Chapter-V

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 32^0C; 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 thermophylic 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 changes 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 the soil and increasing PGR, depends on soil colour-texture-structure, air temperature, soil moisture, day length, intensity of sunlight, thickness and light transmittance of the plastic film **(Chaube and Singh, 2003).**

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 bio-agents, and the crops raised were cauliflower, cabbage, tomato, and onion. 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. 18.

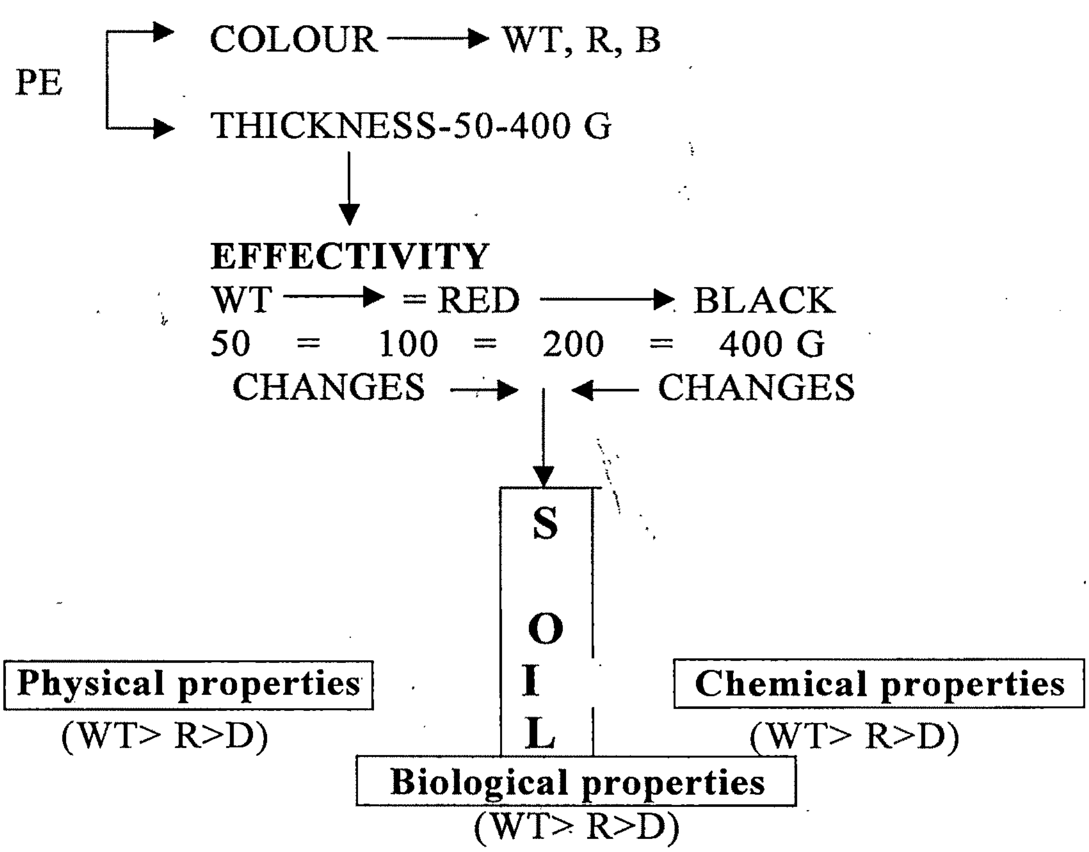


Fig.18 : Effect of soil solarization on soil properties

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 un-mulched 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 fllms, 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. 19).

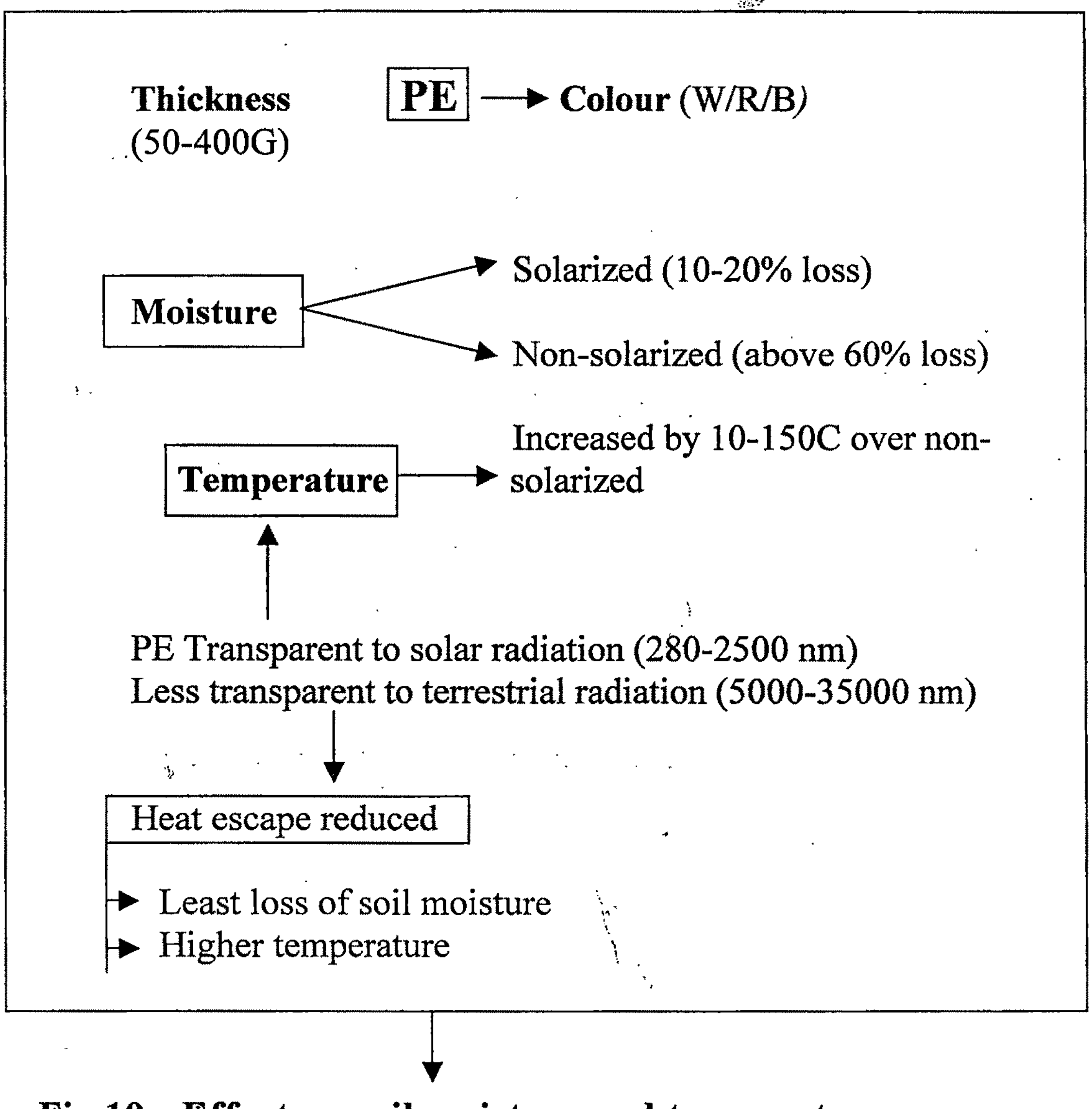


Fig.19 : Effect on soil moisture and temperature

In another flow chart, factors/inputs required for prediction of soil temperature are proposed (Fig. 20).

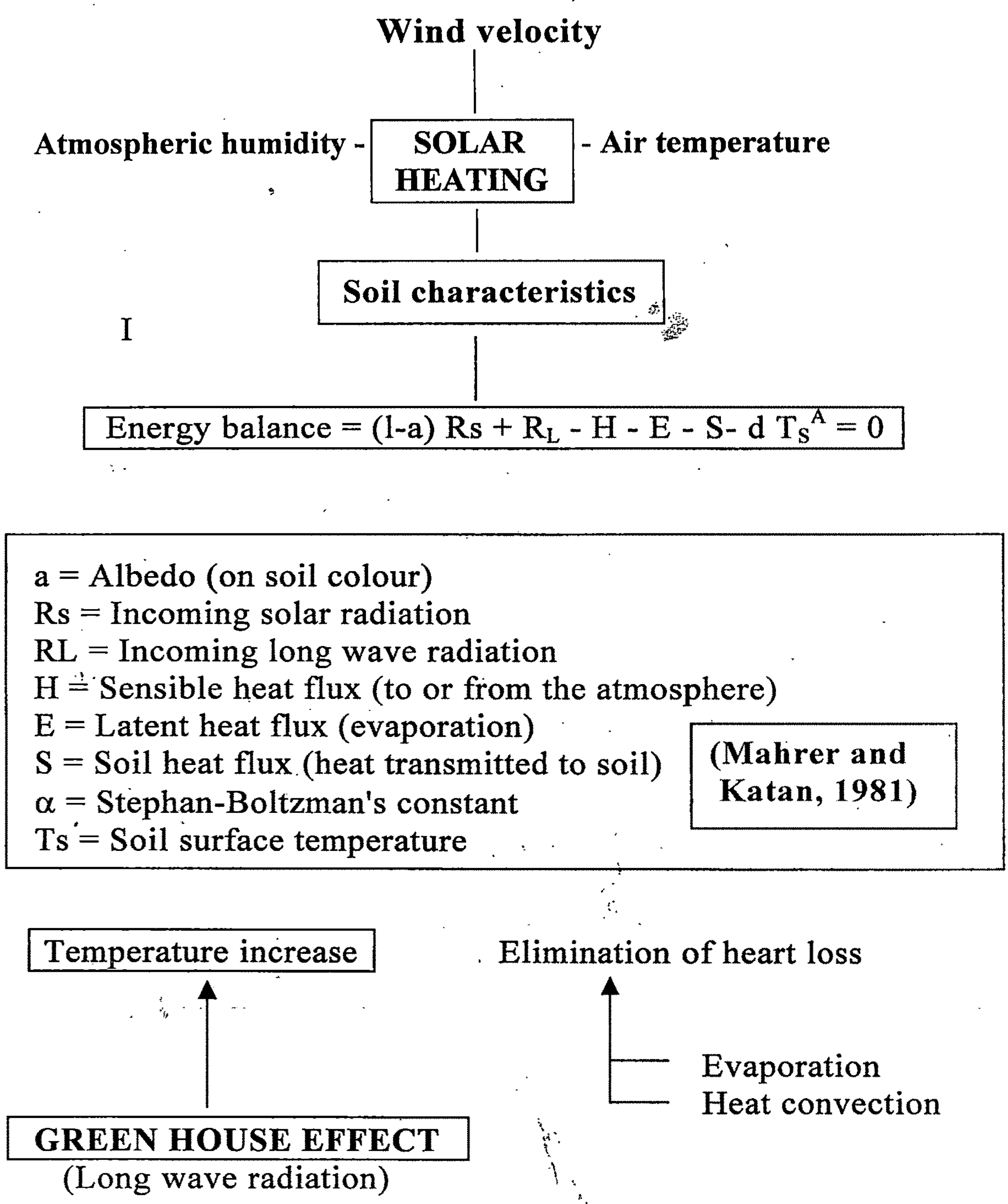


Fig.20 : Calculation of temperature in soil

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. Four crops-cauliflower, cabbage, tomato and onion were raised in sequence. The observations revealed that solarization alône caused significant reduction in seedling mortality of the crops grown. Such observations have invariably been recorded by several workers **(Al-Kafagi** *et al.,* **19.88; 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 A *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).**

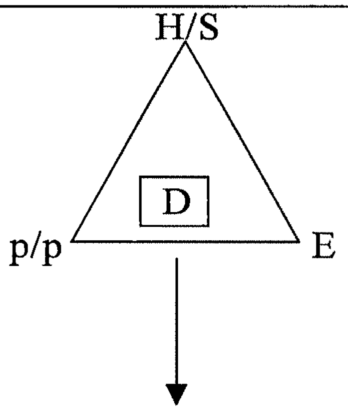
Similarly, the application of biocontrol agents *T. harzianum* and *P. fluorescens* further augmented disease controlling efficiency of solarization. There are numerous references available which clearly reveal the utility of these bio-agents as far as protection of seeds and seedlings is concerned **(Rao 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^{0}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. 21.



DS = IP × DP
IP = ID × I C
DP = susceptibility × Proneness

↑

Solarization of the soil

- 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. 21 : 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 Hartz, 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 P205, 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 Skou..dridakis, 1996; Chen and Katan, 1980; Elad** *et al.*, **1980; Gamliel** *et al.*, **1993).**

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 micro flora. 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 60^0C. The increase and decrease - the daily cycle more lethal to propagules existing at different 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. **Staple.ton**

and DeVay (1985) too have recorded such findings. Surprisingly after solarization, pseudomonads quickly recolonized the soil. Greater increase in populations of fluorescent pseudomonads 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 suppressiveness 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^{0}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 excreted by increased population of antagonists. *Trichoderma, Bacillus* and pseudomonads. Thus, reduction in populations of *Pythium* observed in solarized soil may be attributed to biologic8J 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 confining the previous results **(Ahmad** *et al.*, **1996 ; Esfahani, 1991; Horowitz&Regev(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 conceded 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 × 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 biotical as well as idiotically. **Chaube and Singh (1991)** proposed a mechanism for improved PGR and reduction in disease severity. We endeaour to modify and propose (Fig. 22) another to explain the mechanism.

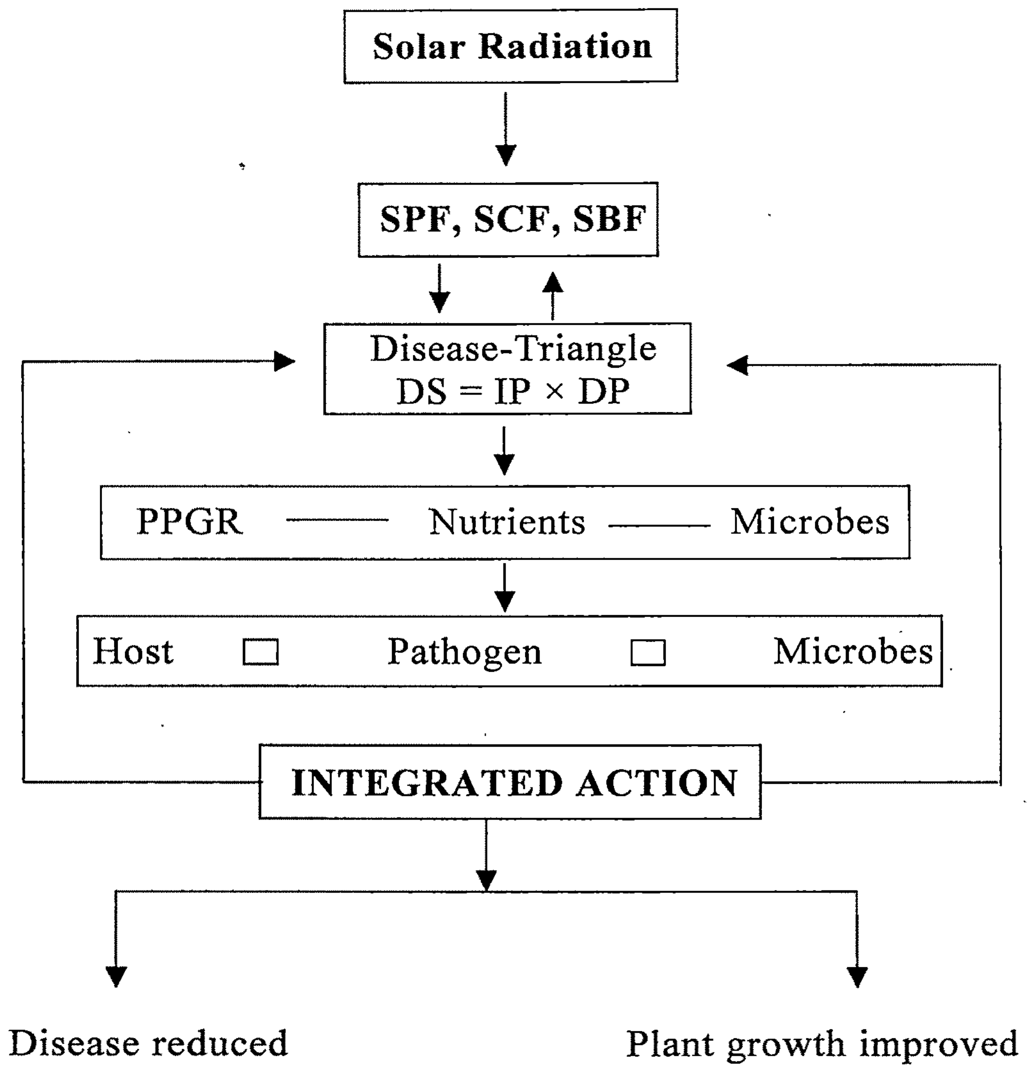


Fig. 22 : Schematic diagram of the mechanisms of disease management and IPGR through solarization

❖ ❖ ❖ ❖ ❖