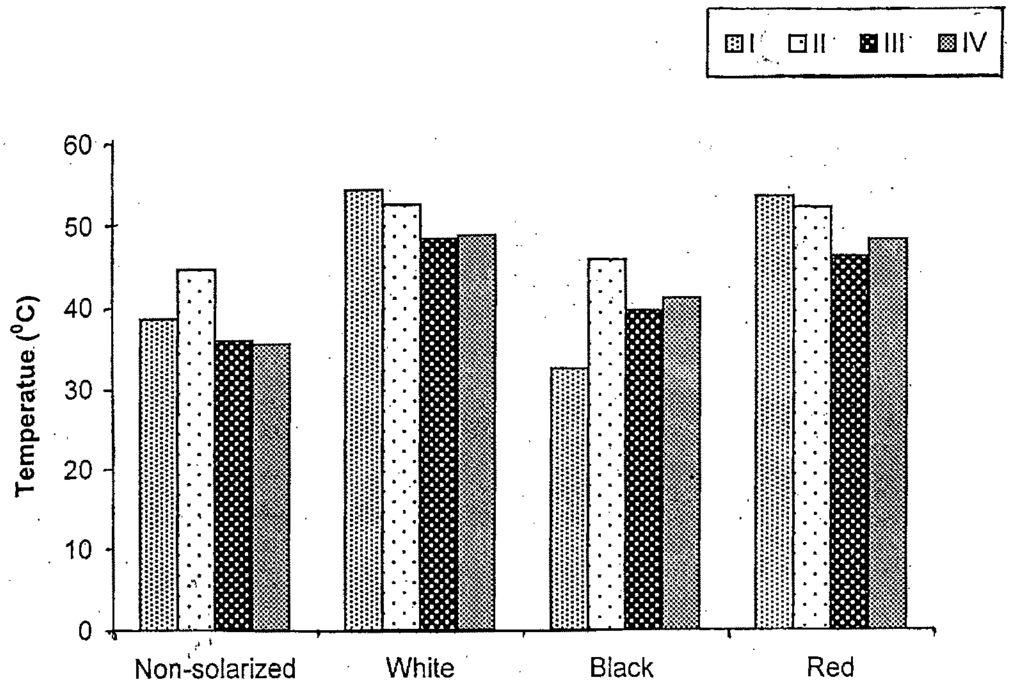


Fig. 9a: Changes in soil temperature during four weeks of solarization

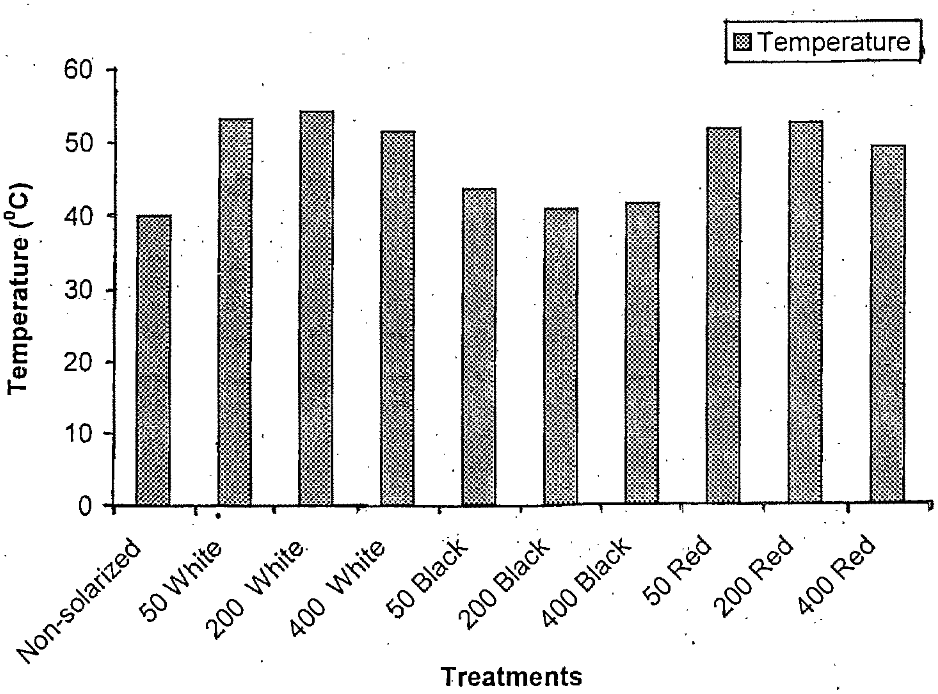


Fig. 9b : Effect of polyethylene thickness on soil temperature (Av. of four weeks)

Table 7 : **Effect of solarization on physico-chemical properties of the soil at VRC**

Treatments	Soil pH	EC (mho/cm)	Available K (kg ha^{-1}	Available P (kg ha^{-1})	Total nitrogen (%)	Organic carbon (%)
1. Non solarized	7.3	0.168	276.26	23.89	0.137	0.657
2. Solarized 50 W	7.0	0.735	319.53	35.84	0.247	0.667
3. Solarized 200 W	6.9	0.495	333.10	37.51	0.201	0.647
4. Solarized 400 W	7.0	0.420	282.17	40.30	0.204	0.693
5. Solarized 50 R	7.0	0.915	324.40	37.33	0.196	0.703
6. Solarized 200 R	7.1	0.525	310.67	32.85	0.175	0.657
7. Solarized 400 R	7.0	0.275	301.93	26.89	0.165	0.683
Cd at 5%	0.31	0.162**	88.85	16.52	0.048*	0.085
CV	2.4	18.08	16.20	27.70	14.37	7.14

Table 8 : **Effect of solarization on physico-chemical properties of the soil at floriculture block**

Treatments	Soil pH	EC (mho/cm)	Available K (kg ha^{-1}	Available P (kg ha^{-1})	Total nitrogen (%)	Organic carbon (%)
1. Non solarized	6.5	0.206	190.40	23.89	0.188	0.703
2. Solarized 50 W	6.6	0.842	240.80	20.91	0.262	0.790
3. Solarized 200 W	6.5	0.393	233.30	19.41	0.230	0.773
4. Solarized 400 W	6.6	0.262	242.70	20.91	0.229	0.793
5. Solarized 50 R	6.7	0.657	238.90	19.71	0.260	0.780
6. Solarized 200 R	6.8	0.807	241.10	25.27	0.205	0.810
7. Solarized 400 R	6.7	0.435	237.10	23.89	0.196	0.830
Cd at 5%	0.27	0.202**	27.57*	8.24	0.027**	0.118
CV	2.31	21.48	6.68	21.06	6.70	8.47

caused no change in pH values of the solarized soils at both the sites. At VRC, neutral soil pH (7.0) was recorded. Variation, neither in colour nor in thickness of the polyethylene, caused any change in soil pH. At floriculture block, soil pH ranged from 6.5 to 6.8. Thus, no significant change was recorded (Table 8).

4.1.4.Electrical conductivity (EC)

The effect of solarization on EC was very much clear and evident (Table-7, 8) and in most treatments significantly higher than that of non-solarized soil. Values were 0.206 mho/cm in non-solarized soil. It increased to 0.842mho/cm but in some treatments the increase was non-significant. It may be obviously due to some experimental error. For instance, in soil solarized with white polyethylene film of 50G thickness, EC was 0.842 mho/cm but under 200G thick, the value was only 0.393. However, the over all picture that emerges, indicates that EC increased as a result of soil solarization. Neither variation in colour nor in thickness of the film caused any substantial change in EC at floriculture site. At VRC (Table 7) changes in EC were almost similar to that of at floriculture block (Table 8). Against a value of 0.108 mho/cm, solarization increased it to 0.915 mho/cm. In most treatments the increase was highly significant. Variation in colour as well as thickness of the film, caused little change that could be described as substantially different (Fig. 10, 11).

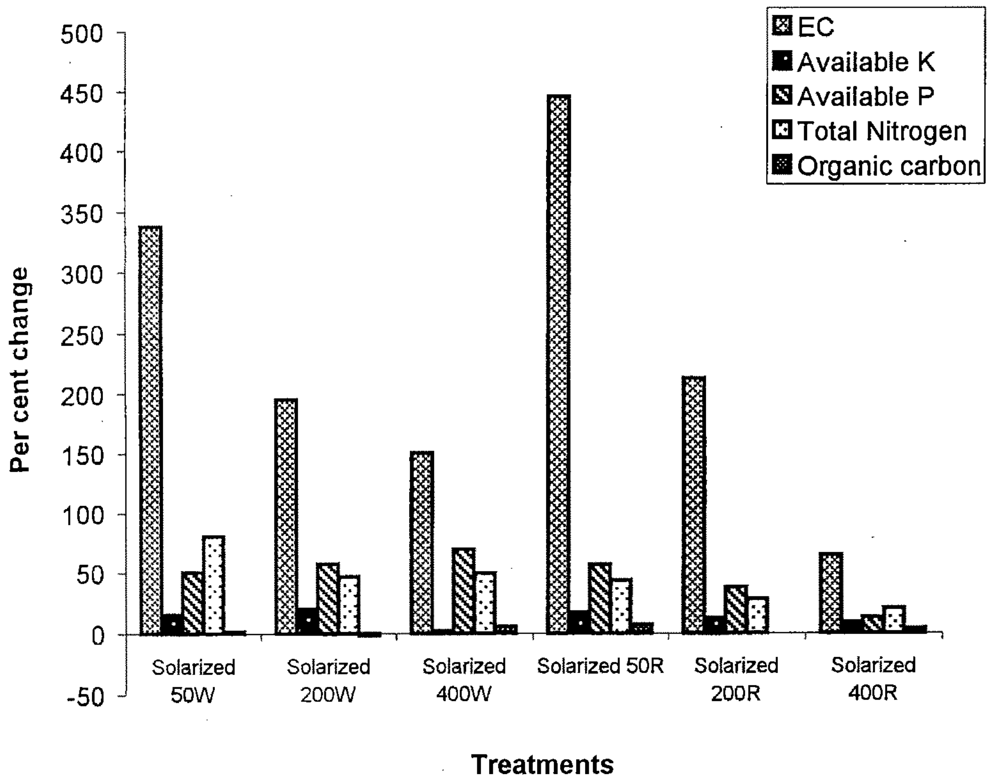


Fig. 10 : Per cent chnage in soil properties over non solarized (at VRC)

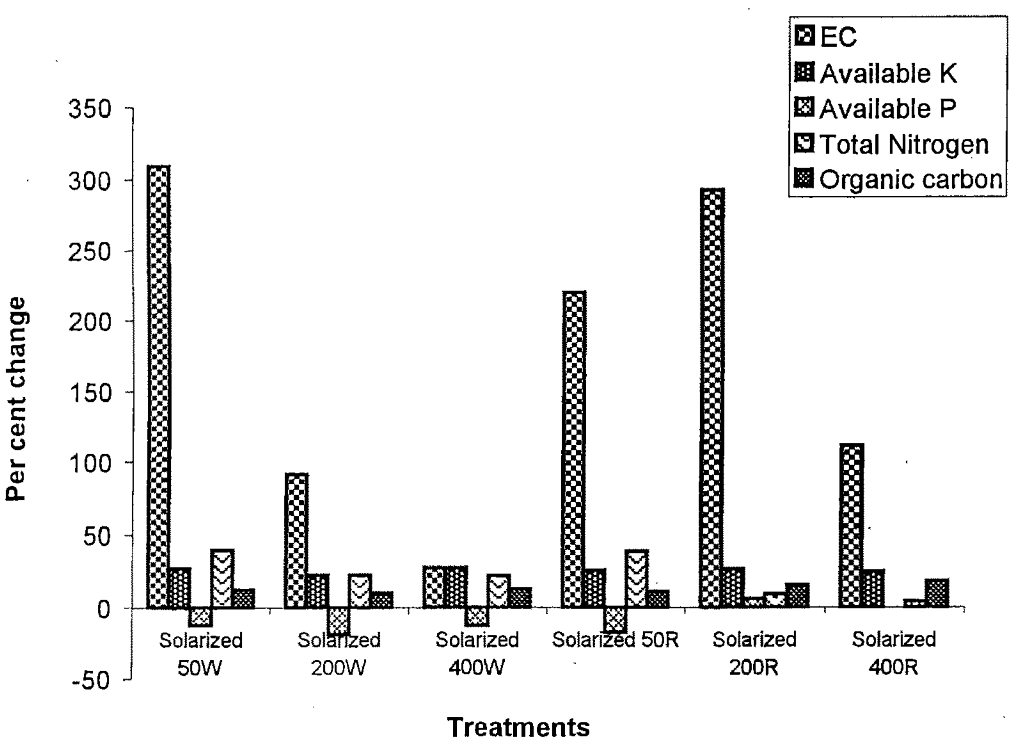


Fig. 11 : Per cent change in soil properties over non solarized (at Floriculture Block)

4.1.5. Available K

Results recorded in Table 7, 8 and Fig. 10, 11 reveal that status of available K changed particularly in solarized soil but the increase was invariably non-significant. It was 276.26 kg ha^{-1} in non-solarized soil of VRC (Table 7). In solarized soil the value was invariably above 300 kg ha^{-1}. Similarly at floriculture site, the value in control was 190.4 kg ha^{-1}. Solarization increased the status to about 240 kg ha^{-1}. Thus, the availability of K increased though non-significantly.

4.1.6. Available P

Changes in the status of available P due to solarization were also positive but non-significant. At VRC, the status of this macro nutrient was 23.89 kg ha^{-1}. Solarization increased this level to about 38 kg ha^{-1}. Similarly at Floriculture block, the increase was there but very minor and not note worthy (Table 7, 8 and Fig. 10, 11).

4.1.7. Total nitrogen

Percentage of total nitrogen at VRC as well as at floriculture block changed significantly. At VRC, in non-solarized soil it was only 0.137 per cent. Solarization raised this value to 0.165 per cent to 0.247 per cent. Thus, the total nitrogen in soil increased significantly. At floriculture block, the increase in percentage of total nitrogen was highly significant. It was 0.188 per cent in non-solarized soil and solarization raised the status of total nitrogen to 0.196 to 0.262 per cent (Table 7, 8 and Fig. 10, 11).

4.1.8. Organic carbon

The status of organic carbon of both the experimental sites did not change significantly. At VRC, minor increase in amount of organic carbon was observed. Similarly at floriculture block as well as the changes were non-significant (Table 7, 8).

4.2. Disease-incidence

Results pertaining to the effects of soil solarization for 30 days and its integration with seed-treatment (fungicides and bioagent) on the incidence of damping-off (pre and post-emergence) of vegetables (cauliflower-cabbage-tomato-onion) and flowers (calendula and aster) raised in sequence in naturally infested soil, are given in Tables 9-14 and Fig. 12, 13, 14. Polyethylene sheets used for solarization were transparent white, black and red with thickness of 50 to 400 G.

4.2.1. Cauliflower (Ist nursery crop)

In non-solarized soil, the incidence of damping- off in cauliflower raised from non- treated seeds, was above 72 per cent and when seeds treated with fungicides and bioagent were sown in such plots, the incidence of damping-off decreased to 43.6 to 69.3 per cent. The results revealed that the seed-treatment with bioagent and fungicides reduced the incidence of the disease non-significantly except for Apron which reduced the disease-incidence substantially and was significantly superior over others. Solarization using transparent white polyethylene of 50G thickness further reduced damping-off incidence. In crops raised without seed-treatment, it was

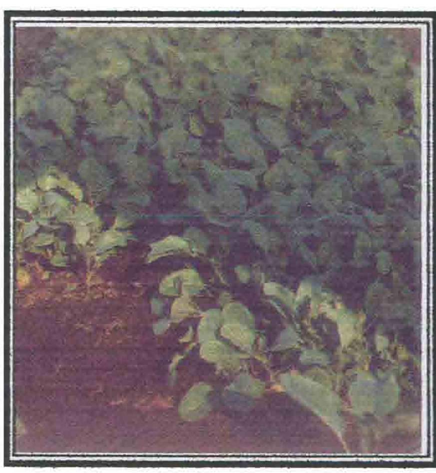
Plate 3. **A-B : Soil solarization - Effect of film thickness**

C : Cauliflower nursery in solarized bed

D : Cauliflower nursery in non-solarized bed

A

B



C **D**

only 44.5 per cent against an incidence of 72.6 per cent in control. Thus, the disease was significantly reduced. The magnitude and extent of reduction was over 38 per cent when compared with incidence in non-solarized soil. Use of fungicides and bioagent for seed-treatment further reduced damping -off approximately by 21 to 43 per cent. over non-solarized soil. The effect of transparent polyethylene sheets with higher thickness (200 G and 400 G) was almost similar to that with 50G. There were no significant differences in disease-incidence. In soil solarized using white polyethylene of 50G, disease-incidence with or without seed-treatment, ranged from 42.9 to 48.5 per cent while in case of 200G, it ranged form 35.5 to 54.3 per cent and with 400G if ranged from 36.1 to 46.5 per cent. Calculation of the average disease-incidence, ignoring the effect of individual film thickness, revealed that solarization with seed-treatments reduced disease-incidence approximately by 17 to 40.5 per cent over check (Table 9).

The mulching of soil for a month using black polyethylene of different thickness (50G to 400G) did not bring any appreciable change in disease management. Even seed-treatments with fungicides and bioagent failed to control the disease. The incidence of damping-off ranged from 55 to 69.6 per cent. However, the effect of solarization achieved through red polyethylene sheeting of different thickness was somewhat noticeable. The effect was significantly superior over to that of black sheeting but inferior to that of white

Table 9 : **Effect of polyethylene mulching and seed-treatments on the incidence of damping-off of cauliflower**

Treatments	**Non-solarized**	**Solarized**											
		White polyethylene				**Black polyethylene**				**Red polyethylene**			
		50 G	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**
(No seed-treatment)	72.6	44.5	43.3	43.2	43.6	69.5	75.5	69.6	71.5	71.5	62.3	58.3	64.0
Thiram	58.6	45.2	54.3	45.1	48.2	62.5	77.7	68.7	69.6	57.4	57.1	53.7	56.0
Vitavax	57.9	45.6	40.8	46.5	44.3	59.9	74.8	64.8	64.8	62.8	61.6	48.9	57.7
Apron	43.6	42.9	35.5	36.1	38.1	56.7	70.7	55.1	60.8	60.1	55.4	48.9	54.8
T. harzianum	69.3	48.5	45.0	46.5	46.6	61.7	62.7	58.7	61.0	68.2	47.9	51.7	55.9
P. fluorescens	69.0	47.3	44.7	44.8	45.6	52.6	55.2	62.4	56.7	54.6	50.6	37.8	47.6
Main plot mean	61.8	45.7	43.9	43.7	44.4	60.5	69.4	63.2	64.3	62.4	55.8	49.9	56.0

Sample size : 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 4.75	cd_1 = 6.58	cd_1 = 11.26
	cd_2 = 9.64	cd_2 = 9.37	cd_2 = 12.74
	cd_3 = 19.29	cd_3 = 18.75	cd_3 = 25.48
	cd_4 = 18.22	cd_4 = 18.30	cd_4 = 25.78

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = ns	ma = ns
	su = ns	su = *	su = ns
	ms = ns	ms = ns	ms = ns

transparent one. Integration of fungicides and bioagent had positive effect on disease control. Among the fungicides, Apron was best and *P. fluorescens* was superior over *T. harzianum* (Fig. 12**A**).

4.2.2. Cabbage (2nd nursery crop)

After 30 days, the cauliflower nursery was removed and cabbage nurseries were raised without any change in treatments and design. In non- solarized plots sown with treated or non-treated seeds, the incidence of damping-off was 67.9 per cent. By seed-treatment with fungicides and bioagent, the incidence of damping-off decreased, but non-significantly. All the three fungicides were almost equally effective. Seed-treatment with *P. fluorescens* was distinctly superior over others (Table 10). Solarization and its integration with fungicides and bioagent used as seed-treatment caused substantial and noticeable reduction in disease-incidence. In plots solarized with transparent polyethylene sheeting of 50 gauge, only 42.1 per cent disease-incidence was recorded against 67.9 per cent in non-solarized plots, without any seed–treatment. Thus, only solarization reduced the disease-incidence by 38 per cent (Fig. 12 **B**). Use of fungicides or bioagent as seed-treatment further increased the disease controlling potential of solarization. Apron was most effective among the fungicides and *P. fluorescens* being the most effective of all. The treatments used for seed-dressing reduced disease-incidence by 30 to 40 per cent over their effects when used under non-solarized conditions.

Table 10 : **Effect of soil solarization and its integration with seed-treatment on damping-off of cabbage**

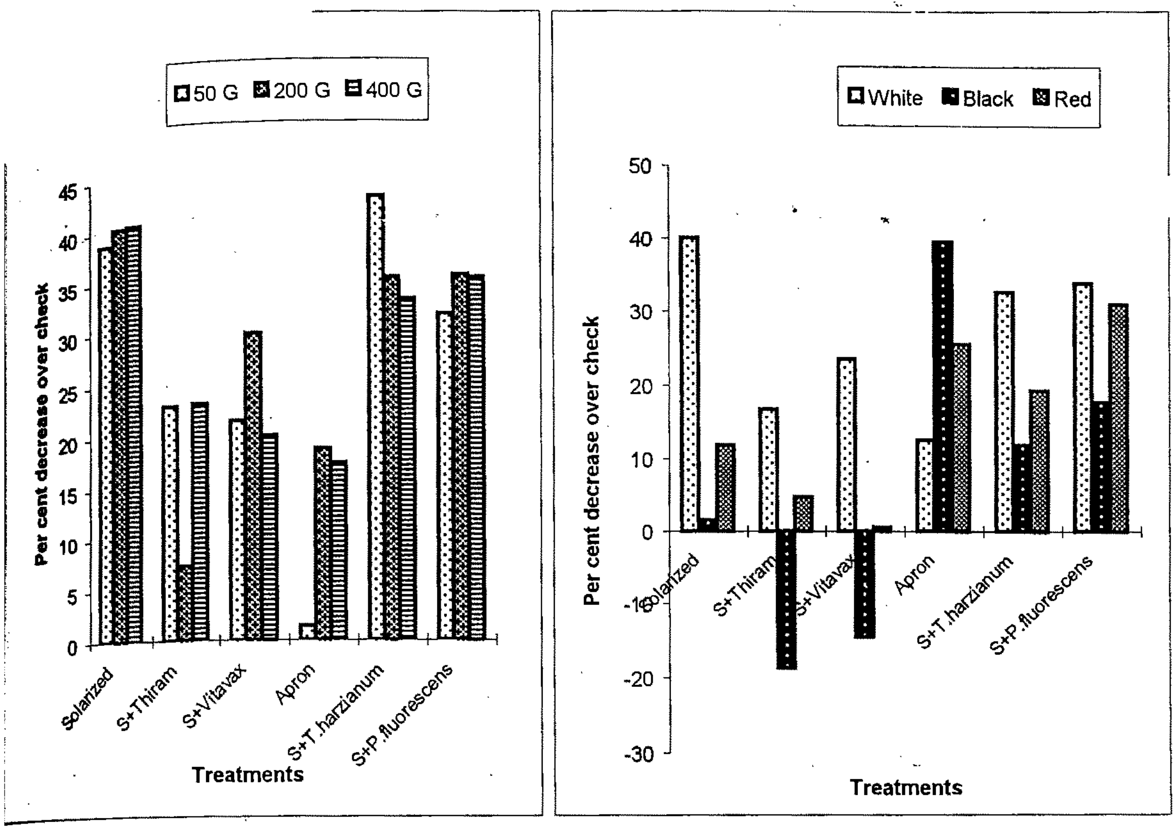
Treatments	**Non-solarized**	**Solarized**											
		White polyethylene				**Black polyethylene**				**Red polyethylene**			
		50 G	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**
(No seed-treatment)	67.9	42.1	41.8	56.1	46.6	49.2	49.0	62.3	53.5	54.5	45.6	52.6	50.9
Thiram	58.8	37.1	40.1	50.3	42.5	43.6	47.1	56.2	49.9	50.6	45.3	50.4	48.7
Vitavax	58.5	34.7	40.0	49.6	41.4	45.6	44.6	49.5	46.5	46.1	45.0	43.1	44.7
Apron	58.9	39.7	36.9	45.2	40.6	44.9	45.9	52.2	47.3	46.5	45.1	46.3	46.0
T. harzianum	60.2	36.9	37.4	43.6	39.3	44.1	44.3	40.2	42.9	38.8	36.6	43.3	39.5
P. fluorescens	53.9	37.8	29.9	41.2	36.3	44.0	43.5	44.3	43.9	43.2	33.9	38.7	38.6
Main plot mean	59.7	38.0	37.7	47.7	41.1	45.7	45.7	50.8	47.4	46.6	41.9	46.6	45.0

Sample size: 20 plants

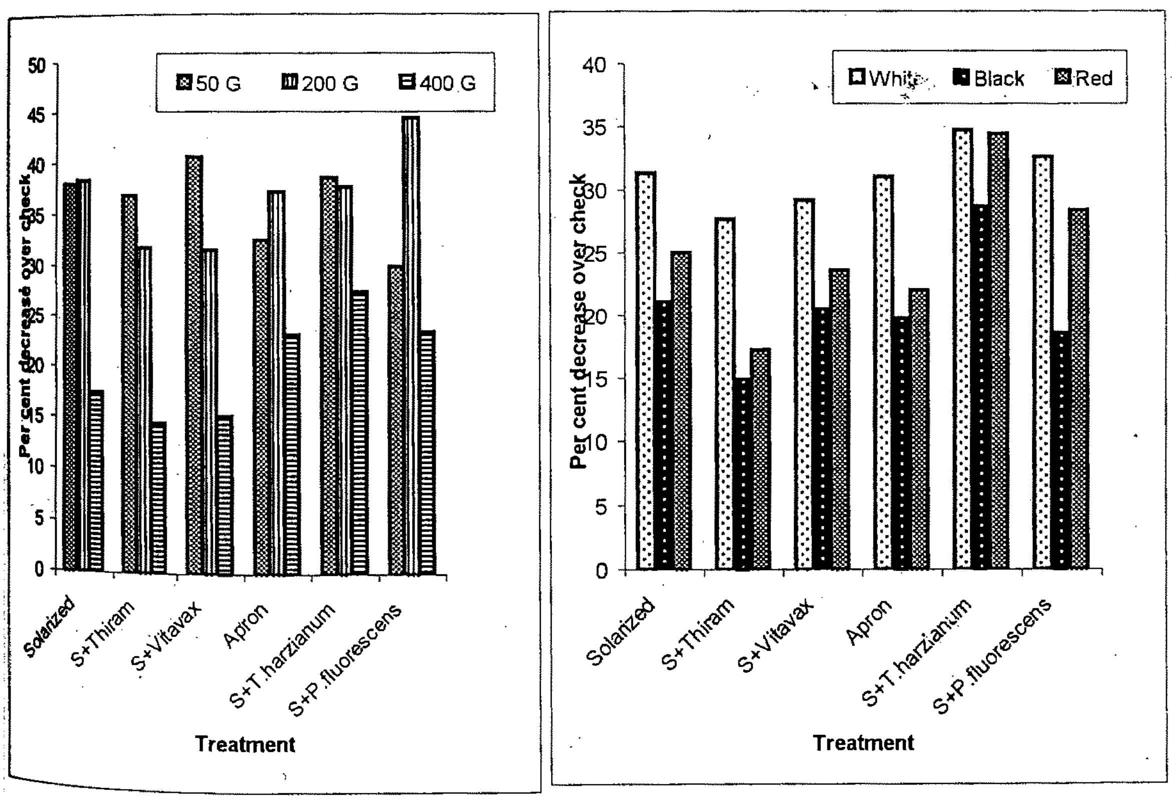
	White polyethylene	Black polyethylene	Red polyethylene
cd at 5%	cd_1 = 32.58	cd_1 = 30.09	cd_1 = 31.05
	cd_2 = 7.41	cd_2 = 6.51	cd_2 = 5.30
	cd_3 = 14.82	cd_3 = 13.03	cd_3 = 10.61
	cd_4 = 35.14	cd_4 = 32.28	cd_4 = 32.47

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = ns	ma = ns	ma = ns
	su = ns	su = *	su = **
	ms = ns	ms = ns	ms = ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness

Effect of polyethylene colour

Fig.12 : Effect of solarization on damping-off incidence

The effect of polyethylene with higher thickness (200G and 400G) when compared to that of 50 G was almost non-significant. With 200 G, per cent reduction in disease- incidence ranged from 31.6 to 44.5 per cent. Seed-treatment with *P. fluorescens* was distinctly superior. With 400 G the reduction in disease-incidence ranged from 14.4 to 23.5 per cent. On an average use of polyethylene sheeting for solarization reduced disease-incidence approximately by 31.3 per cent and seed-treatments further improved disease control.

In plots solarized using black polyethylene sheeting, the incidence of the disease decreased but non-significantly. In totality, the decrease in disease-incidence ranged from 14.9 to 28.7 per cent over the incidence recorded. The effect of solarization where red polyethylene sheeting were employed, was almost similar to that with white sheeting. The differences concerning the effects of thickness of polyethylene sheeting were non-significant. The effect of integration with fungicides and bio-agent was much evident. In totality, reduction in disease-incidence over non-solarized ranged from 17.17 to 34.4 per cent.

4.2.3. Tomato (3rd crop)

Tomato nursery was raised after removal of the cabbage. Thus, 60 days after solarization, this crop was raised using same treatments and design (Table 11 and Fig. 13A). The effect of solarization continued, though with reduced magnitude. In plots solarized with white polyethylene sheeting, on an average 10 per cent

Table 11 : **Effect of soil solarization and its integration with seed-treatment on damping-off of tomato**

Treatments	**Non-solarized**	**Solarized**											
		White polyethylene				**Black polyethylene**				**Red polyethylene**			
		50 G	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**
(No seed-treatment)	67.9	60.3	56.7	61.0	59.3	65.0	78.8	74.6	72.8	68.9	69.7	69.6	69.4
Thiram	67.3	55.6	61.1	57.4	58.0	64.7	75.2	68.1	69.3	64.0	66.0	68.2	66.1
Vitavax	67.8	59.2	63.2	55.4	59.3	66.4	71.7	70.6	69.5	62.4	43.6	62.6	62.8
Apron	65.4	57.2	62.8	56.3	58.8	65.1	65.0	69.4	66.6	64.8	62.9	61.5	63.0
T. harzianum	63.3	53.6	57.1	56.4	55.8	58.0	61.7	64.1	61.2	54.2	57.0	57.0	56.0
P. fluorescens	56.0	59.2	59.1	57.5	58.6	56.5	59.8	63.7	60.0	53.5	54.8	52.1	53.4
Main plot mean	64.46	57.6	60.0	57.3	58.3	62.6	68.7	68.5	66.6	61.3	62.3	61.8	61.8

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 9.21	cd_1 = 11.50	cd_1 = 17.10
	cd_2 = 6.11	cd_2 = 5.40	cd_2 = 7.73
	cd_3 = 12.22	cd_3 = 10.80	cd_3 = 15.40
	cd_4 = 14.41	cd_4 = 15.00	cd_4 = 24.09

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = ns	ma = ns	ma = ns
su = ns	su = **	su = **
ms = ns	ms = ns	ms = ns

reduction in disease-incidence was noted. The incidence of damping-off in plots solarized using black sheeting, was almost similar to that in non-solarized ones. With red sheeting as well, the incidence of damping-off was not affected.

4.2.4. Onion (4th nursery crop)

Ninety days after solarization, the nursery of onion was raised after removal of tomato nursery. The effect of solarization persisted but with much reduced impact. The percentage of disease reduced ranged from about 4 per cent to 19 per cent over non-solarized (Table 12 and Fig. 13 B). The results of solarization obtained by polyethylene with black and red polyethylene sheeting were almost similar to what was observed with the 3rd crop.

4.2.5. Calendula (Ist crop)

In another field trial at Floriculture block, the effect of solarization for a month using three colours and thickness of polyethylene was evaluated on flower crops raised in nurseries. The first crop was calendula and the results so obtained are given in Table 13 and Fig. 14A. In non-solarized plots, despite seed-treatment with fungicides or bioagent, the incidence of damping-off was very high and it ranged from 64 to 81 per cent. Solarization with white transparent polyethylene with thickness of 50 to 400 gauge, the incidence of damping-off was reduced substantially and most significantly. Percentage of healthy seedlings in solarized soil, even without seed-treatments, increased by 56.8 per cent. Seed-treatment

Table 12 : **Effect of soil solarization and its integration with seed-treatment on damping-off of onion**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	68.0	53.6	60.9	56.0	56.8	69.2	61.7	54.5	61.8	63.4	57.7	56.1	59.0
Thiram	73.2	46.2	64.5	52.7	54.4	68.6	53.3	49.7	57.2	50.6	55.4	50.6	52.2
Vitavax	64.7	49.0	61.7	48.9	53.2	61.1	55.8	53.4	56.7	58.5	51.0	52.9	54.1
Apron	53.9	53.1	56.1	54.2	54.4	58.3	51.3	52.4	54.0	53.4	47.4	54.6	51.8
T. harzianum	51.2	56.7	52.7	52.8	54.0	54.8	53.5	55.4	54.5	55.3	54.2	49.1	52.8
P. fluorescens	56.3	53.5	50.5	49.2	51.0	56.3	56.8	49.1	54.0	51.3	42.1	45.2	46.2
Main plot mean	62.9	52.0	57.7	52.3	54.0	61.4	55.4	52.4	56.4	55.4	51.3	51.4	52.7

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 8.15	cd_1 = 7.87	cd_1 = 6.38
	cd_2 = 6.77	cd_2 = 6.35	cd_2 = 12.76
	cd_3 = 13.55	cd_3 = 12.70	cd_3 = 10.61
	cd_4 = 14.75	cd_4 = 13.97	cd_4 = 13.44

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = *	ma = ns	ma = *
	su = ns	su = *	su = **
	ms = ns	ms = ns	ms = ns

Table 13 : **Effect of soil solarization and its integration with seed-treatment on damping-off of calendula**

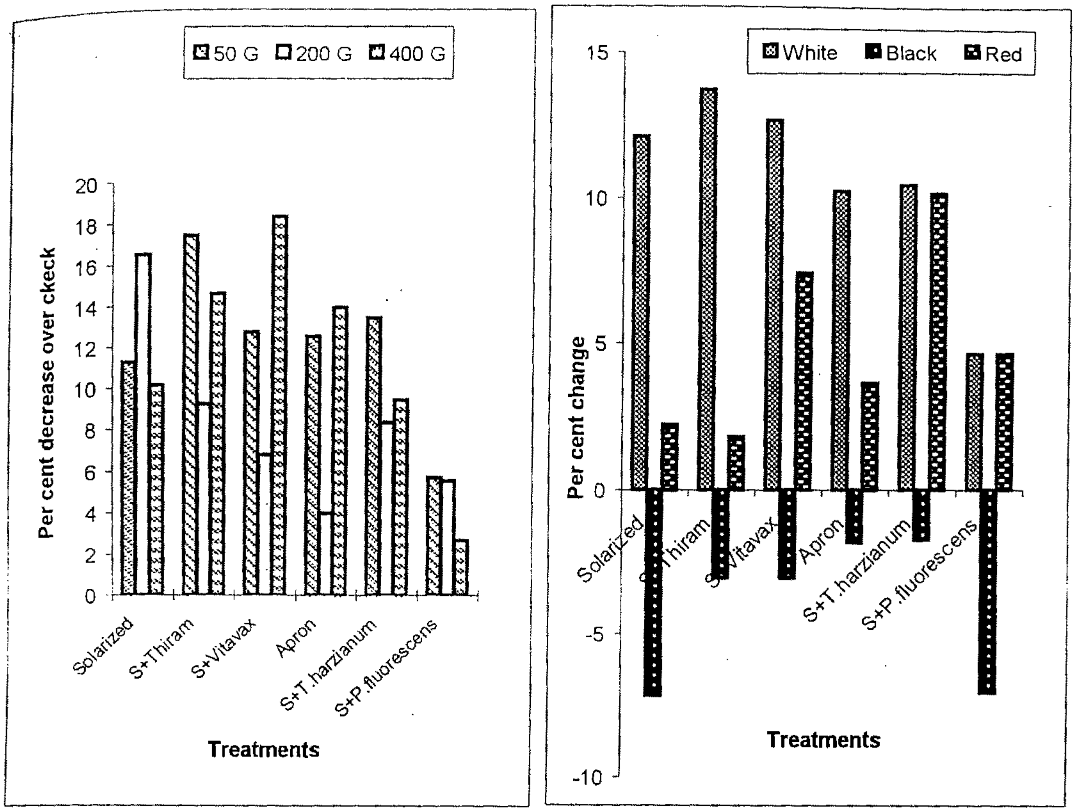
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	49.5	34.3	36.0	37.9	36.06	75.6	67.5	71.0	71.3	55.1	62.3	65.7	61.0
Thiram	81.0	31.0	33.0	38.31	34.1	39.7	63.8	74.2	69.2	49.7	44.7	48.9	47.76
Vitavax	76.3	28.8	31.6	28.66	29.7	61.7	51.0	53.9	55.5	40.6	38.0	37.7	38.76
T. harzianum	76.10	29.5	29.5	30.44	35.78	64.3	57.3	64.4	62.0	51.0	50.5	42.5	48.0
P. fluorescens	64.8	38.6	38.3	30.44	35.78	64.3	57.3	64.4	62.0	51.0	50.5	42.5	48.0
Main plot mean	75.5	32.5	33.7	33.1	33.1	67.0	59.3	63.6	63.3	48.1	49.9	48.9	49.0

Sample size: 20 plants

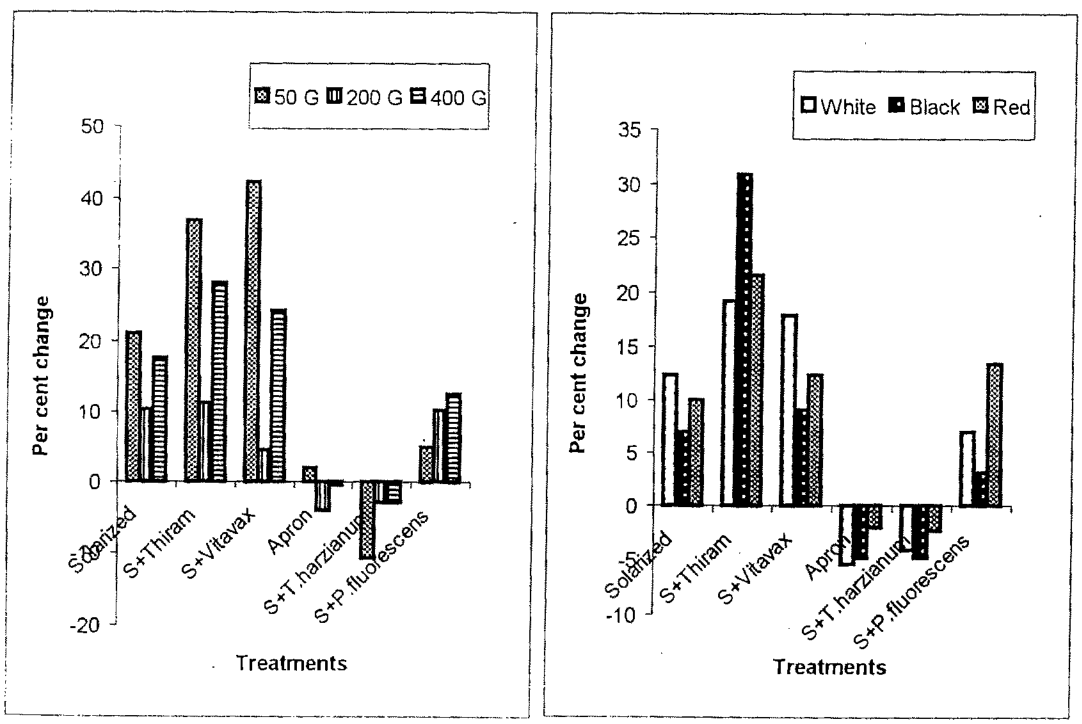
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 4.06	cd_1 = 4.30	cd_1 = 7.60
	cd_2 = 5.64	cd_2 = 7.95	cd_2 = 6.31
	cd_3 = 11.30	cd_3 = 15.91	cd_3 = 12.6
	cd_4 = 10.80	cd_4 = 14.80	cd_4 = 13.5

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = ns	su = **	su = **
ms = ns	ms = ns	ms = ns



A. Tomato



B. Onion

Effect of polyethylene thickness

Effect of polyethylene colour

Fig.13: Effect of solarization on damping-off incidence

with bioagent or fungicides accentuated the positive effects of solarization. The additional reduction in disease ranged from 5 to 25 per cent. Among the seed-treatments, bio-agent *P. fluorescens* was distinctly inferior. The thickness of the polyethylene did not bring any meaningful change in disease-incidence. In plots solarized with polyethylene of 200 G thickness, reduction in disease-incidence ranged from 40.8 to 61.2 per cent. Integration with chemicals and bioagent was marginally effective. The effect of 400G thickness was almost similar. Percentage of reduced disease-incidence ranged from 52 to 62 per cent. In totality, if the thickness factor is ignored, solarization with white treatment polyethylene resulted in approximately 34 to 61 per cent reduction in damping-off incidence (Table 13).

The effect of solarization using red and black polyethylene sheeting was rather minor or moderate. Per cent reduction in disease-incidence over check (non-solarized), with red polyethylene sheeting ranged from 23.3 to 49.2 per cent and with black sheeting from 4.32 to 27.2 per cent (Fig. 14 A).

4.2.6. Aster

After calendula, nursery of aster was raised without any change in location or treatment. The data given in Table 14 and Fig. 14.B reveal that in solarized soil the incidence of disease was reduced by over 13 to 21per cent. Integration with seed-treatments using fungicides and bioagent increased the effect of solarization but

Table 14 : **Effect of soil solarization and its integration with seed-treatment on damping-off of aster**

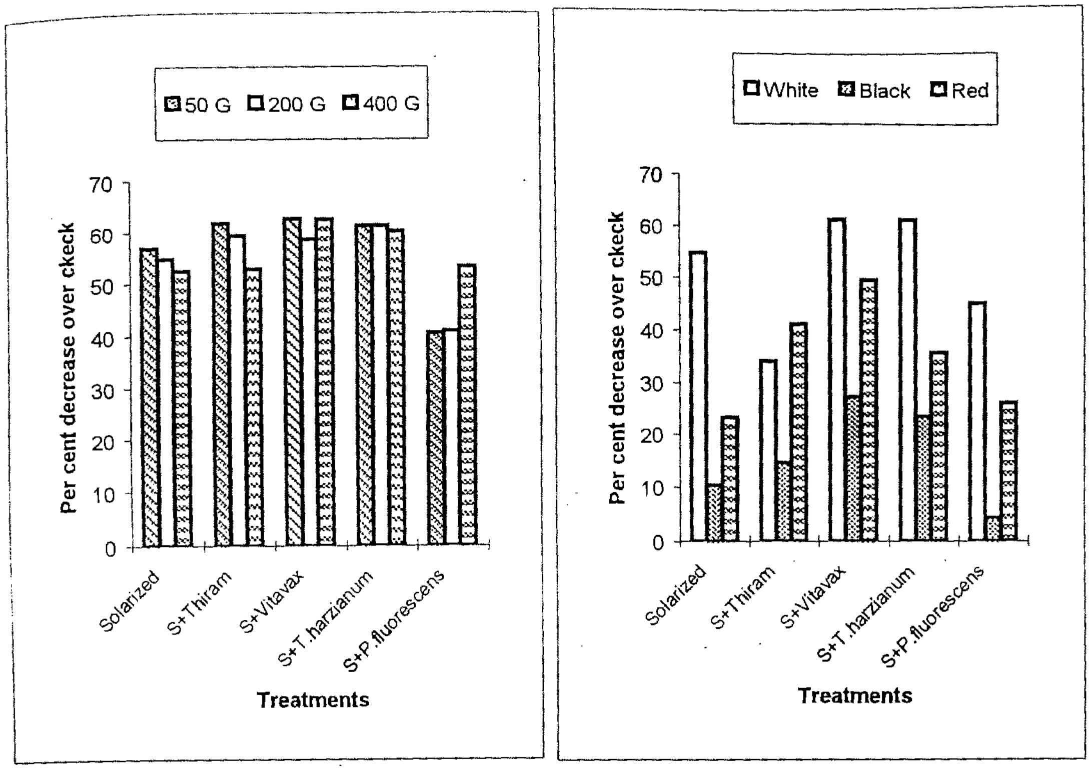
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	63.6	52.1	50.3	55.1	52.5	56.4	58.5	63.1	59.33	52.1	53.7	54.75	53.51
Thiram	56.9	52.9	49.6	49.7	50.7	55.3	62.8	60.6	59.5	53.0	49.8	46.7	49.83
Vitavax	56.3	49.3	41.2	40.0	43.5	47.2	51.2	46.3	46.2	50.0	42.1	47.6	46.56
T. harzianum	56.9	46.3	35.8	40.0	40.7	39.3	38.3	44.1	40.5	43.8	44.9	42.8	43.83
P. fluorescens	51.5	36.9	38.2	30.0	35.01	42.1	44.9	43.7	43.5	48.2	40.0	40.2	42.8
Main plot mean	57.0	47.5	43.0	42.9	44.5	48.1	51.1	51.6	50.2	49.4	46.1	46.4	47.3

Sample size: 20 plants

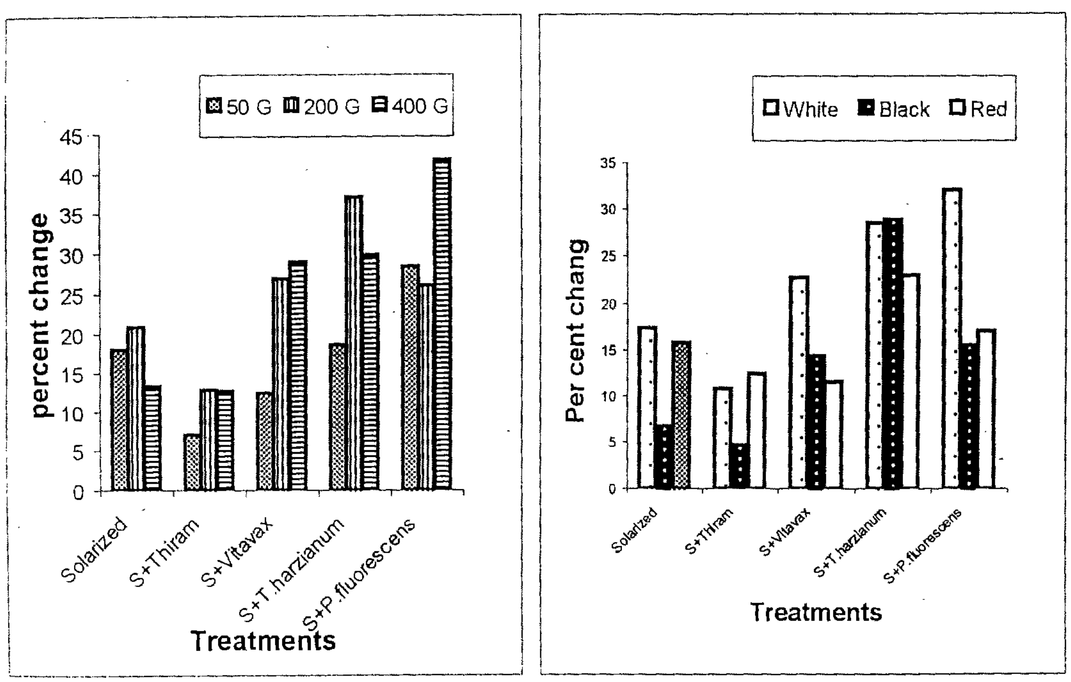
	White polyethylene	Black polyethylene	Red polyethylene
cd at 5%	cd_1 = 10.10	cd_1 = 14.94	cd_1 = 7.40
	cd_2 = 11.40	cd_2 = 8.62	cd_2 = 9.90
	cd_3 = 22.80	cd_3 = 17.23	cd_3 = 19.80
	cd_4 = 22.70	cd_4 = 21.38	cd_4 = 19.10

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = *	ma = ns	ma = *
su = ns	su = **	su = ns
ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 14 : Effect of solarization on damping-off incidence

non-significantly. Integration of bioagent proved superior over the fungicides. *P. fluroscens* was found most effective.

Solarization using red sheeting also affected disease-incidence. Reduction in disease ranged from 11.5 to 22.9 per cent (Table 14 and Fig. 15 B). Among the factors used for integration, *T. harzianum* was most effective. The control of disease in soil solarized using black sheeting was rather low. It ranged from 4.67 to 28.7 per cent. *P. fluorescens* was most effective.

4.3. Soil Solarization and Plant Growth Response

It has invariably been recorded that health of the seedlings raised in solarized soil is significantly improved. In the experiments conducted at VRC and Floriculture block, different growth parameters and/or growth contributing factors of the crops raised in succession, were recorded. The data so recorded are given in Tables 15-44 and Figs. 15-29.

4.3.1. Shoot Length

4.3.1.1. Cauliflower

The effect of different colour and thickness of polyethylene used for solarizing the soil in integration with seed-treatments on the length of 30 days old cauliflower seedlings are given in Table 15 and Fig. 15 A. In solarized plots average shoot length was 8.41cm. Seed-treatment affected shoot length but non-significantly. In plots solarized with white polyethylene sheets, the effect of polyethylene thickness was non-significant. Shoot length in solarized plots

Table 15 : **Effect of soil solarization and its integration with seed-treatments shoot length of cauliflower**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	7.66	12.83	13.33	13.83	13.33	8.76	9.59	9.33	9.23	11.96	13.56	13.76	13.10
Thiram	7.76	13.36	13.10	13.43	13.30	9.13	8.53	9.00	8.88	12.46	13.40	13.56	13.14
Vitavax	8.09	14.16	14.63	14.96	14.60	9.96	9.43	9.23	9.54	12.83	12.86	13.06	12.90
Apron	3.23	14.06	14.96	15.73	14.90	9.59	9.56	8.59	9.25	12.33	12.10	14.23	12.88
T. harzianum	9.30	15.70	15.73	16.36	15.93	12.63	13.60	13.06	13.10	15.20	15.60	16.10	15.63
P. fluorescens	9.43	16.20	17.23	17.76	15.15	13.26	14.66	14.86	14.26	15.56	16.03	15.56	16.05
Main plot mean	8.41	14.38	14.83	15.35	14.85	10.56	10.90	10.68	10.71	13.39	13.92	14.55	13.95

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.68	cd_1 = 0.97	cd_1 = 0.80
	cd_2 = 0.57	cd_2 = 0.68	cd_2 = 0.74
	cd_3 = 1.14	cd_3 = 1.37	cd_3 = 1.49
	cd_4 = 1.24	cd_4 = 1.58	cd_4 = 1.57

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
ma	**	**	**
su	**	**	**
ms	ns	**	ns

increased by about 67.5 per cent. Seed-treatment with thiram and vitavax caused an additional increase of about 8 per cent. Both the bioagent also had positive effect on shoot length. Almost similar effects were recorded in plots solarized with red polyethylene sheets. Shoot length increased approximately by 70 per cent (Table 15 and Fig. 15 A). Black polyethylene was also effective but with lesser magnitude. Increase in growth over those raised in non-solarized soil ranged from 20 to 50 per cent.

4.3.1.2. Cabbage

After the harvest of cauliflower nursery, cabbage seedlings were raised. The effect of solarization persisted and shoot length of seedlings raised in plots solarized with white polyethylene sheets increased by 54.4 per cent over non-solarised (Table 16). Seed-treatment with fungicides and bioagent accentuated the effect of solarization. The effect of soil mulching with red and black polyethylene sheeting continued with this crop as well but the magnitude recorded was lesser compared with that in previous crop (Fig. 15 B).

4.3.1.3. Tomato

Increase in shoot length was observed in case of third nursery crop also, but the increase was non-significant (Table 17). Shoot length in plots solarised with white polyethylene sheeting, increased by 13 per cent. Almost similar observations were recorded with black and red polyethylene sheets (Fig. 16 A).

Table 16 : **Effect of soil solarization and its integration with seed-treatments on shoot length of cabbage**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	8.4	11.92	13.64	13.36	12.97	9.91	11.51	10.36	10.60	10.15	10.60	11.23	10.66
Thiram	8.5	11.30	12.61	13.01	12.30	10.30	11.12	10.90	10.70	10.47	10.90	11.35	10.90
Vitavax	9.3	12.61	11.49	12.83	12.31	11.50	11.58	10.50	11.20	10.20	11.69	11.46	11.11
Apron	9.5	12.10	12.25	12.80	12.38	10.63	11.01	10.85	10.83	10.58	11.28	11.65	11.17
T. harzianum	11.35	14.40	13.99	14.48	14.30	12.81	13.73	12.61	13.05	12.55	13.53	12.70	12.92
P. fluorescens	10.67	15.30	13.01	13.91	14.07	12.88	13.88	13.33	13.36	12.70	12.35	13.26	12.77
Main plot mean	9.77	12.94	12.83	13.28	13.00	11.34	12.14	11.42	11.63	11.11	11.72	11.94	11.60

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 1.04	cd_1 = 0.82	cd_1 = 1.06
	cd_2 = 0.89	cd_2 = 1.16	cd_2 = 0.98
	cd_3 = 1.78	cd_3 = 2.31	cd_3 = 1.96
	cd_4 = 1.92	cd_4 = 2.26	cd_4 = 2.08

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = **	ma = *
	su = **	su = **	su = **
	ms = ns	ms = ns	ms = ns

Table 17 : **Effect of soil solarization and its integration with seed-treatments on shoot length of tomato**

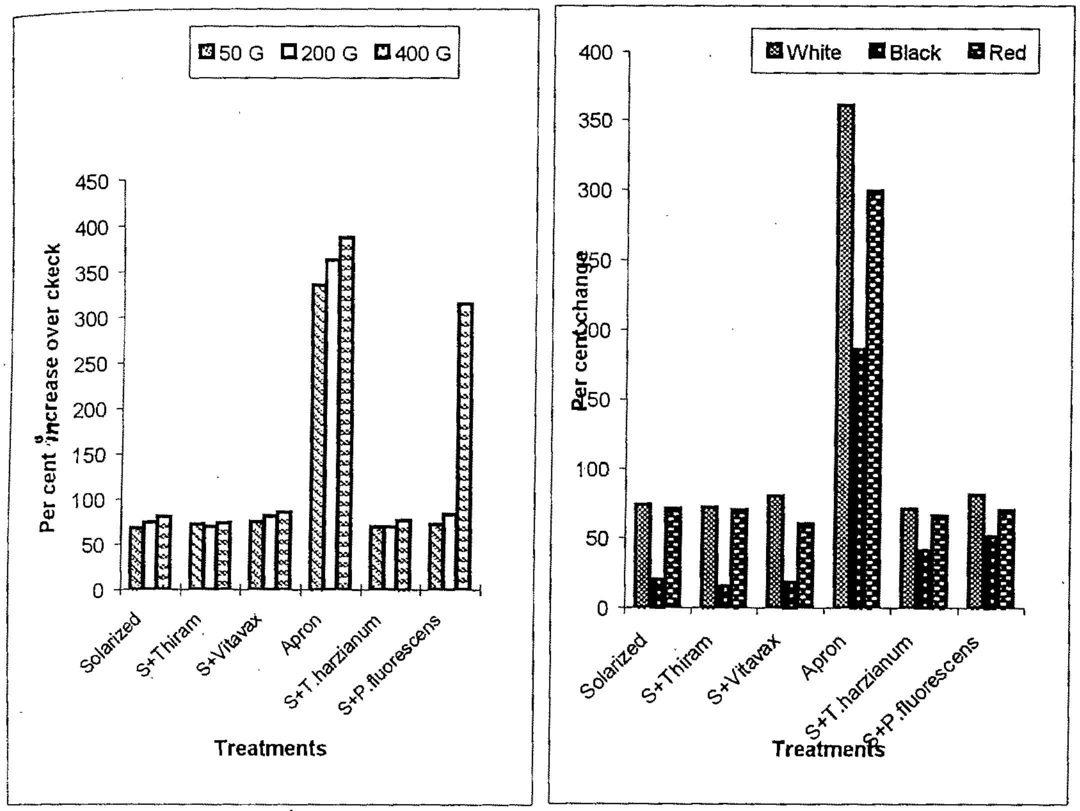
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	7.57	8.99	8.26	8.45	8.56	8.7	8.95	9.03	8.90	8.30	8.54	8.70	8.51
Thiram	7.50	8.72	8.00	8.34	8.35	8.86	8.70	8.94	8.83	7.10	8.91	8.34	8.11
Vitavax	7.98	7.81	8.30	7.72	7.94	8.50	8.35	8.74	8.53	8.51	7.50	8.06	8.26
Apron	7.79	7.92	8.00	7.64	7.85	8.46	7.98	8.19	8.21	8.36	8.36	8.08	8.26
T. harzianum	8.40	9.20	8.70	8.61	8.83	8.39	8.91	8.51	8.60	8.64	9.26	8.66	8.85
P. fluorescens	8.98	8.68	9.00	8.86	8.84	9.50	10.10	8.78	9.46	9.10	8.83	9.00	8.97
Main plot mean	8.04	8.56	8.40	8.27	8.41	8.73	8.84	8.70	8.76	8.34	8.57	8.47	8.46

Sample size: 20 plants

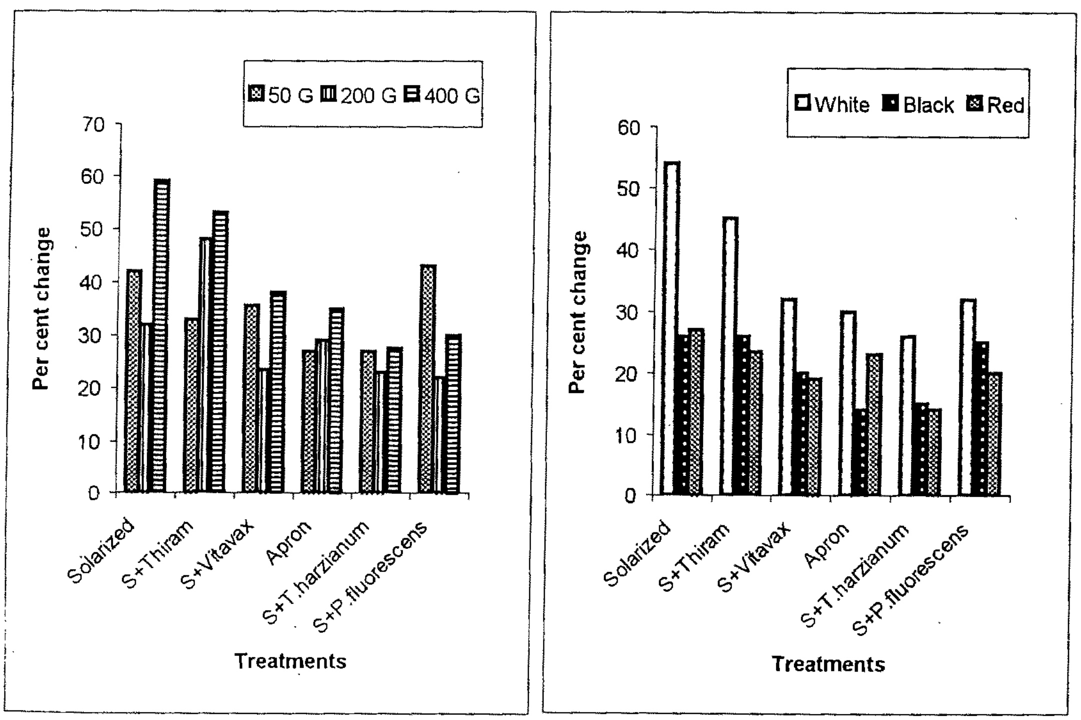
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.68	cd_1 = 0.69	cd_1 = 0.70
	cd_2 = 0.83	cd_2 = 0.59	cd_2 = 0.81
	cd_3 = 1.67	cd_3 = 1.19	cd_3 = 1.64
	cd_4 = 1.66	cd_4 = 1.29	cd_4 = 1.65

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
	ma = ns	ma = *	ma = ns
	su = ns	su = *	su = ns
	ms = ns	ms = ns	ms = ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness — Effect of polyethylene colour

Fig. 15 : Effect of solarization on shoot length

4.3.1.4 Onion

Onion was the third nursery crop raised on same solarized plots in succession (Table 18). The positive effects of solarization persisted but with much reduced effects. Overall increase in shoot length was of about 27 per cent in solarized plots. Seed- treatment either with fungicides or bioagent did not affect shoot length. In plots solarized with black or red polyethylene sheets shoot length increased but non-significantly (Fig. 16 B).

4.3.1.5 Calendula

In another field trial on the feasibility of solarization for raising healthy nurseries of flowers, calendula crop was raised as the first crop. The effect of solarization using white polyethylene sheets was highly significant. Shoot length increased by over 200 per cent (Table 19). Seed-treatment with fungicides and bioagent increased the effectivity of solarization. Variation in thickness of polyethylene sheets did not cause any perceptible change in shoot length. Among the fungicides, differences were very narrow. Thiram treatment increased the shoot length by over 290 per cent while Vitavax did the same by over 230 per cent (Fig. 17 A). Both the bioagent were equally effective.

4.3.1.6 Aster

After the removal of calendula, the nursery of aster was raised. The data presented in Table 20 and Fig. 17 B revealed that effect of solarization persisted. In plots solarized with white polyethylene the

Table 18 : **Effect of soil solarization and its integration with seed-treatments on shoot length of onion**

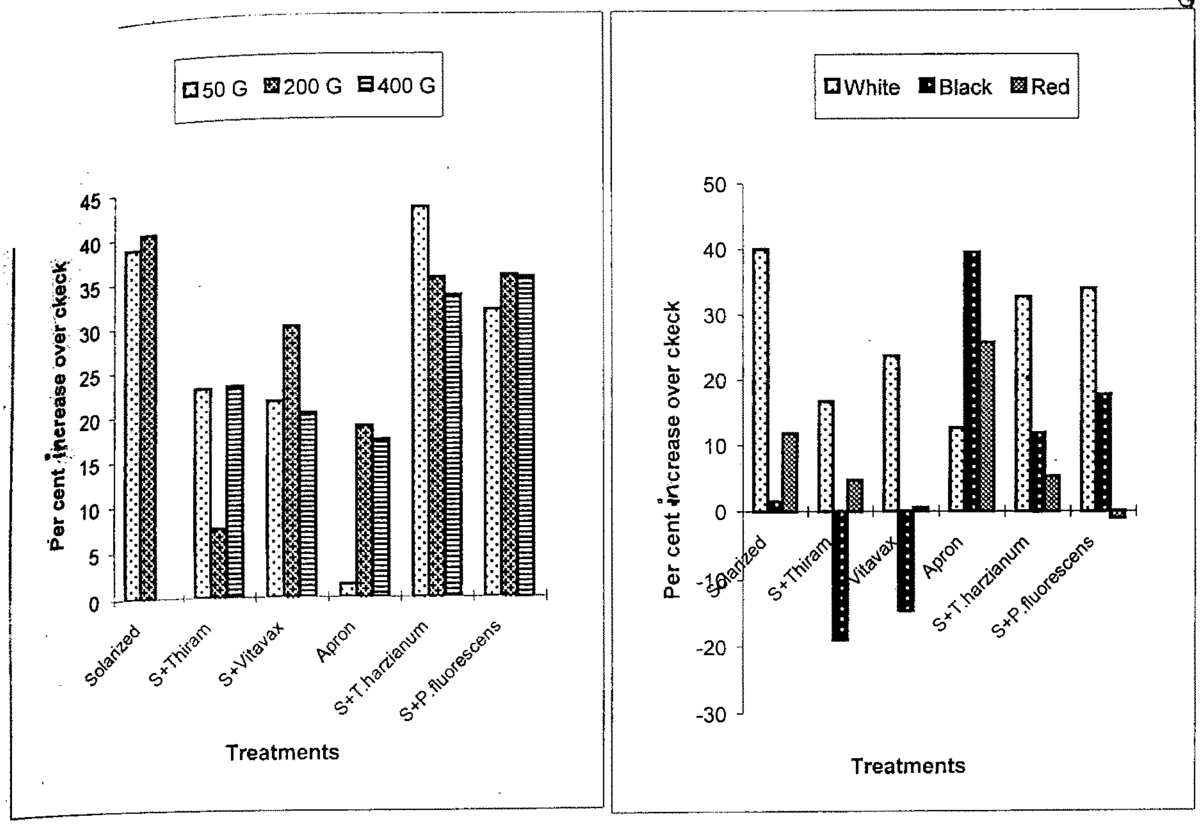
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	7.09	9357	8.50	9.04	9.04	9.71	9.57	9.45	9.57	10.2	9.45	10.8	10.15
Thiram	7.96	9.10	8.60	8.11	8.60	6.80	9.72	8.03	8.18	8.98	8.50	8.77	8.75
Vitavax	7.57	8.37	8.90	8.17	8.50	8.25	9.71	7.70	8.55	9.45	8.34	8.90	8.92
Apron	7.66	8.33	8.20	7.02	7.90	8.20	8.48	8.70	8.46	8.74	8.98	9.57	9.09
T. harzianum	8.36	9.41	9.70	8.60	9.24	8.80	10.50	9.38	9.56	8.67	5.58	8.66	8.63
P. fluorescens	8.57	9.10	9.80	9.71	9.54	9.40	9.40	8.56	9.12	9.31	10.20	9.08	9.53
Mean	7.87	8.98	8.96	8.44	8.81	8.50	9.57	8.64	8.90	9.25	9.01	9.30	9.19

Sample size: 20 plants

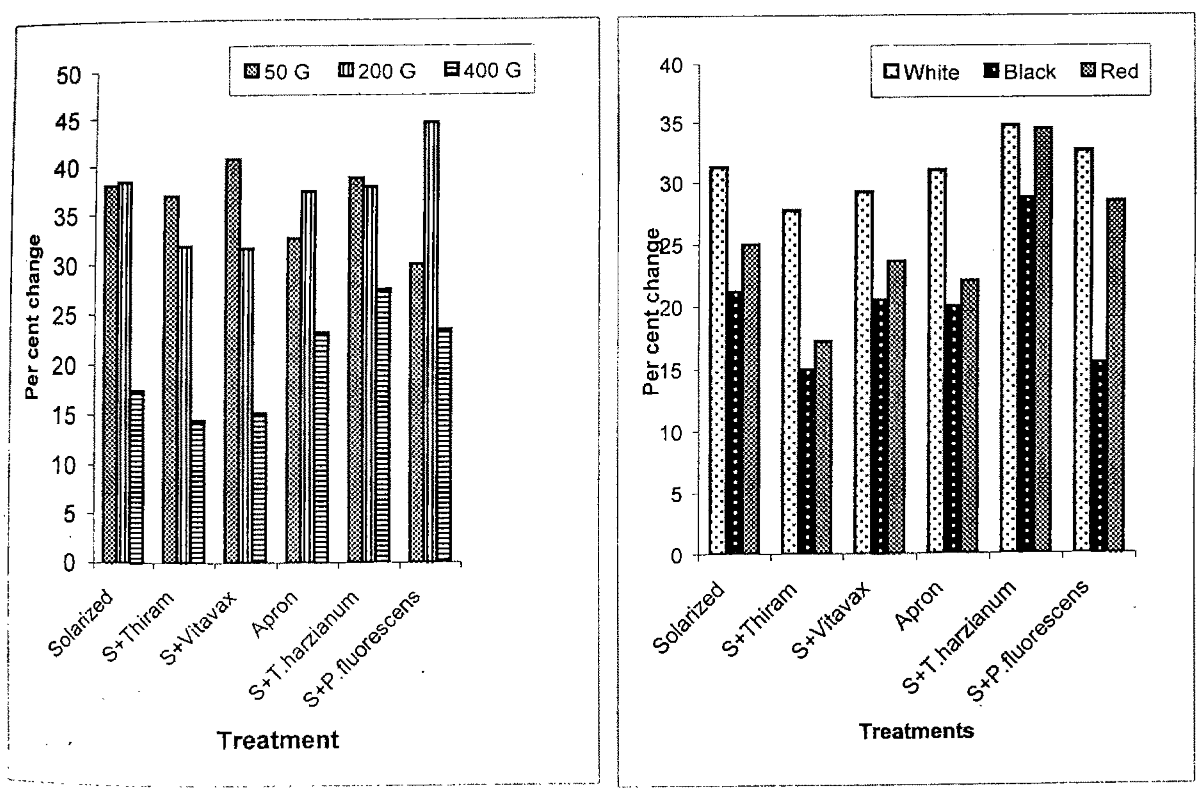
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.27	cd_1 = 0.70	cd_1 = 0.71
	cd_2 = 0.37	cd_2 = 0.49	cd_2 = -
	cd_3 = 0.74	cd_3 = 0.98	cd_3 = 0.99
	cd_4 = 0.73	cd_4 = 1.14	cd_4 = 1.13

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = **	ma = **
	su = **	su = **	su = **
	ms = **	ms = **	ms = **



A. Tomato



B. Onion

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 16 : Effect of solarization on shoot length

Table 19 : **Effect of soil solarization and its integration with seed-treatments on shoot length of calendula**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	3.30	10.50	11.51	12.07	11.36	4.96	6.01	5.47	5.48	8.00	7.00	7.53	7.51
Thiram	3.42	12.80	12.90	14.60	13.43	8.05	7.73	7.18	7.65	8.70	8.90	9.46	9.02
Vitavax	4.62	14.70	14.60	16.50	15.26	6.94	8.96	8.12	8.00	9.96	10.20	10.91	10.35
T. harzianum	4.47	13.30	14.80	13.40	13.80	9.14	7.91	9.20	8.75	9.20	10.70	10.43	10.10
P. fluorescens	4.45	12.05	14.50	13.50	13.50	10.0	9.21	8.50	9.23	9.20	9.80	10.40	9.80
Mean	4.05	12.60	13.80	14.20	13.47	7.83	7.96	7.70	7.83	9.00	9.35	9.75	9.37

Sample size: 20 plants

	White polyethylene	Black polyethylene	Red polyethylene
cd at 5%	cd_1 = 1.24	cd_1 = 1.42	cd_1 = 1.47
	cd_2 = 1.09	cd_2 = 0.97	cd_2 = 0.85
	cd_3 = 2.17	cd_3 = 1.93	cd_3 = 1.70
	cd_4 = 2.30	cd_4 = 2.23	cd_4 = 2.11

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = **	ma = **
	su = **	su = **	su = **
	ms = ns	ms = ns	ms = ns

Table 20 : **Effect of soil solarization and its integration with seed-treatments on shoot length of aster**

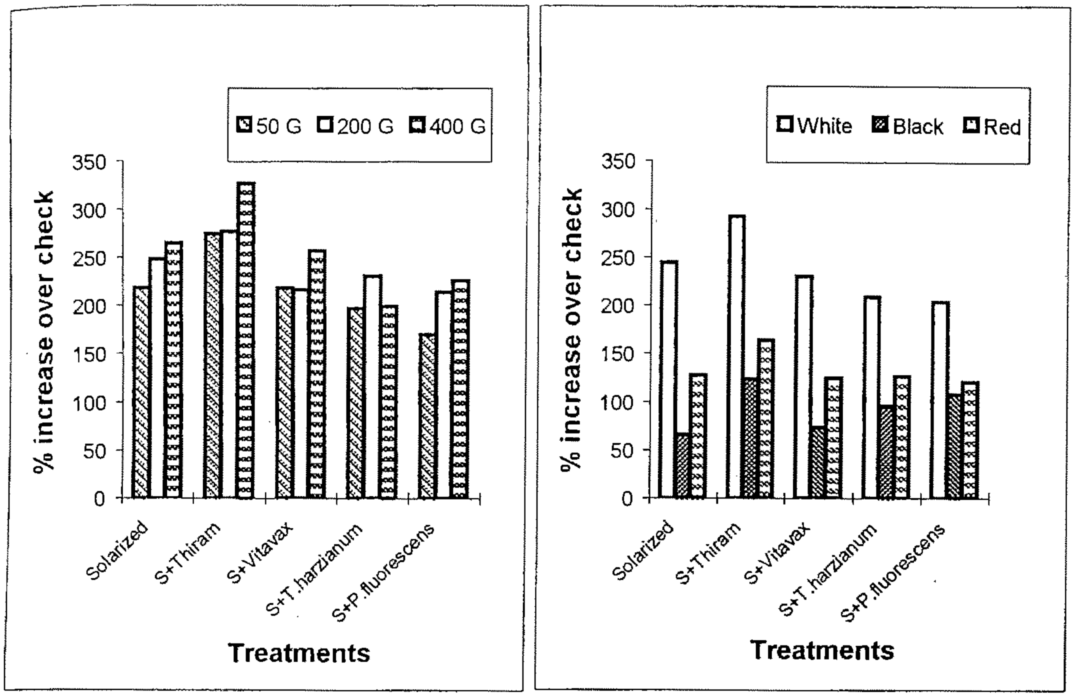
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	1.16	2.87	2.71	2.47	2.68	1.54	1.33	1.36	1.41	1.64	1.86	1.97	1.82
Thiram	1.80	2.16	2.20	2.40	2.25	1.64	1.66	1.71	1.67	1.96	2.00	2.37	2.11
Vitavax	1.62	2.30	2.47	2.48	2.41	2.00	1.83	1.85	1.89	2.09	1.98	2.00	2.02
T. harzianum	1.85	2.60	2.33	2.36	2.43	1.76	2.09	2.57	2.14	2.37	2.30	2.40	2.35
P. fluorescens	1.81	2.20	2.65	2.30	2.38	2.10	2.16	2.41	2.22	2.13	2.36	2.52	2.33
Mean	1.62	2.42	2.47	2.40	2.43	1.81	1.81	1.98	1.86	2.04	2.10	2.25	2.13

Sample size: 20 plants

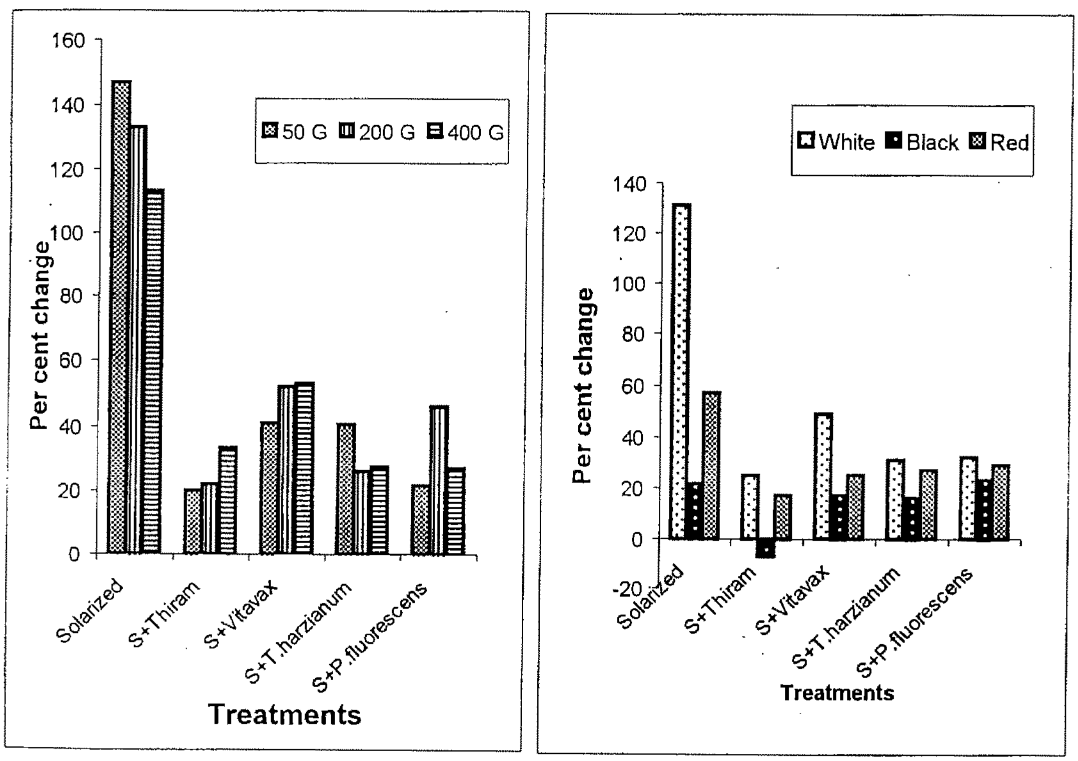
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.56	cd_1 = 0.31	cd_1 = 0.49
	cd_2 = 0.40	cd_2 = 0.35	cd_2 = 0.39
	cd_3 = 0.81	cd_3 = 0.70	cd_3 = 0.76
	cd_4 = 0.91	cd_4 = 0.69	cd_4 = 0.86

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = *	ma = ns	ma = ns
	su = ns	su = **	su = *
	ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness　　Effect of polyethylene colour

Fig. 17 : Effect of solarization on shoot length

overall increase in shoot length was about 131 per cent (Fig. 17 B). Effects due to variation in thickness of the film were non-significant. Seed-treatments with fungicides and bioagent helped in plant growth, reflected as increased shoot length.

4.3.2. Fresh Shoot Weight

4.3.2.1. Cauliflower

Fresh shoot weight of cauliflower seedlings raised in beds solarized with white transparent polyethylene sheeting increased significantly to 29.55 g from 16.23 g in control plots, with a per cent increase of above 100 per cent over check (Table 21). When seeds treated with bioagent were grown in non-solarized plots, significant increase of about 73 per cent in case of *P. fluorescens* and 49 per cent *T. harzianum* was observed over check (Fig. 18 A). Seed-treatment with bioagent was significantly superior over fungicidal seed-treatment.

Per cent increase in fresh shoot weight over check by integration of seed-treatment and solarization ranged from about 60 to 136.5 per cent. Effectivity of Apron increased greatly when integrated with solarization.

Solarization with black polyethylene sheeting caused no significant effect, however integration of seed-treatment with bioagent increased fresh shoot weight by about 31 per cent and 57 per cent in case of seed-treatment with *T. harizanum* and *P. fluorescens* respectively. Under red polyethylene sheets also, bioagent

Table 21 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of cauliflower**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	16.23	28.00	37.33	36.66	29.55	25.00	29.00	29.66	24.97	22.00	23.00	26.00	23.60
Thiram	21.33	28.00	40.33	49.66	34.83	27.66	31.66	33.00	28.41	24.00	26.30	31.30	27.20
Vitavax	17.66	30.00	42.66	47.00	34.33	32.33	31.33	33.33	28.66	27.60	27.30	42.00	32.30
Apron	17.36	31.33	44.66	47.00	35.09	33.00	30.00	33.33	28.92	28.00	29.30	37.00	31.40
T. harzianum	28.33	42.33	44.33	49.66	41.16	35.00	35.00	38.33	34.16	32.3	34.3	45.0	37.2
P. fluorescens	24.00	41.66	51.00	47.00	40.91	35.00	36.00	40.00	33.75	30.00	31.30	47.60	36.3
Mean	20.82	33.55	43.38	46.16	35.98	31.66	32.16	34.61	29.81	27.32	28.58	38.15	31.35

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 4.37	cd_1 = 2.20	cd_1 = 2.77
	cd_2 = 3.58	cd_2 = 3.22	cd_2 = 3.70
	cd_3 = 3.17	cd_3 = 6.45	cd_3 = 7.41
	cd_4 = 7.84	cd_4 = 6.28	cd_4 = 7.30

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
	ma = **	ma = **	ma = ns
	su = **	su = **	su = **
	ms = ns	ms = ns	ms = ns

were distinctly superior over chemical seed-treatment. The per cent increase in fresh shoot weight over check was 27.5 per cent with *T harzianum* and 54.2 per cent with *P. fluorescens* seed-treatment (Table 21). Amongst the colour of polyethylene sheeting, impact of white transparent sheeting was distinctly superior over the rest two (Fig. 18 A).

4.3.2.2.Cabbage

Under white polyethylene, fresh shoot weight of cabbage increased non-significantly without seed-treatment. Amongst the seed-treatments integrated with solarization, significant increase of 41 per cent over check was observed with *P fluorescens* seed-treatment but no effect of seed-treatment alone was visible (Table 22).

Solarization alone under black polyethylene sheets was not effective but integration with seed-treatment was effective. Seed-treatment with *P. fluorescens* increased fresh shoot weight significantly by above 41 per cent over check (Fig. 18 B).

Regarding the thickness of polyethylene sheeting used for solarization, varying pattern of effectivity was observed. For example *P. fluorescens* performed best under 200G thickness. Amongst the colour, white and red both were equally effective (Fig. 18 B).

4.3.2.3.Tomato

Highly significant effect of solarization was observed on tomato seedlings, grown after 60 days of solarization in succession as third

Table 22 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of cabbage**

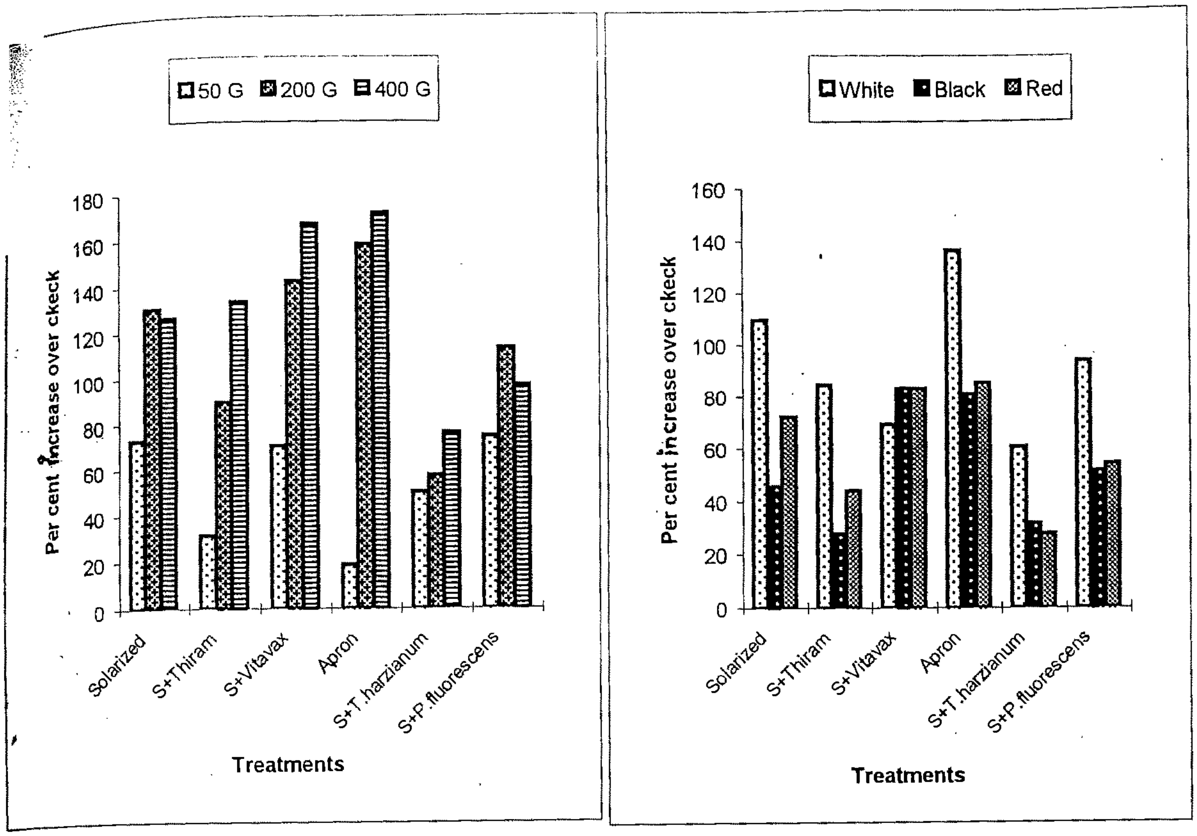
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
(No seed-treatment)	24.70	36.29	33.06	33.33	34.23	28.74	28.21	33.15	30.03	30.38	34.68	34.80	33.30
Thiram	28.58	36.13	35.58	35.31	36.67	32.83	30.71	33.98	32.50	31.11	26.91	34.00	30.67
Vitavax	26.96	36.16	31.83	37.68	35.22	30.21	30.70	32.88	31.26	32.50	36.33	35.45	34.76
Apron	26.30	33.58	32.25	36.00	33.94	32.16	33.10	32.55	32.60	31.13	35.25	36.00	34.12
T. harzianum	32.83	46.83	44.55	39.16	43.51	37.65	38.73	36.88	37.75	42.64	37.81	39.21	39.80
P. fluorescens	29.87	36.35	46.16	43.83	42.11	39.06	34.81	37.30	37.05	44.61	42.38	39.55	42.20
Mean	28.54	37.56	37.24	37.55	37.45	33.44	32.71	34.45	33.53	25.39	35.56	36.51	35.82

Sample size: 20 plants

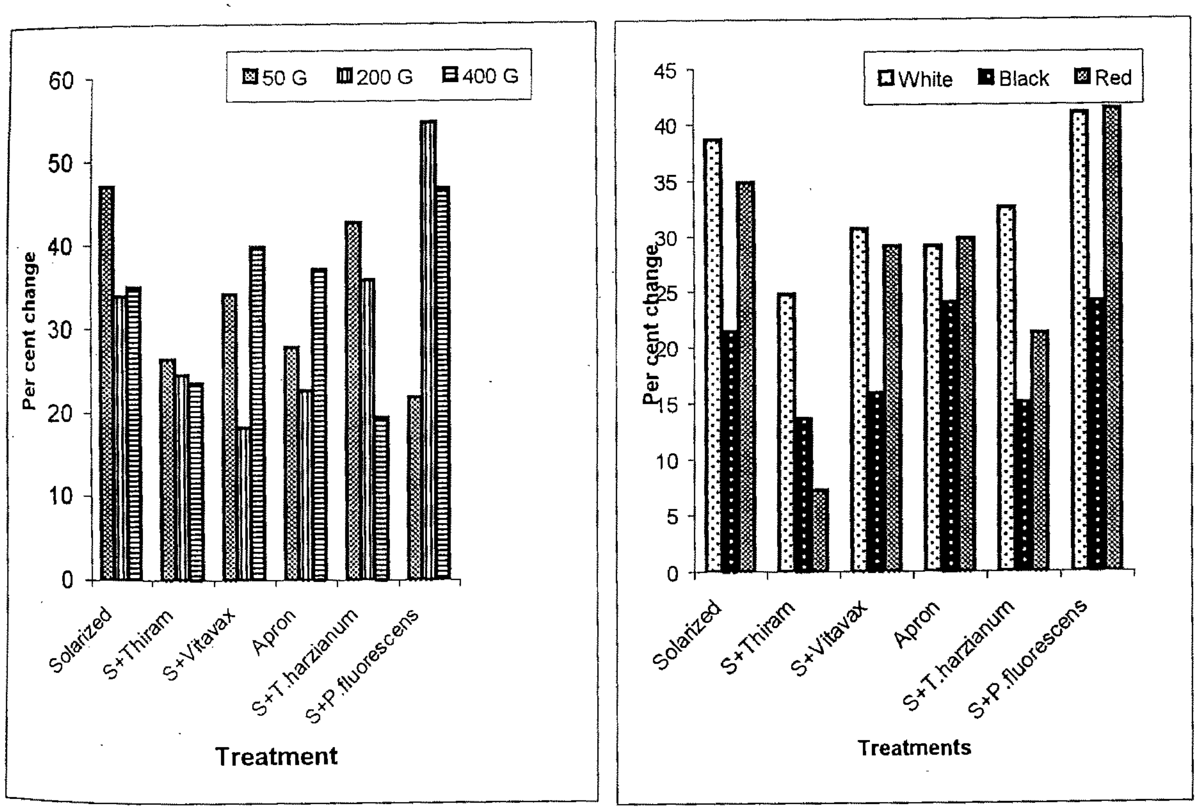
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 7.58	cd_1 = 3.55	cd_1 = 5.15
	cd_2 = 5.03	cd_2 = 3.59	cd_2 = 3.95
	cd_3 = 10.06	cd_3 = 7.19	cd_3 = 7.91
	cd_4 = 11.86	cd_4 = 7.44	cd_4 = 8.84

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
ma	= ns	= *	= *
su	= **	= **	= **
ms	= ns	= ns	= ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 18 : Effect of solarization on fresh shoot weight

crop. Fresh shoot weight increased from 29.66 g to 63.70 g but seed-treatment alone was not effective. However, integration of seed-treatment with bioagent and solarization increased fresh shoot weight of tomato by about 80 per cent in case of *T. harizanum* and 76 per cent in case of *P. fluorescens* seed-treatment over check (Fig. 19 A).

Solarization with black polyethylene sheeting was ineffective but red polyethylene sheeting had significant effect on fresh shoot weight in integration with seed-treatment with bioagent (Table 23). Amongst the colour, white transparent polyethylene sheeting were superior over red and black (Fig. 19 A).

4.2.2.4. Onion

Solarization, seed-treatment or integration of these two increased fresh shoot weight of onion significantly (Table 24). Integration of seed-treatment with *P. fluorescens* was significantly effective and increased fresh shoot weight approximately by 17 per cent over check. Effectivity of fungicides also increased to the level that fresh shoot weight of onion increased significantly up to 46.0 per cent by seed-treatment with thiram.

Under red polyethylene sheeting, somewhat similar results were obtained as with white polyethylene sheeting but extent of increase in fresh shoot weight was lesser to that observed with white transparent sheeting (Fig. 19 B). Solarization under black polyethylene sheets did not increase fresh shoot weight significantly.

Table 23 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of tomato**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	29.66	59.6	63.00	68.60	63.70	37.63	40.66	33.33	35.32	46.00	45.66	42.33	40.91
Thiram	34.66	45.00	58.30	61.00	54.70	41.66	37.66	31.33	36.33	35.33	39.33	43.00	38.08
Vitavax	34.00	49.60	49.30	54.60	51.10	30.00	37.66	35.00	34.41	39.33	37.00	40.20	37.63
Apron	35.66	50.30	45.60	53.30	49.70	38.00	36.66	33.00	35.83	39.33	32.30	39.23	36.63
T. harzianum	40.00	58.00	73.66	84.30	72.0	43.66	44.66	46.66	46.66	43.75	47.33	39.40	50.00
P. fluorescens	42.00	64.30	75.30	83.30	74.30	44.33	42.00	44.00	43.08	46.66	42.50	43.33	43.62
Mean	35.00	54.50	61.00	67.50	61.00	39.21	39.21	37.38	38.12	42.33	39.36	43.01	40.17

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 11.21	cd_1 = 9.50	cd_1 = 6.43
	cd_2 = 10.43	cd_2 = 6.90	cd_2 = 5.95
	cd_3 = 20.85	cd_3 = 13.82	cd_3 = 11.90
	cd_4 = 22.02	cd_4 = 15.76	cd_4 = 12.58

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = ns	ma = ns
	su = **	su = *	su = ns
	ms = ns	ms = ns	ms = ns

Table 24 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of onion**

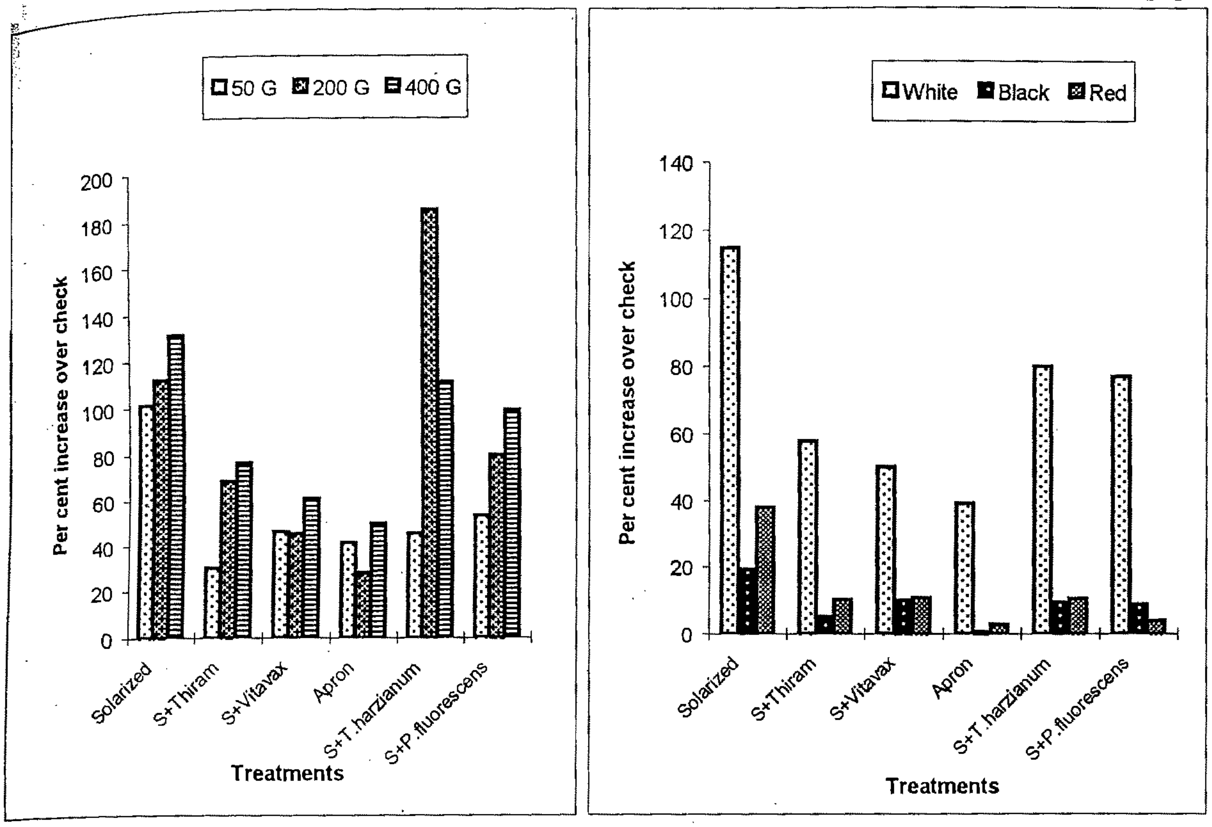
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	3.83	4.70	4.76	4.23	4.56	3.70	3.56	3.83	3.69	4.10	3.99	4.16	4.08
Thiram	3.13	4.69	4.59	4.43	4.57	3.66	3.83	4.01	3.83	3.96	3.77	3.40	3.71
Vitavax	3.73	4.83	4.06	4.90	4.59	3.58	3.56	3.83	3.65	3.69	3.80	3.26	3.58
Apron	3.66	4.16	3.83	3.61	3.86	3.95	3.56	3.93	3.81	3.96	3.93	2.98	3.62
T. harzianum	4.70	4.56	4.30	4.20	4.35	4.23	4.03	4.13	4.13	4.84	4.04	4.06	4.31
P. fluorescens	4.20	4.56	5.13	5.06	4.91	3.58	4.06	4.06	5.09	4.40	4.13	4.35	4.29
Mean	3.87	4.58	4.44	4.40	4.47	3.80	3.77	3.96	3.84	4.16	3.94	3.70	3.96

Sample size: 20 plants

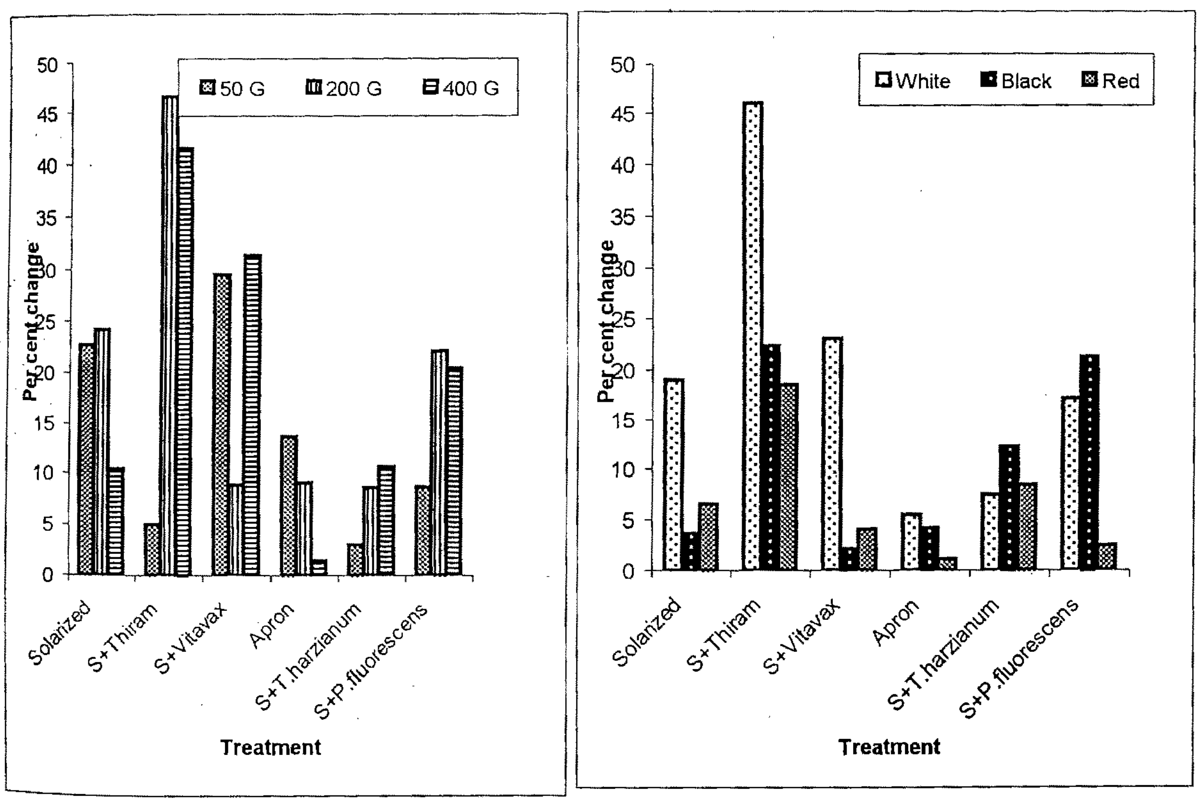
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	$cd_1 = 0.23$	$cd_1 = 0.15$	$cd_1 = 0.34$
	$cd_2 = 0.24$	$cd_2 = 0.31$	$cd_2 = 0.72$
	$cd_3 = 0.49$	$cd_3 = 0.62$	$cd_3 = 0.25$
	$cd_4 = 0.50$	$cd_4 = 0.59$	$cd_4 = 0.52$

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = ns	ma = *
su = **	su = **	su = **
ms = **	ms = ns	ms = *



A. Tomato



B. Onion

Effect of polyethylene thickness   Effect of polyethylene colour

Fig. 19 : Effect of solarization on fresh shoot weight

4.2.2.5 Calendula

Solarization increased fresh shoot weight of calendula highly significantly, irrespective of colour of polyethylene sheets used for solarization. But seed-treatment alone could not have any significant effect. By integration with solarization, efficacy of seed-treatment increased fresh shoot weight significantly. Per cent increase observed due to integration of solarization and seed-treatment reached up to 46 per cent over check with Thiram seed-treatment (Table 25). Chemical seed-treatment was more effective in integration with solarization in increasing fresh shoot weight of calendula (Fig. 20 A).

4.2.2.6 Aster

Fresh shoot weight of aster seedlings increased significantly (Table 26). The increase was about 130 per cent over check by solarization without seed-treatment. Seed-treatment with bioagents further significantly increased fresh shoot weight of aster too, by 176 per cent and 143 per cent over check with *T. harzianum* and *P. fluorescens,* respectively. Integration of these two further increased the fresh shoot weight but non-significantly. The seed-treatment alone or in integration were not found significant under black polyethylene sheets. Similarly, solarization under red polyethylene sheets could not increase fresh shoot weight significantly in integration with seed-treatment.

Per cent increase over check (Fig. 20 B) shows that solarization with white transparent polyethylene sheets was distinctly superior

Table 25 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of calendula**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	1.79	3.80	4.10	4.50	4.13	1.73	2.37	2.55	2.21	2.71	2.85	3.20	2.92
Thiram	2.12	5.30	4.97	5.00	5.09	2.63	2.63	3.01	2.75	2.95	3.07	3.45	3.15
Vitavax	1.91	4.90	4.80	5.32	5.00	2.71	2.96	2.76	2.81	3.16	3.33	3.51	3.33
T. harzianum	1.70	4.70	5.00	4.40	4.70	3.53	3.41	3.40	3.44	3.54	3.75	3.62	3.63
P. fluorescens	1.87	4.00	4.77	4.90	4.55	3.44	3.35	3.45	3.45	3.38	3.68	3.82	3.62
Mean	1.87	4.50	4.74	4.80	4.68	2.81	2.94	3.03	2.93	3.15	3.33	3.52	3.33

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.63	cd_1 = 0.23	cd_1 = 0.47
	cd_2 = 1.56	cd_2 = 0.43	cd_2 = 0.35
	cd_3 = 0.47	cd_3 = 0.87	cd_3 = 0.71
	cd_4 = 1.10	cd_4 = 0.81	cd_4 = .78

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
ma	= **	= **	= **
su	= *	= **	= *
ms	= *	= ns	= ns

Table 26 : **Effect of soil solarization and its integration with seed-treatments on fresh shoot weight of aster**

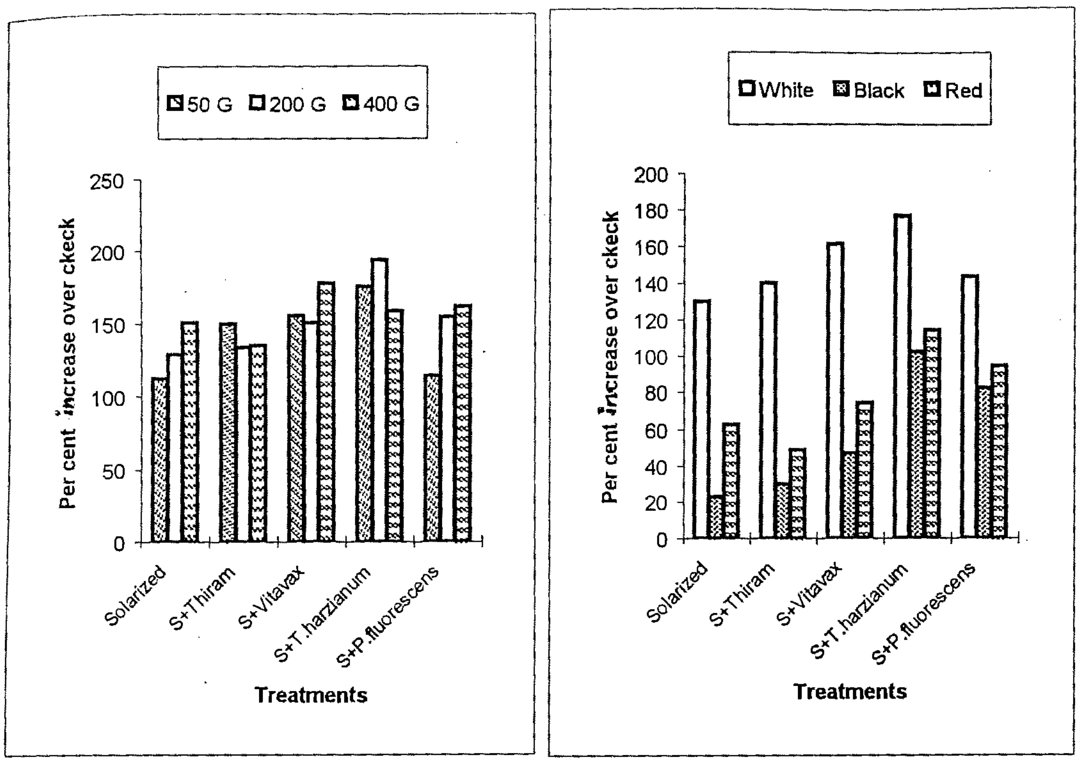
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	5.78	1.02	10.00	11.60	10.60	8.47	9.90	9.70	9.35	11.60	10.10	18.30	11.45
Thiram	7.23	12.40	10.50	12.50	11.80	8.63	13.10	13.20	11.60	12.10	13.50	14.20	11.70
Vitavax	8.07	13.0	12.0	13.20	12.70	9.20	12.20	12.70	11.30	14.30	11.40	18.20	12.50
T. harzianum	9.41	13.40	13.10	13.30	13.20	10.70	15.0	10.60	11.90	13.40	14.40	15.00	13.06
P. fluorescens	8.75	14.20	14.80	13.70	14.20	10.30	13.40	13.50	12.40	13.11	14.40	15.60	12.96
Mean	7.84	12.60	12.10	12.80	12.50	9.34	12.70	1.90	11.30	12.90	12.76	16.20	12.30

Sample size: 20 plants

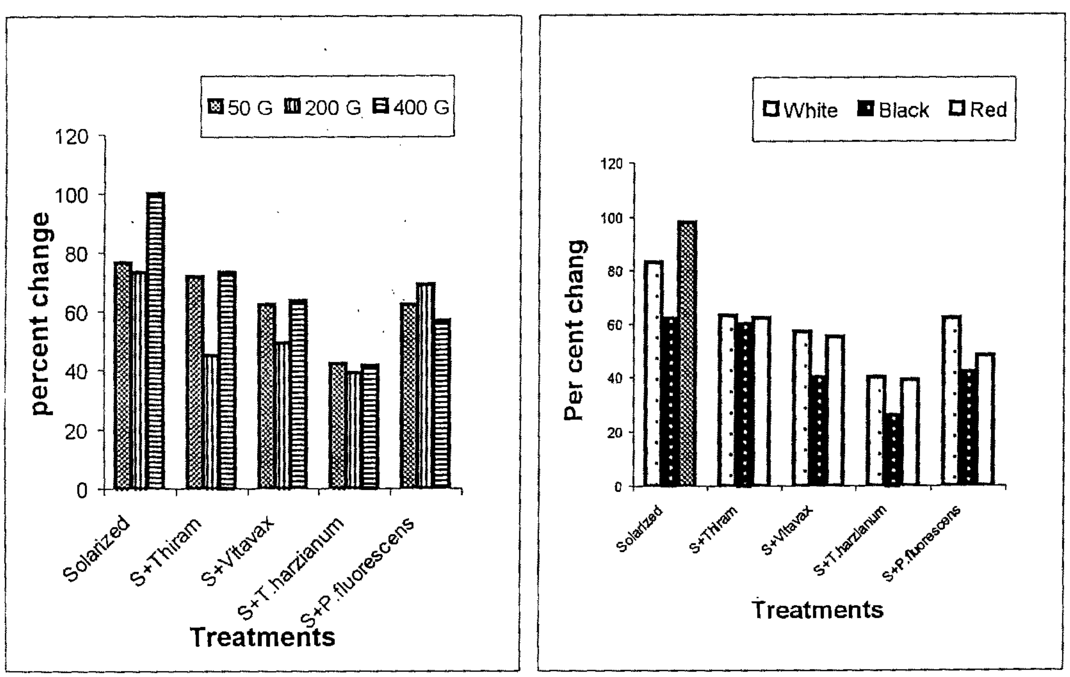
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 1.56	cd_1 = 2.20	cd_1 = 1.78
	cd_2 = 1.31	cd_2 = 2.28	cd_2 = 2.10
	cd_3 = 2.63	cd_3 = 4.57	cd_3 = 4.20
	cd_4 = 2.81	cd_4 = 4.63	cd_4 = 4.15

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = **	ma = **
	su = **	su = ns	su = ns
	ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness **Effect of polyethylene colour**

Fig. 20 : Effect of solarization on fresh shoot weight

over rest two and the thickness of 200 G resulted in maximum per cent increase in fresh shoot weight of aster compared to 50 G or 400 G.

4.3.3 Dry shoot weight

4.3.3.1 Cauliflower

The results concerning the effects of solarization and its integration with seed-treatments on dry shoot weight are presented in Table 27 and Fig. 21 A. In non-solarized soil, dry shoot weight of seedlings raised without seed-treatment was 2.69g and increased significantly to 4.53 g and 4.27 g in seedlings raised from seed treated with bioagents *T. harizanum* and *P. fluorescens,* respectively. Fungicidal seed-treatment also improved weight but non-significantly.

Solarization with white transparent polyethylene sheets increased dry shoot weight significantly to 5.69 g even in plots sown without treated seeds. Integration of seed-treatment and solarization further caused significant increase from 5.69 g to 7.40 g and 7.44g with *T. harzianum* and *P. Fluorescens* seed-treatments, respectively.

Fungicidal seed-treatment though did not have significant effect of its own, but in integration with solarization it also increased dry shoot weight to 6.06 g, 5.95 g and 5.74 g by treating the seeds with Thiram, Vitavax and Apron, respectively (Table 27).

The impact of polyethylene sheets was non-significant. Nevertheless, per cent increase over check was maximum (above 128

Table 27 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of cauliflower**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	2.69	5.30	6.18	5.59	5.69	4.09	4.46	4.49	4.34	4.31	5.13	4.84	4.76
Thiram	2.81	5.38	6.69	5.81	6.06	4.32	4.28	4.30	4.30	4.65	5.61	6.64	5.30
Vitavax	3.19	5.00	6.34	6.53	5.95	4.16	4.50	4.82	4.50	4.71	4.50	5.15	4.78
Apron	3.71	5.34	6.22	5.67	5.40	4.46	4.56	4.62	4.54	5.53	5.35	5.93	5.60
T. harzianum	4.53	7.00	7.26	7.95	7.40	4.76	5.25	6.30	5.43	5.73	6.20	6.30	6.07
P. fluorescens	4.72	7.33	7.47	7.54	7.44	5.22	5.40	6.26	5.62	6.87	6.62	6.46	6.65
Mean	3.51	5.89	6.69	6.52	6.37	4.50	4.74	5.13	4.79	5.30	5.57	5.72	5.53

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	$cd_1 = 1.03$	$cd_1 = 0.38$	$cd_1 = 0.76$
	$cd_2 = 0.54$	$cd_2 = 0.45$	$cd_2 = 0.55$
	$cd_3 = 1.09$	$cd_3 = 0.90$	$cd_3 = 1.10$
	$cd_4 = 1.43$	$cd_4 = 0.90$	$cd_4 = 1.25$

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = **	su = **	su = **
ms = ns	ms = ns	ms = ns

per cent) under 200 G thickness in plots sown with non treated seed but when seed-treatment was integrated with solarization, maximum increase was observed under 400 G thickness.

Under black and red polyethylene sheets also, integration of bio-agent seed-treatment was effective. Per cent increase in dry shoot weight over check (Fig. 21 A) shows that white transparent polyethylene sheets was best as it increased dry shoot weight up to a maximum of 115 per cent over check, followed by red (88.6) and black (5.3 per cent) coloured polyethylene sheets.

4.3.3.2 Cabbage

Dry shoot weight was 2.40 g in control plots, which increased significantly, to a mean value of 4.46 g after solarization. Seed-treatment with bioagent affected dry shoot weight significantly (Table 28).

In fact, solarization or seed-treatment increased dry shoot weight significantly, but no significant effect of integration of these two was observed. For example, dry shoot weight was 4.46 g in solarized plots without seed-treatment and it was 4.53 g in non-solarized plots sown with *P fluorescens* treated seeds. Integration of solarization and seed-treatment with *P. fluorescens* increased dry shoot weight but non-significantly. Under black and red polyethylene sheets also, the impact of *P. fluorescens* seed-treatment was maximum amongst the seed-treatments under red polyethylene sheets. Apron too, was found effective besides *P. fluorescens*. But

Table 28 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of cabbage**

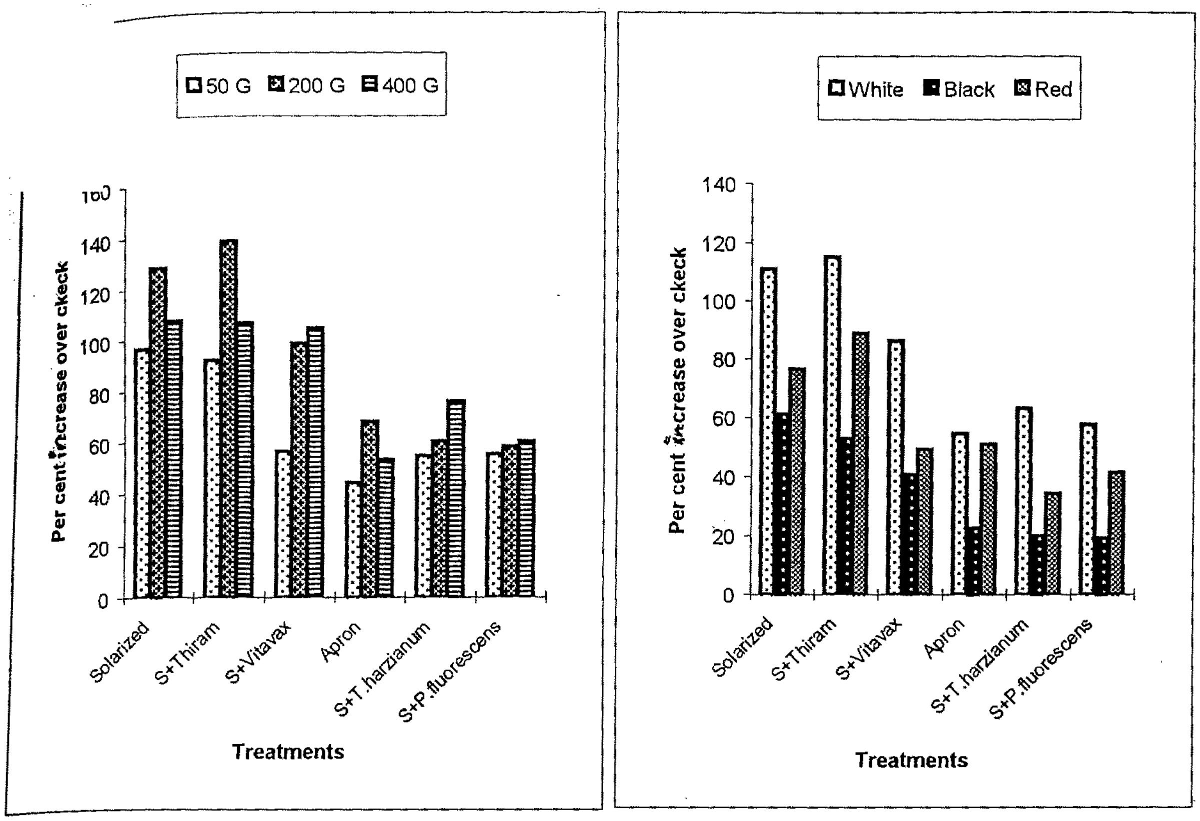
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	2.40	4.90	4.09	4.41	4.46	3.51	3.89	4.40	3.93	3.83	4.53	4.35	4.29
Thiram	2.51	3.73	4.24	4.36	4.11	3.40	3.69	4.39	3.82	3.68	3.69	4.35	3.90
Vitavax	2.74	3.70	4.09	4.39	4.06	3.15	3.72	3.77	3.54	3.87	3.76	4.51	4.04
Apron	3.03	3.62	7.70	4.61	4.31	3.50	4.00	4.63	4.04	3.13	4.02	3.87	3.67
T. harzianum	3.75	4.54	4.33	4.59	4.47	5.12	4.41	4.99	4.58	5.71	5.62	5.27	5.53
P. fluorescens	4.53	4.84	5.56	4.96	5.12	4.64	4.69	5.25	4.86	5.47	5.61	5.55	5.54
Mean	3.16	4.23	4.50	4.55	4.43	3.89	4.15	4.57	4.20	4.28	4.54	6345	4.49

Sample size: 20 plants

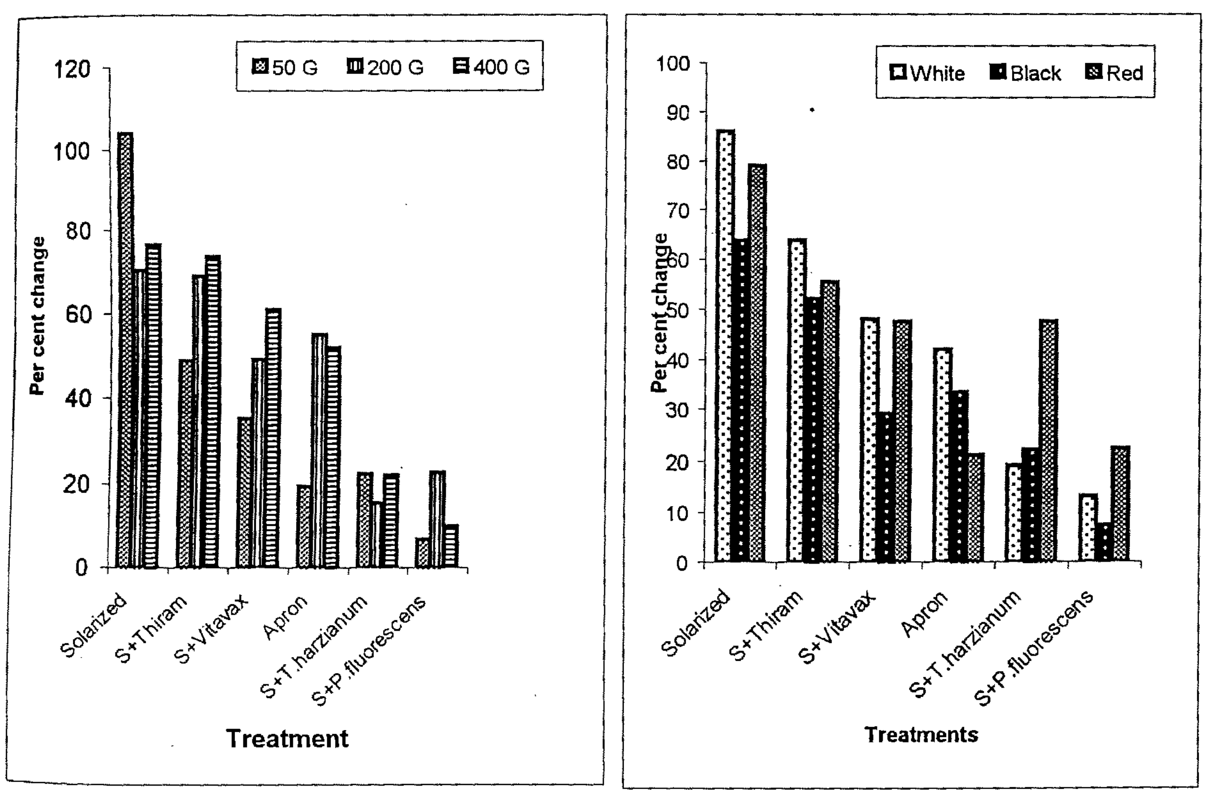
cd at 5%	cd_1 = 0.62	cd_1 = 0.88	cd_1 = 0.38
	cd_2 = 0.55	cd_2 = 0.43	cd_2 = 0.58
	cd_3 = 1.10	cd_3 = 0.87	cd_3 = 1.17
	cd_4 = 1.18	cd_4 = 1.18	cd_4 = 1.13

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = *	ma = **
su = **	su = **	su = **
ms = ns	ms = ns	ms = ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 21 : Effect of solarization on dry shoot weight

chemical seed-treatment was observed to have no effect on dry shoot weight when integrated with solarization, except apron that too under black polyethylene sheets, which resulted in a little increase over plants raised in solarized plots without seed-treatment. Under red polyethylene sheets only *T. harzianum* seed-treatment had significant effect on dry shoot weight resulting in about 47 per cent increase over check. Variation in thickness of polyethylene sheets invariably had non-significant effect on dry shoot weight (Fig. 21 B). In fact per cent increase over check was maximum under 50 G thick polyethylene sheets.

4.3.3.3 Tomato

The effect of seed-treatment was non-significant. However, integration with solarization under white polyethylene sheets and seed-treatment with thiram increased dry shoot weight significantly from 2.23 g to 3.90 g. Under black polyethylene sheets, the change in dry shoot weight was non-significant. Solarization under red polyethylene sheets significantly increased dry shoot weight of tomato by over 62 per cent and 51 per cent with Thiram and Apron seed-treatments, respectively (Table 29 and Fig. 22 A).

4.3.3.4 Onion

The effect of solarization and its integration with seed-treatment on the dry shoot weight of the 4th crop grown in succession at VRC, is presented in Table 30. Solarization alone with white transparent polyethylene sheets increased dry shoot weight

Table 29 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of tomato**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	2.54	3.90	4.11	3.56	3.85	3.58	4.03	3.68	3.76	4.21	4.16	4.00	4.12
Thiram	2.23	3.66	4.01	4.01	3.90	4.00	3.83	3.90	3.91	3.73	4.16	3.81	3.90
Vitavax	3.00	3.80	4.13	3.80	3.91	2.86	3.86	3.30	3.34	3.55	3.55	3.80	3.63
Apron	2.55	3.40	3.92	4.15	3.82	3.93	3.90	3.85	3.90	3.63	3.80	4.18	3.87
T. harzianum	3.41	4.18	4.25	4.70	4.37	4.11	4.50	4.58	4.40	4.19	4.30	4.62	4.37
P. fluorescens	3.50	4.30	4.33	4.40	4.30	4.41	4.23	4.31	4.31	4.36	4.35	4.55	4.42
Mean	2.87	3.87	4.12	4.13	4.03	3.82	4.06	3.93	3.94	3.93	4.05	4.16	4.01

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.43	cd_1 = 0.99	cd_1 = 0.41
	cd_2 = 0.73	cd_2 = 0.68	cd_2 = 0.65
	cd_3 = 1.47	cd_3 = 1.36	cd_3 = 1.31
	cd_4 = 1.41	cd_4 = 1.58	cd_4 = 1.26

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = ns	ma = **
	su = ns	su = ns	su = ns
	ms = ns	ms = ns	ms = ns

Table 30 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of onion**

Treatments	**Non-solarized**	**Solarized**											
		White polyethylene				**Black polyethylene**				**Red polyethylene**			
		50 G	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**	**50 G**	**200 G**	**400 G**	**Mean**
Control	1.50	2.33	2.10	2.20	2.21	2.50	2.20	2.00	2.23	2.00	2.60	2.00	2.20
Thiram	1.80	2.36	1.85	2.00	2.07	2.00	2.00	1.92	1.97	2.00	2.03	2.00	2.01
Vitavax	1.80	2.36	1.85	2.00	2.07	2.00	2.00	1.92	1.97	2.00	2.03	2.00	2.01
Apron	1.61	1.99	2.00	2.05	2.01	1.85	2.03	1.81	1.89	1.90	2.50	1.95	2.11
T. harzianum	2.00	2.30	2.30	2.03	2.21	2.30	2.11	1.96	2.12	2.20	2.00	2.00	2.06
P. fluorescens	2.00	2.40	2.50	2.30	2.40	2.04	2.17	2.04	2.08	2.09	2.70	2.17	2.32
Mean	1.79	2.23	2.16	2.10	2.16	2.12	2.10	1.93	2.05	2.05	2.32	2.07	2.14

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	$cd_1 = 0.36$	$cd_1 = 0.15$	$cd_1 = 0.19$
	$cd_2 = 0.23$	$cd_2 = 0.18$	$cd_2 = 0.18$
	$cd_3 = 0.46$	$cd_3 = 0.36$	$cd_3 = 0.37$
	$cd_4 = 0.55$	$cd_4 = 0.36$	$cd_4 = 0.38$

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = ns	ma = **	ma = **
	su = *	su = *	su = *
	ms = ns	ms = ns	ms = *

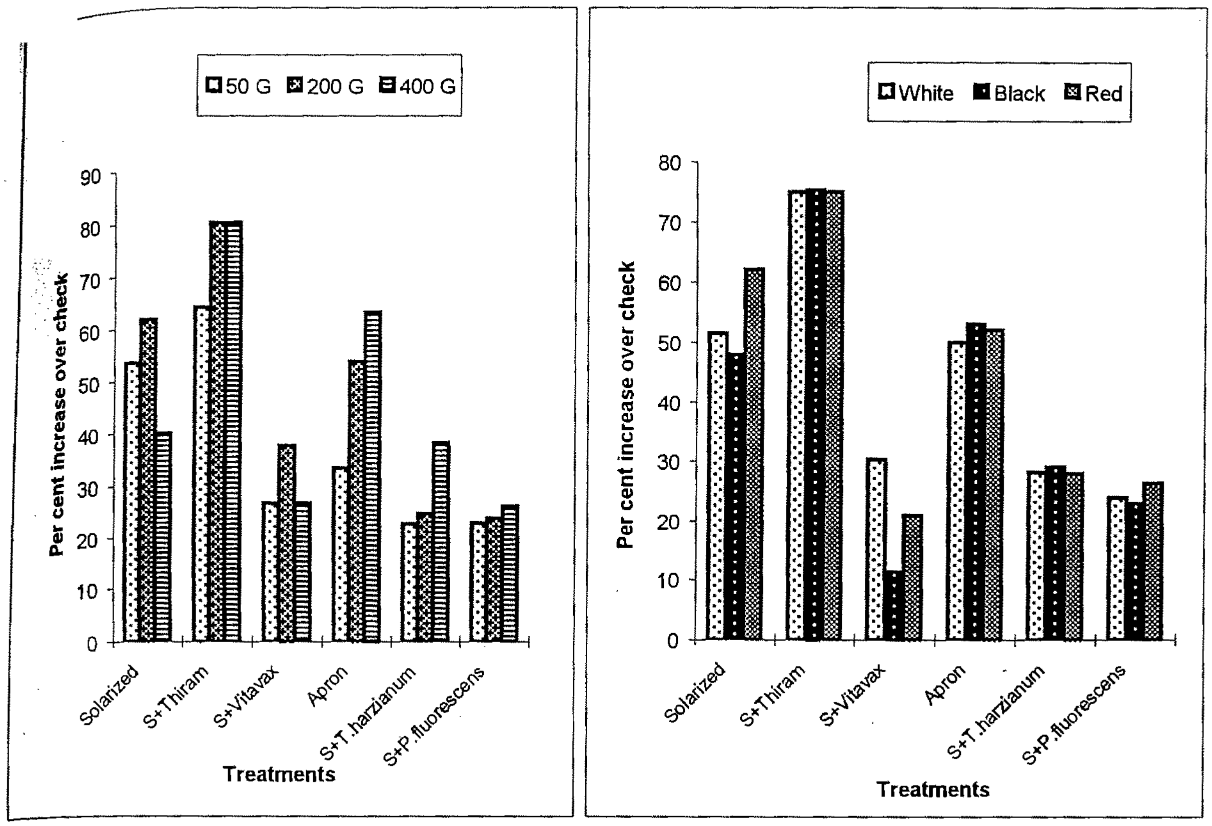
significantly but seed-treatment alone with fungicides was not effective but bioagent increased dry shoot weight to 2.0 g from 1.5 g in non-seed treated control. Integration of solarization and seed-treatment was not significant.

Under black polyethylene sheets also solarization without seed-treatment and seed-treatment alone with bioagent increased dry shoot weight significantly but integration was not effective. But under red polyethylene sheets integration of seed-treatment with Vitavax and apron and solarization increased dry shoot weight though non-significantly to 2.17 g and 2.71 g, respectively with respective per cent increase of about 20 per cent and 37 per cent over check (Fig. 22 B).

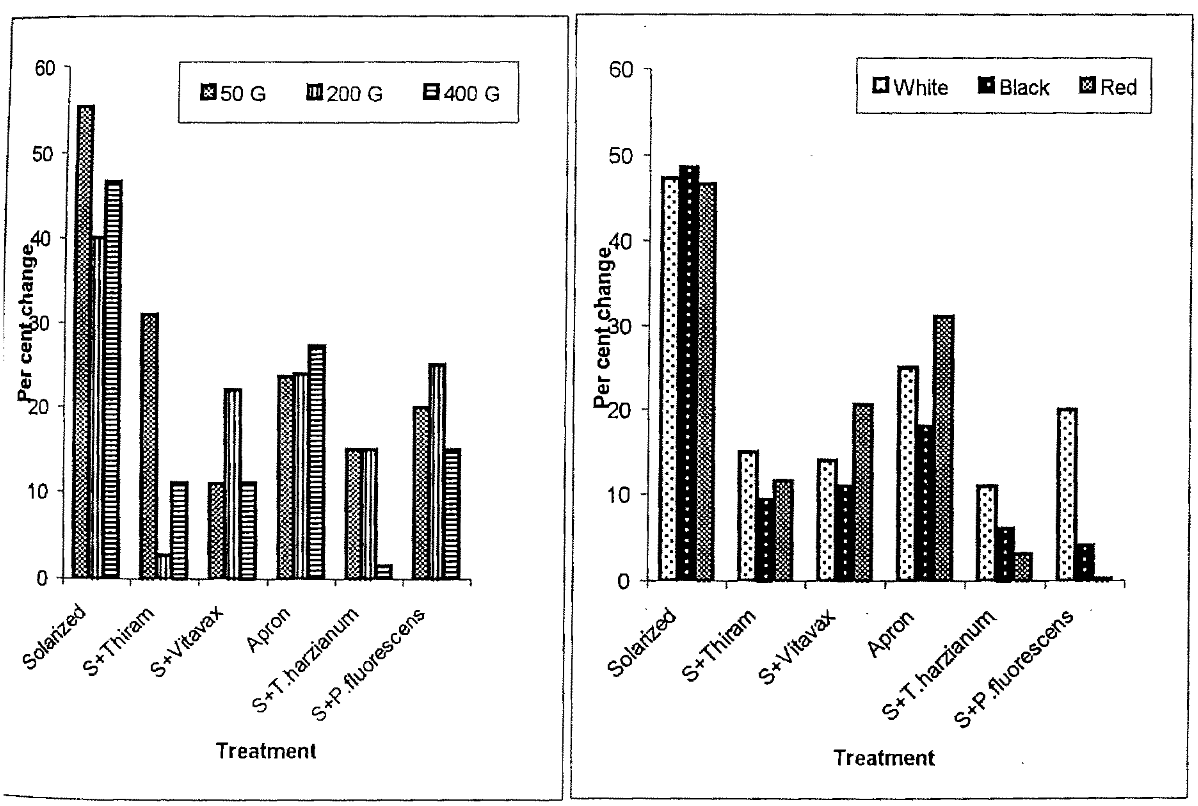
Fifty G thickness of polyethylene sheets was most effective when no seed-treatment was done but different seed-treatments had varied reaction under polyethylene sheets of different thickness. Vitvax seed-treatment gave best results under red polyethylene with a maximum per cent increase of above 20 per cent over check (Fig. 22 B).

4.3.3.5 Calendula

Calendula was the first crop raised after solarization for 30 days. In control plots dry shoot weight was 0.28 g. A tremendous increase of above 200 per cent was observed under white transparent polyethylene sheets with Thiram seed-treatment followed by *P. fluorescens* (193 per cent) and *T. harzianum* (186 per cent) over



A. Tomato



B. Onion

Effect of polyethylene thickness **Effect of polyethylene colour**

Fig. 22 : Effect of solarization on dryshoot weight

check. But seed-treatment alone did not being any significant increase in dry shoot weight (Table 31).

Under black polyethylene sheets (*T. harzianum* and *P. fluorescens*) bioagent increased dry shoot weight by above 60 per cent and 70 per cent, respectively over check.

Vitavax seed-treatment was most effective when treated seeds were sown in plots solarized under red polyethylene sheets with a significant increase in dry shoot weight about 122 per cent over check (Fig. 23 A).

Differences in dry shoot weight due to variation in polyethylene sheets' thickness were inconsistent but colour of polyethylene sheets did affect the dry shoot weight. Maximum increase in dry shoot weight ranging from 100 per cent to 215 per cent over check was observed under white transparent polyethylene sheets with almost all the seed-treatments (Fig. 23 A).

4.3.3.6 Aster

The effect of solarization was highly significant as it increased dry shoot weight of aster from 24.87 to 55.47 per cent but seed-treatment alone did not cause any significant effect on dry shoot weight.

Under white polyethylene sheets, maximum increase was observed (60 per cent) when *P. fluorescens* treated seeds were sown. Integration of seed-treatment with solarization increased dry shoot weight from 2.17 g to 2.64 g but it was non-significant. Solarization

Table 31 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of calendula**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.28	0.59	0.68	0.70	0.65	0.28	0.32	0.28	0.29	0.43	0.44	0.45	0.44
Thiram	0.36	0.59	0.78	0.80	0.72	0.46	0.42	0.37	0.41	0.47	0.54	0.52	0.51
Vitavax	0.27	0.70	0.91	0.95	0.85	0.34	0.43	0.43	0.40	0.56	0.56	0.70	0.60
T. harzianum	0.030	0.77	0.87	0.86	0.83	0.57	0.43	0.44	0.48	0.52	0.55	0.55	0.54
P. fluorescens	0.30	0.88	0.81	0.88	0.85	0.58	0.48	0.49	0.51	0.52	0.57	0.54	0.54
Mean	0.30	0.70	0.81	0.84	0.78	0.44	0.43	0.40	0.42	0.50	0.53	0.55	0.53

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	$cd_1 = 0.82$	$cd_1 = 0.63$	$cd_1 = 0.11$
	$cd_2 = 0.80$	$cd_2 = 0.83$	$cd_2 = 0.75$
	$cd_3 = 0.16$	$cd_3 = 0.22$	$cd_3 = 0.15$
	$cd_4 = 0.16$	$cd_4 = 0.16$	$cd_4 = 0.17$

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = **	su = **	su = **
ms = ns	ms = ns	ms = ns

with black polyethylene sheets was least effective. The increase ranging from 13 per cent 37 per cent over check was recorded (Table 32). In fact, integration of solarization and seed-treatment was not significant but noticeable increase in dry shoot weight was observed compared to seed-treatment or solarization alone.

In case of aster best results were observed under red polyethylene sheets as compared to the rest two (Fig. 23 B).

4.3.4 Fresh root weight

4.3.4.1 Cauliflower (Ist crop)

Observations pertaining to fresh root weight of 30 days old cauliflower plants are presented in Table 33 and Fig. 24 A. It is evident that fresh root weight of plants raised in non-solarized soil did not differ. It was 2.77 g in check. Treatment of the seeds with bioagent and fungicides improved root weight but non-significantly. Among the treatments effect of bioagent was obvious. The root weight of the seedlings raised in soil solarized using white transparent polyethylene of 50G, increased significantly. In solarized soil even without integration with seed-treatment, the weight increased by 67.8 per cent over check (Fig. 24 A). Fungicides and bioagent improved root weight further, under solarized conditions. For example seed-treatment with thiram improved weight by 56 per cent over check. In solarization using white sheeting of 200 G, root weight increased by over 39 per cent to 77.3 per cent. Among the integrating variables thiram was most effective. Almost similar

Table 32 : **Effect of soil solarization and seed-treatment integration on dry shoot weight of aster**

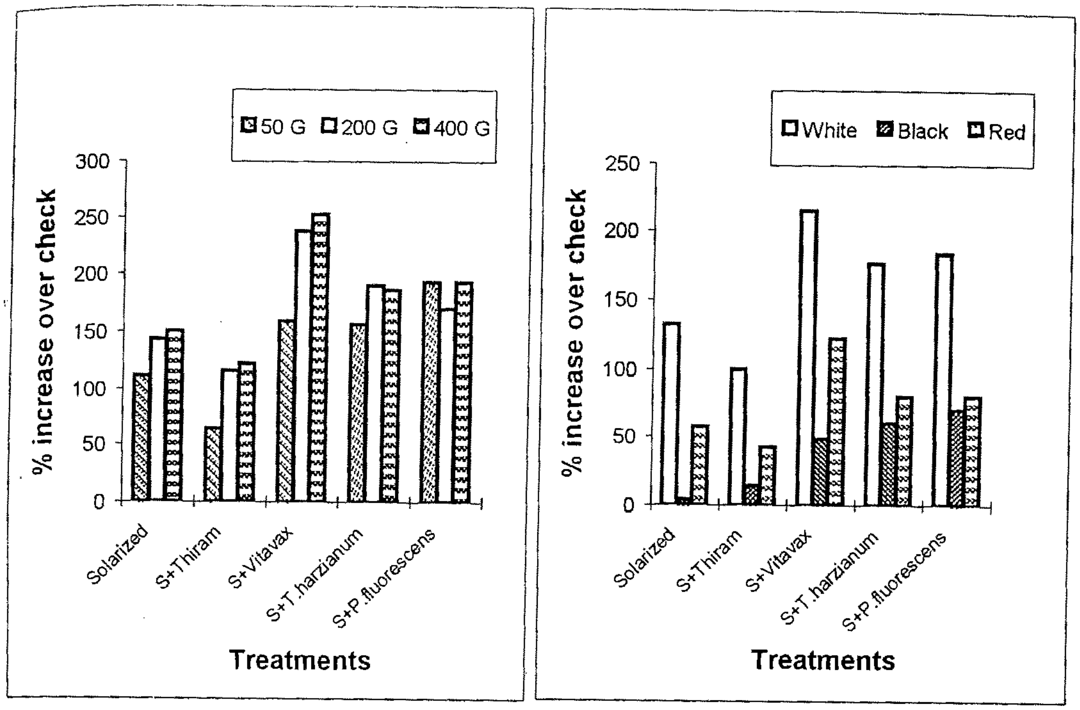
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	1.46	2.09	2.07	2.35	2.17	1.78	1.65	1.52	1.65	2.17	2.71	2.24	2.37
Thiram	1.50	2.26	2.34	2.22	2.27	1.94	2.04	1.76	1.91	1.90	2.85	2.37	2.37
Vitavax	1.58	2.17	2.35	2.41	2.31	2.13	2.13	1.86	2.04	2.55	2.44	2.50	2.49
T. harzianum	2.05	2.44	2.40	2.84	2.56	2.05	2.60	2.53	2.39	2.80	2.93	2.65	2.79
P. fluorescens	1.83	2.55	2.90	2.48	2.64	2.34	2.64	2.56	2.51	2.70	2.46	2.66	2.26
Mean	1.68	2.30	2.41	2.46	2.39	2.05	2.21	2.07	2.11	2.42	2.68	2.48	2.52

Sample size: 20 plants

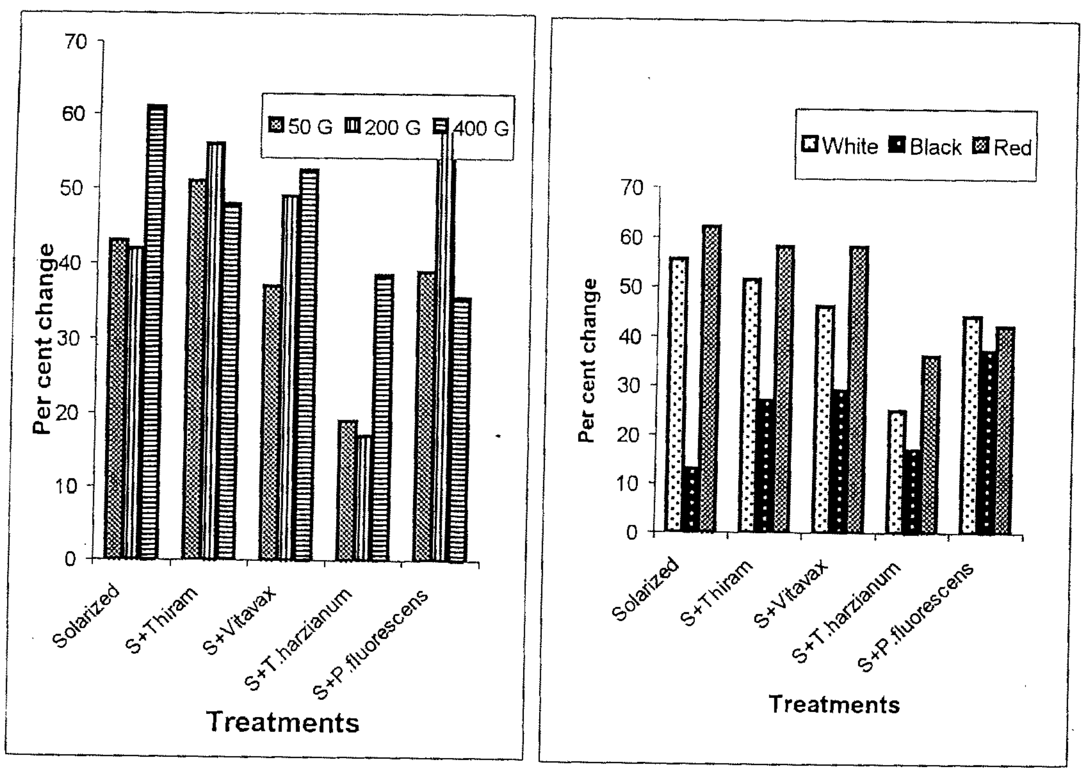
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.17	cd_1 = 0.29	cd_1 = 0.47
	cd_2 = 0.32	cd_2 = 0.35	cd_2 = 0.28
	cd_3 = 0.65	cd_3 = 0.71	cd_3 = 0.56
	cd_4 = 0.60	cd_4 = 0.70	cd_4 = 0.68

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = *	ma = *
	su = *	su = **	su = *
	ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness **Effect of polyethylene colour**

Fig. 23 : Effect of solarization on dry shoot weight

Table 33 : **Effect of soil solarization and its integration with seed-treatments on fresh root weight of cauliflower**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	2.773	4.646	4.690	4.956	4.266	3.536	3.430	5.636	3.344	3.763	4.426	4.130	3.773
Thiram	3.133	4.900	5.546	5.633	4.803	3.373	3.920	3.856	6.675	6.623	4.086	4.033	3.761
Vitavax	3.666	4.620	5.400	5.836	4.930	4.020	3.283	3.876	3.761	4.340	4.070	4.096	4.093
Apron	3.513	4.636	4.98	5.203	4.509	3.386	3.700	3.750	3.312	3.850	4.306	4.733	4.125
T. harzianum	3.933	5.563	6.110	6.536	5.535	4.646	4.413	4.756	4.437	4.993	52.33	5.026	4.784
P. fluorescens	3.853	5.810	5.910	6.090	5.475	3.863	4.053	4.776	4.179	4.650	4.903	4.823	4.555
Main plot mean	3.528	5.029	5.44	5.709	4.926	3.804	3.800	4.098	3.315	4.195	4.504	4.472	4.182

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.37	cd_1 = 0.44	cd_1 = 0.37
	cd_2 = 0.46	cd_2 = 0.43	cd_2 = 0.40
	cd_3 = 0.93	cd_3 = 0.85	cd_3 = 0.81
	cd_4 = 0.93	cd_4 = 0.90	cd_4 = 0.83

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = ns	ma = **
su = **	su = **	su = **
ms = ns	ms = ns	ms = ns

observations were recorded with 400G as well. Improvement in weight computed over non-solarized, ranged from about 48 to 78 per cent. In overall analysis, solarization with white polyethylene sheeting, the weight increased by about 40 to 80 per cent. Variation in thickness of polyethylene sheets and treatment variables were mostly non-significant but solarization was proved highly significant.

4.3.4.2 Cabbage (IInd crop)

Observations on fresh root weight of 30 days old cabbage seedlings are given in Table 34 and Fig. 24 B. In non-solarized soil the weight of the roots raised from untreated seeds was 1.089 g. Treatment with fungicides and bioagent improved root weight significantly and substantially. Integration of fungicides as seed dressers increased root weight by about 100 per cent. Bioagent *T. harzianum* and *P. fluorescens* further improved root weight that too significantly.

When the crops were raised in solarized soil (white polyethylene 50G) after the harvest of cauliflower, the effect of solarization was evident. Against a weight of 1.08 g in non-solarized (check), the weight in solarized soil with seed-treatments increased to 2.80 g. Apron was more effective compared to other two fungicides and both the bioagent were distinctly superior. In terms of per cent increase over non-solarized, 159 per cent increase was observed in plots sown with non treated seeds. Application of fungicides and bioagent through seed, improved weight over non solarization. The

Table 34 : **Effect of soil solarization and its integration with seed-treatments on fresh root weight of cabbage**

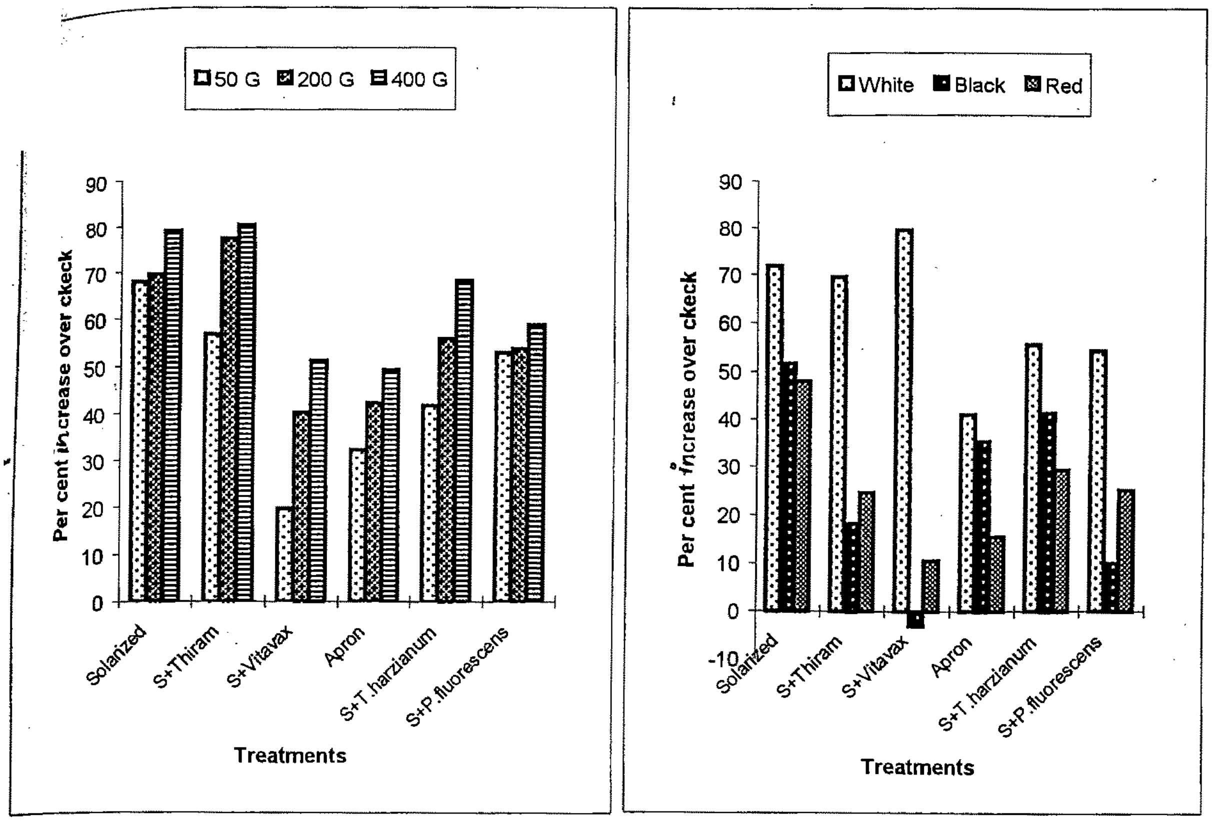
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	1.08	2.80	4.20	4.03	3.67	2.83	3.41	3.70	3.31	3.75	4.71	5.08	4.51
Thiram	2.28	5.23	3.62	3.75	3.20	3.17	3.68	3.93	3.6	4.38	4.61	4.73	4.57
Vitavax	2.15	2.63	4.33	4.68	3.88	3.40	3.21	3.77	3.46	3.62	4.61	5.25	4.49
Apron	2.44	3.35	3.91	4.06	3.77	3.07	3.85	4.18	3.70	3.75	4.43	4.95	4.37
T. harzianum	3.56	3.87	3.44	4.41	3.90	4.16	4.18	4.06	4.13	5.46	6.00	6.83	6.09
P. fluorescens	3.50	4.50	4.11	4.83	4.48	3.83	4.61	4.80	4.41	5.33	6.00	5.92	5.75
Mainplot mean	2.49	3.23	3.88	4.29	3.80	3.41	3.82	4.18	3.80	4.84	5.06	5.40	5.10

Sample size: 20 plants

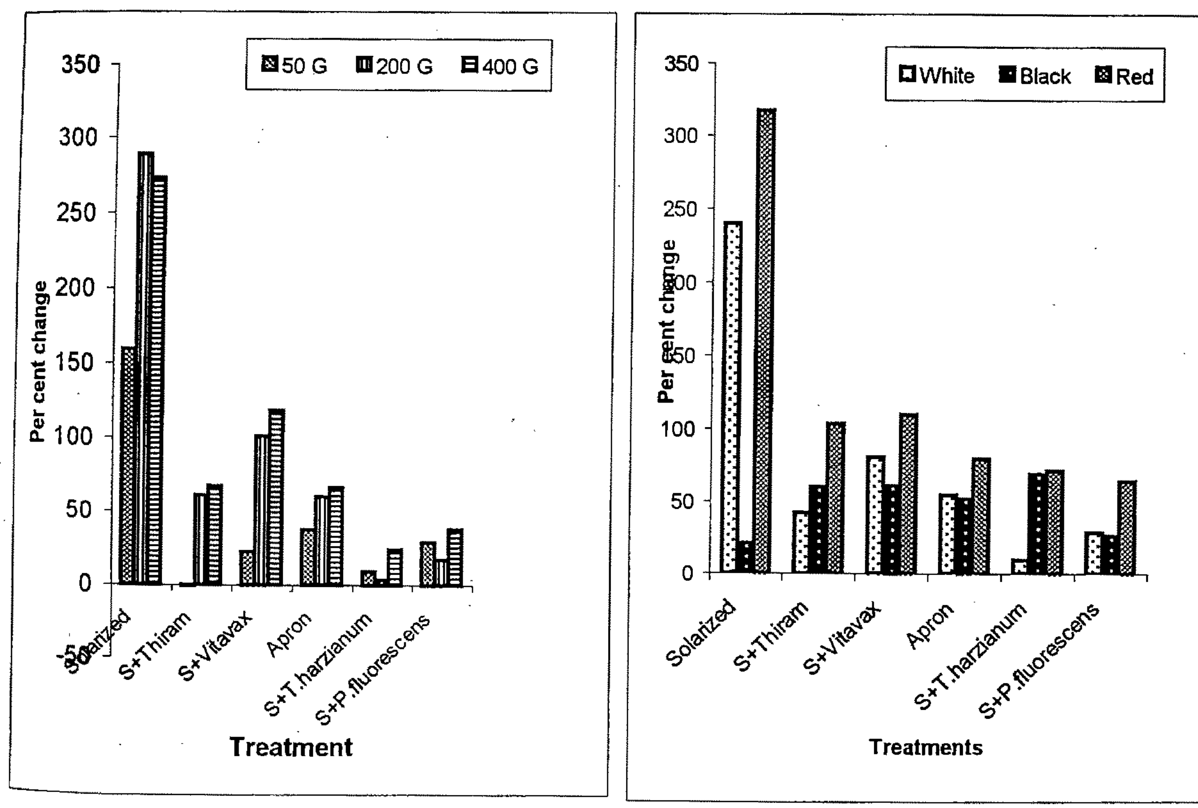
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.85	cd_1 = 0.53	cd_1 = 0.76
	cd_2 = 0.54	cd_2 = 0.49	cd_2 = 0.72
	cd_3 = 1.08	cd_3 = 0.99	cd_3 = 1.45
	cd_4 = 1.30	cd_4 = 1.04	cd_4 = 1.53

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = *	ma = **	ma = **
	su = **	su = **	su = **
	ms = *	ms = ns	ms = ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 24 : Effect of solarization on fresh root weight

trend and pattern of effect continued with 200G as well as with 400G and weight increased by 289 and 273 per cent, respectively. On an average, solarization with white polyethylene, irrespective of thickness, increased fresh root weight by about 240 per cent. Seed-treatments further improved effectivity of solarization.

Solarization using black and red polyethylene sheeting also affected fresh root weight. Per cent increase in root weight with black sheeting was 206 per cent while with red it was 317 per cent. With these variables also the effect/integration of fungicides and bioagent was obvious though differences in between were minor and non-significant.

4.3.4.3 Tomato (IIIrd crop)

The nursery of tomato was raised after removal of the cabbage seedlings *i.e.* 60 days after solarization. The effects on fresh root weight are recorded in Table 35 and Fig. 25 A. In non-solarized soil the weight of the fresh roots ranged from 2.02 g to 3.38. Bio-agent *P. fluorescens* was distinctly superior over others. Under solarized condition, the root weight was improved by about 50 per cent with 50G, 18 to 77 per cent with 200G and above 30 to 99 per cent with 400G. Solarization alone, increased weight by 77 per cent, solarization + thiram seed-treatment by 78 per cent, solarization + vitavax by 63.8 per cent, apron by 54 per cent, and 54.1 and 21 per cent with *T. harzianum* and *P. fluorescens* seed-treatments respectively.

Table 35 : **Effect of soil solarization and its integration with seed-treatments on fresh root weight of tomato**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	2.17	3.56	3.67	3.84	3.70	3.38	3.23	3.33	3.31	3.27	3.58	3.66	3.5
Thiram	2.04	3.23	3.61	4.06	3.63	3.66	6.68	3.41	3.58	2.98	3.86	3.37	3.40
Vitavax	2.02	3.20	3.46	3.28	3.31	3.25	3.11	3.28	3.21	3.45	3.83	3.81	3.70
Apron	2.16	3.43	2.91	3.65	3.33	2.95	3.25	3.42	3.20	3.25	3.19	3.46	3.30
T. harzianum	2.68	3.78	3.88	4.13	3.93	3.22	3.58	3.75	3.51	4.08	4.16	3.81	4.01
P. fluorescens	3.38	3.88	3.99	4.41	4.09	3.70	3.76	4.42	9.96	3.60	4.40	4.46	4.15
Mainplot mean	2.41	3.51	3.59	3.88	3.66	3.36	3.44	3.50	3.43	3.44	3.84	3.76	3.68

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.48	cd_1 = 0.74	cd_1 = 0.99
	cd_2 = 0.68	cd_2 = 0.67	cd_2 = 0.89
	cd_3 = 1.37	cd_3 = 1.34	cd_3 = 1.79
	cd_4 = 1.34	cd_4 = 1.42	cd_4 = 1.90

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = *	ma = *
su = ns	su = ns	su = ns
ms = ns	ms = ns	ms = ns

Black sheeting used for solarization also caused weight improvement. The increase ranged from 17 to 59 per cent. Almost similar results were recorded with red polyethylene sheeting. Per cent increase in root weight over control, ranged from 22.7 to 83 per cent.

4.3.4.4 Onion (4th crop)

Ninety days after solarization and after raising three nurseries, onion was grown as 4th nursery crop. The positive effect of solarizaiton persisted with white polyethylene and approximately 34.8 per cent increase in fresh root weight was recorded (Table 36). The effect of solarization achieved through mulching with black polyethylene sheets on growth promotion was minor and erratic. Among the seed-treatments, *T. harzianum* was most effective as it increased fresh root weight by about 31 per cent over check. Use of red polyethylene was as effective as the white transparent one. Percent growth improved, ranged from less than a percent to 27 per cent. Seed-treatment with Thiram was also effective up to some extent (Fig. 25 B).

4.3.4.5 Calendula

In field experiment conducted at floriculture block, the first crop raised was calendula. In non-solarized plots with or without seed-treatment, weight of the roots ranged from 0.16 g to 0.43 g. The fresh root weight in plots solarized with transparent polyethylene sheets (50 G) ranged from 0.47 to 0.61 g. In most treatments the weight increased approximately by 200 per cent. Almost similar

Table 36 : **Effect of soil solarization and its integration with seed-treatments on fresh root weight of onion**

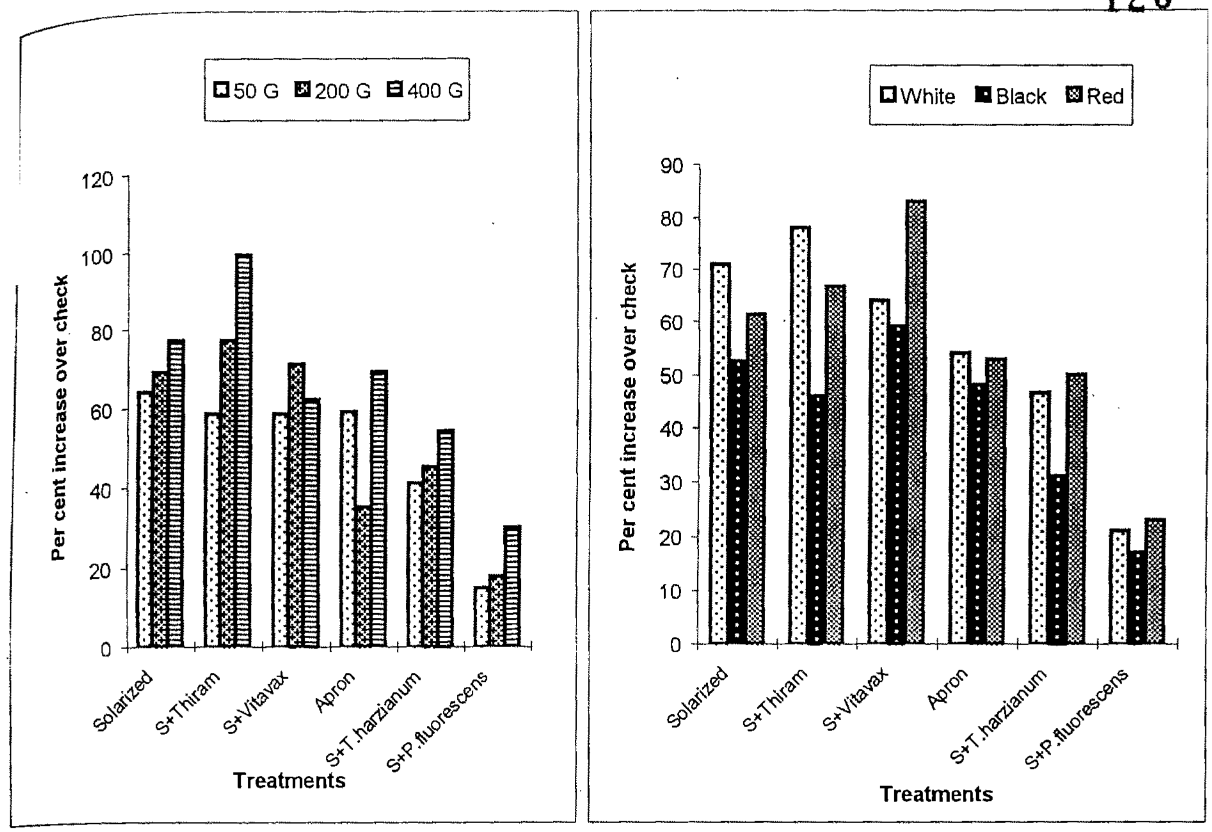
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.89	1.33	1.1	1.18	1.20	0.76	0.81	0.87	0.81	1.21	1.1	1.09	1.13
Thiram	0.81	1.01	1.0	0.81	0.94	0.72	0.98	0.81	0.83	1.06	0.86	1.09	1.00
Vitavax	0.81	0.98	0.98	0.83	0.93	0.69	0.74	0.86	0.76	0.96	0.79	0.89	0.88
Apron	0.90	0.95	0.92	0.84	0.90	0.66	0.82	.074	0.75	0.80	0.88	0.99	0.89
T. harzianum	0.86	1.0	0.92	1.05	0.99	1.23	0.96	1.20	1.13	0.90	1.10	1.04	1.01
P. fluorescens	1.0	0.87	1.0	0.95	0.94	0.89	0.87	1.03	0.93	0.99	0.95	1.11	1.01
Main plot mean	0.88	1.02	0.98	9.45	3.81	0.82	0.87	0.92	0.87	0.94	0.94	1.03	0.97

Sample size: 20 plants

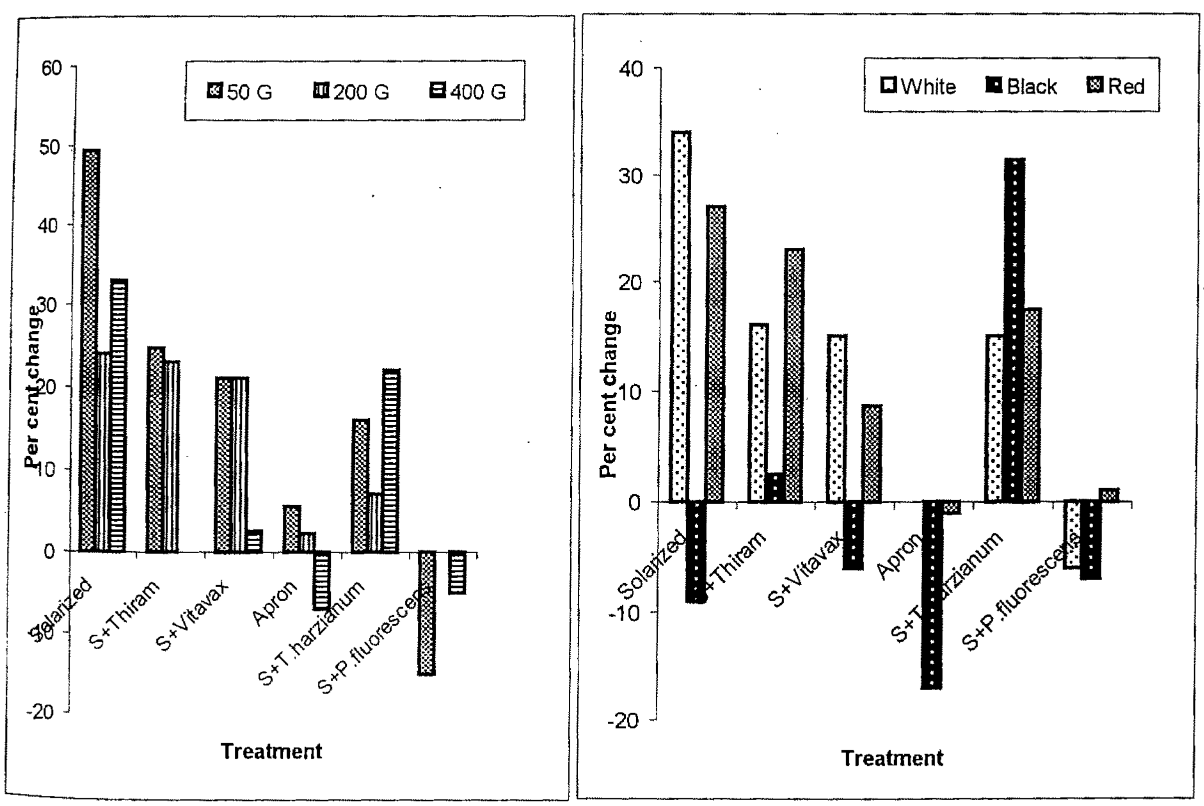
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.23	cd_1 = 0.22	cd_1 = 0.14
	cd_2 = 0.17	cd_2 = 0.18	cd_2 = 0.14
	cd_3 = 0.35	cd_3 = 0.36	cd_3 = 0.29
	cd_4 = 0.39	cd_4 = 0.39	cd_4 = 0.30

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = ns	ma = ns	ma = ns
	su = ns	su = *	su = *
	ms = ns	ms = ns	ms = ns



A. Tomato



B. Onion

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 25 : Effect of solarization on fresh root weight

results were recorded with 200 and 400 G. The extent and magnitude of increase with 200 G ranged from over 200 to 300 per cent and with 400 G up to 346 per cent. Overall increase in fresh root weight was invariably over 200 per cent. Solarization using black polyethylene also affected fresh root weight positively. It ranged from 48.8 to 146 per cent. Almost similar observations were recorded with red polyethylene sheets. The weight with seed-treatments + solarization was improved by over 100 to 200 per cent (Table 37 and Fig. 26 A).

4.3.4.6 Aster

After calendula, nursery of aster was raised. The observations recorded with respect in fresh root weight revealed that effect of solarization persisted (Table 38). Weight with 50 G treatment increased by 44.3 to 62.4 per cent. Almost similar increase was recorded with 200 G and 400 G. overall, solarization with white transparent polyethylene sheets increased fresh root weight by 35.5 to 62.4 per cent (Fig. 26 B). Among fungicides and bioagent used for seed-treatment, *P. fluorescens* looked superior. Solarization using red sheets was found as effective as the white ones. Overall increase in fresh root weight over check (non-solarized) ranged invariably between 30 to 40 per cent. However, the positive effect observed with black sheets in first crop calendula was almost nullified. The increase in weight was minor and non-significant.

Table 37 : **Solarization + seed-treatment : effect on fresh root weight of calendula**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.433	0.41	0.51	0.47	0.46	0.20	0.23	0.23	0.22	0.28	0.28	0.29	0.28
Thiram	0.13	0.51	0.53	0.58	0.54	0.38	0.30	0.28	0.32	0.34	0.40	0.43	0.39
Vitavax	0.17	0.61	0.62	0.67	0.63	0.27	0.38	0.32	0.32	0.40	0.44	0.46	0.43
T. harzianum	0.16	0.58	0.60	0.58	0.58	0.35	0.35	0.33	0.34	0.33	0.36	0.45	0.38
P. fluorescens	0.17	0.54	0.60	0.57	0.57	0.40	0.35	0.29	0.34	0.31	0.35	0.50	0.38
Main plot mean	0.15	0.53	0.57	0.58	0.56	0.32	0.32	0.29	0.31	0.33	0.37	0.43	0.38

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.04	cd_1 = 0.07	cd_1 = 0.08
	cd_2 = 0.05	cd_2 = 0.04	cd_2 = 0.05
	cd_3 = 0.10	cd_3 = 0.08	cd_3 = 0.10
	cd_4 = 0.10	cd_4 = 0.10	cd_4 = 0.10

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = **	su = **	su = **
ms = ns	ms = ns	ms = ns

Table 38 : **Solarization + seed-treatment : effect on fresh root weight of aster**

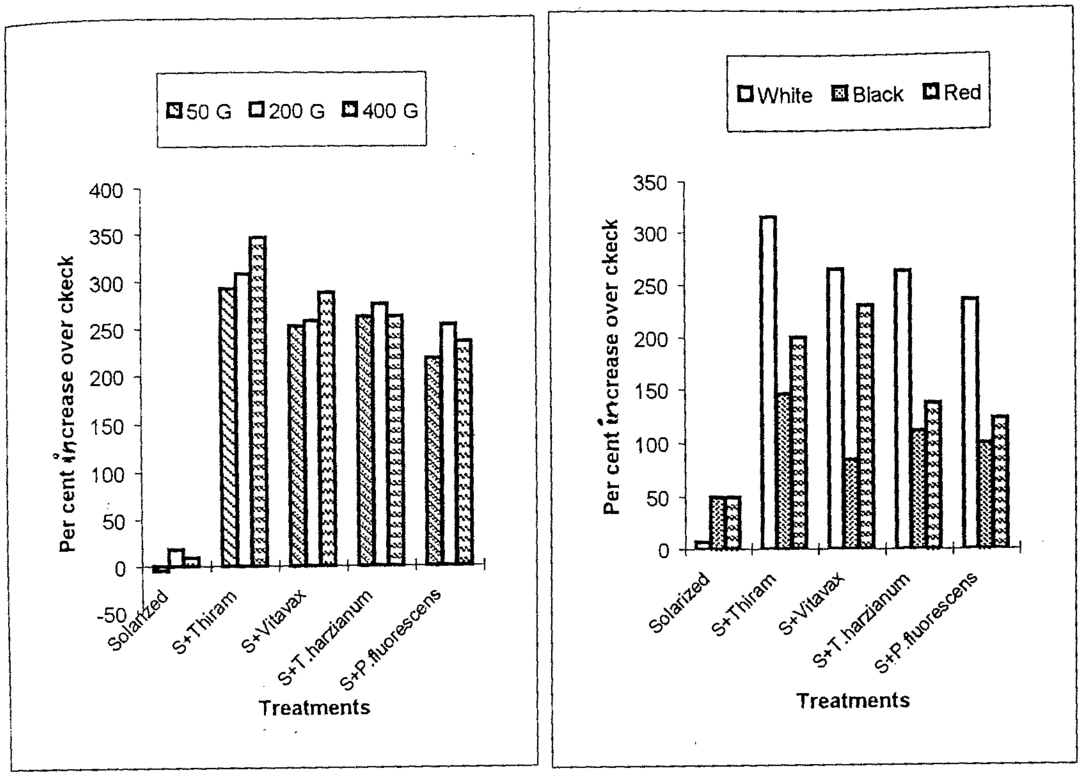
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	1.65	2.68	2.47	2.9	2.68	1.46	1.65	1.47	1.52	2.02	2.13	2.36	2.27
Thiram	1.85	2.81	2.53	3.0	2.78	1.66	1.82	1.61	1.69	2.66	2.60	2.67	2.64
Vitavax	1.85	2.74	2.51	2.8	2.68	1.74	2.31	1.70	1.91	2.37	2.14	2.44	2.31
T. harzianum	2.17	3.2	2.61	3.02	2.94	2.07	3.15	2.36	2.52	2.60	2.63	2.92	2.71
P. fluorescens	2.01	2.90	2.90	3.1	2.96	2.33	2.70	2.70	2.57	2.97	2.63	2.72	2.77
Main plot mean	1.91	2.86	2.60	2.95	2.80	1.85	2.33	1.97	2.05	2.52	2.50	2.62	2.54

Sample size: 20 plants

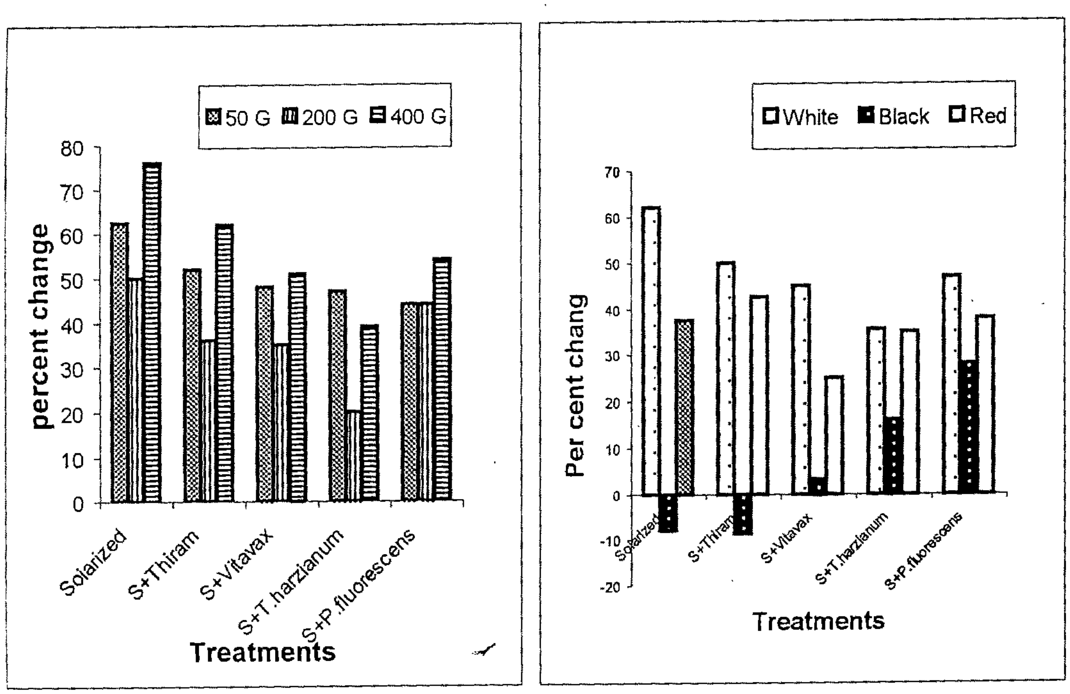
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.46	cd_1 = 0.77	cd_1 = 0.53
	cd_2 = 0.36	cd_2 = 0.30	cd_2 = 0.40
	cd_3 = 0.71	cd_3 = 0.61	cd_3 = 0.81
	cd_4 = 0.79	cd_4 = 0.94	cd_4 = 0.90

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	White polyethylene	Black polyethylene	Red polyethylene
	ma = **	ma = ns	ma = ns
	su = ns	su = **	su = ns
	ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness　　Effect of polyethylene colour

Fig. 26 : Effect of solarization on fresh root weight

4.3.5 Dry Root Weight

In order to confirm the effect of solarization with or without seed-treatments, the samples used for recording fresh root weight were dried for subsequent recording of dry root weight. The data are given in Tables 39-44 and Figs. 27-29.

4.3.5.1 Cauliflower

Dry root weight of first nursery crop cauliflower in non-solarized plot was 0.32 g. Integration of seed-treatments improved dry root weight although only non-significantly. Solarization with white transparent polyethylene increased dry root weight significantly. With 50G polyethylene, the weight ranged from 0.59 g to 0.74 g (Table 39). The effect of both the bioagent was distinctly superior. In terms of per cent increase, it ranged from over 36 to 97 per cent. Almost similar effects were observed with 200 and 400 G. The weight was improved by 42 to 95 per cent with 200 G and by 32 to 106 per cent with 400 G. Overall the increase in dry weight with white polyethylene ranged from about 30 to 94 per cent. Almost similar effect was observed with red polyethylene sheets (Fig. 27 A).

The improvement in dry root weight ranged from 20 to 78 per cent. Integration of solarization with seed-treatment using fungicides and bioagent further increased dry root weight. Solarization using black polyethylene was also effective but inferior to white and red sheets. Overall improvement in dry root weight ranged from 12 to 50 per cent (Fig. 27 A).

Table 39 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of cauliflower**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.32	0.63	0.57	0.66	0.62	0.55	0.46	0.45	0.48	0.52	0.59	0.61	0.57
Thiram	0.45	0.66	0.64	0.73	0.67	0.50	0.55	0.54	0.53	0.52	0.53	0.59	0.54
Vitavax	0.39	0.59	0.76	0.66	0.67	0.53	0.43	0.55	0.50	0.62	0.64	0.69	0.63
Apron	0.49	0.67	0.73	0.65	0.68	0.53	0.57	0.57	0.55	0.57	0.58	0.59	0.58
T. harzianum	0.50	0.73	0.78	0.87	0.79	0.63	0.72	0.73	0.69	0.75	0.65	0.69	0.69
P. fluorescens	0.54	0.74	0.78	0.83	0.78	0.73	0.74	0.66	0.74	0.73	0.74	0.68	0.71
Main plot mean	0.45	0.66	0.71	0.73	0.70	0.59	0.58	0.58	0.58	0.62	0.62	0.63	0.62

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.057	cd_1 = 0.060	cd_1 = 0.035
	cd_2 = 0.061	cd_2 = 0.055	cd_2 = 0.065
	cd_3 = 0.120	cd_3 = 0.110	cd_3 = 0.130
	cd_4 = 0.120	cd_4 = 0.110	cd_4 = 0.120

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = **	ma = **	ma = **
	su = **	su = **	su = **
	ms = ns	ms = ns	ms = ns

4.3.5.2 Cabbage

Thirty days after solarization and removal of first crop cauliflower, nursery of cabbage was raised. The effect of solarization with seed-treatment was highly significant over non-solarization with seed-treatment. In non-solarized plots the dry root weight ranged from 0.12 g to 0.31 g. Among the treatments, bioagent were distinctly superior. Solarization using white sheets of 50 G increased weight up to 206 per cent. Almost similar effects were observed with 200 G and 400 G. Overall, solarization alone increased weight by 213 per cent. Among the fungicides apron was distinctly superior (238 per cent). The effect of red polyethylene sheets used for solarization was almost similar to white sheets with respect to effectivity.

The effectivity of solarization achieved through the use of black polyethylene mulches too, persisted in the 2nd crop as well. Overall dry root weight was increased by about 25 to 50 per cent. The effect of integration with fungicides and bioagent was also apparent and visible (Table 40 and Fig. 27 B).

4.3.5.3 Tomato

Sixty days after solarization and after second nursery of cabbage, tomato nursery was raised. The data on dry root weight are given in Table 41 and Fig. 28 A. The effect of solarization was significant. Against a weight of 0.88 g in non-solarized, it increased to 2.5 g in solarized plots. This signifies the persistence of the effectivity of the solarization. Invariably all the treatments except *P.*

Table 40 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of cabbage**

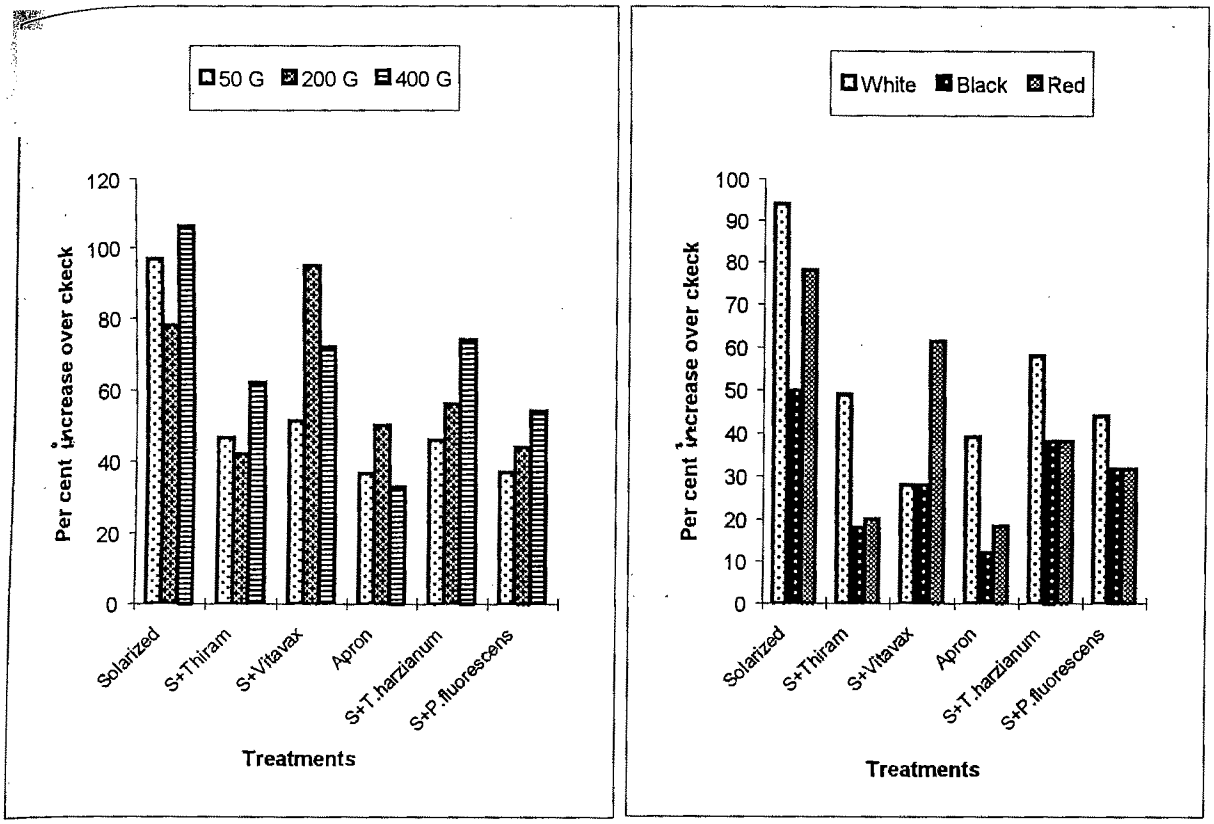
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.15	0.46	0.46	0.48	0.47	0.27	0.48	0.47	0.40	0.46	0.50	0.51	0.49
Thiram	0.16	0.41	0.49	0.49	0.45	0.27	0.38	0.53	0.39	0.46	0.47	0.39	0.44
Vitavax	0.12	0.31	0.44	0.45	0.40	0.28	0.46	0.54	0.42	0.45	0.52	0.47	0.48
Apron	0.13	0.40	0.48	0.45	0.44	0.31	0.33	0.47	0.37	0.36	0.45	0.47	0.42
T. harzianum	0.27	0.51	0.54	0.50	0.51	0.42	0.52	0.34	0.42	0.45	0.55	0.55	0.51
P. fluorescens	0.31	0.48	0.51	0.56	0.52	0.40	0.57	0.31	0.42	0.48	0.55	0.65	0.55
Main plot mean	0.19	0.43	0.48	0.48	0.46	0.32	0.46	0.32	0.40	0.44	0.51	0.50	0.48

Sample size: 20 plants

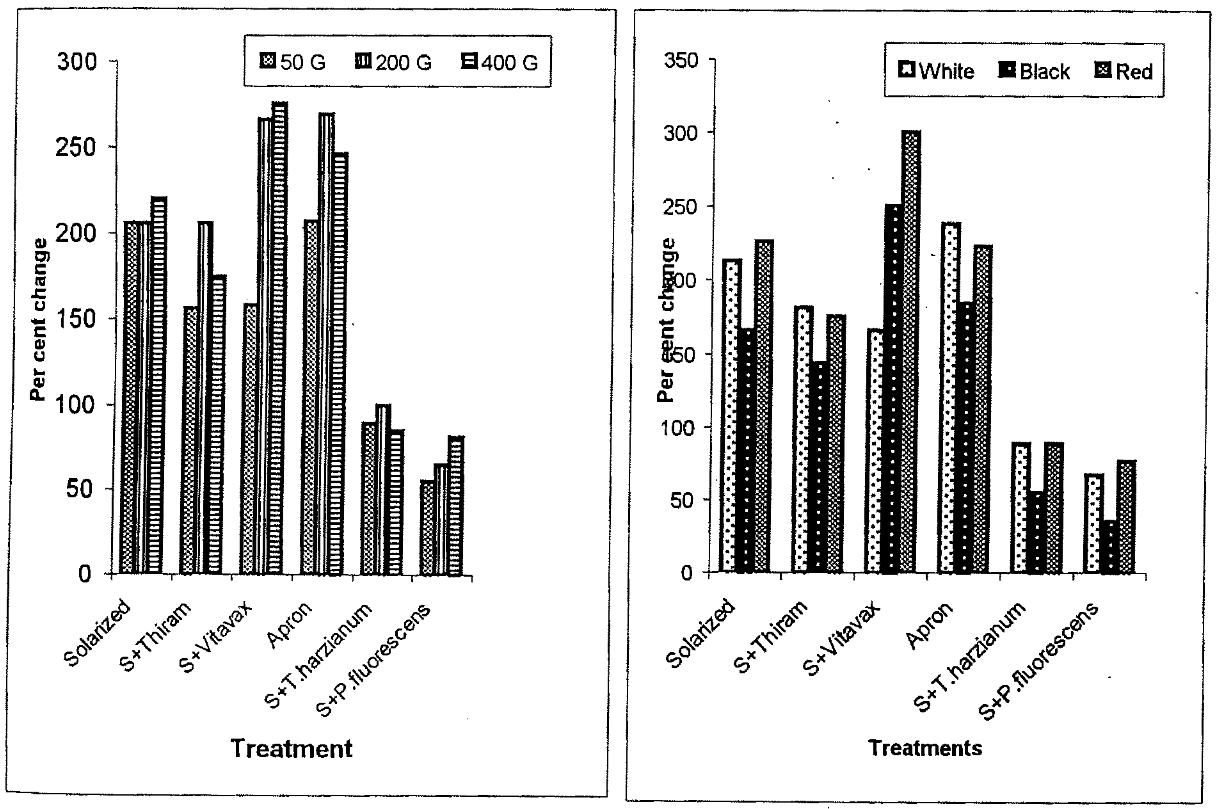
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.055	cd_1 = 0.049	cd_1 = 0.052
	cd_2 = 0.084	cd_2 = 0.075	cd_2 = 0.074
	cd_3 = 0.160	cd_3 = 0.150	cd_3 = 0.140
	cd_4 = 0.160	cd_4 = 0.146	cd_4 = 0.140

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = *	su = **	su = **
ms = ns	ms = ns	ms = ns



A. Cauliflower



B. Cabbage

Effect of polyethylene thickness **Effect of polyethylene colour**

Fig. 27 : Effect of solarization on dry root weight

Table 41 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of tomato**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.88	0.208	2.43	3.0	2.5	2.43	2.26	1.80	2.16	2.0	1.60	1.60	1.73
Thiram	0.54	2.21	2.45	2.5	2.38	1.86	1.92	1.98	1.92	1.43	2.1	1.70	1.81
Vitavax	1.12	2.37	1.94	2.24	2.18	2.05	1.87	2.17	2.03	0.833	1.05	1.56	1.14
Apron	1.06	1.77	2.27	2.45	2.16	2.30	2.53	2.46	2.43	1.10	0.70	1.25	1.01
T. harzianum	1.45	2.34	2.54	2.80	2.56	2.13	2.43	2.38	2.31	1.56	1.81	2.63	2.0
P. fluorescens	2.36	2.30	2.39	2.46	2.38	2.45	2.37	2.32	2.38	1.53	1.90	1.95	1.8
Main plot mean	1.30	2.18	2.34	2.57	2.36	2.20	2.23	2.18	2.20	1.44	1.52	1.78	1:58

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.73	cd_1 = 0.65	cd_1 = 0.30
	cd_2 = 0.59	cd_2 = 0.52	cd_2 = 0.62
	cd_3 = 1.18	cd_3 = 1.04	cd_3 = 1.23
	cd_4 = 1.30	cd_4 = 1.15	cd_4 = 1.17

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = *	ma = *	ma = ns
	su = ns	su = ns	su = *
	ms = ns	ms = ns	ms = ns

fluorescens, increased the dry root weight by over 75 to 184 per cent. Solarization using black polyethylene mulches also affected root growth and thereby dry root weight. In totality the weight increased up to 14.5 per cent. Red polyethylene sheets used for solarization were also effective. Increase in dry root weight was 96.6 per cent in solarized soil over non-solarized. The effect of seed-treatments was also visible but it was somewhat erratic.

4.3.5.4 Onion

After tomato, nursery of onion was raised in the same plot and design. The effects observed on dry root weight are given in Table 42 Fig. 28 B. The effect of solarization persisted even after 100 days, as the effect was significant. In plots solarized using white transparent polyethylene (50 G-400G), the increase in dry root weight over non-solarized was up to 133 per cent. Solarization with red polyethylene was equally effective. Irrespective of the thickness, the weight increased up to 193 per cent in solarized soil. Plants raised in plots mulched with black polyethylene sheeting also revealed increased plant growth response. In solarization plots, the increase was to the extent of above 66 per cent.

4.3.5.5 Calendula

Effects of solarization and seed-treatment on dry root weight are recorded in Table 43 Fig. 29 A. The results reveal that effect of solarization and treatments was highly significant. In non-solarized plots, root weight ranged from 0.02 to 0.04g. Solarization increased

Table 42 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of onion**

Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.15	0.40	0.32	0.25	0.32	0.12	0.20	0.32	0.21	0.49	0.44	0.40	0.44
Thiram	0.16	0.37	0.32	0.22	0.30	0.13	0.20	0.27	0.20	0.42	0.43	0.38	0.41
Vitavax	0.27	0.36	0.30	0.33	0.33	0.14	0.18	0.30	0.21	0.42	0.40	0.41	0.41
Apron	0.19	0.32	0.26	0.27	0.29	0.20	0.18	0.25	0.21	0.45	0.38	0.37	0.40
T. harzianum	0.2	0.35	0.33	0.30	0.33	0.13	0.22	0.38	0.24	0.44	0.37	0.40	0.40
P. fluorescens	0.28	0.41	0.31	0.32	0.35	0.14	0.17	0.27	0.19	0.49	0.46	0.43	0.46
Main plot mean	0.21	0.37	0.31	0.28	0.32	0.14	0.19	0.30	0.21	0.45	0.41	0.40	0.42

Sample size: 20 plants

cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.72	cd_1 = 0.03	cd_1 = 0.06
	cd_2 = 0.06	cd_2 = 0.04	cd_2 = 0.05
	cd_3 = 0.11	cd_3 = 0.07	cd_3 = 0.09
	cd_4 = 0.13	cd_4 = 0.07	cd_4 = 0.10

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = *	ma = **	ma = **
su = ns	su = ns	su = ns
ms = ns	ms = ns	ms = ns

Table 43 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of calendula**

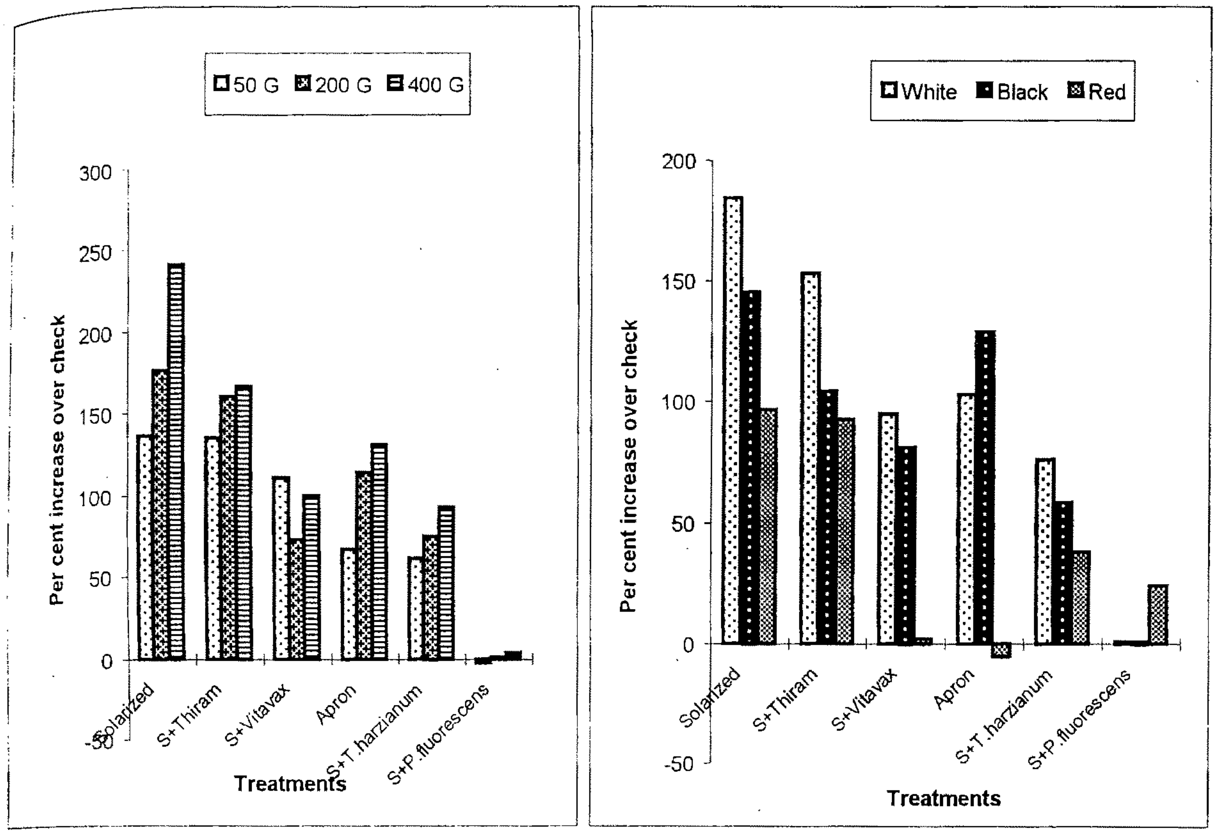
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.03	0.05	0.12	0.11	0.08	0.04	0.05	0.55	0.04	0.08	0.06	0.06	0.06
Thiram	0.02	0.10	0.11	0.13	0.09	0.09	0.06	0.06	0.06	0.07	0.09	0.10	0.07
Vitavax	0.04	0.13	0.14	0.15	0.12	0.06	0.08	0.07	0.06	0.08	0.10	0.08	0.07
T. harzianum	0.03	0.11	0.13	0.10	0.09	0.08	0.07	0.08	0.07	0.07	0.08	0.08	0.08
P. fluorescens	0.03	0.10	0.12	0.13	0.09	0.08	0.08	0.07	0.07	0.07	0.08	0.09	0.08
Main plot mean	0.03	0.10	0.12	0.12	0.09	0.07	0.07	0.06	0.60	0.07	0.08	0.08	0.07

Sample size: 20 plants

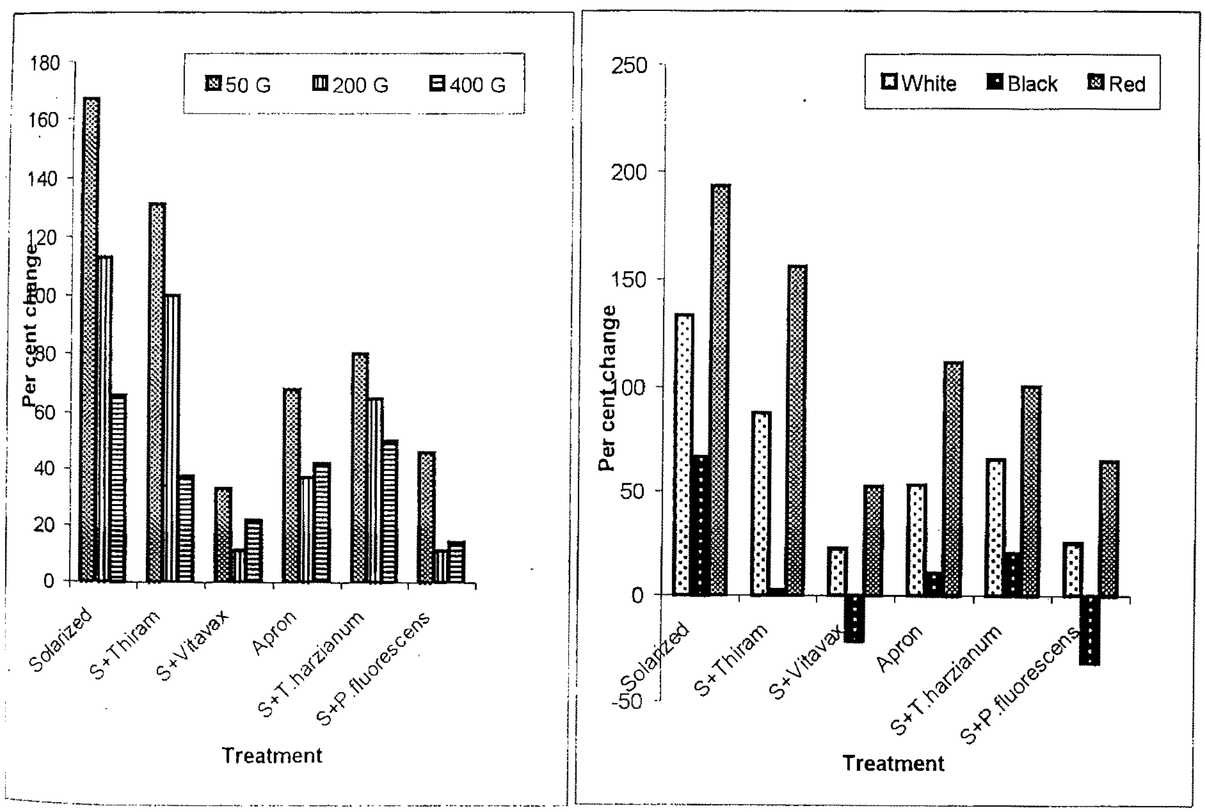
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.006	cd_1 = 0.010	cd_1 = 0.012
	cd_2 = 0.011	cd_2 = 0.011	cd_2 = 0.014
	cd_3 = 0.020	cd_3 = 0.020	cd_3 = 0.020
	cd_4 = 0.020	cd_4 = 0.020	cd_4 = 0.028

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

ma = **	ma = **	ma = **
su = **	su = **	su = ns
ms = *	ms = ns	ms = ns



A. Tomato



B. Onion

Effect of polyethylene thickness

Effect of polyethylene colour

Fig. 28 : Effect of solarization on dry root weight

the same from 0.08 to 0.12 g. In solarized plot with or without seed-treatment, the increase was 166 per cent. With seed-treatment the increase was 200 to 350 per cent. The effect of solarization with red polyethylene sheeting was also substantial. Dry root weight increased by 100 per cent in solarized soil without seed-treatment. Integration of seed-treatment using bioagent or fungicides further augmented the effectivity of solarization. Thiram caused 250 per cent increase over check while bioagent increased the same approximately by 150 per cent. It was of interest to note that solarization, even with black polyethylene sheets increased dry root weight substantially. The effect of bioagent was striking. Both the bioagent in integration with solarization, increased dry root weight by 126 per cent over check.

4.3.5.6 Aster

After calendula, nursery of the flower aster was grown. Solarization with white polyethylene (50G-400G) increased dry root weight by about 50 to 75 per cent. Almost similar effects were noted with solarization achieved through red sheets. The increase over non-solarized ranged from 25 to 85 per cent. The effect of solarization through black polyethylene sheeting was also notable. Invariably the increase was above 50 per cent over non-solarized treatments (Table 44 and Fig. 29 B).

Table 44 : **Effect of soil solarization and its integration with seed-treatments on dry root weight of aster**

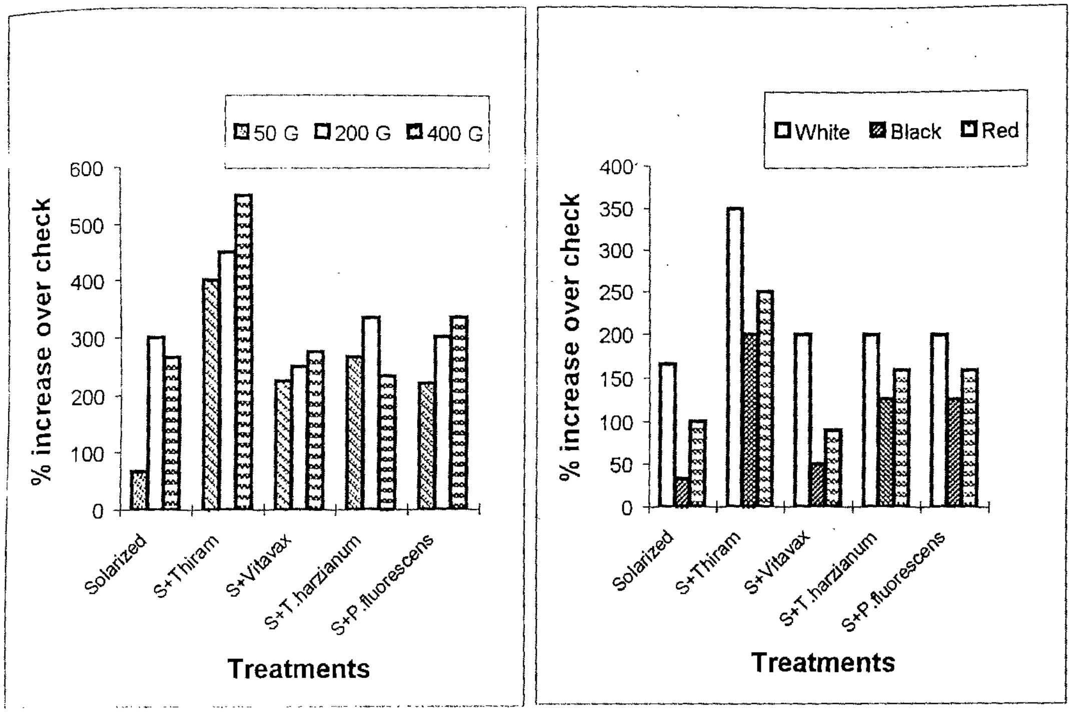
Treatments	Non-solarized	Solarized											
		White polyethylene				Black polyethylene				Red polyethylene			
		50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean	50 G	200 G	400 G	Mean
Control	0.39	0.62	0.69	0.63	0.66	0.46	0.42	0.42	0.43	0.59	0.62	0.67	0.62
Thiram	0.39	0.57	0.59	0.65	0.60	0.67	0.52	0.58	0.59	0.60	0.61	0.70	0.63
Vitavax	0.43	0.49	0.61	0.82	0.64	0.82	0.67	0.60	0.69	0.59	0.72	0.86	0.72
T. harzianum	0.45	0.75	0.76	0.82	0.77	0.75	0.77	0.87	0.79	0.77	0.81	0.10	0.56
P. fluorescens	0.47	0.70	0.66	0.71	0.69	0.74	0.80	0.79	0.77	0.78	0.81	0.96	0.85
Main plot mean	0.43	0.63	0.63	0.74	0.68	0.69	0.64	0.65	0.66	0.67	0.72	0.85	0.74

Sample size: 20 plants

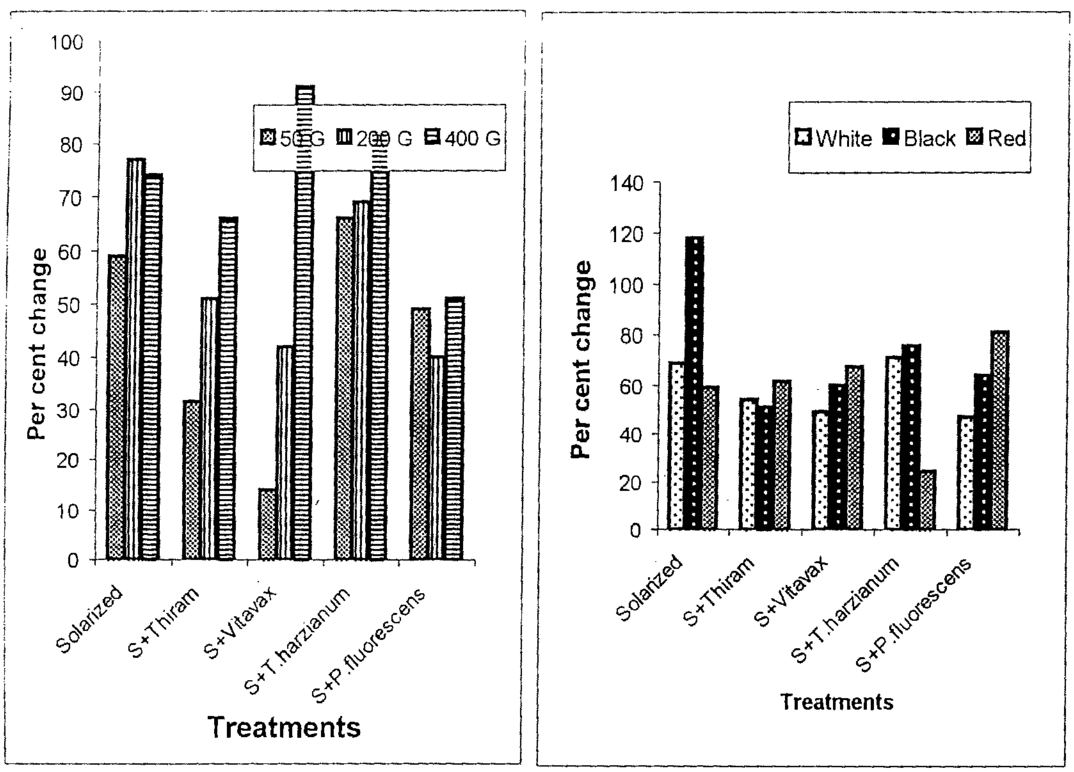
cd at 5%	White polyethylene	Black polyethylene	Red polyethylene
	cd_1 = 0.185	cd_1 = 0.23	cd_1 = 0.34
	cd_2 = 0.110	cd_2 = 0.13	cd_2 = 0.22
	cd_3 = 0.230	cd_3 = 0.26	cd_3 = 0.43
	cd_4 = 0.270	cd_4 = 0.33	cd_4 = 0.51

cd_1 = for comparing main plot means
cd_2 = for comparing sub plot means
cd_3 = for comparison between two sub plot means at same level of main plot
cd_4 = for comparison between two main plot means at same or different levels of sub plot

	ma = *	ma = ns	ma = ns
	su = ns	su = **	su = ns
	ms = ns	ms = ns	ms = ns



A. Calendula



B. Aster

Effect of polyethylene thickness Effect of polyethylene colour

Fig. 29 : Effect of solarization on dry root weight

4.4 Solarization during winter and its integration with organic amendments : Effect on plant growth response

It has imaginably been advocated that soil solarization as a hydrothermal technique should be practiced during hot summer days when solar radiations are intense and high. Innumerable research papers have confirmed the scientific and practical utility of the technique for the management of soil pests and increased plant growth response.

In an attempt, soil was solarized during winter with or without organic amendment to assess the effect of solarization on plant growth. The results of the glasshouse experiments conducted are described in this chapter.

4.4.1 Effect on soil temperature

4.4.1.1 Non-amended soil

Average soil temperature (both minimum and maximum) recorded for 5 weeks are shown in Fig. 30. Minimum temperature during 5 weeks of observations ranged in between 10 to 15°C both in non-solarized and solarized soil. Maximum temperature in non-solarized soil ranged from 25 to 33°C. However, in solarized soil, the maximum temperature ranged from about 34 to 40°C.

When per cent changes in minimum and maximum temperature was computed (Fig. 31), per cent increase in minimum temperature of solarized soil over non-solarized soil ranged from 3 to 12 per cent. Per cent increase in maximum temperature ranged from

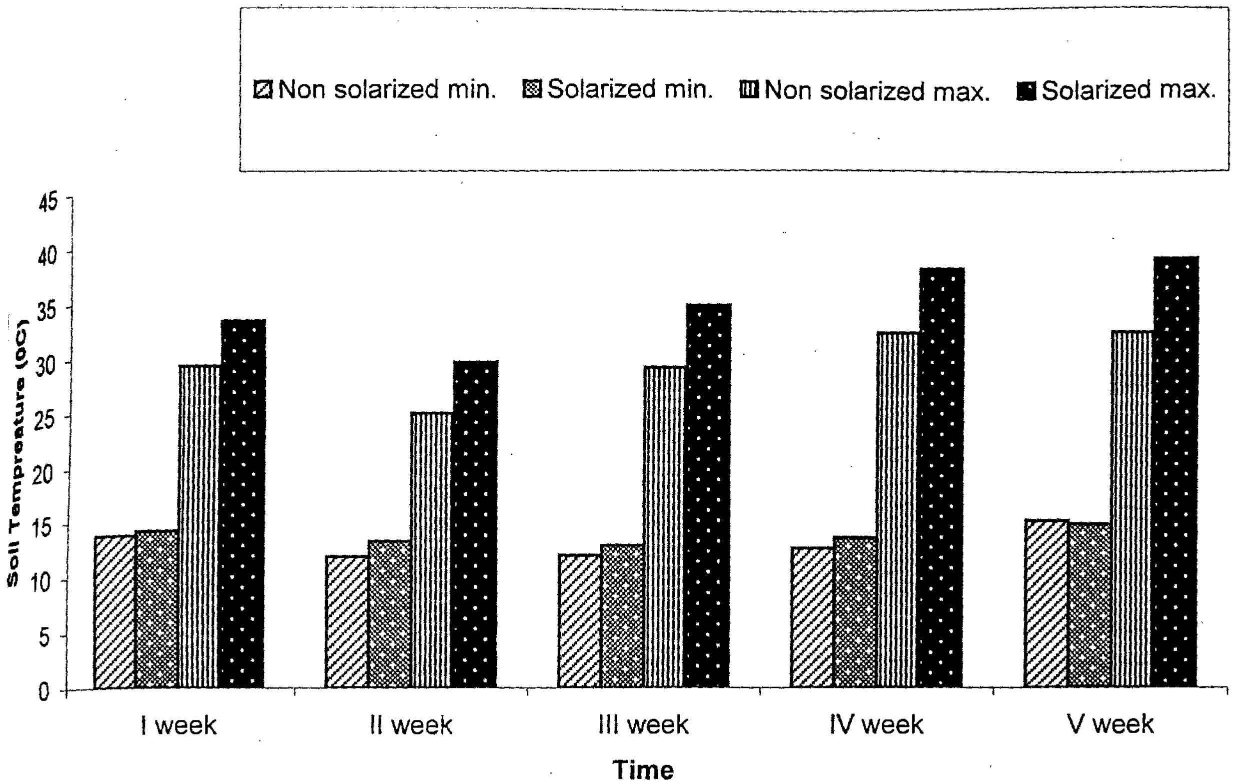


Fig. 30: Effect of solarization at low temperature on soil temperature

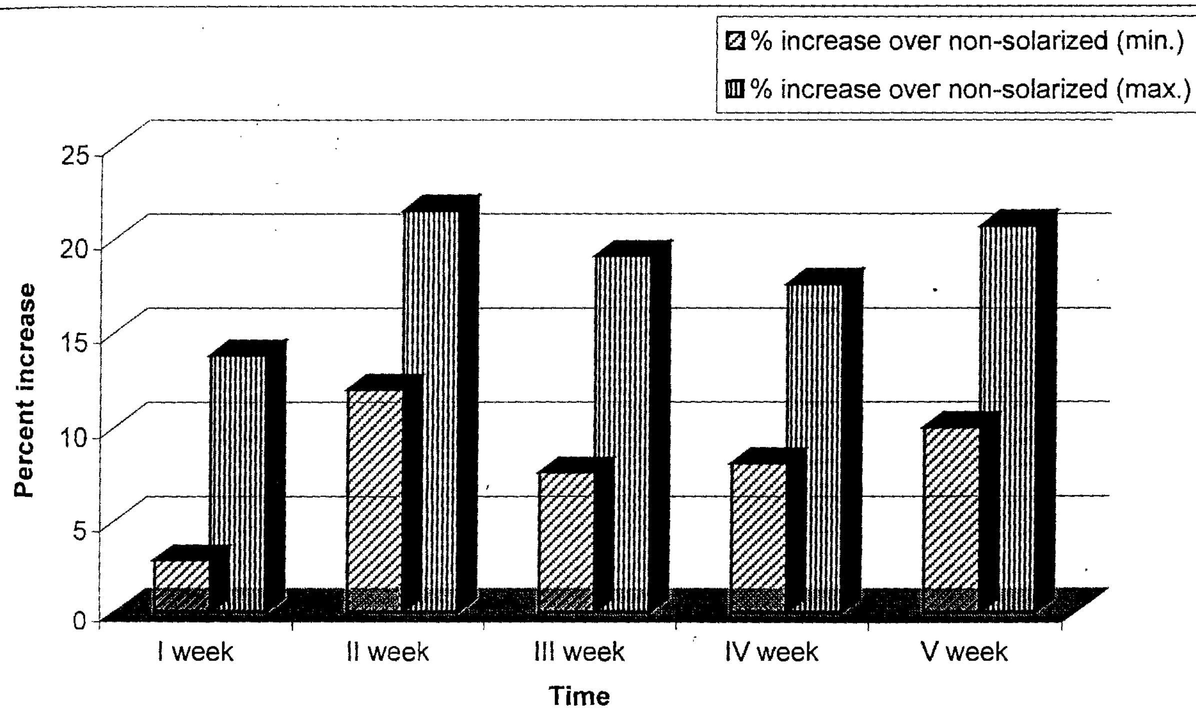


Fig. 31: Percent increase over non-amended solarized

12 to about 20 per cent. Thus, it is concluded that solarization of non amended soil during winter did change both minimum and maximum soil temperature (Fig. 31).

4.4.1.2 Amended soil

Changes in temperature (both minimum and maximum) due to solarization of amended soil are shown in Fig. 32. In soil amended with chicken manure, changes in minimum temperature during 5 weeks, varied substantially. Increase during Ist week was above 50 per cent but in 2nd week the extent of increase was about 30 per cent. In subsequent 3rd and 4th week the increase was negligible 16-18 per cent. Similarly the changes in maximum temperatures in soil amended with chicken manure (Fig. 32) have varied. During the first two weeks, the temperatures increased by about 25 per cent. It further increased (32%) in 3rd week, 58 per cent in 4th week and about 50 per cent in the 5th week. When a comparison with minimum temperature is made, the trend had been of increased temperature due to amendment. The effect spent compost used as amendment also revealed that amendments do control changes in soil temperature. The changes in minimum temperature were almost similar to that of chicken manure amendment. However, increase in maximum temperature was less than 20 per cent but in 4th and 5th week, the increase was above 40 per cent (Fig. 33).

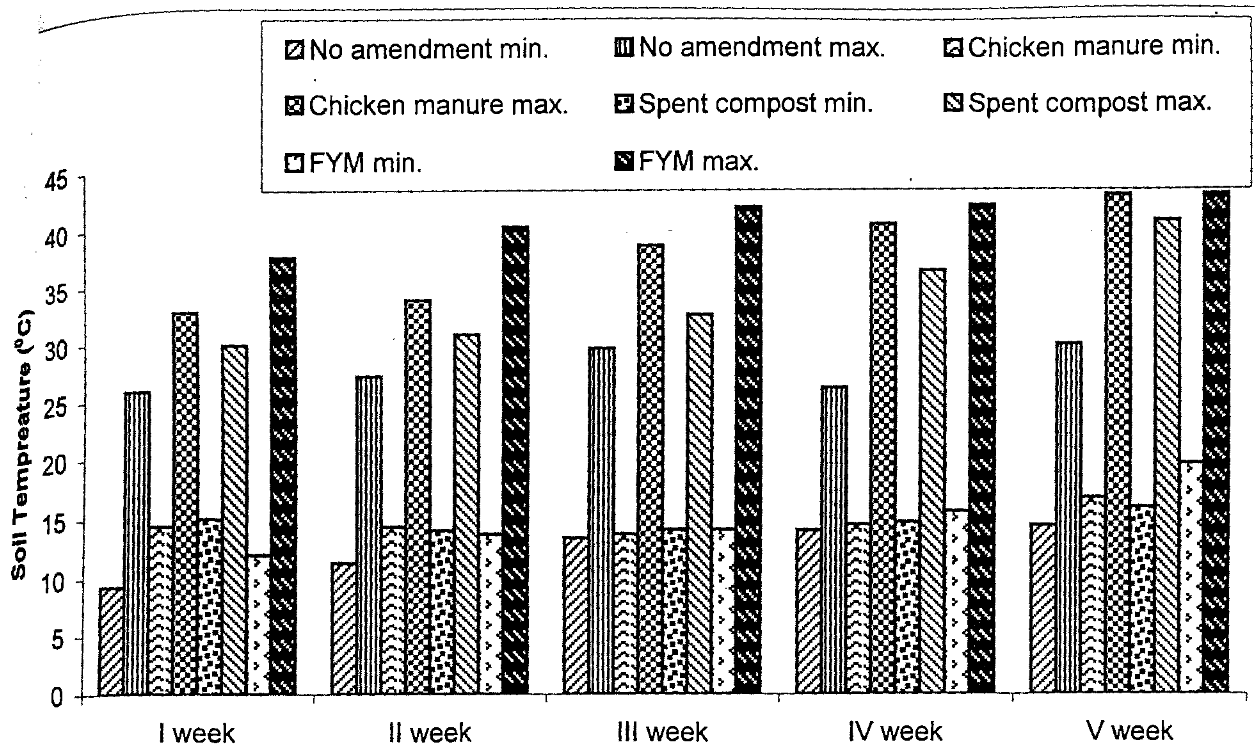


Fig. 32: Effect of solarization + organic amendments on soil temperature

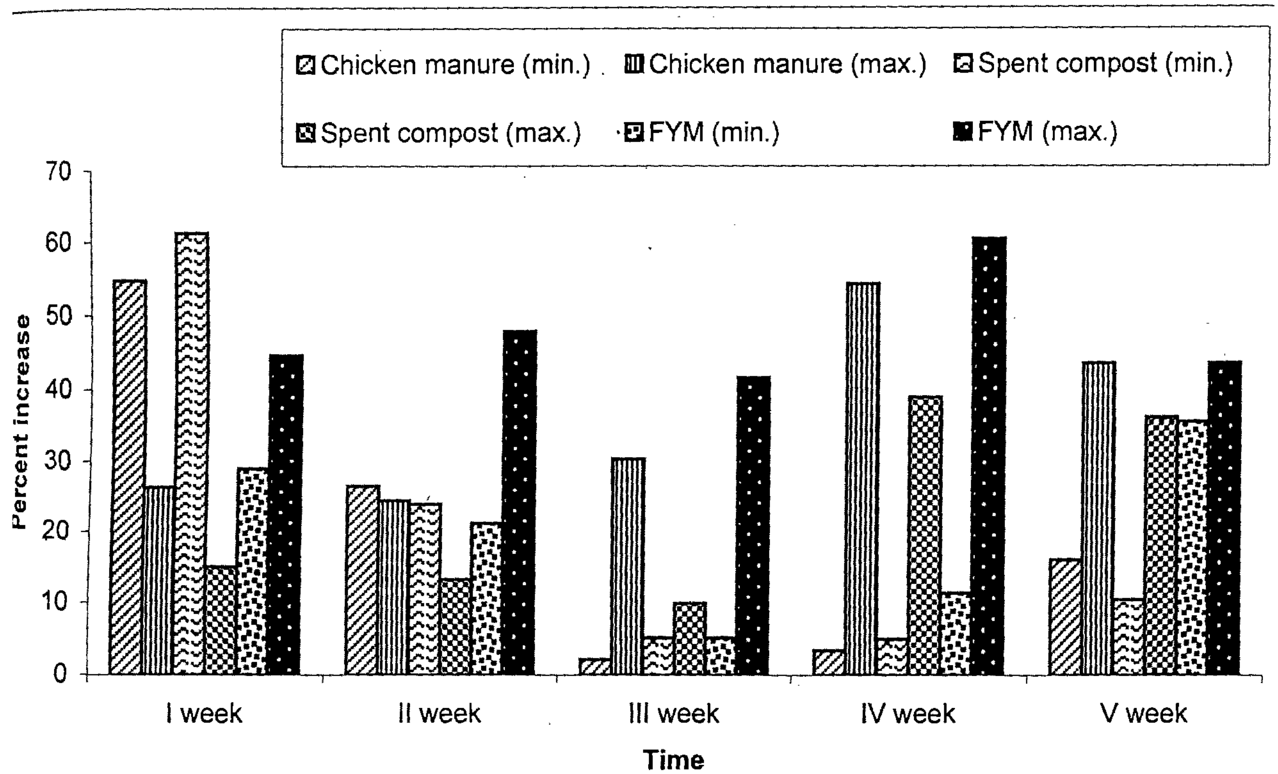


Fig. 33: Percent increase over non-amended solarized

4.4.2 Solarization at low temperature : Plant growth response

4.4.2.1 Tomato

The effects of solarization carried out at low temperatures during winter and its integration with organic amendment on plant growth of tomato are given in Table 45. Solarization for 5 weeks improved root length and fresh root weight significantly over to that of non-solarized treatment. Shoot length, dry root weight, fresh shoot weight as well as dry root weight was also improved but non-significantly. Root length due to solarization was increased by 35 per cent. Among the amendment used spent compost, chicken manure and FYM increased root length by over 31 to 35 per cent. Cotton seed cake was distinctly superior as if increased root length by about 5 per cent. The increase in shoot length ranged from over 22 to 52 per cent. Fresh root weight that was improved significantly, was increased to the extent of 167.85 per cent over the plants growth under non-solarized conditions. The increase in dry root weight ranged from 3 to 33 per cent and that of fresh shoot weight ranged from 54 to 130 per cent. Dry shoot weight increased by over 14 to 53 per cent.

4.4.2.2 Brinjal

In another experiment, seedlings of brinjal were raised and growth parameters were measured. The results so obtained are given in Table 46. All the six growth parameters that were recorded, increased significantly over to that of non-solarized treatment. While

Table 45 : **Soil solarization at low temperature and its integration with organic amendments : effect on growth response (Tomato)**

Sl. No.	Treatments	Growth parameters (mean of 3 replication)											
		Root length (cm)	% change over check	Shoot length (cm)	% change over check	Fresh root weight (g)	% change over check	Dry root weight (g)	% change over check	Fresh shoot weight (g)	% change over check	Dry shoot weight (g)	% change over check
1.	Non solarized (check)	4.92	-	10.60	-	0.118	-	0.033	-	0.760	-	0.104	-
2.	Solarized (non-amended)	6.68	35.77	13.00	22.50	0.133	12.71	0.039	18.00	1.170	54.00	0.119	14.40
3.	2 + spend compost	6.48	31.71	15.40	45.66	0.316	167.80	0.044	33.33	1.253	65.00	0.153	43.10
4.	2 + chicken manure	6.07	23.40	15.20	43.50	0.225	90.70	0.038	15.00	1.310	72.40	0.159	53.00
5.	2 + FYM	6.86	39.43	16.10	52.16	0.201	70.33	0.037	12.00	1.616	112.60	0.134	28.80
6.	2 + cotton seed cake	7.72	57.00	14.00	34.34	0.152	28.80	0.034	3.00	1.541	130.20	0.123	48.50
	Cd at 5%	1.56*		5.44		0.045**		0.012		0.62		0.69	
	CV	13.37		21.20		13.00		14.23		16.60		18.00	

Table 46 : **Soil solarization at low temperature and its integration with organic amendments : effect on growth response (brinjal)**

Sl. No.	Treatments	Growth parameters (mean of 3 replication)											
		Root length (cm)	% change over check	Shoot length (cm)	% change over check	Fresh root weight (g)	% change over check	Dry root weight (g)	% change over check	Fresh shoot weight (g)	% change over check	Dry shoot weight (g)	% change over check
1.	Non solarized (check)	5.60	-	5.10	-	0.080	-	0.015	-	0.384	-	0.051	-
2.	Solarized (non-amended)	6.90	21.70	5.80	13.88	0.107	33.75	0.027	3.70	0.398	27.45	0.065	80.00
3.	2 + spend compost	7.02	23.60	5.90	14.84	0.151	88.00	0.032	41.00	0.541	21.57	0.062	113.3
4.	2 + chicken manure	5.50	-1.80	5.70	11.72	0.166	107.50	0.037	14.00	0.437	23.53	0.063	146.7
5.	2 + FYM	7.20	27.20	7.80	52.34	0.120	50.00	0.034	24.20	0.477	123.50	0.114	126.70
6.	2 + cotton seed cake	8.10	43.60	7.20	41.21	0.106	32.50	0.035	48.70	0.571	62.75	0.083	133.30
	Cd at 5%	1.51*		0.90**		0.044*		0.010**		0.14		0.027**	
	CV	12.35		7.95		19.85		18.80		16.38		20.00	

Plate 4. **Effect of low temperature solarization + Organic amendment on plant growth**

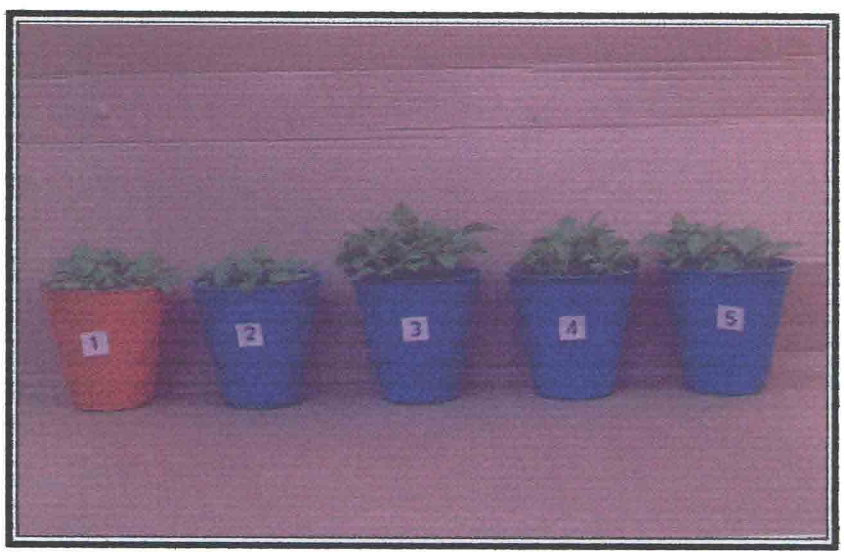
A : Tomato

1. **Non-solarized, non-amended**
2. **Solarized (Amended)**
3. **Solarized + Chicken manure**
4. **Solarized + Spent compost**
5. **Solarized + FYM**

B : Brinjal

1. **Non-solarized (Non-amended)**
2. **Solarized (Amended)**
3. **Solarized + FYM**
4. **Solarized + Chicken manure**
5. **Solarized + Spent compost**

A



B

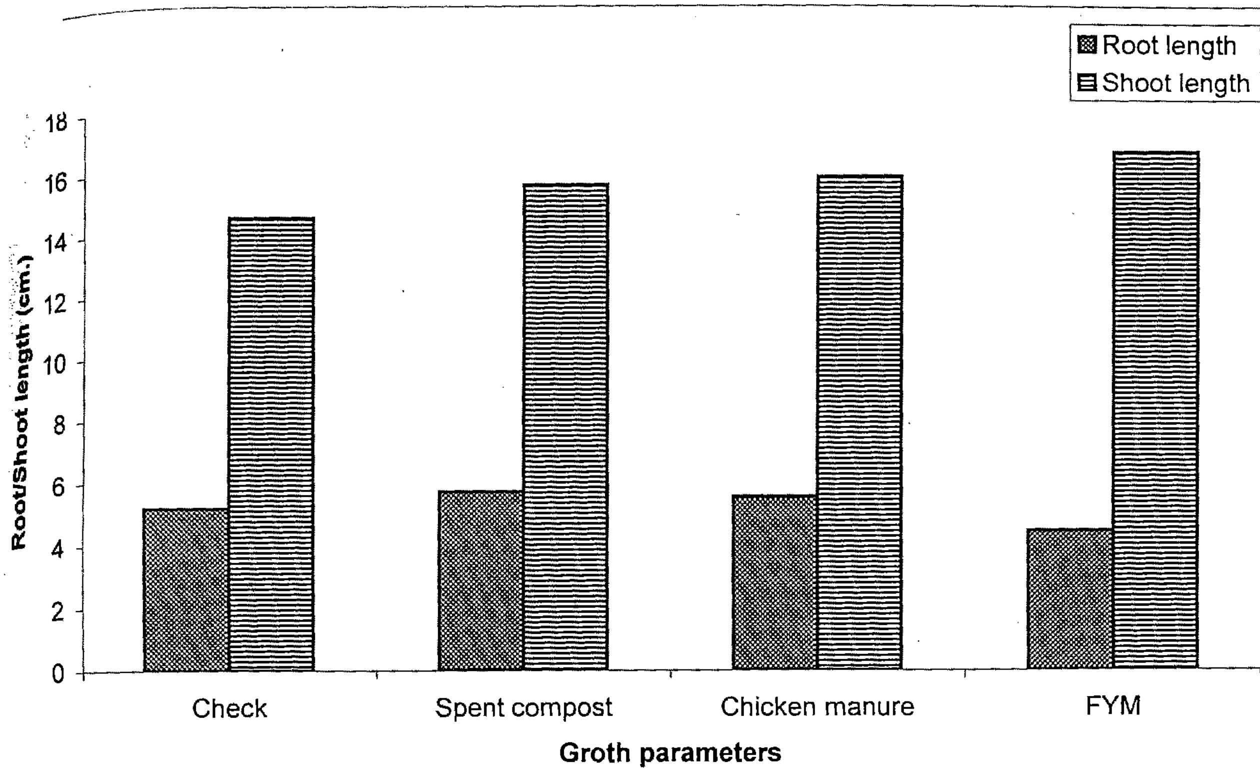


Fig. 34 : Effect of organic amendment + solarization on growth parameters (Tomato)

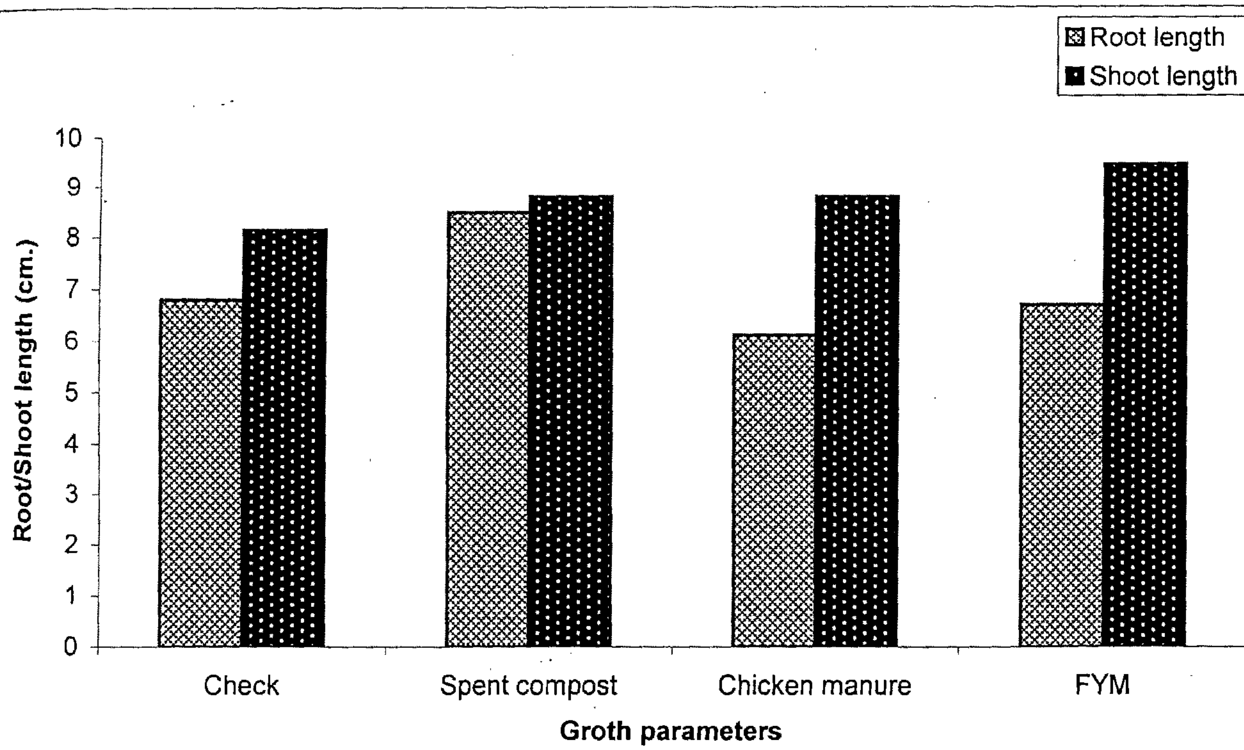


Fig. 35 : Effect of organic amendments + solarization on growth parameters (Brinjal)

Plate 5. **Effect of solarization at low temperature and organic amendment on plant growth**

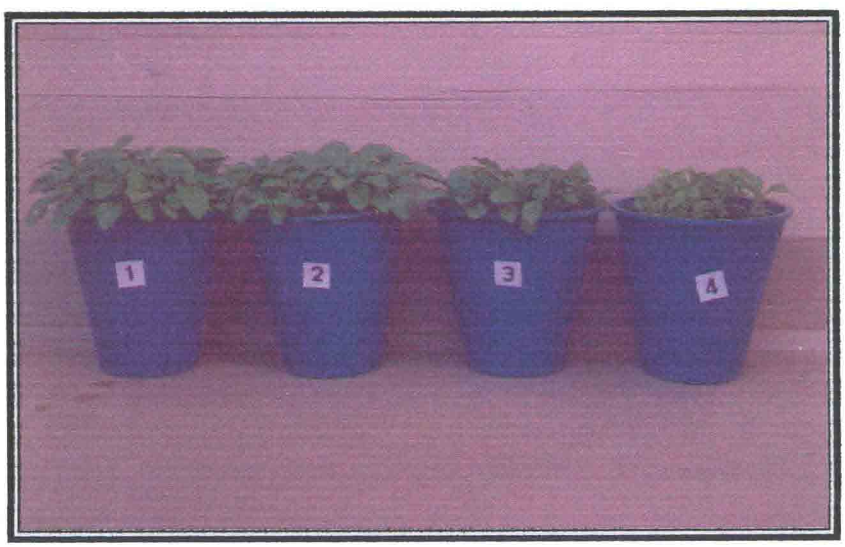
A : Tomato

1. **Check (non-solarized, non-amended)**
2. **Solarized + Chicken manure**
3. **Solarized + Spent compost**
4. **Solarized + FYM**

B : Brinjal

1. **Solarized + FYM**
2. **Solarized + Chicken manure**
3. **Solarized + Spent compost**
4. **Non-solarized non-amended (Check)**

A



B

the increase in root length, fresh root weight, fresh shoot weight, was significant, the increase of shoot length, dry root weight and dry shoot weight was highly significant. Computation of per cent increase over check revealed that root length increased up to 43 per cent, shoot length up to 52 per cent, fresh root weight up to 107 per cent, fresh shoot weight up to 40 per cent, dry shoot weight up to 123 per cent and dry weight up to 146 per cent. Among the amendments use, cotton seed cake was superior over other amendments. Result of another experiment in which solarization was done by covering organically amended soils in pots, with polyethylene sheets are presented in Fig. 34 and 35. Increased shoot and root length as compared to non-solarized was recorded.

4.5 Effect of soil microorganisms

Populations of soil microorganisms were enumerated just before mulching and then at 30 day time intervals. Results of the study are presented in Tables 47-52 and Figs. 36-41.

4.5.1 Total fungi

Solarization for a month reduced pre-solarized population/counts (c.f.u. per gram soil) of total fungi. The magnitude of decline ranged between 68-82 per cent. In unmulched soil the changes were non-significant and negligible. Populations recovered and increased with time and at harvest of first crop (at 30 days after solarization), counts of total fungi ranged from $29.33 \times 10^{-3} - 39.0 \times 10^{-3}$/g soil compared with $14.0 \times 10^3 - 19.33 \times 10^3$ cfu/g soil immediately after solarization. Nevertheless populations of soil fungi were significantly lower to initial counts or population in non-solarized plots. After 60 days of solarization and growth of 2nd nursery crop, total fungal populations recovered almost fully, as no significant differences in total fungi in solarized and non-solarized plots were observed. Similarly, the population levels assessed at 90th day and 120th days after solarization, differed non-significantly from initial count or populations in non-solarized plots; but in some cases total fungal populations levels exceeded to that of initial counts (Table 47).

No significant effect of polyethylene sheet thickness and colour on the recovery of total fungi after solarization was observed (Fig. 36).

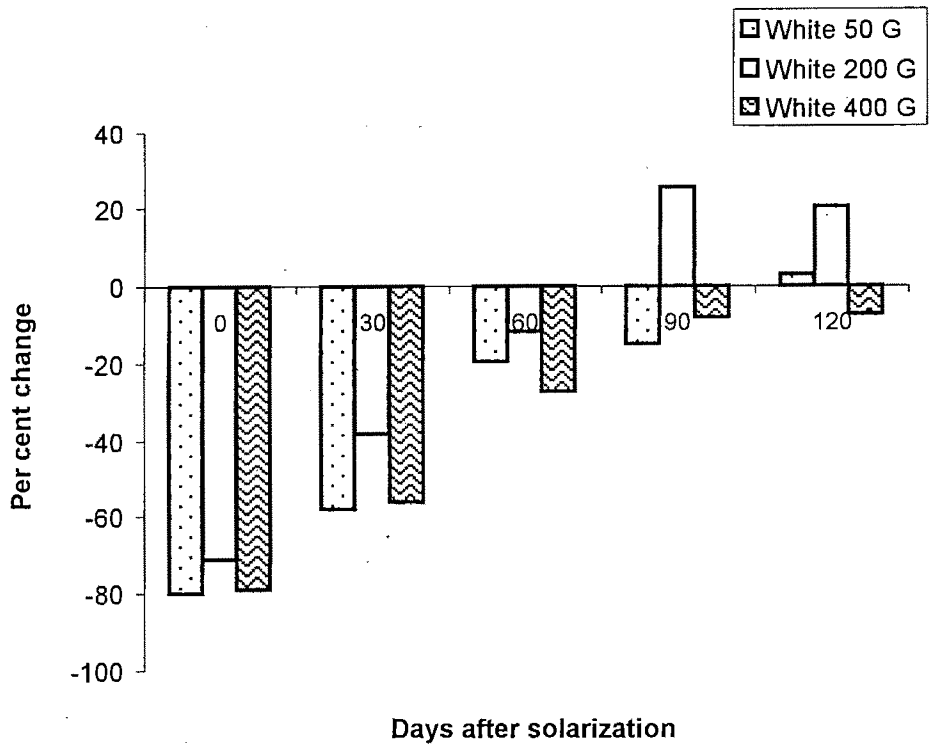
4.5.2 *Trichoderma* spp.

Population counts (c. f. u. per gram soil) of *Trichoderma* were almost same before solarization which declined significantly just after solarization. The decline ranged from 75 to 92 per cent over initial counts. Numbers of *Trichoderma* increased with time to 6.33×10^3 c.f.u./g soil, 8.45×10^3 and 6.67×10^3 c.f.u./g soil in plots solarized with white, black and red polyethylene respectively. Although *Trichoderma* population were lower to the initial counts after 30 days of solarization, however, the differences in populations, in non-solarized and solarized plots were non-significant.

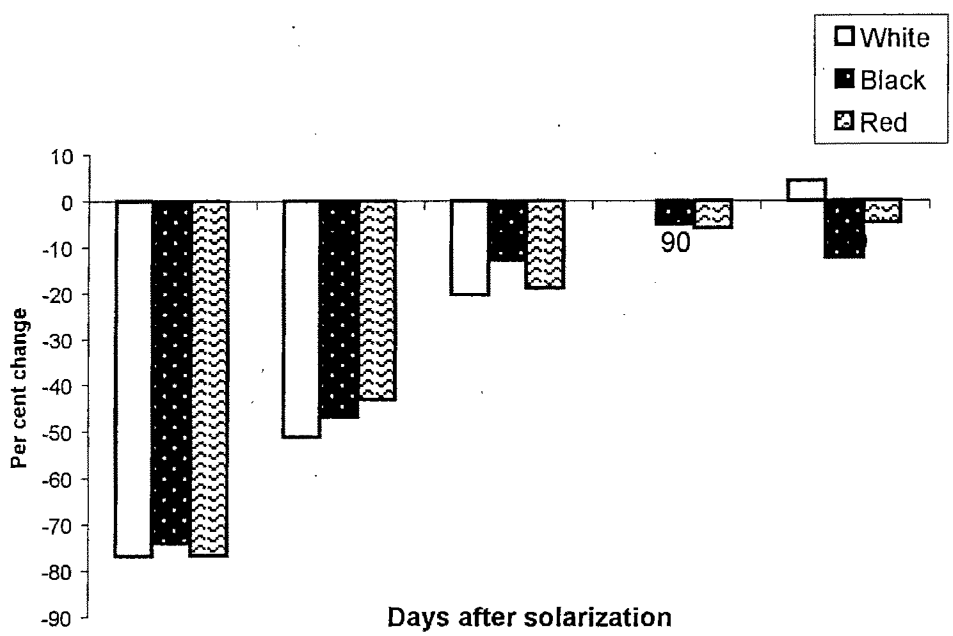
When assessed at 60th day after solarization populations exceeded the initial counts after complete recovery. Increase over

Table 47 : **Effect of polyethylene mulching on soil fungi**

Time of Isolation after solarization	Colony forming units per gram soil × 10^3													Cd at 5 %
	Non-solarized	White polyethylene				Black polyethylene				Red polyethylene				
		50G	200G	400G	Mean	50G	200G	400G	Mean	50G	200G	400G	Mean	
Initial	50.00	59.67	59.33	73.33	67.44	57.00	64.67	74.33	65.33	58.00	71.00	61.33	63.44	15.7
At 0 day	49.67	14.00	17.00	15.33	15.44	18.33	19.33	33.33	17.00	15.67	14.33	14.33	14.78	9.8**
At 30th day	53.67	29.33	36.67	32.33	32.78	29.33	46.00	49.00	34.78	34.67	35.00	39.00	36.22	6.9**
At 60th day	55.67	56.00	52.33	53.33	53.89	52.00	64.00	55.33	57.11	47.33	55.00	52.33	51.55	23.1
At 90th day	48.67	59.33	74.33	67.33	67.00	67.33	66.33	52.67	62.11	69.00	55.33	55.00	59.78	17.6
At 120th day	58.00	71.67	71.33	68.00	70.33	53.00	64.33	54.67	57.33	65.67	58.67	57.00	60.45	13.0
cd at 5%	13.65	cd_3 13.98		cd_4 12.52		cd_3 18.26		cd_4 16.40		cd_3 10.46		cd_4 17.44		



A. Effect of polyethylene thickness



B. Effect of polyethylene colour

Fig. 36 : Per cent change in total fungi over initial count

initial counts ranged from 24.48-38.4 per cent. Population further increased by 28.85, 50.00 and 44.00 per cent over initial counts in plots solarized under white, black and red polyethylene sheets respectively, when assessed 90 days after solarization (Fig. 37 B).

Effect of solarization persisted up to 120 days after solarization in plots solarized under white transparent PES, since population further increased significantly by 54.55 per cent over initial counts. But no further increase was observed in rest of the solarized plots (Table 48 and Figs. 37 A, B).

4.5.3 *Pythium* spp.

Populations reduced below detectable levels in plots solarized under white transparent polyethylene sheets, immediately after solarization and extremely low numbers of propagules were observed in plots solarized with black or red polyethylene sheets compared with 13.67 × 10^3 c.f.u./g soil in non-solarized plots (Table 49).

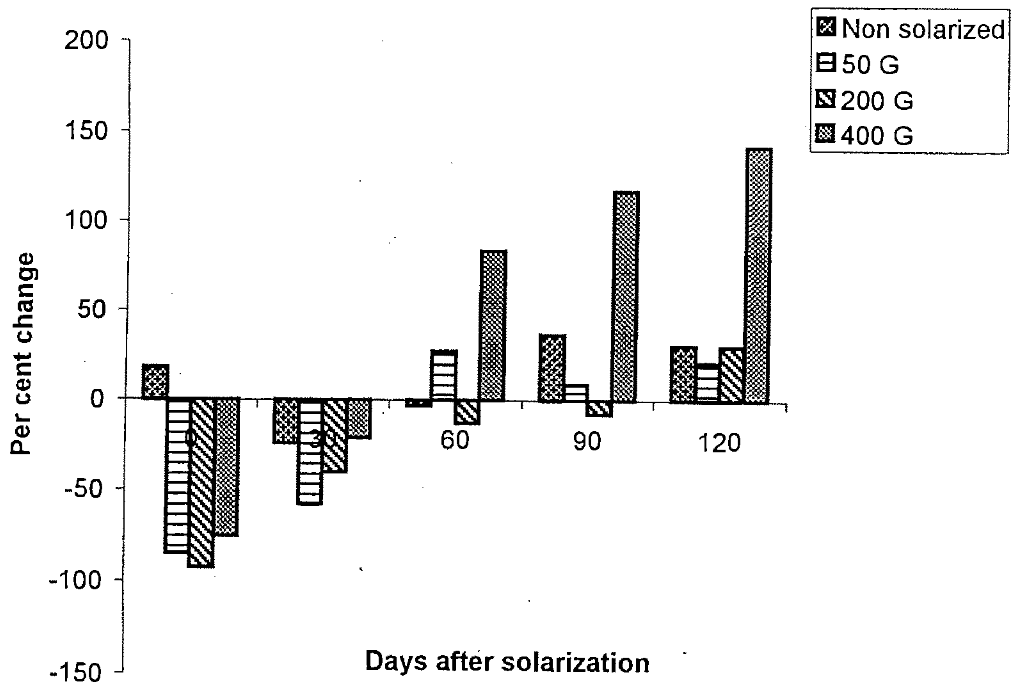
Thirty days after solarization *Pythium* spp. were suppressed completely in plots solarized under white transparent polyethylene sheets but in rest of the solarized plots. Suppression of *Pythium* propagules remained evident up to 120 days after solarization, since per cent decrease of 59-87.5% over initial counts was observed in population (Fig. 38 A, B).

4.5.4 Total bacteria

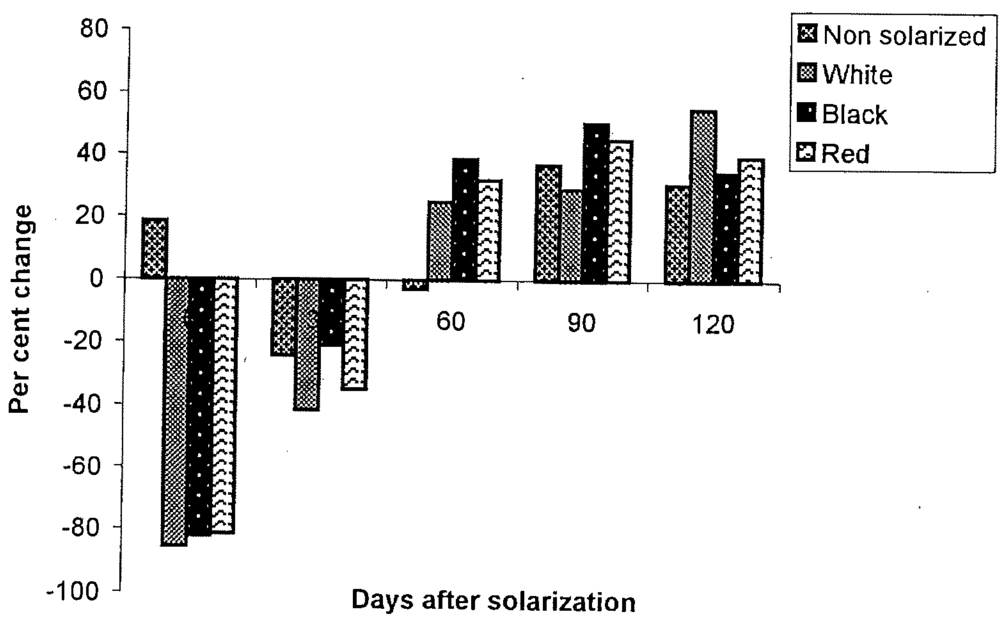
Total bacterial populations were significantly reduced by solarization. Total bacteria counted immediately after solarization

Table 48 : **Effect of soil solarization on natural population fungal antagonist *Trichoderma***

Time of Isolation after solarization	Colony forming units per gram soil × 10^3													cd at 5%
	Non-solarized	Solarized												
		White polyethylene				Black polyethylene				Red polyethylene				
		50G	200G	400G	5 %	50G	200G	400G	Mean	50G	200G	400G	Mean	
Initial	11.00	11.00	13.33	8.00	10.76	10.37	12.00	19.67	10.68	9.67	9.67	11.33	10.22	5.29
At 0 day	13.00	1.67	1.00	2.00	1.56	2.00	2.00	1.67	1.89	2.33	2.00	1.33	1.89	3.50**
At 30th day	8.33	4.67	8.00	6.33	6.33	5.67	9.00	10.67	8.45	5.67	5.67	8.67	6.67	4.01
At 60th day	10.67	14.00	11.67	14.67	13.45	14.67	16.33	13.33	14.78	15.33	13.33	11.67	13.44	5.68
At 90th day	15.00	12.00	12.33	17.33	13.89	15.33	16.67	16.00	16.00	15.33	17..67	11.33	14.78	5.52
At 120th day	14.33	13.33	17.33	19.33	16.66	12.00	12.67	18.33	14.33	13.67	16.67	12.33	14.22	4.94*
cd at 5%	5.82	Cd_3 4.31		cd_4 4.25		cd_3 3.81		cd_4 4.10		cd_3 5.50		cd_4 5.30		



A. Effect of polyethylene thickness

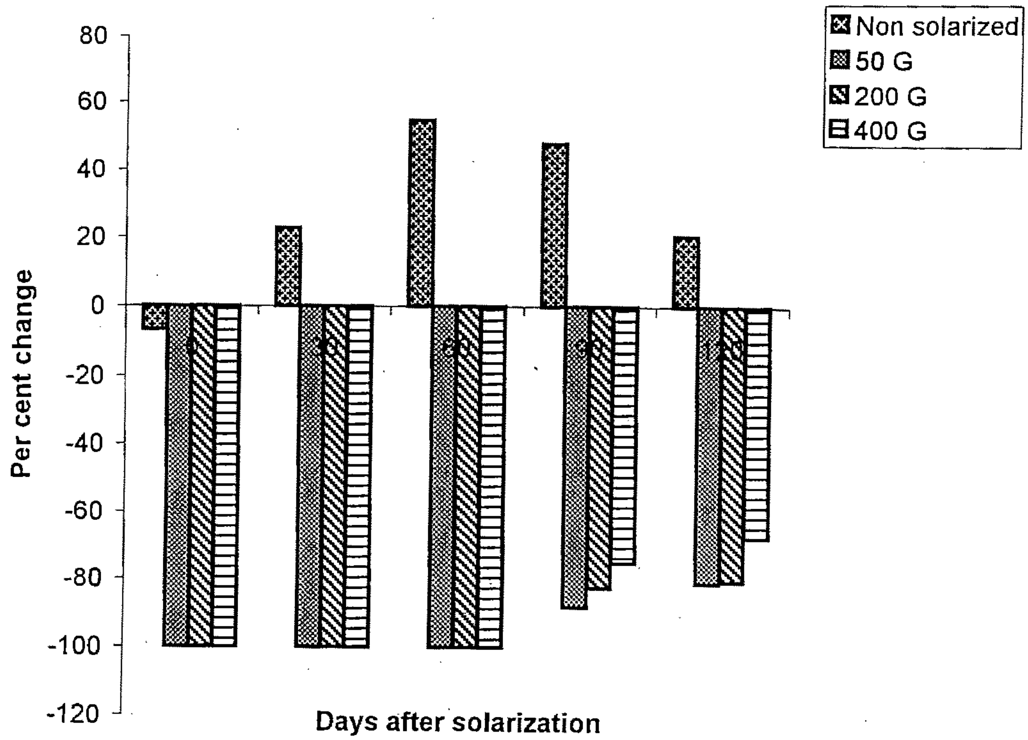


B. Effect of polyethyle colour

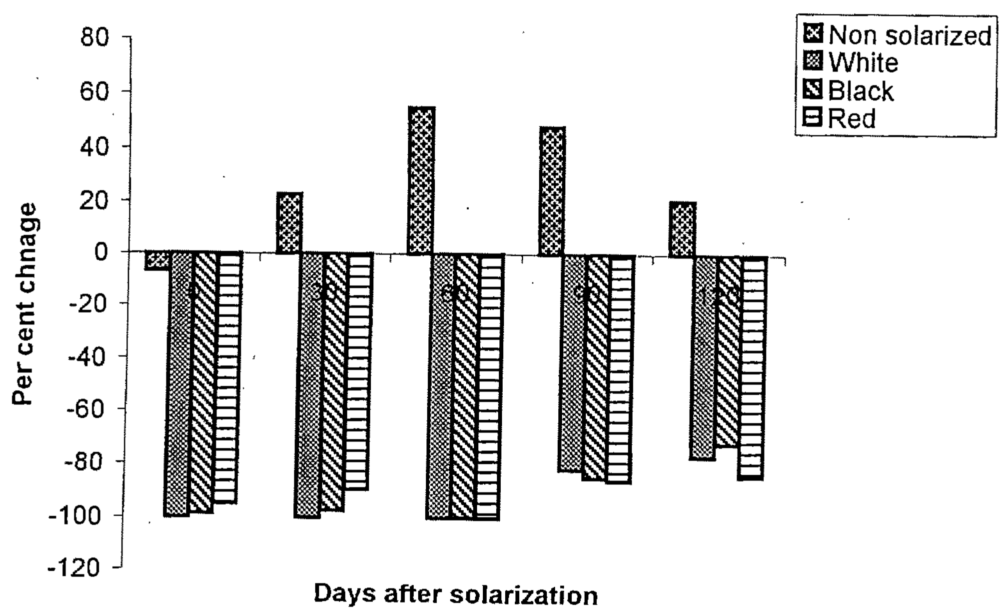
Fig. 37 : Per cent change in populations of *Trichoderma* sp. over initial count

Table 49 : **Effect of polyethylene mulching on damping-off causing fungus-*Pythium***

Time of Isolation after solarization	Colony forming units per gram soil × 10^3													cd at 5%
	Non-solarized	Solarized												
		White polyethylene				Black polyethylene				Red polyethylene				
		50G	200G	400G	5 %	50G	200G	400G	Mean	50G	200G	400G	Mean	
Initial	14.67	14.00	17.00	13.33	14.78	21.33	17.67	12.33	17.11	18.33	16.33	20.00	18.22	6.8
At 0 day	13.67	0.00	0.00	0.00	0.33	0.33	0.00	0.67	1.33	0.67	1.33	0.67	0.89	1.6**
At 30th day	18.00	0.00	0.00	0.00	0.00	0.00	1.33	0.00	0.44	3.30	1.00	1.33	1.88	2.0**
At 60th day	22.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.1**
At 90th day	21.67	1.67	3.00	3.33	2.67	3.67	1.33	2.68	2.56	2.67	2.67	2.33	2.56	6.0**
At 120th day	17.67	2.67	3.33	4.33	3.44	2.67	2.67	5.00	3.45	3.33	2.33	3.00	2.89	5.8**
cd at 5%	9.76	cd_3 3.13		cd_4 4.63		cd_3 5.23		cd_4 5.71		cd_3 5.61		cd_4 7.92		



A. Effect of polyethylene thickness



B. Effect of polyethylene colours

Fig. 38 Per cent change in soil populations of *Pythium* sp. over initial count ranged from 13.0 × 10^6 to 19.67 × 10^6 c.f.u. per gram soil compared to 38.67 × 10^6 c.f.u. per gram in non-solarized plots (Table 50). Populations recovered within 30 days after solarization, as non-significant differences in populations were observed in non-solarized and solarized plots.

Total bacterial counts at the harvest of second crop (60 days after solarization) revealed that populations of soil bacteria not only fully recovered but increased tremendously by above 52-123% over initial counts. Maximum increase of 123 per cent and 120.55 per cent was observed in plots solarized with 50 gauge thick red polyethylene sheet, respectively and minimum (52 per cent) was observed in plots solarized under 400 gauge black polyethylene sheets (Fig. 39 A, B).

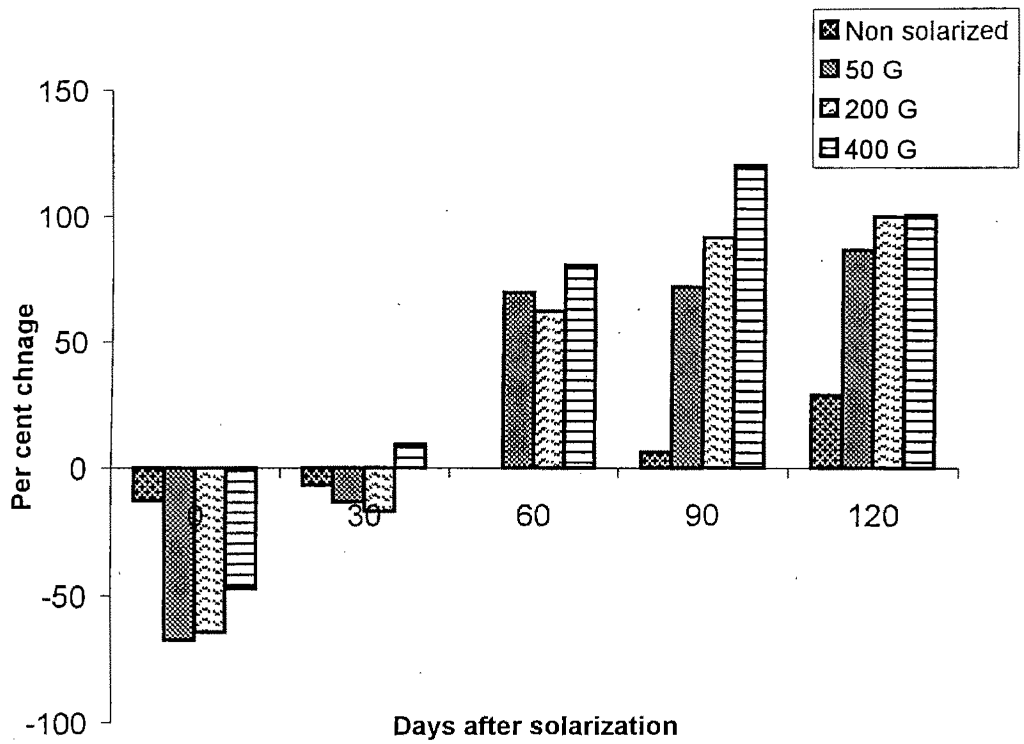
Population after 90 days and 120 days of solarization showed non-significant differences from the population levels attained after 60 days of solarization.

4.5.5 *Bacillus* spp.

Population reduced drastically by 62.3, 64.8 and 41.1 per cent after solarization over initial counts in plots mulched under white, black and red polyethylene sheets, respectively. Populations recovered after 30 days of solarization as non-significant differences in populations were observed in solarized and non-solarized plots (Table 51). In fact, in solarized plots population of *Bacillus* exceeded over its initial counts. However, the increase was non-significant, but

Table 50 : **Changes in total bacterial flora in solarized soil**

Time of Isolation after solarization	Colony forming units per gram soil × 10^3													cd at 5%
	Non-solarized	Solarized												
		White polyethylene				Black polyethylene				Red polyethylene				
		50G	200G	400G	5 %	50G	200G	400G	Mean	50G	200G	400G	Mean	
Initial	44.33	42.33	43.00	37.33	40.89	43.66	40.33	45.33	43.11	33.33	39.67	46.33	39.78	13.1
At 0 day	38.67	14.00	15.67	19.67	16.45	15.67	16.00	19.67	17.22	18.00	16.00	13.00	15.67	8.4**
At 30th day	41.33	36.67	35.67	40.67	37.67	35.33	35.33	40.66	31.11	42.33	39.00	36.33	39.22	12.1
At 60th day	44.33	71.66	69.67	67.33	69.55	72.67	74.00	69.00	71.90	74.33	63.00	73.67	70.33	24.1
At 90th day	47.00	72.67	82.33	82.33	78.11	77.67	71.67	74.00	74.45	74.33	79.00	66.00	73.11	24.3
At 120th day	57.00	79.00	86.00	75.00	80.00	73.00	76.33	82.00	77.11	68.67	76.33	79.67	74.89	22.9
cd at 5%	21.8	cd_3 16.41		cd_4 15.54		Cd_3 19.90		cd_4 20.30		cd_3 15.40		cd_4 18.06		



A. Effect of polyethylene thickness

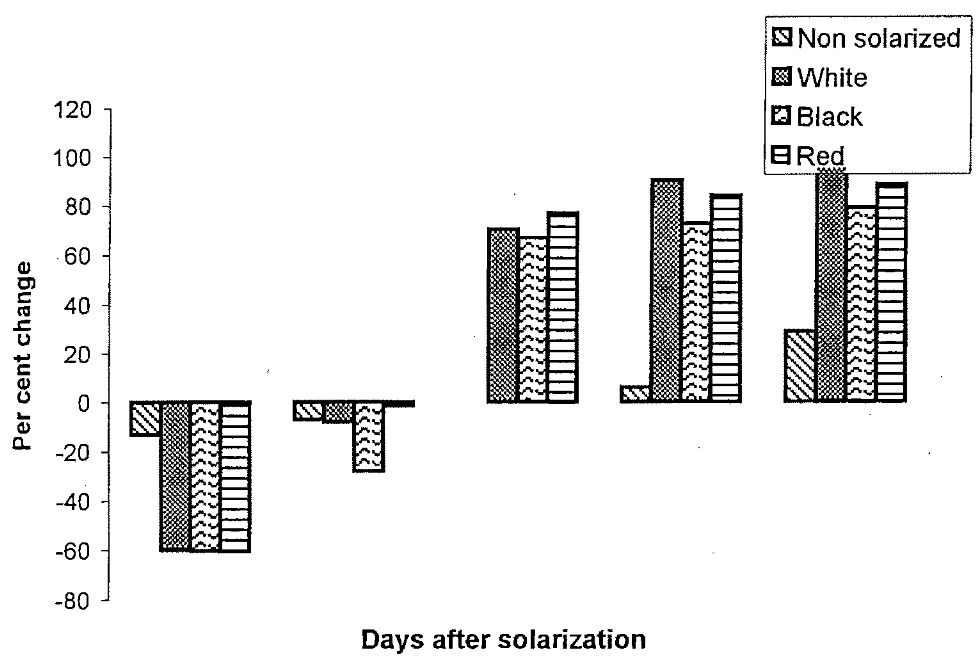


Fig. 39 : Per cent change in total bacteria over initial count

Table 51 : **Effect of thickness and colour of polyethylene sheeting on soil populations of *Bacillus* spp.**

Time of Isolation after solarization	Colony forming units per gram soil × 10^3													cd at 5%
	Non-solarized	Solarized												
		White polyethylene				Black polyethylene				Red polyethylene				
		50G	200G	400G	5 %	50G	200G	400G	Mean	50G	200G	400G	Mean	
Initial	25.67	24.33	33.23	25.00	27.55	26.00	30.67	41.33	32.67	25.67	24.67	20.00	23.45	12.8
At 0 day	32.00	9.66	10.33	10.67	10.22	13.33	12.00	9.00	11.44	13.67	12.33	14.67	21.44	6.9**
At 30th day	34.00	32.33	38.33	38.00	36.22	27.33	38.67	38.67	34.90	35.00	39.33	38.33	37.55	14.0
At 60th day	38.00	47.67	45.33	44.33	45.78	61.00	46.67	40.33	49.33	50.00	40.67	45.67	45.45	19.6
At 90th day	54.67	51.33	61.00	55.00	55.76	61.00	64.00	50.00	58.33	62.67	67.33	66.33	65.44	17.0
At 120th day	35.00	65.00	61.33	56.66	61.00	61.00	53.00	49.33	54.44	65.33	55.00	48.33	56.22	19.8
cd at 5%	12.10	cd_3 13.94		cd_4 17.81		cd_3 15.84		cd_4 15.68		cd_3 18.17		cd_4 17.63		

by the end of 60^{th} day after solarization, populations of *Bacillus* increased significantly in solarized plots with a maximum increase being of 93.8 per cent over initial counts in plots solarized with red PES (Figs. 40 A, B).

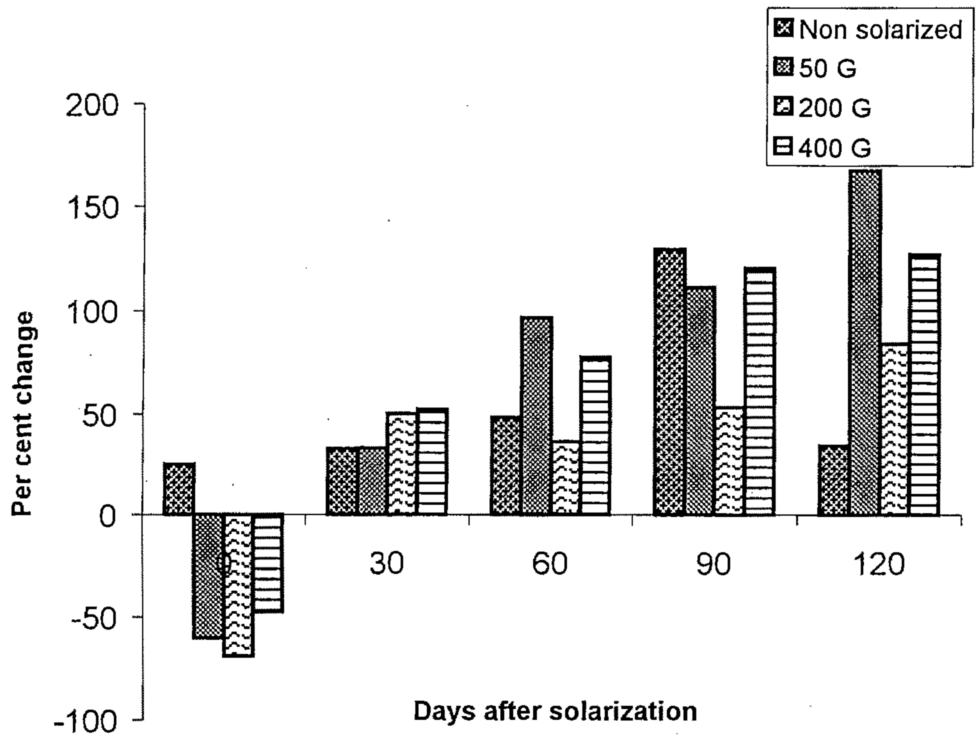
Population counts at 90 or 120 days after solarization showed that population attained in solarized plots were maintained except a slight reduction in population in plots solarized under black polyethylene sheets (Fig. 40 B).

4.5.6 Fluorescent pseudomonads

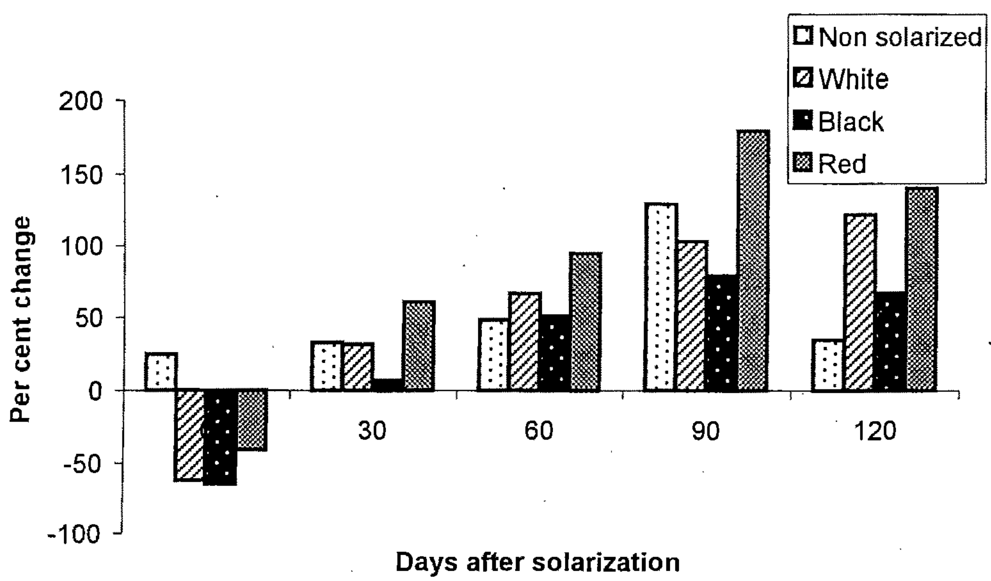
In contrast to the effect on fungi and total bacteria, fluorescent pseudomonads did not decline significantly by solarization. $11.33 \times 10^6 - 15.33 \times 10^6$ c.f.u./g soil were observed in solarized plots compared with 16.0×10^6 c.f.u./g soil in non-solarized plots (Table 52).

Effect of solarization was observed as a significant increase was noted in fluorescent pseudomonads population within 30 days of solarization. The increase in population were significantly higher in solarized plots than in non-solarized plots as the numbers of fluorescent pseudomonads in solarized plots ranged from 30.0×10^6- 44.33×10^6 cfu/g soil in solarized plots compared with 28×10^6 cfu in non-solarized plots.

Effect of solarization persisted up to 60 days, since further significant increase over initial counts in population were observed. Population fluctuations observed at 90^{th} day or 120^{th} day after



A. Effect of polyethylene thickness

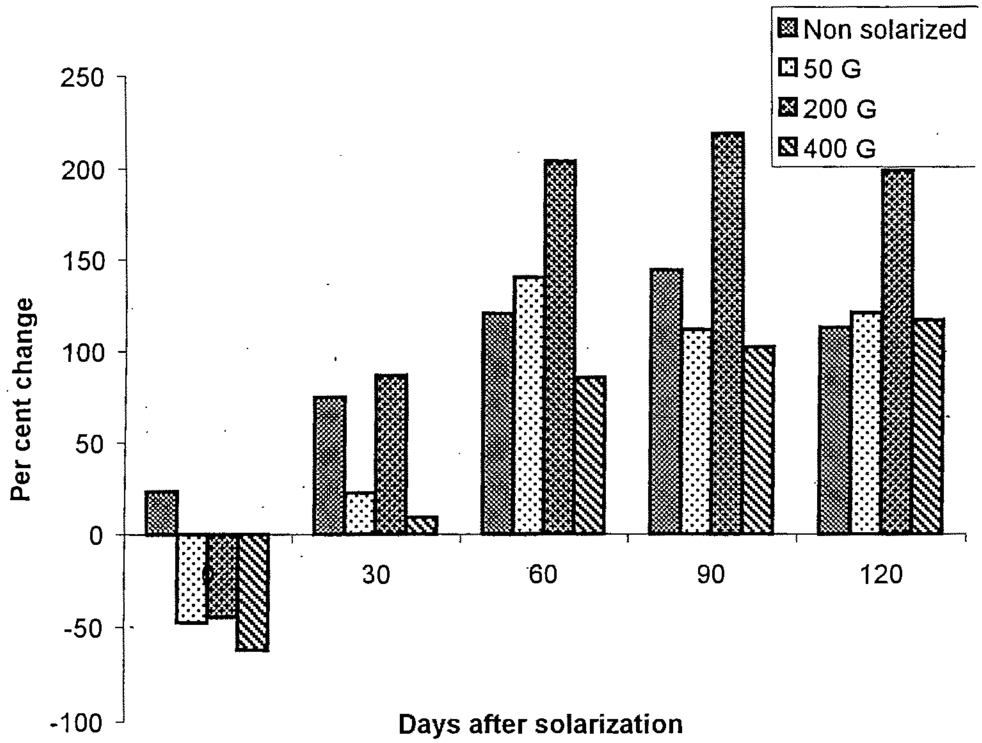


B. Effect of polyethylene colour

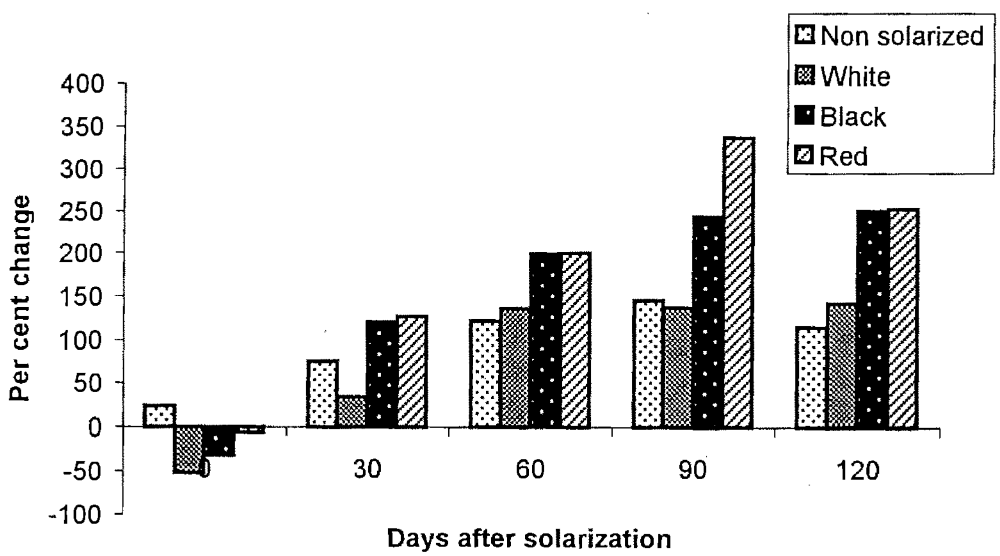
Fig. 40 : per cent change in populations of *Bacillus* sp. over initial count

Table 52 : **Effect of polyethylene mulching on the populations of fluorescent pseudomonads- The PGPR**

Time of Isolation after solarization	Colony forming units per gram soil × 10^3														cd at 5%
	Non-solarized	Solarized													
		White polyethylene				Black polyethylene				Red polyethylene					
		50G	200G	400G	5 %	50G	200G	400G	Mean	50G	200G	400G	Mean		
Initial	13.00	25.33	20.00	30.00	25.11	19.33	17.33	16.00	17.55	16.67	15.00	14.67	15.45		8.7*
At 0 day	16.00	13.33	11.33	11.33	12.00	12.63	12.00	11.33	12.00	15.33	13.33	14.67	14.44		4.7
At 30th day	28.00	31.00	37.33	32.67	33.67	30.00	41.33	44.33	38.55	31.00	36.00	37.67	34.89		8.6*
At 60th day	32.33	60.67	60.67	55.67	59.00	53.33	60.67	43.00	52.33	44.67	46.67	47.33	46.22		23.6
At 90th day	39.00	53.67	63.67	60.67	59.34	56.33	63.67	59.67	59.89	63.00	70.67	68.67	67.45		18.2
At 120th day	34.00	56.00	59.67	65.00	60.22	65.00	52.67	66.00	61.22	59.00	58.33	55.33	54.22		19.4
cd at 5%	7.63	cd_3 17.60		cd_4 17.95		cd_3 13.60		cd_4 14.81		cd_3 15.90		cd_4 17.80			



A. Effect of polyethylene thickness



B. Effect of polyethylene colour

Fig. 41 : Per cent change in populations of fluorescent Pseudomonads over initial count

solarization were non-significant since population in non-solarized plots also increase over initial counts. The increase may be attributed to the changes in soil environment, in favour of fluorescent pseudomonads and/or due to the crops raised.

4.6 Effect on weeds

Populations of weeds were recorded before and after solarization. The data so obtained are presented in Table 53. In non-solarized plots the weed density per sq. m did not change but in solarized plots almost all the weeds principally the species of *A. conjiodes, C. dectylon, C. rotundus, E. hitra and Parthenium* sp. were eliminated except for *rotundus,* which was reduced by 82.61 per cent under black or red polyethylene sheeting but eliminated completely under white transparent polyethylene sheets (Table 53).

Table 53: **Effect of weed density/s.q. m (VRC)**

Weed species	**Initial**	**Non solarized control**	**Solarized**									**%Control over non-solarized**
			White polyethylene			**Red polyethylene**			**Black polyethylene**			
			50	**200**	**400**	**50**	**200**	**400**	**50**	**200**	**400**	
1. *Ageratum conijodes*	14.5	13	0	0	0	0	0	0	0	0	0	100
2. *Agropyron repens*	5.0	4	0	0	0	0	0	0	0	0	0	100
3. *Amaranthus* spp.	3.0	1	0	0	0	0	0	0	0	0	0	100
4. *Chinopodium album*	2.5	1	0	0	0	0	0	0	0	0	0	100
5. *Cleon* spp.	1.5	0	0	0	0	0	0	0	0	0	0	100
6. *Cynodon dectidlon*	19.5	18	0	0	0	0	0	0	0	0	0	100
7. *Cyperus rotundus*	10.0	23	0	0	0	3	1	3	6	6	3	82.16
8. *Euphorbia hirta*	22.0	21	0	0	0	0	0	0	0	0	0	82.16
9. *Oxalis* spp.	80.0	48	0	0	0	0	0	0	0	0	0	82.16
10. *Phyllanthus niruri*	2.0	3	0	0	0	0	0	0	0	0	0	82.16
11. *Parthenium* spp.	20.0	38	0	0	0	0	0	0	0	0	0	82.16
12. *Solanum nigrum*	2.0	1	0	0	0	0	0	0	0	0	0	82.16
13. *Vernonia cinera*	1.5	1	0	0	0	0	0	0	0	0	0	82.16
14. Unidentified	4.75	5	0	0	0	0	0	0	0	0	0	82.16

DISCUSSION

5. DISCUSSION

The success of solarization is based on the fact that most plant pathogens and pests are mesophylic, i.e. they are unable to grow at temperatures above 32°C; they are killed directly or indirectly by the temperatures achieved during solarization of the moist soil under transparent plastic films which greatly restrict the escape of volatiles (gases, water vapour) **(DeVay, 1991)**. Thermotolerant and thermophilic soil microflora (both inhabitants and invaders) usually survive the soil solarization process **(Stapleton and DeVay, 1984).**

However, all soilborne organisms, if not directly inactivated by heat, may be weakened and become vulnerable to gases produced in solarized soil or to change in microflora and thus are managed by some form of biocontrol **(Katan, 1987; Sapleton and DeVay, 1982).** The thermal decline of soilborne organisms during solar heating depends on both, the soil temperatures and exposure time which are inversely related. Effectiveness of solarization for disinfesting soil and increasing PGR, depends on soil colour-texture-structure, air temperature, soil moisture, day length, intensity of sunlight, thickness and light transmittancy of the plastic film.

In the present investigations, the effect of soil mulching with polyethylene films on the seedling diseases (damping-off) of horticultural crops, plant growth, changes in physico-chemical and biological properties of soil have been studied. Inputs and variables included in the study were colour and thickness of polythene, seed-treatment with fungicides and bioagents, and the crops raised were cauliflower, cabbage, tomato, onion, calendula and aster. The results so recorded are discussed in the following paragraphs.

Polythene colour

The effect of different coloured polyethylene mulches (black, red and white transparent) on soil temperature and the resultant effects on disease-index, physico-chemical and biological properties of the soil were studied. It was invariably observed that highest temperature developed under white transparent mulch followed by red and black mulches. Almost similar observations were recorded by **Alkayssi and Alkaraghouli (1991).** They concluded that heat flux is one of the components of the energy balance and is closely related to the amount of radiation transmitted through mulches. High values and even distribution of soil heat flux were found under transparent and red mulches. The soil heat flux under black mulch was strongly skewed toward lower value. The observations were in accordance with their observations.

Low density polyethylene **(Clarke, 1987)** is widely used for agricultural mulch because of its flexibility, tensile strength and resistance to physical damage. It is beyond doubt, that polyethylene is an ideal film for solar heating of soil because it is essentially transparent to solar radiation (280 to 2500 nm), extending to the far infra red, but much less transparent to terrestrial radiation (5000-35000 nm), and thus reducing the escape of heat from the soil **(Chaube and Singh, 1991).**

In several research reports, it is fully established that thicker polyethylene films (2-6 mil) or the thinner film (1.0-1.5 mil), both are effective for solar heating. However, increased comparable effectivity is associated with its transmittancy. In our study, thickness of the polyethylene film, used as a variable though, did not cause any significant effects on all factors (physical/chemical/biological) but it is in accordance with observations recorded and cited by others. The summarized effects of colour and thickness with mechanism(s) operative are hypothesized in Fig. 42.

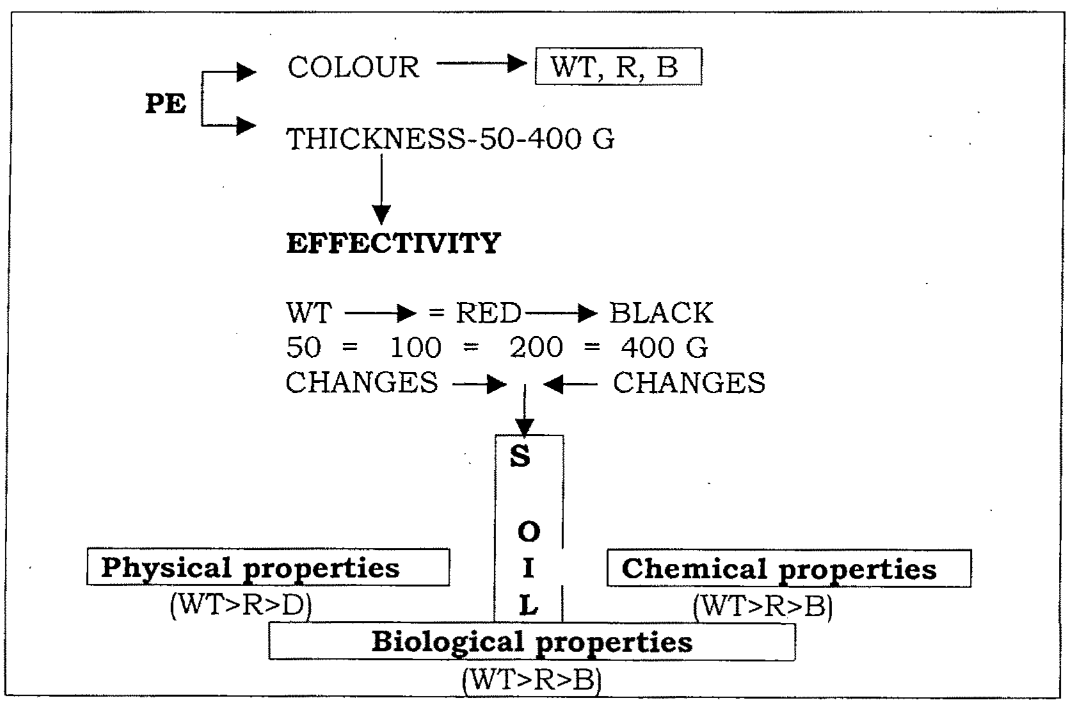


Fig.42 : **Effect of soil solarization on soil properties**

Physico-chemical changes

Soil moisture is a critical variable in soil solarization, since the transfer of heat in soil is greatly increased by moisture. In our study, to maximize this effect in soil, pre-irrigation of soil was done. Moisture when measured after a month of solarization revealed only minor loss of moisture from mulched plots while from unmulched plots the loss was substantial. It is so, obviously because from uncovered plots, the solar radiation falling on the earth will cause loss of moisture through evapotranspiration since layer of plastic film provides insulation against the escape of both the heat and moisture from the soil, the moisture content of solarized soil remained almost the same. Several workers working on different aspects of soil solarization have also made similar observations **(Ahmad *et al.*, 1996; Chen and Katan, 1980; Katan, 1987)**. Thus, observations on moisture conservation in solarized soil are in accordance with the observations of others.

Temperature of the moist soil is the main variable in the process of solarization. In present study, the temperature of the soil solarized with white (transparent) and red polyethylene increased on the whole by about 10-15°C. This observation is in accordance with the observations made by several workers **(Chelemi *et al.*, 1994; Esfahani, 1991; Maura *et al.*, 1994; Mishra, 1997; Tacconi and Santi, 1994)**. Compared to transparent polyethylene films, black PE containing carbon black, absorbs solar radiation and thus reduces the heating of soil by several degrees **(Anonymous, 1984; Hancock, 1988).** Based on information and observations available, the reasons and effects of maintenance of soil moisture and increased temperature are summarized in flow chart (Fig. 43).

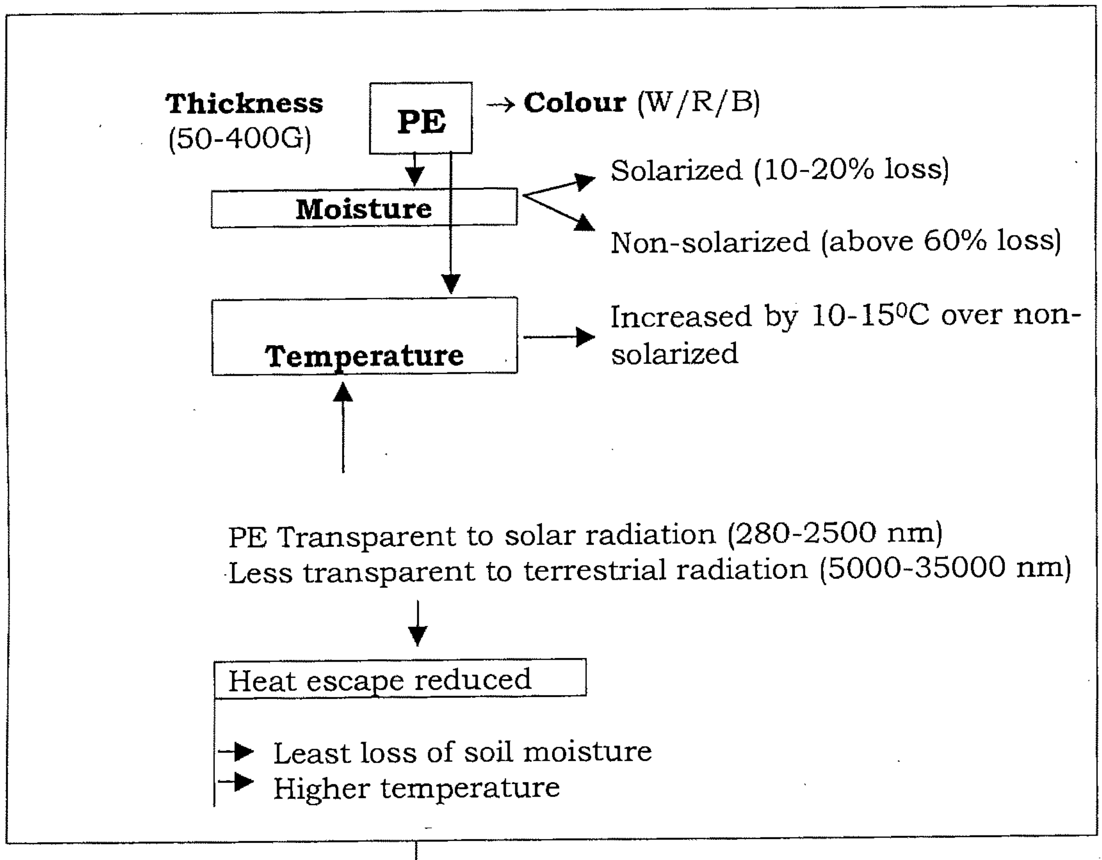


Fig.43: **Effect on soil moisture and temperature**

In another flow chart, factors/inputs required for prediction of soil temperature are proposed (Fig. 44).

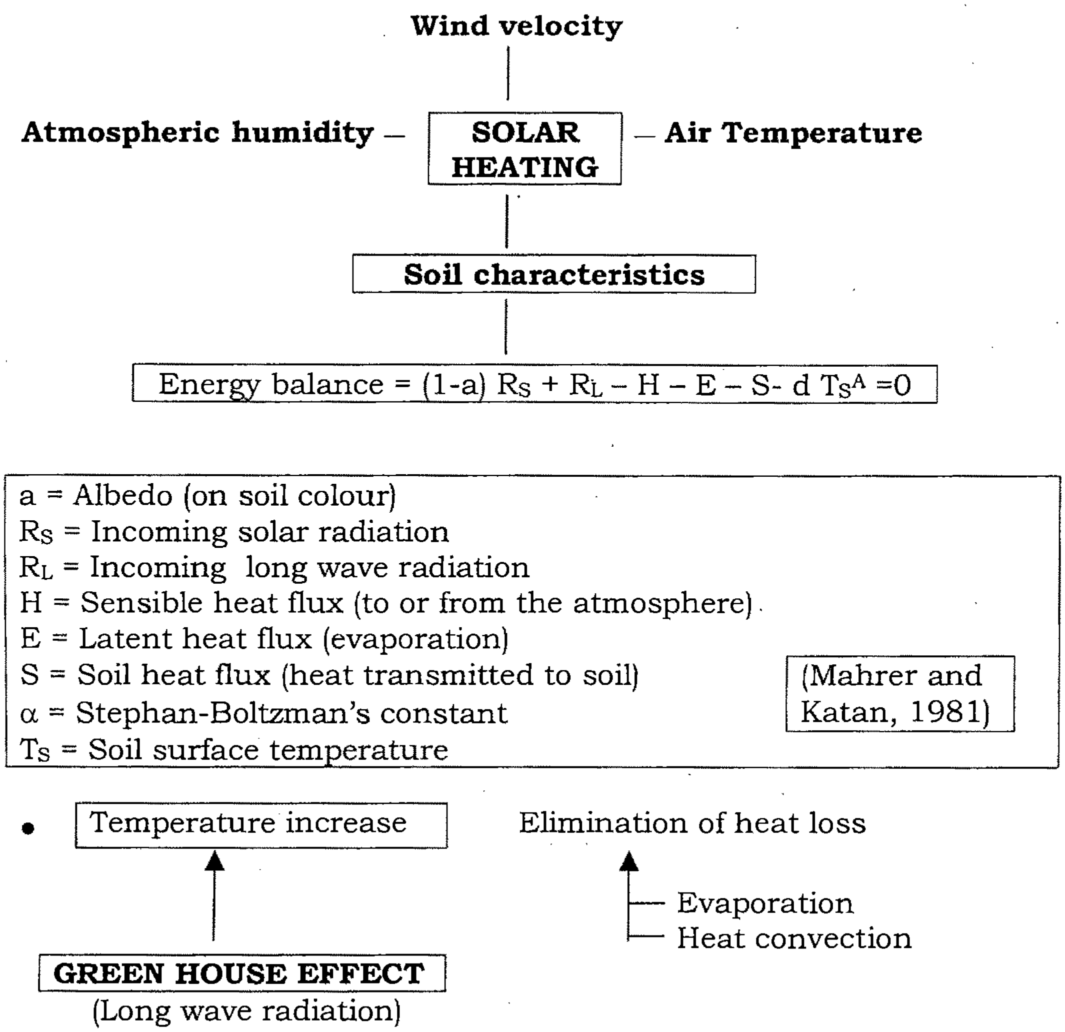


Fig. 44: **Calculation of temperature in soil**

Solarization has been reported to affect several soil properties **(Ahmad *et al.*, 1996; Chen and Katan, 1980; Kaewrung *et al.*, 1989; Kumar and Yaduraju, 1992; Stapleton *et al.*, 1985)**. In present investigations, solarization had no effect on soil pH. However, reduction in soil salinity due to solarization is reported **(Abdel-Rahim *et al.*, 1988)**. Electrical conductivity increased significantly. Similar observations have been made by several others **(Arora, 1998; Arora and Yaduraju, 1998; Patel and Patel, 1997; Stapleton *et al.*, 1985)**. However, **Ahmad *et al.* (1996)** and **Kumar and**

Yaduraju (1992) have reported reduced electrical conductivity levels following solarization. Significant increase in electrical conductivity might have been due to presence of different ions/nutrients in soil water/soil colloids, released as a consequence of heat-effect generated by solarization.

Soil organic carbon, a measure of available nitrogen in soil, remained almost unchanged after solarization. Such observations have been made by **Ahmad *et al.* (1996), Arora (1998), Arora and Yaduraju (1998)** and **Kumar and Yaduraju (1992)**. However, **Patel and Patel (1997)** reported increased percentage of organic carbon in solarized soil. It is possibly due to differences in the experimental conditions, including locations and biological properties of the soil. Total soil nitrogen in the present study increased significantly due to solar heating of the soil. Several researchers **(Daelemans, 1989; Grunzweig *et al.*, 1998; Patel and Patel, 1997; Stapleton *et al.*, 1985)** have also made such observations. Total soil nitrogen might have increased after solarization because of stimulation of soil physical and/or biological activities/reactions causing degradation of organic matter, by the heat-effect and releasing the nitrogen fraction too, into the soil colloids. And also because of prevention of loss by volatilization due to polyethylene cover. In addition, when soil is heated, much of the resident microbiota are killed and degraded, thus liberating the mineral nutrients. During solarization increased amounts of nitrogen (Principally NH_4-N and/or NO_3-N) usually are liberated **(Chen and Katan, 1980; Stapleton *et al.*, 1985)**.

The amount of available phosphorus estimated from solarized soil was found affected only marginally. The increase was invariably minor and non-significant. It is not contrary to observations made by **Kaewrung *et al.* (1989).** However, several others have reported increased 'P' content in solarized soil **(Ahmad *et al.*, 1996; Arora, 1998; Patel and Patel, 1997).** Inconsistent changes in available K content of soil were observed after solarization in the present study. Significant increase in available K in solarized soil has been reported **(Arora ,1998; Gruntzweig *et al.*,1998; Patel and Patel, 1997). Ahmad *et al.* (1996)** reported higher levels of K in solarized plots but **Kaerwrung *et al.* (1989)** observed no effect of concentration on K^+ in soil after solarization. A summary of causes and consequences of solarization on soil's physics and chemistry is shown in Fig. 45.

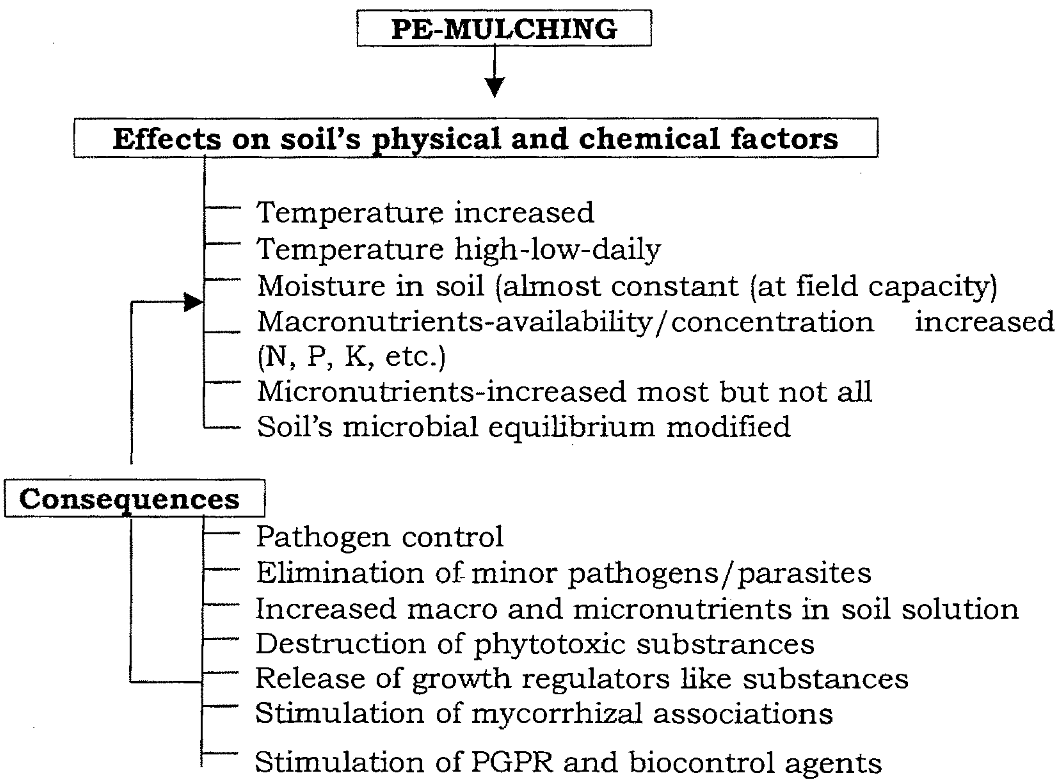


Fig. 45 : **Solarization changes soil's physics and chemistry**

Disease-incidence

One of the principle reasons for using the technique of soil solarization is to reduce the incidence of pre as well as post-emergence damping-off of horticultural crops raised in nurseries. In the present study, solarization was done at two sites. At VRC, four crops-cauliflower, cabbage, tomato and onion were raised in sequence while at floriculture block calendula and aster were grown. The observations revealed that solarization alone caused significant reduction in seedling mortality of the crops grown. Such observations have invariably been recorded by several workers **(Al-Kafagi *et al.*, 1988; Esfahani, 1991; Minuto *et al.*, 1995; Mishra, 1997; Wajid *et al.*, 1995)**.

Integration of solarization with seed-treatment using seed dressing fungicides (Vitavax, Thiram, Apron) and biocontrol agents (*T. harzianum* and *P. fluorescens*) further increased disease controlling potential of the solarized soil. During solarization, the propagules of such pathogens as *Pythium, Fusarium, S. rolfsii* and *R. solani* are drastically reduced due to hydrothermal effects generated during solarization. Since the inoculum potential of these pathogens are either reduced or suppressed, the infection of seedlings got automatically reduced. In addition, the biological vacuum that is created due to destruction of the general microflora, biological control automatically comes into play. Most biocontrol agents are thermotolerant. Their populations after solarization increase very fast due to physical and biological spaces that are available in plenty. Therefore, besides direct physical effects of solarization, biological factors particularly recolonization of the soil and rhizosphere provides control of the seedlings being raised in nurseries.

Integration with seed dressing fungicides further increased and strengthened disease control. It is so, obviously because the fungicides applied through seeds are known to provide temporary protection to the radicles and plumules that emerge and which ultimately develop into plants **(Rao and Krishnappa, 1995; Mishra, 1997)**.

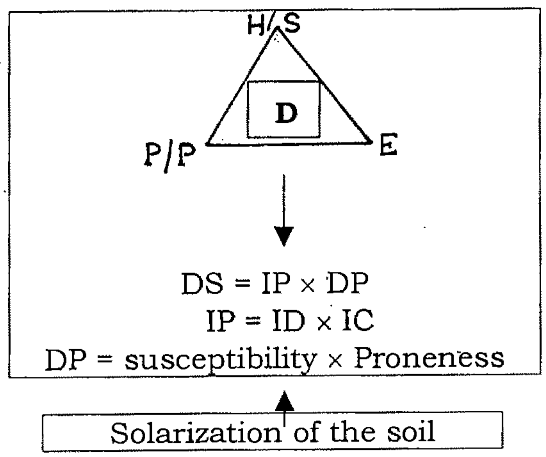
Similarly, the application of biocontrol agents *T. harzianum* and *P. fluorescens* further augmented disease controlling efficiency of solarization. There are numerous references available which clearly reveal the utility of these bioagents as far as protection of seeds and seedlings is concerned **(Rao and Krishnappa, 1995)**.

Thus it is clear from the citations that solarization does reduce diseases of nursery crops significantly. Thermal inactivation of the pathogen (The physical effect) appears the major one. Drastic reduction in counts of *Pythium* sp., the major pathogen were found. Its recovery was too low and too slow to warrant any other treatment. Similarly several others **(Esfahani, 1991 and Mishra, 1997)** have recorded significant reduction in inoculum potential of the pathogens causing damping-off. In a number of studies, we have found that a variety of soil borne pathogens are killed in the temperature range of 37-50°C in both soil and agar. Percentage of survival when plotted against exposure time of a given temperature yields sigmoid curve. A linear relationship ($r=-0.99$) appears invariably upon plotting logarithms of the time required to kill 90 per cent of the propagules against the temperature. If one takes **Yarwood's (1975)** proposal for adoption of temperature coefficient (Q_{10}) for determining the time temperature relationships in heat inactivation, then Q_{10} for inactivation is calculated as:

$$Q_{10} = \left(\frac{ED_{50} \text{ at } T_1}{ED_{50} \text{ at } T_2} \right) \frac{10}{T_2 - T_1}$$

Where, T_1 and T_2 are the lower and higher temperature, respectively.

Besides thermal inactivation, several other processes are operative simultaneous and concurrently. The overall mechanisms operative in reducing disease-incidence are outlined in Fig. 46.



- Thermal inactivation ← (ID × IC)

ID reduced ← weakened propagules sublethal heating
- Microbial killing
- Fungistasis annulment ← lysis
- Mycoparasitism by antagonists
- Competition/antibiosis operative
- Effect on host due to cross-protection

Fig. 46 : **Solarization and suppression of diseases and their causal agents**

Growth response

Soil solarization invariably improved plant health, of the crops grown in solarized soils. This increased plant growth response was measured by measuring parameters like shoot length, fresh weight of roots and shoots as well as dry weight of roots and shoots. Similar observations have been made by workers working on soil solarization **(Elad *et al.*, 1980; Greenberger *et al.*, 1987; Martyn and Hertz, 1986; Pullman *et al.*, 1981; Stapleton *et al.*, 1985).** The reason for PGR could be many. Since pathogens parasitizing the plants are decimated, the health improved automatically. Besides this, the weeds that compete for soil nutrition are eliminated so least competition. In addition, killed weeds decompose to add organic matter to soil, thus providing additional nutrients and creating favourable microbial environment. All these add positively to crop health. The best probable reason recorded so far is increased solubility and availability of several nutrients (macro- and micro-trace) in moist soils solarized during hot sunny days. Significant increase in EC, nitrogen, and minor increase in and P_2O5, organic carbon in enough proportions. All such increased availability affect crop growth positively **(Chaube and Singh, 1991; Greenberger *et al.*, 1987; Stapleton *et al.*, 1987).** Microbial factor is another important factor. Mycorrhizal association found increased in most of the research reports. PGPR (*P. fluorescens* and *Bacillus* sp.) favoured to grow and dominate rhizosphere niches. Biocontrol agents like *Trichoderma* spp. favoured to grow and multiply in solarized soils. All such developments are in favour of good plant health. Our observations are in accordance with those, which are in majority.

Invariably significant increase in plant growth including yield has been recorded **(Bourbos and Skoudridakis, 1996; Chen and Katan, 1980; Elad *et al.*, 1980; Gamliel *et al.*, 1993)**.

Solarization at low temperature

In an unusual attempt, a simulated field trial was conducted during winter (low temperature 4-30°C) to explore the possible use of solarization during such periods. It was also attempted to know as to what extent the low temperature solarization hastens the decomposition of organic amendments. The soil temperature increased during solarization and in amended soil the temperature was invariably on higher side. **Blok *et al.* (2000)** and **Gamliel and Katan (1993a,b)** too have made such observations. Such rise in temperature during organic matter decomposition are known. Since increased temperature must have favoured thermotolerants dominated by decomposers within fungi and bacteria. Decomposition increases heat generation, gaseous productions and other activities (physical, chemical and biological).

Improved growth response as observed in present study in organically amended soil, might have been for obvious reasons of increased availability of mineral nutrients released by decomposition process **(Blok *et al.*, 2000; Gamliel and Stapleton, 1993b)**. This trial opens up the possible use of this technique during winters (if the land is free). Improved plant growth response and reduction in deleterious agents can be achieved during solarization at low temperature.

Soil Microbiology

In the present study, several groups of organisms and/or specific ones were assessed periodically to observe changes in major constituents of soil microflora. Factors included were fungi, bacteria, *Pythium* sp., *P. fluorescens*, *Bacillus* sp., *Trichoderma*, the biocontrol agents. Solarization for a month, in general caused significant reduction in microbial cfu. Fungi reduced by over 60 per cent, bacteria by about 80 per cent, Pythium by almost 100 per cent.

During solarization the temperature reaches up well above 60°C. The increase and decrease - the daily cycle more lethal to propagules existing at diffeent niches in soil. Among eliminations taking place include those that grow at low temperature. Even those propagules that can tolerate increased temperature because of resting structures, get weakened and thus eliminated in competition of microbial growth. Populations of oxidase negative fluorescent pseudomonads and gram negative bacteria *Bacillus* species reduced significantly during soil solarization. **Stapeton and DeVay (1985)** too have recorded such findings. Surprisingly after solarization, pseudomonads quickly recolonized the soil. Greater increase in populations of fluorescent pseudodonads under which transparent polyethylene of 200 G thickness may be attributed to greater temperature white favoured their growth. With progress of nursery raising, the populations of fungi, bacteria, PGPR, recovered, rather increased in most cases. However, there was change in microbial make-up. Before solarization soil had a mixed population of 6 to 7 fungi but after solarization fungi like *Trichoderma, Aspergillus,* and an unidentified non-pathogenic *Fusarium* dominated.

Thus a shift in microbial populations was observed. Antagonists increased in solarized soil. Thus, soil suppresiveness increases. The introduction of suppressiveness is purely microbial. This accounts for biological control of fungi like *Pythium, Fusarium, Sclerotium* and *Rhizoctonia,* as recorded in the study. Such shifts have been recorded by several others **(Gamliel and Stapleton, 1993 a,b; Stapleton and DeVay, 1986; Tjamos and Fravel, 1995).**

Populations of fungi that were reduced drastically, recovered fully within 60 days of solarization, and then increased gradually over initial population by over 150-200 per cent up to 120 days after solarization, which might have resulted in long-term effectivity of soil solarization. Benefits of soil solarization have been reported to last for about three growing seasons **(Greenberger *et al.*, 1987; Katan, 1987; Stapleton and DeVay, 1986; Tjamos and Paplomatas, 1988).**

Population of damping-off causing pathogen, *Pythium* sp. were reduced below detectable levels up to 60 days after solarization. Suppression of *Pythium* population by solarization has earlier been reported **(Pullman *et al.*, 1981; Gamliel and Stapleton, 1993a).**

Reduction in soil populations of *Pythium* was because of high temperature during solarization as temperatures of 37-39°C are lethal to *Pythium* spp. **(Pullman *et al.*, 1981).**

Long-term suppression of populations *Pythium* species, following solarization may be the result of antagonism excerted by increased population of antagonists. *Trichoderma, Bacillus* and pseudomonads. Thus, reduction in populations of *Pythium* observed in solarized soil may be attributed to biological control mechanisms in addition to thermal killing. Increased population of bacterial antagonists in solarized soil might be an important factor in the suppression of pathogens as shown in previous studies **(Cook and Baker, 1983; Gamliel and Katan, 1991, 1993; Stapleton and DeVay, 1984)**.

Weed control

Solarization of wet soil for a period of four weeks reduced weed growth and development in all the fourteen species of weeds recorded. Except *C. rotundus*, that was reduced only to the extent of 80 per cent, remaining weeks were eliminated thus confirming the previous results **(Ahmad *et al.*, 1996; Esfahani, 1991; Horowitz. 1980; Katan *et al.*, 1980; Rubin and Benzamin, 1981)**.

The reason for survival and appearance of about 25 per cent population of *C. rotundus* could be the location of its suckers (the survival and propagating structure at different soil horizons). There appears the possibility that suckers survived in the horizons were temperature did not reach lethal proportions. Therefore the weed concerned appeared after solarization.

Based on the information generated here and elsewhere the scenario that develops is that the solarization is a technique which affects disease triangle (Pathogen↔Host↔Environment) and also the equation DS = IP(IDXIC)X DP (Susceptibility x Proneness).

In terms of principal, practices and philosophy, it has intrinsic integrated action. The pathogens are killed by physical/biological/chemical means), the host is healthier (soil chemistry/soil microbiology) and the environment changes biotically as well as abiotically. **Chaube and Singh (1991)** proposed a mechanism for improved PGR and reduction in disease severity. We endeaour to modify and propose (Fig. 47) another to explain the mechanism.

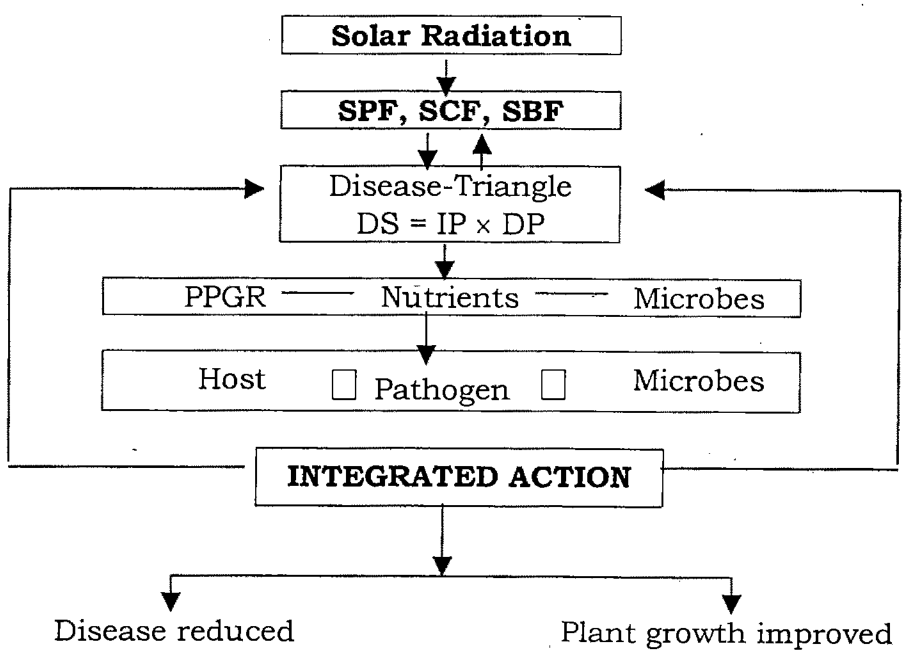


Fig. 47 : **Schematic diagram of the mechanisms of disease management and IPGR through solarization**

SUMMARY

6. SUMMARY

Physico-chemical properties

1. Polyethylene mulching of soil was proved to conserve approximately 50-60 per cent soil moisture.
2. In solarized soil the temperature increased by over 10-12^{0}C. White transparent and red coloured polyethylene sheeting increased soil temperature more efficiently as compared to black.
3. Soil solarization for 30 days did not change soil pH but status of electrical conductivity (EC) was improved significantly. Average increase was 234 per cent at VRC and 175 per cent at floriculture block.
4. Levels of available phosphorus and potash per hectare did change positively but non-significantly. Availability of potash increased by 13 per cent and that of phosphorus by 47 per cent over non-solarized soil at VRC. At floriculture block, respective changes were of 23 and 20.5 per cent over check.
5. Organic carbon did not change but total nitrogen increased significantly. The increase was to the extent of 80 per cent.

Disease-incidence

1. Soil solarization reduced damping-off (pre + post emergence) of cauliflower by over 40 per cent. Integration with chemical and bioagent seed-treatments further increased effectivity of solarization seed-treatment with apron and BCA's (*Trichoderma harzianum and Pseudomonas fluorescens*) were distinctly superior.

2. Black and red polyethylene used for mulching were inferior to white transparent film as incidence of damping-off was higher.
3. Incidence of damping-off of cabbage, raised after cauliflower, too reduced by over 30 per cent. Integration of seed-treatment improved disease controlling potential of solarized soil.
4. Tomato nursery was raised as third crop and incidence of damping-off was reduced but non-significantly.
5. In onion nursery as fourth crop raised in succession, per cent decrease in damping-off incidence was approximately 10-15 per cent over control.
6. At floriculture block, calendula was raised as first nursery crop. Solarization alone reduced damping-off by over 54 per cent. Seed-treatments further accentuated the effect of solarization. Seed-treatment with *T. harzianum* was superior over others.
7. After removal of calendula, nursery of aster was raised. Incidence of damping-off decreased, but by about only 20 per cent.

Growth response

Soil solarization with or without seed-treatment caused significant improvement in health of seedlings raised in nurseries. Improved plant health measured through changes in shoot length, fresh and dry root weight as well as fresh and dry root weight are as follows :

Shoot length

1. (a) Shoot length of cauliflower increased by over 80 per cent while in cabbage the increase was approximately 40-45 per cent.

Improvement in shoot length of tomato and onion was marginal or non-significant.

(b) Shoot length of calendula increase by over 200 per cent and that of aster by over 130 per cent.

Fresh shoot weight

2. (a) Like other growth parameters, fresh shoot weight of cauliflower increased approximately by over 100 per cent. Improved fresh shoot weight of cabbage was approximately 40 per cent but that of tomato was over 100 per cent. Fresh shoot weight of onion increased only marginally.

   (b) Fresh shoot weight of calendula increased by over 130 per cent and in case of aster raised as second crop, the improvement was over 80 per cent.

v. Dry shoot weight

3. (a) In solarized plots dry shoot weight of cauliflower, cabbage, tomato and onion increased by 110, 86, 15 and 47 per cent, respectively over to that recorded under non-solarized condition.

(b) Dry shoot weight of calendula increased by about 130 per cent and that of aster by about 55 per cent.

Fresh root weight

4. (a) Fresh root weight of cauliflower increased approximately by 70 per cent while that of cabbage to the extent of 240 per cent. Fresh root weight of tomato and onion increased by over 70 and 35 per cent, respectively.

(b) Fresh root weight of calendula increased by over 250 per cent while in of aster the improvement was around 60 per cent.

Dry root weight

5. (a) Solarization increased dry root weight of cauliflower by over 90 per cent while that of cabbage up to 200 per cent. Similarly dry root weight of tomato and onion also increased substantially.

   (b) Dry root weight of calendula increased by 150 to 350 per cent and that of aster by above 60 per cent.

Soil microflora

1. Populations of fungi declined sharply when estimated after a month's solarization. The reduction ranged from 70 to 80 per cent. 30 days after mulching and raising first nursery, the populations recovered steadily and reduction reached below 50 per cent and then increasing by 20 to 30 per cent.
2. Total fungi recovered almost fully after raising three nursery crops subsequently.
3. Though thickness of the film caused non-significant effect, as variable but colour had significant effect. White and red were distinctly superior over black.
4. Like fungi, total bacteria too, declined sharply after solarization but recovery was much faster than fungi as by 60th days populations increased up to 70 per cent over initial count.
5. The increase in bacterial flora estimated at 120 days showed steady increase and attained more than 88 per cent over its

original population indicating suitability of physico-chemical and biological niche for bacterial growth.

6. Similar to fungi and bacteria, counts of naturally occurring counts of *Trichoderma* declined by over 80 per cent immediately solarization. Subsequently crop cultivation helped in recovery of its population and by 120th day the increase was about 45 per cent over its natural counts.
7. Effect of solarization was drastic on natural populations of *Pythium* species. The recoverable population declined by 95 to 100 per cent. It was only after 90 days that some minor recovery took place but it was non-significant.
8. The PGPR, *Pseudomonas fluorescens* too, declined but not to the magnitude that observed with other microflora. After solarization the reduction was about 50 per cent but by 60th day i.e. after two nurseries the recovery was of high magnitude reaching up to190 per cent over initial population.
9. Maximum reduction in populations of PGPR was caused by white, followed black and then red film. The subsequent increase was however, highest in red followed by black and then white.
10. Solarization reduced populations of *Bacillus* species by over 60 per cent but in subsequent months increased approximately by 60 to 179 per cent over their initial population.

Weed control

1. All the fourteen species of weeds dominated by *Ageratum conjoides, Cynodon, Euphorbia, Oxalis, etc.* occuring naturally

were fully eliminated. However, the control of *C. rotundus* was only 82 per cent.

2. White polyethylene followed by red and then black was effective in controlling weeds. Thickness of polyethylene as variables were non-significant.

Solarization at low temperature

1. Daily temperature increased by about 60 per cent in organically amended soil compared to 20 per cent in non-amended solarized soil over to that in non-solarized soil.
2. An additional increase of about 4-7^{0}C in daily temperature during solarization was observed by incorporation of organic amendments before solarization.
3. Plant growth was improved in organically amended solarized soils. Except cotton seed cake other amendments improved plant growth. FYM amendment was proved superior over others in case of tomato.
4. Spent compost and chicken manure incorporation before solarization increased shoot and root length but FYM was superior over others in both the crops (tomato and brinjal).

REFERENCES

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 soils. *Plant Dis.* 72 : 143-146.

Abu-Blan, H.A. and Abu-Gharbiech, W.I. 1994. Effect of soil-solarization on winter planting of potato, cauliflower and cucumber in the Central Jordan Valley. *Dirasat-Series, B-Pure and Applied Sciences* **21** : 203-213.

Abu-Gharbiech, W.I.; Saleh, W.H. and Al-Banna, L. 1991. Plant production and protection paper (application of solar heater water for soil-solarization) No. 109 : 69-77.

Abu-Irmaileh, B.E. 1991. Weed control in squash and tomato fields by soil-solarization in the Jordan Valley. Weed Res. Oxford 31 : 125-133.

Adams, P.B. 1971. Effect of soil temperature and soil amendments on *Thielaviopsis* root rot of sesame. *Phytopathology.* 61 : 93-97.

Adetunji, I.A. 1994. Response of onion to soil solarization and organic mulching in semi arid tropics. *Sci. Hort.* 60 : 161-166.

Ahmad-Y.; Hameed-A. and Aslam-M. 1996. Effect of soil-solarization on corn stalk rot. *Plant and Soil.* 179 : 17-24.

Al-Kafagi, H.M.; Jarjes, M.M. and Al-Hassan, K.K. 1988. chemical-physical and biological control of *Phytium aphanidermatum* *Arab J. Plant Prot.* 6 : 94-96.

Alkayssi, A.W. and Alkaraghouli, A.A. 1991. Influence of different colour plastic mulches used for soil solarization on the effectiveness of soil heating. I[st] Int. Conf. on Soil Solarization : 297-302.

Al-Raddad, A.M.M. 1979. Soil-disinfestation by plastic tarping. M.Sc. Thesis, University of Jordan. 95 pp.

Al-Samaria, F.H.; Al-Rawi, F.A. and Al-Bahadli, A.H. 1988. Reinfestation of soil after different disinfestation treatment. *Arab J. Plant Prot.* 6 : 113-118.

Altman, J. 1970. Increased and decreased plant growth response resulting from soil fumigation. Pages 216-221 in : *Root Disease and Soil-Borne Pathogens,* T.A. Tousson. R.V. Bega, R.E. Nelson, eds. pp. 216-6221. Univ. Calif. Press, Barkeley.

Anonymous. 1984. Plastic mulch : the choice of film. *Plasticulture* 62 : 37-44.

Antoniou, P.P.; Tjamos, E.C.; Andreou, M.T.; Panagopoulos, C.G. and Vanachter, A. 1995. Effectiveness, modes of action and commercial application of soil-solarization for control of *Clavibacter michiganensis* sub sp. *michiganensis* of tomatoes. *Acta Hort.* 382 : 119-128.

Arora, A. 1998. Soil solarization : Effects on soil moisture, soil temperature and chemical properties of the soil. *Crop-Res. Hisar* 16 : 41-49.

Arora, A. and Yaduraju, N.T. 1998. High temperature effects of germination and viability of weed seeds in soil. *J. Agron. Crop. Sci.* 181 : 35-43.

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

Avidov, E.; Aharonson, N.; Katan, J.; Rubin, B. and Yarden, O. 1985. Persistence of terbutrin and atrazin in soil as affected by soil disinfestation and fungicides. *Weed Sci.*. 33 : 457-461.

Avidov, Z. 1956. Bionomics of the tobacco white fly (*Bemisia tabaci*) in Israel. *Ktavim* 7: 25-41.

Avissar, R.; Mahrer, Y.; Margulies, L. and Katan, J. 1986a. Field aging of transparent polyethylene mulches : I. Photometric properties. *Soil Sci. Am. J.* 50 : 202-205.

Avissar, R.; Naot, O.; Mahrer, Y. and Katan, J. 1986b. Field aging of transparent polyethylene mulches : II. Influence on the effectiveness of soil heating. *Soil Sci. Am. J.* 50 : 205-209.

Baker, K.F. 1962. Principles of heat treatment of soil and planting material. *J. Aust. Inst. Agric. Sci.* 28 : 118-126.

Baker, K.F. 1970. Selected killing soil microorganisms by aerated steam. Pages 234-239 in : *Root Disease and Soilborne Pathogens*,. T.A. Tousson, R.V. Bega, R.E. Nelson, eds. Univ. of Calif. Press, Berkeley.

Baker, K.F. and Cook, R.J. 1974. Biological Control of Plant Pathogens. San Francisco, Freeman. 433 pp.

Barbercheck, M.E. and Von Broembsen. 1986. Effects of soil solarization on plant parasitic nematodes and *Phytophthora cinnamomi* in South Africa. *Plant Dis.* 70 : 945-950.

Bawazir, A.A.; Rowaished, A.K.; Bayounis, A.A. and Al-Jounaid, A.M. 1995. Influence of soil mulching with sawdust and transparent polyethylene on growth and yield of okra and weed control. *Arab J. Plant Prot.* 13 : 89-93.

Ben-Yephet, Y.; Melero, J.M.; DeVay, J.E. 1986a. Synergistic interaction of solarization and metham-sodium in controlling microsclerotia of *Verticillium dahliae.* 4th Int. Verticillium Symp. Guelph, Canada.

Ben-Yephet, Y.; Melero-V. J.M. and DeVay, J.E. 1988b. Interaction of soil-solarization and metham sodium in destruction of *Verticillium dahliae and Fusarium oxysporum* f. sp. *vasinfectum. Crop Prot.* 7 : 327-331.

Ben-Yephet, Y.; Melero-V.,S. M. and DeVay J.E. 1988. Interaction of soil solarization and metham-sodium in the destruction of *Verticillium dahliae* and *Fusarium oxysporum* f.sp. *vasinfectum. Crop Prot.* 7: 327-330.

Ben-Yephet, Y.; Melero-V.J.M.; DeVay, J.E. and Elmore, C.L. 1986b. interaction of solarization and metham sodium in controlling soilborne pathogens and weed and on yield in raddish. *Phytopathology* 76 : 842.

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 polythene film on survival of *Fusarium oxysporum* f. sp. *vasinfectum*. *Phytoparasitica* 15 : 181-185.

Bicici, M.; Cinar, O. and Erkilic, A. 1994. Cultural, physical chemical and biological methods to control stem rot, *Sclerotium rolfsii* Sacc. in peanut. *Turkish J. Agric. Forestry* 18 : 423-435. (Abst.).

Black, C.A. 1965. Methods of soil analysis, Part II. American Society of Agronomy, Madison, Wisconsin, U.S.A.

Blok, W.J.; Lamers, J.G., Termorshuizen, A.J. and Gerrit, J.B. 2000. Control of soilborne plant pathogens by incorporating fresh organic amendments followed by tarping. *Phytopathology* 90 : 253-259.

Bollen, G.J. 1974. Fungal recolonization of heat-treated glasshouse soils. *Agro-Ecosystems*. 1 : 139-55.

Bourbos, V.A. and Skoudridakis, M.T. 1996. Soil solarization for the control of Verticillium wilt of greenhouse tomato. *Phytoparasitika*. 24 : 227-280.

Bourbos, V.A. and Skoudridakis, M.T.; Darakis, G. A. and Koulizakis, M. 1997. Calcium cyanamide and soil solarization for the control of *Fusarium solani* f. sp. *cucurbitiae* in greenhouse cucumber. *Crop Prot.* 16 : 383-386.

Broadbent, P.; Baker, K.F.; Franks, M. and Holland, J. 1977. Effect of *Bacillus* spp. on increased growth of seedlings in steamed and in non-treated soil. *Phytopathology* 67 : 1027-1034.

Brock, T.D. 1978. Thermophylic microorganisms and their life at high temperature. Springer-Verlag, New York.

Brown, J.E.; Stevens, C., Khan, V.A.; Hochmuth, G.J.; Splittstoesser, W.E.; Granberry, D.M. and Early, B.C. 1991. Improvement of plastic technology for soil solarization. *FAO Plant Prod. Prot. Paper 109.* 277-298.

Cartia, G. 1989. Soil-solarization experiments in Sicily. *Informatore Fitopatologica* 39 : 49-52.

Cartia, G.; Cipriano, T. and Oruartarone, G. 1987. Use of solaraization and fumigants against underground parasites of carrot in Sicily. *Informatore Fitopatologica* 31 : 43-46.

Cenis, J.L. 1984. Control of nematode *Meloidogyne javanica* by soil solarization. *Proc. 6th Congr. Union Phytopath. Mediterr. Cairo, Egypt.* 1-6 October, p. 132.

Cenis, J.L. 1987. Double plastic sheet for improving soil solarization efficiency. 73. In: *Proc. 7th Cong. Mediter. Phytopathol. Union (Spain).*

Chadha, K.L. 2000. An overview of the hi-tech horticulture : Opportunities and Constraints. National Seminar on hi-tech Horticulture, 26 June, 2000, Bangalore. 30 p.

Chaube, H.S. and Singh, U.S. 1991. Plant Disease Management : Principle and Practices. C.R.C. Press F.L., U.S.A. 329 pp.

Chauhan, Y.S.; Nene, Y.L; Johansen, C.; Haware, M.P.; Saxena, N.P.; Singh, S.; Sharma, S.B.; Sahrawat, K.L.; Burford, J.R.; Rupela, O.P.; Kumar, J.V.; Rao, D.K. and Sithanantham, S. 1988. Effect of soil-solarization on pigeonpea and chickpea. *Research Bulletin* II. ICRISAT Patancheru. 16pp.

Chellemi, D.O.; Olsen, S.M.; Mitchell, D.J.; Secker, I and McSorely, R.; 1997. Adaptation of soil solarization to the integrated management of soilborne pests of tomato under humid conditions. *Phytopathology* 87 : 250-258.

Chellemi-D.O.; Olsen, S.M. and Mitchell, D.J. 1994. Effects of soil-solarization and fumigation on survival of soilborne pathogens of tomato in Northern Florida. *Plant Dis.* 78 : 1167-1172.

Chen, Tu. C.C. and Hwang, Y.H. 1987. Effect of solar energy and green manures on the control of southern blight of Tomato. Research Bulletin, Taiwan District Agricultural Improvement Station, Taiwan. No. 21, 33-41 (Abst.).

Chen, Y. and Katan, J. 1980. Effect of solar heating of soils by transparent polyethylene mulching on their chemical properties. *Soil Sci.* 130 : 271-277.

Chen, Y.; Gamliel, A.; Stapleton, J.J. and, Aviad, T. 1991. Chemical, physical and microbial changes related to plant growth in disinfested soil. Pages 103-129 in: *Soil Solanization.* J. Katan and J.E. DeVay, eds. CRC Press. Boca Raton, FL.

Chet, I. 1987. *Innovative Approaches to Plant Disease Control.* John Wiley and Sons. N.Y.

Chet, I.; Elad, Y.; Kalfan, A.; Hadar, Y. and Katan, J. 1982. Integrated control of soilborne and bulb-borne pathogens in Iris. *Phytoparasitica* 10 : 229-231.

Clarke, A.D. 1987. Some plastic industry developments, there impact on plastic film for agricultural application. *Plasticulture* 74 : 15-26.

Coelho, L.; Chellemi, D.O. and Mitchell, D.J. 1999. Efficacy of solarization and cabbage amendment for the control of *Phytophthora* spp. in North Florida. *Plant Disease* 83 : 293-299.

Cook, R.J. and Baker, K.F. 1983. *The Nature and Practice of Biological Control of Plant Pathogens*. The Amer. Phytopath. Soc., SL Paul, M.N.

Cook, R.J.; Sitton, J.W. and Haglund, W.A. 1987. Influence of soil treatment on growth and yield of wheat and implication for control of *Pythium* root rot. *Phytopathoglogy* 77 : 1192-2298.

Courter, J.W. and Oebker, N.F. 1964. Comparison of paper and polyethylene mulching on yields of certain vegetable crops. *Proc. Amer. Soc. for Hort. Sci* 85 : 526-531.

Coyne, D.L. and Plowright, R.A. 1998. Use of solarization to control *Heterodera Sacchari* and other plant parasitic nematodes in the field : a modified technique for experimental purposes. *Int. J. Nematol.* 8 : 81-84.

Daelemans, A. 1989. Soil solarization in west Cameroon : effects on weed control, some chemical properties and pathogens of the soil. *Acta Hort.* 255 : 169-175 (Abst.).

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

Dawson, J.R.; Johnson, R.A.; Adams, I.P. and Last, F.T. 1965. Influence of steam air mixtures, when used for heating soil on biological and chemical properties that affect seedling growth. *Am. Appl. Bio.* 56 : 243-251.

Dennis, C. and Webster, J. 1971a. Antagonistic properties of specific group of *Trichoderma I.* Production of non-metabolite antibiotics. *Tr. Br. Mycology. Soc.* 57 : 25-39.

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 control of fungal and bacterial plant pathogens including biocontrol. In: *Proc. FAO Plant Prod. Prot. Paper 109:* 79-93.

eVay, J.E. and Katan J. 1991. Mechanism of pathogen control in olarized soils. Pages 87-101 in: *Soil Solarization*. J. Katan and J.E. DeVay eds. CRC Press, Boca Raton, FL.

Domsch, K.H. 1964. Soil fungicides. *Ann. Rev. Phytopathology* 2 : 293-320.

Dwivedi, R.S. and Dubey, R.C. 1987. Effect of soil solarization on the population dynamics of *Macrophomina phaseolina* (Tassi) Goid and general soil microflora. *Int. J. Trop. Plant Dis.* 5 : 67-73.

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

Dwivedi, S.K.; Ambasht, R.S. and Dwivedi, R.S. 1993. Toxicity of some antagonistic fungi on pathogenic fungi of two economic crops. *National-Academy Science Letters*. 16 : 7-8.

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

El-Shami, M.A.; Salem, D.E.; Fadl, F.A. and Fl-Zauat, M.M. 1990. Soil-solarization and plant disease management. III. Effect of the solarization of soil infested with Fusarium with pathogen on the growth and yield of tomatoes. *Agric. Res. Rev.* 68 : 613-623.

El-Shami. 1990. Soil solarization and plant disease management I. Monitoring of temperature in solarized soil in relation to some soil properties. *Atric. Res. Rev.* 68 : 589-599.

Ennis, R.S.1987. Plastigone, a new time controlled photodegradable plastic mulch film. In: *Proc. Nat. Agr. Plastics Cong.* 20: 83-90.

Esfahani, Mehdi Nasar. 1991. Effect of soil solarization on soilborne seedling disease of some vegetable crops. Thesis, Ph.D. G.B. Pant Univ. Agric. & Tech., Pantnagar, India. 260 pp.

Freeman, S. and Katan, J. 1988. Weakening effect on propagules of Fusarium by sublethal heating. *Phytopathol.* 78: 1656-1616.

Gamliel, A. and Katan, J. 1987. Microbial phenomena related to increased growth response in solarized soils. *Phytopathology* 17: 1715-1718.

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 exucdates and germinating seeds in solarized soil. *Phytopathology* 82 : 328-332.

Gamliel, A. and Stapleton, J.J. 1993a. Effect of chicken compost or ammonmium phosphate and solarization on pathogen control. Rhizosphere microorganism and lettuce growth. *Plant Dis.* 77 : 886-891.

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

Gamliel, A. and Stapleton, J.J. 1997. Improvement of soil-solarization with volatile compounds generated from organic amendments. *Phytoparasitica.* 25 : 31S-38S.

Gamliel, A., Hadar, E. and Katan, J. 1989. Solarization to improve yield of Gypsophila in monoculture system. *Acta Hort.* 255: 131-138.

Gamliel, A.; Hadar, E. and Katan, J. 1993. Improvement of growth and yield of chalk plant (*Gypsophila paniculata*) by solarization or fumigation of soil or container medium in continuous cropping system. *Plant Dis.* 77 : 933-938.

Ganguli, A.K.; Pankaj and Sirohi, A. 1996. Effect of soil solarization of rice nursery beds to suppress plant parasitic nematodes. *International Rice Research Notes.* 21 : 2-3.

Garibaldi, A. and Gullino. M.L. 1991. Use of solarization in marginally suitable climates. FAO Plant Prod. Prot. Paper 109, 253-265.

Gharti, D.B. 1994. Soil-solarization : A component in management of seedling diseases of True Potato Seed (TPS) crop. M.Sc. Thesis, G.B. Pant Univ. Agric. & Tech., Pantnagar, India. 85 pp.

Gonzalez, T. R.; Agudo, B.M.; Lopez- M.C. and Zarayoza-Larios, C. 1992. Integrated use of solarization and glyphosate in the control of *Cyperus rotundus* L. *Proceedings of the* 1992 *Congress of the Spanish Weed Science Society* : 337-340.

Gonzalez-Torres, R.; Melero-Vara, J.M.; Gomez-Vazquez, Z. and Jimenez-Diaz, R.M. 1993. Effect of soil solarization and fumigation on fusarium wilt of watermelon grown in plastic houses in South-Eastern Spain. *Plant Pathology* 42 : 858-864.

Greco, N.; Brandonisio, A. and Elia, F. 1985. Control of *Dytylenchus dipsaci, Heterodera carotae* and *Meloidogyne javanica* by solarization. *Nematol. Medit.* 13 : 191-197.

Greenberger, A.; Yogev, A. and Katan, J. 1984. Biological control in solarized soils Proc. Sixth Cong. *Mediter Phytopathogloy.* Union Cairo Egypt. pp. 112-114.

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

Grinstein, A.; Katan, J.; Abdul-Razik, A.; Zeidan, O. and Eld, Y. 1979a. Control of *Sclerotium rolfsii* and weeds in peanuts by solar heating of soil. *Plant dis. Rep.* 63 : 1056-1059.

Grinstein, A.; Orion, D.; Greenberger, A. and Katan, J. 1979b. Solar heating of the soil for the control of *Verticillium dahliae and Pratylenchus thornei* in potatoes. Pages 431-438 in : *Soilborne Plant pathogens* B. Schipper and W. Gams, eds. Academic, New York.

Grooshevoy, S.E. 1939. Disinfection of seed-bed soil in cold frames by solar energy. The A.I. Mikoyan Pan-Soviet Science Research Tob and Indian Tob. Ind. (VITIM), Krasnodar, Publ. 137, Inst. Tob. *Rev. Appl. Mycol.* 18 : 635-636.

Grunzweig, J.M.; Katan, J.; Ben-Tal, Y. and Rabinowich, H.D. 1998. The role of mineral nutrients in the increased growth response of tomato plants in solarized soil. *Plant and Soil* 206 : 21-27.

Hancock, M. 1988. Mineral additives for thermal barrier plastic films. *Platsticulture* 79 : 4-49.

Hanras, J.C. 1979. Agricultural and horticulture uses for photodegradable polyethylene films. *Plasticulture* 41: 43-58.

Hardy, G.E. and Sivasithamparam 1985. Soil solarization: effects on fusarium wilt of carnation and Verticillium wilt of egg plant. Proc. 4th Int. Cong. Plant Pathol. 279p.

Harender Raj, Bhardwaj, M.L.; Sharma, N.K. and Raj, H. 1997. Soil solarization for the control of damping off of different vegetable crops in the nursery. *Indian Phytopath.* 50 : 524-528.

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

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

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

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

Hidebrand, D.M. 1985. Soil solar heating for control of damping off fungi and weeds at Colorado State Forest Service Nursery. *Tree Planters Notes* 36 : 28-34.

Hopen, H.J. 1965. Effects of black and transparent polyethylene mulches on soil temperature, sweet corn growth and maturity in a cool growing season. *Proc. Am. Sco. Hort. Sci.* 86 : 415-420.

Horiuchi, S. 1990. Solarization for greenhouse crops in Japan. *First Int. Conf. Soil Solarization, Amman, 6* (Abst.).

Horiuchi, S.C. 1984. Soil-solarization for suppressing soilborne disease in Japan. Pages 11-23 in : *Soilborne Crop Diseases in Asia.* Fertilizer and Technology Centre, Tiwan. FFTC Book Series No. 26.

Horowitz, M. and Ragev, Y. 1980. Mulching with plastic sheets as a method of weed control. *Hassodesh.* 60 : 395-99.

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

Jackson, M.L. 1956. Soil chemical analysis advance course. Published by Auther. Univ. Wisconsin, Medison, USA.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice-Hall of India, Pvt. Ltd. New Delhi.

Jacobsohn, R.; Greenberger, A..; Katan, J.; Levi, M. and Alon, H. 1980. Control of Egyptian broomrape (*Orobanche aegyptiaca*) and other weeds by means solar heating of the soil by polyethylene mulching. *Weed Sci.* 28 : 312-316.

Kaewrung, W.; Sivasithamparam, K. and Hardey, G.E. 1989. Use of soil solarization to control root rots in gerberas (*Gerbera famesonii*). *Bio. Fert. Soils.* pp. 38-47.

Kamra, A. and Gaur, H.S. 1998. Control of nematodes, fungi ad weeds in nursery beds by soil solarization. *Int. J. Nematol.* 8 : 46-52.

Kassaby, F.Y. 1985. Solar-heating soil for control of damping-off diseases. *Soil Bio. and Biochem.* 17 : 429-434.

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

Katan, J. 1981. Solar heating of soil for control of soilborne pests. *Ann. Rev. Phytopathol.* 19 : 211-236.

Katan, J. 1984. The role of soil disinfestation in achieving high production in horticultural crops. *Br. Crop. Prot. Conf.* pp. 1189-1196.

Katan, J. 1985. Solar disinfestation of soils. Pages 274-278 in: *Proc. 4th Inter. Cong. Plant Pathol.* CA. Paker, A.D. Rovira, K.J. Moore and P.T.W. Wong, eds. The Amer. Phytopathol. Press. St. Paul, M.N.

Katan, J. 1987. Soil-Solarization. Pages 77-105 in : *Innovative Approaches to Plant Disease Control.* Chet, I. ed. John Wiley and Sons. New York.

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

Katan, J.; Greenberger, A.; Alon, H. and Grinstein, A. 1976. Solar heating by polyethylene mulching for the control of diseases caused by soilborne pathogens. *Phytopathology* 66 : 683-688.

Katan, J.; Grinstein, A.; Fishler, G.; Frank, A.Z.; Rabinowitch, H.D.; Greenberger, A.; Alon, H. and Zig, U. 1981. Long-term effects of solar heating of the soil. *Phytoparasitica.* 9 : 236 (Abst.).

Katan, J.; Grinstein, A.; Greenberger, A.; Yarden, O. and DeVay, J.E. 1987. The first decade (1976-86) of soil solariztion (solar heating): a chronological bibliography. *Phytoparasitica* 15: 229-255.

Katan, J.; Rotem, I.; Finkel, Y. and Daniel, J. 1980. Solar heating of the soil for the control of pink rot and other soilborne diseases in onions. *Phytoparasitica.* 8 : 39-50.

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

Keinath, A.P. 1995. Reduction in inoculum density of *Rhizoctonia solani* and control of belly rot on pickling cucumber with solarization. *Plant Dis.* 79 : 1213-1219.

Ki, K.U. and Kim, K.C. 1985. Possibility of soil for control of damping off disease. *Soil Biol. Biochem.* 17 : 429-434.

King, E. O.; Wood, M. K.and Raney, D. E. 1954. Two simple media on the demonstration of pyocianin and fluoricin. *J. Lab. Clinical Med.*44: 301-307.

Kulkarni, R.N.; Kalra, A. and Ravindra, N.S. 1992. Integration of soil solarization with host resistance in the control of die back and collar and root diseases of periwinlkle. *Trop. Agric.* 69 : 217-222.

Kumar, B. and Yaduraju, N.T. 1992. Effect of solarization on the temperature and physico-chemical properties of soils. *Plasticulture* 94. 13-20.

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

Lazarovits, G.; Hawke, M.A.; Tomlin, A.D.; Olthof, T.H.A. And Squire, S. 1991. Soil solarization to control *Verticillium dahliae* and *Pratylenchus penetrans* on potatoes in control Ontario. *Can. J. Plant Pathol.* 13: 116-123.

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

Lin-Chein, Y. and Huang, S. 1995. Mechanism of solarization for controlling soilborne diseases. *Bulletin of Taichung District Agricultural Improvement Station* 49 : 19-13 (Abst.).

Lingappa, Y. and Sussman, A.S. 1959. Changes in the heat resistance of ascospores of *Neurospora* upon germination. *Am. J. Bot.* 46 : 671-678.

Lochhead, A.G. 1950. Qualitative studies of soil organisms. *Can. J. Res.* 18 : 42-53.

Lodha, S.; Sharma, S.K. and Aggarwal, R.K. 1997. Solarization and natural heating of irrigated soil amended with cruciferous residue for improved control of *Macrophomina phaseolina. Plant Pathol.* 46 : 1865-190.

Lodha, S.; Singh, M. and Sharma, B.M. 1991. Solarization brings down soilborne pathogens in arid lands. *Indian Farming* 40 : 12-13.

Lopez-Herrera, C.J. and Perez-J.R.M. 1998. Soil solarization in established avocado trees for control of *Dematophora necatrix. Plant Disease* 82 : 1088-1092.

Lopez-Herrera, C.J.; Pevez-J., R.M.; Zea-B., T.; Basallote-U., M.J. and Melero-V., J.M. 1998. Soil solarization in established avocado trees for control of *Dematophora necatrix.* Plant Dis. 82: 1088-1092.

Lopez-Herrera, C.J.; Porez-J., R.M.; Basallote-U., M.J.; Bonilla-T.S. and Melero-V., J.M. 1997. Effect of soil solarization on the control of Phytophthora root rot in avocado. *Plant Pathol.* 46: 329-340.

Lopez-Herrera, C.J.; Verdu-Valinte, B. and Melero-Vara, J.M. 1994. Eradication of primary inoculum of *Botrytis cinerea* by soil solarization. *Plant Disease* 78 : 594-597.

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

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

Mahrer, Y.; Avissar, R.; Naot, O. and Katan, J. 1987. Intensified soil-solarization with closed greenhouse. Numerical and Experimental Studies. *Agric. Meteorol.* 41 : 325-334.

Mahrer, Y.; Naot, E.R. and Katan, J. 1984. Temperature and moisture regimes in soil mulched with transparent polyethylene. *Soil Sc.Soc. Amer. J.* 48: 362-367.

Malik, A. 1999. Epidemiological studies on Alternaria blight of mustard. Ph.D. Thesis. G.B. Pant Univ. Agric. & Tech., Pantnagar, India.

Malik, M.A.S. and Tran, U.V. 1973. A simplified mathematical model for preparing the nocturnal output of solar stile. *Soil Energy.* 14 : 371-385.

Mansooria, B. and Jaliani, N.K.I. 1996. Control of soilborne pathogens of watermelon by solar heating. *Crop Prot.*15 : 423-424.

Mansour, M. and Sultan, M. 1991. Economics assessment of the long-term effects of the soil heating technology in beni suef governorate. Ist Int. Conf. on Soil Solarization : 367-375.

Martin, J.P. 1950. Use of acid, rose bengal and streptomycin in the plate method for estimating soil fungi. *Soil Sci.* 69: 215-232.

Martyn, R.D. and Hartz, T.K. 1986. Use of soil-solarization to control Fusarium wilt of watermelon. *Plant Dis.* 70 : 762-766.

McCain, A.H.; Bega, R.V. and Jenknson, J.C. 1986. Effect of fall sowing and solar heating of soil on two conifer seedling disease. *Tree Planters Notes.* 37: 17-20. Univ. of Calif., Berkeley, CA. USA.

McSorley, R. and Parrado, J.L. 1986. Application of soil solarization to Rock dale soils. Beltwide cotton Res. Conf. National Cotton Council. (Memphis T.N.) p. 36.

Melero-V., J.M.; Blanco-L., M.A.; Bejarano-A., J. and Jimenez D., R.M. 1995. Control of Verticillium wilt of cotton by means of solarization and tolerent cultivars in southern spain. *Plant Pathol.* 44: 250-260.

Melero-V.J.M.; Blanko-L. M.A. Bezarano-A. J. and Jimenez-D. R.A. 1995. Control of *Verticillium* wilt of cotton by means of soil solarization and tolerance cultivars in Southern Spain. *Plant Pathol.* 44: 250-260.

Minuto, A.; Migheli, Q.; Garibaldi, A. and Vanachter, A. 1995. Integrated control of soilborne plant pathogens by solar heating and antagonistic microorganisms. *Acta. Hort.* 382: 138-143.

Mishra, D. 1999. Effect of soil solarization and its integration with fungicide and biocontrol agents on microbial population and seeding diseases of some vegetable crops. M. Sc. Thesis. G. B. Pant Univ. Ag.&Tech., Pantnagar. 53.

Mishra, S. 1997. Effect of soil-solarization and chemical seed treatment on damping-off of cauliflower, tomato and onion. M.Sc. Thesis G.B. Pant Univ. Agric. Tech. Pantnagar, India.11 p.

Moens, M. and Aicha, B. 1990. Control of pepper wilt to *Tunisia parasitica.* 46 : 103-109.

Mohamed, M.S. 1990. Effect of soil-solarization incidence of Fusarium wilt of broad bean (*Vicia faba*). *J. Agric. Sci.* 21 : 49-58.

Moura, M.L.R.; Palminha, J.; Cockshul, F.E.; Tuzel, Y.; Gul, A. 1994. A nonchemical method for the control of *Pyrenochaeta lycopersici* of tomato in the north of Portugal. *Acta Hort.* 366 : 317-322.

Munnecke, D.E. and Van Gundy, S.D. 1979. Movement of fumigants in soil, dosage, responses and differential effects. Ann. Rew. *Phytopathol.* 17 : 405-429.

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

Nadar, E.; Sofer, S.; Brosh, S.; Mordechai, M.; Cohn, E. and Katan, J. 1983. Control of clover cyst nematodes on carnation. *Hadesseh.* 63 : 1698-1700. (Hebrew with English summary).

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

Niessen, A. 1978. Photometric properties of the plastic used as shelter covers. *Plasticulture* 40: 15-28.

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

Olsen, S.R.; Cole, C.V.; Watanabe, P.S. and Dean, C.A. 1954. Estimation of available phosphorus in soils by extracting with sodium bicarbonate U.S. Deptt. Agric. No. 939 (C.F. Black, C.A. 1965). *Methods of Soil Analysis*. Part 2. Am. Soc. Agron. Inc. Medison, Wisconsin, U.S.A.

Osman, A.R.; Fahim, M.M.; Sahab, A.F. and Abdel-Kader, M.M. 1987. Soil-sollarization for the control of lupin wilt. Egyptian J. Phytopathol. 18 : 75-88. Fac. Agric.Univ. Cairo. Egypt.

Pandey, A.K.; Arora, D.K.; Pandey, R.R. and Srivastava, A.K. 1996. Integrated control of *Fusarium* wilt of chickpea by solar heating of soil amended with oilseed meals and fungicides. *Indian Phytopath.* 49: 247-253.

Papavizas, G.C. and Lumsden, R.D. 1980. Biological control of soilborne fungal propagules. *Ann. Rev. Phytopathol.* 18: 399-413.

Patel, B.K. and Patel, H.R. 1997. Effect of nematicides, soil solarization, rabbing and green manuring on some physical and chemical properties of soil in nematode infested bidi tobacoo nursery. *Tobacco Research* 23: 19-26.

Patel, B.N.; Patel, K.D.; Patel, H.R. 1996. Integrated management of damping-off of bidi tobacco nursery. *Tobacco-Res.* 22: 14-17.

Patel, H.R. and Makwana, M.G. 1995. Integrated management of phytonametodes in bidi tobacco nursery through soil solarization, rabbing and carbofuran. *Tobacco Research.* 18: 33-37.

Patel, H.R.; Makwana, M.G. and Patel, B.N. 1995. The control of nematode and weeds by soil solarization in tobacco nurseries : effect of the film thickness and of the covering duration. *Plasticulture.* 107 : 21-27.

Peethambaran, C.K. and Singh, R.S. 1978. Note on selective medium for isolation of *Pythium. Pantnagar. J. Res.* 2: 134-136.

Pereira, J.C.R.; Chaves, G.M.; Zambolim, L.; Matsuoka, K.; Acuna, R. S. and Vale,F. R. X. 1996. Control of *Sclerotium cepivorum* by the use of vermicompost, solarization, *Trichoderma harzianum* and *Baiellus subtilis. Summa-Phytopathologia.*22:228-234.(Abst.)

Perry, K.B.; Ristaino, J.B. and Lumsden, R.D. 1996. Soil-solarization and *Gliocladium virens* reduce the incidence of southern blight (*Sclerotium rolfsii*) in bell pepper in the field. *Biocontrol Sci. Tech.* 6 : 583-593.

Peurer, N.G.; Gubramaniam, C.K.; Muhr, G.R. and Ray, H.E. 1973 Soil fertility evaluation to some Indian Farmers. *Mysore Deptt. Agric.*, Bangalore.

Pinkas, Y.; Kariv, A. and Katan, J. 1984. Soil-solarization for the control of *P. cinnamomi* : Thermal and biological effects. *Phytopathology.* 74 : 796-799.

Porter, I.J. and Merriman, L.R. 1983. Effect of solarization of soil on nematodes and fungal pathogens at two sites in Victoria. *Soil Biol. Biochem.* 45 : 39-44.

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

Pullman, G.S. 1979. Effectiveness of soil-solarization and soil flooding for control of soilborne diseases of *Gossypium hirsutum* L. in relation to population dynamics of pathogens and mechanisms of propagule death. Ph.D. Thesis Univ. Calif. Davis. 95 p.

Pullman, G.S.; DeVay, J.E.; Garber, R.H. and Weinhold, A.R. 1981. Soil-solarization for the control of Verticillium wilt of cotton and the reduction of soilborne populations of *Verticillium dahliae, Pythium* sp., *Rhizoctonia solani* and *Thielaviopsis, Phytopathology* 71 : 654-959.

Pullman, G.S.; DeVay, J.E.; Weinhold, R.H. and Weinhold, A.R. 1979. Control of soilborne pathogens by plastic traping of soil Pages 429-446 in : *Soilborne plant pathogens.* B. Schippers and W. Gams eds. London, New York, San Francisco.

Rabinowithch, H.D.; Katan, J. and Ratem, I. 1981. The response of onion to solar heating agriculture practice and pink root disease. *Sci. Hort.* 15 : 331-340.

Raio, A.; Zoina, A. and Moore, L.W. 1997. The effect of solar heating of soil on natural and inoculated agrobacteria. *Plant Pathol.* 46 : 320-328.

Raj, H.; Kapoor, I.J. 1993. Soil-solarization for the control of tomato wilt pathogen (*Fusarium oxysporum*) Zeitschrift fiir pflanzenkrankherton and pflanzenuchuts. 100 : 652-661(Abst.).

Raj, H; Bhardwaj, M.L. and Sharma, N.K. 1997. Solarization for the control of damping off of different vegetable crops in the nursery. *Indian Phytopathology* 50 : 524-528.

Ramakrishnan, G. 1989. Isolation of microorganisms from the soil. Pages 225-257 in : Management of Plant Diseases by Non chemical methods. Jayarajal *et al.* Eds. T N Agri. Univ. Coimbatore, India.

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

Ramirez-V.; and Munnecke, D.M. 1988. Effect of solar heating and soil amendments with cruciferous residues on *Fusarium oxysporum* f. sp. *conglutinans* and other organisms. *Phytopathology* 78 : 289-295.

Rao, D.V.S. Sitaramaiah, K. and Maiti, S. 1996. Management of Plant parasitic nematodes in betelvine gardens through non-chemical methods. Indian Journal of Nematology 26 : 93-97.

Rao, V.K. and Krishnappa, K. 1995. Integrated management of *Meloidogyne incognita, Fusarium oxysporum* f. sp. *cireri* wilt disease complex in chickpea. *Int. J. Pest Management.* 41 : 234-237.

Rao, V.K. and Krishnappa, K. 1996. Rhizosphere mycoflora of chickpea infested with meliodogyne incognita. *Indian J. Mycol. and Plant Pathol.* 26 : 103-104.

Rao, V.K. and Krishnappa, K. 1996. Soil solarization for the control of soilborne pathogen complexes with special reference to *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *ciceri. Indian Phytopath.* 48 : 300-303.

Ravindra, H.; Onkarappa, T.; Krishnappa, K.; Karegowda, C. and Lokmanya, D.S. 1997. Effect of soil solarization on root-knot nematodes parasitic to FCV tobacco in the nursery. *Annals Plant Protect. Sci.* 5 : 66-69.

Raymundo, S.A.; Alclzar, J. and Salas, R. 1986. A technique for testing the efficacy of soil solarization in controlling root-knot nematodes at varying soil depths. *J. Nematol.* 18: 629-632.

Ristaino, J.B. and Thomas, W. T. 1997. Agriculture, methyl bromide and ozone hole. *Plant Dis.* 81: 964-976.

Ristaino, J.B.; Perry, K.B. and Lumsdeen, R.D. 1996. Soil solarization and *Gliocladium virens* reduce the incidence of southern blight (*Sclerotium* rolfsii) in bell pepper in the filed. *Biocontrol Sci.Tech.* 6: 583-593.

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.D. 1981. Solar solarization as a tool for weed control. Abst. *Weed Sci. Soc. Am.* pp. 133.

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

Sastry, R.K. and Chattopaddhyay, C. 1999. Effect of soil solarization on *Fusarium oxysporum* f. sp. *carthamie* populations in endemic soils. *Indian Phytopath.* 52: 51-55.

Satour, M.M.; El-Sherif, E.M.; El-Ghareeb, L.; El-Handad, S.A. and El-Wakil., H.R. 1991. Achievement of soil-solarization in Egypt. No. 109: 200-212 .

Schor, R.; Grinstein, A.; Katan, J.; Cohel, R. and Gamliel, A. 1986. Control of corky root in processing tomatoes. *B and C Tests.* Vol. I APS Press, St. Paul Mn., 23 p. (Abst.).

Sharma, R.; Rai, R.R. and Farhat, S. 1996. Integration of soil solarization, carbofuran and neem cake applications for nematode management in tomato. *Indian J. Plant Prot.* 24: 110-114.

Shreshtha, S.M. 1992. Biocontrol potential of *Trichoderma harzianum* and *Gliocladium virens* lentil wilt complex. Ph.D. Thesis, G. B.Pant Univ of Ag. and Tech., Pantnagr. 210.

Silverstein, S.S. 1976. Effect of infra red transparency on the heat transfer through windows : A clarification of the greenhouse effect. *Science.* 193 : 229-231.

Singh, R. 1990. Studies on Epidemiology and management of Karnal bunt of wheat. Ph.D. Thesis, 1990. G.B. Pant Univ. Agric. & Tech., Pantnagar, India.

Singh, R.; Jariwala, S. and Rai, B. 1996. Effect of soil-solarization on wilt disease of pigeonpea (*Cajanus cajan* L. Mill. sp.). *Phytopathologica polonica.* 12 : 139-146(Abst.)

Singh, R.S. 1997. Introduction to principles of Plant Pathology. IIIrd edition. Oxford and IBH Publishing Co. New Delhi. pp. 1.

Singh, R.S. and Mitchell, J.E. 1971. A selective method for isolation and measuring populations of *Pythium* in soil. *Phytopathology* 51: 440-444.

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

Sivan, A. and Chet, I. 1993. Integrated control of *Fusarium* crown and root rot of tomato with *Trichoderma harzianum* in combination with methyl bromide or soil-solarization. *Crop Prot.* 12 : 380-386.

Skoglund, L.G.; Rasmussen; Dykes, C.; Brown, W.M. and Weinstein, G.A. 1986. Effect of combined chemical and solar treatment on population densities of *Fusarium* spp. *Phytopathology*. 76 : 846 (Abst.).

Smith, E.W.; Wehner, F.C. and Katze, J.M. 1984. Effect of soil-solarization and fungicide soil drenching on crater disease of wheat. *Plant Dis.* 68 : 582-584.

Sood, A.K.; Kalha, C.S.; Parashar, A. 1998. Ecofriendly methods for the management of bacterial wilt of tomato caused by *Ralstonia solanacearum.* Bacterial-Wilt Newsletter 15: 7.

Standifer, L.; Wilson, F.C. and Porche, S. R. 1984. Effects of solarization on soil weed seed population. *Weed Sci.* 32: 569-573.

Stapleton, J. 1997. Soil solarization an alternative soil disinfestation strategy comes of age. Sustainable Agriculture. 9 : 7-9.

Stapleton, J.J. 1991. Soil-solarization in tropical agriculture for pre and post-plant applications. *FAO, Plant Production and Protection Paper.* 109: 220-228.

Stapleton, J.J. and DeVay, J.E. 1982. Effect of soil solArization on population of selected soilborne microorganisms 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 components of soil-solarization as related to changes in soil microflora and increase 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 (Abst.).

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

Stapleton, J.J. and Duncan, R.A. 1998. Soil disinfestation with cruciferous amendments and sublethal heating : Effect on *Meloidogyne incognita, Sclerotuism rolfisii* and *Pythium ultimum*. *Plant Pathol.* 47: 737-742.

Stapleton, J.J. and Garza-Lopez, J.G. 1988. Mulching of soils with transparent (solarization) and black polyethylene films to increase growth of annual and pernnial crops in south western mexico. *Tropical Agric.* 65: 29-33.

Stapleton, J.J. DeVay, J.E. and Lear. B. 1991. Simulated and field effects of ammonia based fertilizers and soil solarization on pathogen survival soil fertility and crop growth. Pages 331-342 in: *Soil Solarization.* J.E. DeVay J.J. Stapleton and C.L. Elmore, eds. Plant Prod. Pap. 109 FAO, Rome.

Stapleton, J.J.; Paplomatas, E.J.l Wakeman, R.J. and DeVay, J.E. 1993. Establishment of apricot and almond trees using soil mulching with transparent (solarization) and black polyethylene film effect on Verticillium wilt and tree health. *Plant Pathol.* 42: 333-338.

Tjamos, E.C. and Fravel, D.R. 1995. Detrimental effects of sublethal heating and *Talaromyces flavus* on microsclerotia of *Verticillium dahliae. Phytopathology* 85 : 388-392.

Tjamos, E.C. and Paplomatas, E.J. 1987. Effect of solarization on the survival of fungal antagonist of *Verticillium dahliae. EPPO Bul.* 17: 645-653.

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

Tjamos, E.C. Karapapas, V. and Bardas, D. 1989. Low cost application of soil solarization in covered plastic houses for control of Verticullium wilt of tomatoes in Greece. *Acta Hort.* 255: 139-150.

Tjamos, E.C., Paplomatas, E.J. and Biris, D.A. 1986. Recovery of Verticillium wilted olive trees after individual application of soil solarization. *4th. Inter. Verticillium Symp.*, Univ. of Guelph, Guelph, Canada.

Tjamos, E.C., Paplomatas, E.J. and Biris, D.A. 1987. Recovery of *Verticilium dahliae* for olive trees after individual application of soil solarization. Can. J. *Plant Pathol.* 9: 86-87.

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

Usmani, S.M.Z. and Ghaffar, A. 1982. Polyethylene mulching of soil to reduce viability of scelrotia of *Sclerotium oryzae. Soil Biol. Biochem.* 14 : 203-206.

Vanderberg, J. and Tiessen N. 1972. Influence of wax-coated and polyethylene-coated paper mulch on growth and flowering of tomato. *Hort. Sci.* 464-465.

Vannacci, G.; Triolo and Meterazzi, M. 1988. Survival of *Sclerotinia minor* (Jagger) sclerotia in solarized soil. *Plant and Soil* 109 : 49-55.

Waggoner, P.E.; Miller, P.M. and DeRao, H.C. 1960. Plastic mulching principles and benefits. Connecdicut Agricultural Experiments Station Bulletin : 44 pp.

Wajid, S.M.A.; Shenoi, M.M. and Shreenivas, S.S. 1995. Seed bed soil-solarization as a component of integrated disease management. *Tobacco Research* 21 : 58-65.

Walksman, S.A. and Starkey, R.L. 1923. Partial sterilization of soil, microbiological activities and soil fertility. I. *Soil Sci.* 16: 137-157.

Warcup, J.H. 1957. Chemical and biological aspects of soil-sterilization. *Soil Ferti.* 20: 1-5.

Webb,R.R. 1986.Control of damping-off of cucumber, using soil-solarization. B. and T. Tests. APS Press St.Paul. MN Vol.1.pp. 8.

Yarwood, C.E. 1975. Temperature coefficient in Plant Pathology. *Phytopathology* 65 : 1198-1201.

Yucel, S. 1995. A study on soil-solarization and combined with fumigant application to control Phytophthora crown blight (*P. capsici leonian*) on peppers in the East Mediterranean region of Turkey. *Crop Prot.* 14: 653-655.

* * * * * * *

VITA

- Born in Tehri (Garhwal) U.P. on 28th December, 1974.
- Received primary education from her native village Seem (Ranikhet) of district Almora.
- Passed High School Examination of U.P. Board (Ist division) in 1989 from Pantnagar.
- Passed intermediate Examination (Ist division) of same board in 1991 from Ranikhet, Almora.
- Received B.Sc. Ag. & A.H. degree (Ist division) form G.B. Pant University of Agriculture and Technology, Pantnagar.
- Received M.Sc. Ag. (Plant Pathology) degree form the same university in 1997.
- Recipient of ICAR-NET certificate.

Name	:	**Deepa Khulbe**	Id. No.: 19484
Semester and year of Admission	:	I[st] semester, 1997-98	Degree : Ph.D.
Major	:	Plant Pathology	
Department	:	Plant Pathology	

Thesis title : **SOIL SOLARIZATION : EFFECT ON SOIL'S NUTRIENTS, MICROORGANISMS AND PLANT GROWTH RESPONSE**

Advisor : **Dr. H. S Chaube**

ABSTRACT

Soil solarization, a hydrothermal disinfestation approach, operates through complex mechanisms creating physical, chemical and biological changes in soil. Such changes reflect on improved plant growth and reduced nursery diseases. In the present study, effects of colours, thickness, duration of solarization and its integration with seed-treatments, on damping-off of horticultural crops, plant growth and changes in physico-chemical properties of soil were studied.

The results recorded included (1) moisture content of solarized soil did not change, non-solarized soil lost it by over 60%, (2) soil temperature increased by 10-15^{0}C. White transparent polyethylene was most effective and thickness caused no significant changes. While there was no change in soil pH, electrical conductivity, total nitrogen and available potassium increased significantly. Available phosphorus and organic carbon changed non-significantly.

Incidence of damping-off reduced, mostly significantly. Disease reduction was highest in the first two crops. The effect of solarization persisted and integration with seed-treatments improved disease control. The effect on plant growth was notable. Significant to highly significant increase in biomass of plants was recorded. Growth promotory effects lasted for six months or duration of four nurseries.

Microbial equilibrium was modified. Most organisms were eliminated and/or reduced during solarization. *Pythium* was almost completely eliminated. Thermotolerent and thermophilic sapropathytes recovered and occupied niches. Among them, the counts of antagonists *Trichoderma, Bacillus* sp. and pseudomonads increased many folds. This provided biological control as the cultivation progressed. Weeds except *C. rotundus* were controlled.

Solarization at low temperature is possible and profitable. Plant growth improved substantially and organic matter decomposition hastened. Based on the analysis of the information gathered, the mechanism to explain its integrated character is proposed.

(H.S. Chaube)
Advisor

(Deepa Khulbe)
Authoress