WEED MANAGEMENT IN COCOA NURSERY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**Weed management in cocoa nursery**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.
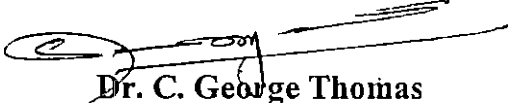
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*Affectionately dedicated
to my beloved parents*

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Introduction

INTRODUCTION

Cocoa (*Theobroma cacao* L.), a native of South America, is an important beverage crop all over the world. Cocoa prefers a tropical humid climate and in India,Kerala state leads in area and production. Its cultivation is being encouraged in Kerala as it fits well under coconut and arecanut based farming systems.

Cocoa is propagated through seedlings and budded plants. Budded plants are preferred now for planting due to a variety of reasons; prime being the necessity to do away with high variability exhibited by seedling progenies. For budding also, seedlings as rootstocks have to be prepared in large numbers and maintained in the nursery for 3-6 months before budding. The seedling nursery for cocoa must be planned in such a way as to raise the maximum number of healthy and vigorous stock seedlings which would attain buddable girth within the shortest time. This is possible only if the seedlings are grown in a competition free environment. Restricting weed growth in cocoa seedling nursery is thus a major factor that has to be given due importance. In the nurseries, weeds germinate and grow luxuriously along with seedlings and frequent weeding is necessary to keep them under check. Manual weeding, the conventional method resorted in nurseries, however, is labour intensive and time consuming. Alternative weed control strategies must be tried in this context.

Soil solarization is a non-chemical, eco-friendly technology, which is being successfully used for the control of weeds in many parts of the world. It involves covering the moist soil with transparent polyethylene sheets during the hottest period of the year, a technique developed and perfected in Israel (Katan *et al.*, 1976). Higher temperature can suppress germination of weed seeds and kill the germinating seedlings. Besides controlling weeds, solarization inhibits soil borne pathogens including nematodes and increases nutrient availability.

Fumigation of soil is done primarily to disinfect soil to ward of soil borne pathogens, nematodes and insects. Dazomet, a fumigant effective in controlling pathogens and nematodes in soil was reported to kill weed seeds too (McElroy, 1985).

Several biofertilizers are being recommended for improving the nutrient status of the soil and thus vigour of crops. Use of *Azospirillum*, and Vesicular Arbuscular mycorrhizal fungi,(VAM fungi-now called AM fungi) are well accepted as efficient biofertilizers for the early growth and vigour of seedlings of many crops. However, the effect of these biofertilizers on weed growth have not been studied in detail.

Soil solarization followed by the application of biofertilizers is an efficient practise, as solarization increases the growth of beneficial organisms in soil and increases the plant growth. Kurian (1992) suggested that VAM fungi combined with soil solarization could be one of the approaches to increase plant growth through non chemical means.

Pre-emergence herbicides also be used as an alternative to manual weeding. It control weeds effectively during the early growth of seedlings and save lot of labour involved in weeding.

Taking all these aspects into consideration, the present investigation was carried out in two separate experiments titled "Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora" and "Pre-emergence herbicides for the control of weeds in cocoa nursery" with the following objectives.

1. To test the feasibility of soil solarization and fumigation as measures for controlling weeds in cocoa nursery.

2. To determine the effects of *Azospirillum* and VAM fungi inoculation in nurseries coupled with soil solarization on the growth of cocoa seedlings and to assess its effects if any, on weed germination and growth.

3. To find out a suitable pre-emergence herbicide for controlling weeds in the nursery.

4. To assess the impact of various treatments on disease incidence in the nursery.

Review of Literature

2.   REVIEW OF LITERATURE

Weeds are a real menace to nursery plants especially in the early stages of growth. Because of the presence of rich organic manure in the potting mixture and also frequent irrigation, weeds grow luxuriantly in the nursery medium and compete with the seedlings. Cocoa seedlings are usually retained in the nursery for more than six months. In cocoa, nursery management must be to obtain healthy, good quality seedlings in less time of growth. Conventional hand weeding is found to be labour intensive and costly. Some alternative approaches to weed management not only limit the population of weeds but also give other benefits to the crop plants. Weed management strategies involving solarization, biofertlizers and pre-emergence herbicides with special reference to nursery plants and their effects on soil and plants are reviewed in this chapter.

2.1   Solarization

Soil solarization is a non-chemical method of controlling soil borne pests including weeds. Solarization in agriculture includes the thermal, chemical and biological changes in the soil caused by solar radiation when covered by clear plastic film especially when the soil has high moisture content (Stapleton and DeVay,1986).Thus it can be defined as a method of hydrothermal disinfestation of moist soil accomplished by covering with transparent polyethylene sheet during the hottest period of the year.

2.1.1   Principles of soil solarization

Mulching the soil with polyethylene reduces heat convection and water evaporation from the soil to the atmosphere. Because of the formation of water droplets on the inner surface of the polyethylene film, its transmissivity to incoming shortwave solar radiation is increased but prevented the escape of

outgoing longwave radiation from the soil, resulting in better heating   due to an increase in its green house effect.

As described by Katan (1980) the basic principles of solarization are as follows:

1. Transparent polyethylene should be used for covering the soil as it transmits most of the solar radiation.

2. Solarization should be carried out during the period of high temperature and intense solar radiation.

3. Soil should be kept wet during mulching to increase thermal sensitivity of resting structures.

4. The thinnest polyethylene trap possible should be used as it is cheaper and more effective.

5. Mulching period should be sufficiently extended, usually for four weeks or longer, in order to achieve the control of soil borne pests at all designed depths.

6. The soil should be in good tilth, allowing close contact between plastic sheets and the soil.

7. Take adequate care to prevent the formation of air pockets, which reduces heat conduction.

The above principles indicate that the effectiveness of solarization depends on many factors like the polyethylene film types and their characteristics, the soil moisture, the duration of solar heating and the season of solarization.

Polyethylene film types and other characteristics

The superiority of transparent polyethylene for solarization has been established by many workers -Katan, 1980 and Stapleton *et al.*, 1987. It was reported that transparent polyethylene raised soil temperature at 15-23 cm depth by 10-18°C while black polyethylene raised the temperature only upto 8-12°C

(Stapleton *et al.*, 1987). As Waggoner *et al.* (1960) reported, black polyethylene, eventhough heated by itself, is less efficient in heating the soil.

Thinner polyethylene sheets are preferred for solarization treatments than thicker sheets. Mudalagiriyappa *et al.* (1999) reported, in a trial with 0.05 mm and 0.075 mm polyethylene sheets, that the temperature increase was 50.5°C and 49.1°C respectively and that 0.05 mm film gave better weed control compared to 0.075 mm when solarized for 45 days.

According to Garibaldi (1987), polyvinylchloride (PVC) was more effective than polyethylene in maintaining high soil temperature. Nevertheless, double-layered polyethylene film gave 1°c to 2°C higher soil temperature than those obtained with PVC.

Soil moisture content and solarization

For the solarization to be effective, the soil must be moist. Moist soil, either irrigated before mulching or irrigated under the plastic film, increases the thermal sensitivity of soil-borne microflora and fauna as well as transfer or conduction of heat in the soil (Mehrer and Katan, 1981).

Yaduraju and Ahuja (1990) reported that polyethylene mulching for 30 days with irrigation recorded lower grass weed population than polyethylene mulching for 30 days without irrigation. According to them, the better effect of polyethylene mulching of wet soil might be due to a greater sensitivity of imbibed weed seeds to heat.

Duration of solar heating

As temperatures at the deeper layers of soil are lower than at the upper layers, the mulching period should be sufficiently extended in order to get the maximum effect. Yaduraju and Ahuja (1990) reported that the grass weed

population was substantially reduced due to polyethylene mulching with irrigation for 30 days but not for 15 days. Bhasker and Nanjappa (1997) reported a solarization period of 40 days for effective control of weeds. They tried soil solarization for 40 days using transparent polyethylene sheet along with one hand weeding 45 days after sowing and observed that it effectively controlled dicots, monocots and sedges and thereby recorded the lowest dry weight of weeds. However, soil solarization of 20 days was less effective.

The weed dry weight produced per 0.25 m^2 with 15, 30 and 45 days solarization with polyethylene film 90 days after sowing in groundnut plot was 30 g, 15 g and 8.1 g respectively (Mudalagiriyappa *et al.*, 1999). The findings suggested that solar heating period of 30 days or more is required for the control of soil born pest and weeds.

Best Season for solarization

To get the best results out of solarization, it should be carried out during the periods of high temperature and intense solar-radiation (Katan, 1980).

Malathrakis and Kambourakis-Tzagaroulakis (1989) observed that soil solarization increased the soil temperature to 45°C at 10 cm depth during July, while when the experiment was repeated in August, the temperature was only 40°C. In Kerala, peak soil temperature of 63°C and 59°C in the solarized soil at 5 and 10 cm depth was reported by Vilasini (1996) during April-May. In another study in Kerala, Sainudheen (2000) reported soil temperatures of 56.9°C in April and 49°C in May at 5 cm depth in the solarized soil.

Eventhough, March-April period is the hottest period in Kerala,it may not be possible to do solarization for all the crops during this time. For crops such

as pepper and cocoa, solarization of potting mixture must be done earlier so as to plant the vines or seeds at the appropriate time in the nursery.

2.1.2   Solarization effects on weeds

Effects on weed emergence

Soil solarization has been widely tested as a viable method of controlling pests including weeds in many countries. Investigations by Urzad (1977) and Grinstein *et al.* (1979) threw light on weed control through solarization. Most of the annual and perennial weeds are effectively controlled by solarization (Katan, 1980). Yaduraju (1993) reported that soil solarization for 4-6 weeks give satisfactory control of many annuals, some perennials and parasitic weeds. Madalagiriyappa *et al.* (1999) reported a significant reduction of many monocots, dicots and sedges.   In general, winter annual weeds were most effectively controlled by soil solarization than summer annuals, which were not susceptible (Elmore, 1990).

The possible mechanisms of weed control suggested by Katan (1981) are (1) thermal killing of weed seeds; (2) thermal killing of weeds induced to germinate; (3) breaking of seed dormancy and consequent killing of the germinating seed; and (4) biological control through weakening or other mechanisms. According to Benjamin and Rubin (1982) the effect of soil solarization on weeds appears to be based on a combination of high soil temperature in the top soil layers and the factors such as toxic products resulting from rapid organic matter decomposition

Several workers reported many cases of the control of weeds through solarization.

Horowitz *et al.* (1983) reported that the effectiveness of solarization was different for different weed species. Annual weeds like *Portulaca oleracea* was

controlled well. However, *Malva nicaensis* was resistant. Egley (1983) reported 64-98 per cent weed control by solarization for 1-4 weeks. Significant reduction in weed emergence was obtained in *Sida spinosa* and *Amaranthus* spp. In cotton fields of Israel, solarization reduced population of *Avena* sp. and *Chenopodium* sp. by 60 to 100 per cent (Katan *et al.*, 1983). Standifer *et al.* (1984) reported that solarization controlled *Eleusine indica* effectively. Braun *et al.* (1987) found solarization causing significant reduction in *Echinochloa crusgalli* and *Digitaria sanguinalis*. Ragone and Wilson (1988) reported that solarization for six weeks controlled grass weeds like *Brachiaria mutica, Digitaria* sp. and *Panicum maxima* for three months. Broad leaved weeds like *Euphorbia hirta, Cleome viscosa, Ludwigia* sp. and *Phyllanthus niruri* were also reduced.

Chandran (1989) reported the control of many weeds by solarization, which included *Ageratum conyzoides, Alternanthera sessilis, Brachiaria ramosa, Curculigo orchioides, Desmodium tridentata, Hemidesmus indicus, Isachne miliacea, Merrimea tridentata* and *Oldenlandia corymbosa*. Kurian (1992) reported the control of *Alysicarpus* sp., *Amaranthus viridis, Cassia* sp., *Centrosema* sp., *Knoxia* sp., *Hyptis suaveolens, Mimosa pudica, Phyllanthus niruri, Scoparia dulcis, Sida rhombifolia, Stachytarpheta indica* and *Vernonia cineria*. Binimol (2000) reported the control of *Borreria hispida, Phyllanthus niruri, Cleome viscosa, Mimosa pudica* and *Emelia sonchifolia* through solarisation.

Perennial weeds are a little difficult to be controlled by soil solarization. Solarization for 30 days with 100 μm polyethylene increased *Cyperus rotundus* population but controlled *Cynodon dactylon* (Yaduraju and Ahuja, 1990). However, solarization for two and three months reduced the population of *Cyperus rotundus* by 95 per cent and 99 per cent respectively as reported by Lopez and Gonzalez (1995). *Commelina benghalensis* though responded to solarization was not completely killed (Chittapur, 1998).

Solarization effects on buried weed seeds

The reserves of dormant weeds in agricultural soils provide a source of seeds for persistent weed problems that often require repeated control measures (Hosmani and Habeeburrahaman, 1992). As suggested by Yaduraju (1993), soil solarization is desirable as a means of reducing dormant weed seed reserves in soil. The solarization treatment kills non-dormant seeds and greatly reduces the number of weed seedling that otherwise would have emerged (Egley, 1983). Solarization for 40 days killed seeds of *Commelina communis* in the top layer upto 11 cm but that of *Cyperus* sp. and *Echinochloa* sp. upto 3-4 cm (Standifer *et al.*, 1984).

Solarization effect on weed dry matter production

Soil solarizartion had conspicuous effect in reducing dry weed biomass compared to summer ploughing in rice nursery (Patel and Mehta, 1989). Soil solarization for 40 days with transparent polyethylene had given significantly higher reduction in total dry weight of weeds at all growth stages of sunflower than that in black polyethylene (Bhasker and Nanjappa, 1997). Soil solarization with transparent polyethylene 0.050 mm and 0.075 mm for 45 days reduced the weed dry weight in groundnut (Mudalagiriyappa *et al.*, 1999). Lower weed dry weight was observed with 0.05 mm transparent polyethylene solarized for 60 days in sunflower (Chandrakumar *et al.*, 2001). Solarization with transparent polyethylene recorded the highest reduction in dry weight of weeds in tomato (Kumar *et al.*, 2001).

2.1.3   Solarization effects on soil

Soil temperature

The upper 15-30 cm of soil show diurnal temperature changes influenced by day and night air temperature (Yaduraju, 1993). Typical maximal soil temperature in solarization plots are 8 to 12°C higher than in corresponding

non-solarized plots (Katan, 1980). Benjamin and Rubin (1982) reported an increase in soil temperature by 10-15°C in the top 5-10 cm by solarization in Israel. From a study in Kerala, Kurian (1992) reported an increase of 6-11.5°C increase in soil temperature when atmospheric temperature was 20°C to 38°C.

Alexander (1990) reported peak soil temperature of 55°C, 51°C, 47°C and 43°C at 13 cm, 38 cm, 63 cm and 99 cm depth, respectively in solarized plot. Bhasker and Nanjappa (1997) observed highest temperatures of 50.1°C and 42.8°C at 5 and 10 cm depths, respectively compared to 43.6°C and 39.8°C in the uncovered plots in Banglore.

From a study in Kerala, Vilasini (1996) recorded peak soil temperature of 63°C and 59°C in the solarized soil at 5 and 10 cm depth when atmospheric temperature of the experimental area ranged from 23°C to 39°C. Sainudheen (2000), however, recorded a slightly lower peak temperature of 59°C and 48°C at 5 cm and 10 cm depths when the atmosphere temperature ranged from 25.6°C to 36.5°C.

Soil chemical properties

Chemical changes that takes place in soil are altered by solarization. Plastic mulched and steamed soils usually contain higher levels of soluble mineral nutrients than unmulched soils (Baker and Cook, 1974; Jones *et al.*, 1977). This phenomenon was also noticed on solarization treated soils of Israel (Chen and Katan, 1980) and California (Stapleton *et al.*, 1985).

Organic matter

Soil solarization, although is a moderate heating treatment of the soil did not result in significant changes in total organic matter content in the soil (Chen and Katan, 1980; Stapleton *et al.*, 1985; Kaewruang *et al.*, 1989a and Vilisini, 1996). Water-soluble organic matter (or low molecular weight fulvic acid), however, increased significantly (Chen and Katan, 1980). An increase in

organic carbon content was noticed in solarized plots compared to non-solarized plots (Chandran, 1989; Kurian, 1992).

Nitrogen

Significant increase nitrate nitrogen (NO_3^--N) and ammoniacal nitrogen (NH_4^+-N) were consistently found in solarized soil(Chen and Katan, 1980). Stapleton *et al.* (1985) reported solarization increased concentration of nitrate (NO_3^--N) and ammoniacal (NH_4^+-N) nitrogen upto six times compared to non-treated soil. A rapid decline in soil electrical conductivity and corresponding decline in nitrate nitrogen was noticed after solarization by Hori *et al.* (1979). This suggests the accumulation of ammoniacal nitrogen under reductive and high temperature conditions in the soil. Studies of Kaewruang *et al.* (1989a and b) clearly showed that solarized soils had significantly higher levels of nitrate nitrogen and ammoniacal nitrogen at 0-10 cm depth in comparison with control. Kodama *et al.* (1980) reported a drastic reduction of nitrite and nitrate bacteria in solarized soil. This in turn indicated a delay in ammonia nitrification after the treatment terminated.

The reports by Daelemans (1989) and Kurian (1992) suggested that solarization had no significant influence on total nitrogen content of soil. However, an increase in available nitrogen content was noticed in solarized soil compared to non-solarized plots (Chen and Katan, 1980; Chandran, 1989; Vilasini, 1996 and Binimol, 2000).

Phosphorus and potassium

In general, availability of phosphorus and potassium content increased in some soils because of solarization. Availability of phosphorus in the soil was significantly increased by solarization (Stapleton *et al.*, 1985; Chandran, 1989;

Vilasini, 1996 and Binimol, 2000). A significantly lower phosphate concentration in the solarized soil was, however, reported by Kaewruang *et al.* (1989b).

There are conflicting reports about the status of available potassium due to solar heating. According to Stapleton *et al.* (1985) and Chandran (1989), there were no changes in the available potassium content of soil due to solarization. However, later reports suggest that availability of potassium was increased by solarization (Kaewruang, 1989a; Kurian, 1992; Vilasini, 1996 and Binimol, 2000).

Other nutrients

Solarization exerted marked influence on the exchangeable cations in the soils, especially the availability of calcium and magnesium (Chen and Katan, 1980; Katan, 1981; Stapleton *et al.*, 1985; Kurian, 1992), calcium (Chandran, 1989), sodium (Kurian, 1992) and chlorine (Chen and Katan, 1980). Stepleton *et al.* (1985) observed that solarization does not consistently affect available iron, manganese, zinc, copper and chlorine in the soil.

2.1.4   Effect of solarization on microbial population

Due to solarization several changes were reported to occur in the population of soil microorganisms.

Soil fungi

At Varanasi, India, there was reduction in total fungi in the 0-10 cm depth of solarized soil; however, it was found to increase when solarized plots were under shade (Dwivedi and Dubey, 1987). At Sicily, Italy, it was observed that the total fungal population was decreased by 50 to 53 per cent due to solarization (Cartia *et al.*, 1987). Meron *et al.* (1989) reported 50 to 100-fold decrease in the number of fungi. Chandran (1989), Kurian (1992), Vilasini (1996) and Binimol

(2000) also observed reduction in total fungal population because of solarization. However, antagonistic fungi were reported to survive or even increase in number in solarized soil (Kaewruang *et al.*, 1989a).

Soil Bacteria

Reports on the effects of solarization on bacterial population are not similar to fungi. As reported by Chandran (1989), the popularion of bacteria was not significantly changed after solarization. In Israel, Meron *et al.* (1989) reported an increase in the *Pseudomonas* population 50 to 100 fold in the rhizosphere of tomato and cotton. On the contrary, Kurian (1992), Vilasini (1996) and Binimol (2000) reported that solarization reduced the total bacterial population. Solarization reduced *Pseudomonas* sp. population in the field (Vilasini, 1996). Kodama *et al.* (1980) reported a drastic reduction of nitrite and nitrate bacteria in solarized soil.

Actinomycetes

Population levels of actinomycetes were not greatly affected by solarization (Stapleton and DeVay, 1982 and Kaewruang *et al.*, 1989a). A slight increase in actinomycetes population was noticed in solarized plots (Chandran, 1989). However, Kurian (1992), Vilasini (1996) and Binimol (2000) reported a reduction in the population of actinomycetes as a result of solarization.

Solarization on mycorrhizal colonization

Soil solarization for 30 days was found to increase mycorrhizal infection by 20 per cent in cowpea (Nair *et al.*, 1990). Kurian (1992) observed that colonization by VA mycorrhiza was more in chilli plants grown in solarized soil than in non-solarized plots. Afek *et al.* (1991) and Kurian (1992) suggested that VAM combined with solarization can be one of the best approaches to replace or at least reduce the use of chemicals in agriculture. On contrary to this Binimol (2000)

reported that pepper cuttings grown in solarized potting mixture exhibited lesser root colonization of VAM.

2.1.5 Solarization effects on crop growth and yield

Many researchers have reported growth and yield improvement of crops grown in solarized soils. Upon solarization, minerals are released and the nutritional status of the soil is improved, which results in increase in yield. Other mechanisms for stimulation of plant growth are destruction of pathogen and nullification of toxins in soil (Katan, 1981), production of beneficial chemicals like fulvic acid (Davis and Sorenson, 1986), stimulation of beneficial organisms (Nair *et al.*, 1990) and control of weeds (Yaduraju, 1993).

Growth parameters like height and number of leaves per plant were not significantly influenced by solarization in cowpea, although it improved the stand · of the crop and yield (Chandran, 1989). In ginger, the height, number of leaves per plant, number of tillers, leaf length, leaf breadth and weight of shoot were positively influenced by solarization (Vilasini, 1996).

Favourable effects of solarization on the growth and yield of many crops were reported. It increased growth and yield in cowpea (Chandran, 1989; Nair *et al.*, 1990), chillies (Cartia *et al.*, 1989; Kurian, 1992), egg plant (Katan *et al.*, 1976), peach (Stapleton and DeVay, 1982), sorghum (Habeeburrahaman, 1992), tobacco (Meti, 1993), sunflower (Bhasker and Nanjappa, 1997) and groundnut (Biradar *et al.*, 1997 and Mudalagiriyappa *et al.*, 1999).

2.1.6 Solarization effects on disease incidence

Solarization as a method of plant disease control was first used by Jones *et al.* (1966) against southern blight of tomatoes. Katan *et al.* (1976, 1983) demonstrated the usefulness of the method for the control of diseases caused by

Verticillium, Fusarium, Rhizoctonia, Sclerotium, Pyrenochaeta and several other soil borne pathogens. Apart from thermal killing of the plant pathogens, a number of biological effects have also been attributed to solarization in controlling the pathogens (Katan, 1981; Chandran, 1989).

Several diseases are reported to be controlled by solarization. Verticillium wilt in egg plant and tomato (Katan *et al.*, 1976), pink root in onion (Katan *et al.*, 1980), Fusarium infection in onion (Katan, 1980), Fusarium wilt of pegeon pea (ICRISAT, 1986), collar rot of cowpea (Chandran, 1989), damping off disease of chilli (Kurian, 1992), soft rot of ginger (Vilasini, 1996) and *Phytophthora* rot in pepper (Binimol, 2000) were controlled through solarization.

2.2   Fumigation

Dazomet is a soil fumigant effective against germinating weed seeds, nematodes, soil fungi and soil insects. It is primarily used for preplanting control of all these in tobacco and forest nursery crops and is now marketed for a wide range of field and green house crops as Basamid Granular (BASF, 1984). When applied to moist soils, the active ingredient in the product breaks down into methyl isothiocyanate and had a broad spectrum of effectiveness against soil borne pests including nematodes, fungi and weeds (McElroy, 1985).

Dazomet was very effective against *Phytophthora*, reducing its population to 2.3 propagules per gram of soil compared to the control level of 243 propagules per gram of soil. It was shown to decrease seedling mortality while increasing over all quality (McElroy, 1985).

Dazomet application strongly suppressed colonization of the linseed roots by AM fungi. It also reduced the biomass of saprophytic fungi in the soil while biomass of bacteria in the soil was not affected by dazomet application (Olsson *et al.*, 1999).

Weed control with dazomet varied with time. It was more active in spring and winter than summer. Spring application of dazomet produced better weed control than metham-sodium another soil fumigant. However dazomet 600 kg ha^{-1} was the best treatment during summer, if it was independently sealed, with polyethylene or roller (Figuerou and Kogan, 1995).

2.3   Biofertilizers

Biofertilizers or microbial inoculants can be defined as preparations containing live or latent cells of efficient strains of nitrogen fixing, phosphate solubilising or cellulolytic microorganisms used for application of seed, soil or compost, with the objective of multiplying microorganisms and accelerate certain microbial processes to augment the extent of availability of nutrients in a form, which can be easily assimilated (Rao, 1981). Vesicular arbuscular mycorrhizae (VAM fungi - At present VAM is referred as AM fingi), *Azospirillum* and their combination included in the present investigation are reviewed here.

Vesicular arbuscular mycorrhizae (VAM)

Vasicular arbuscular mycorrhizae are the most widely occurring symbiotic fungi under varying climates of temperate, tropical and artic (Bhandari *et al.*, 1990).

Most of the plants belonging to gramineae and leguminosae have VAM association under natural condition. Girija and Nair (1985) studied the natural occurrence of VAM in a number of crop plants in Kerala including cocoa and found that cocoa plants had 91.2 per cent colonization under natural condition. Improved growth and nutrient uptake due to VA mycorrhizal association have been demonstrated in many, horticultural crops including pepper and cocoa (Bagyaraj and Manjunath, 1980; Mosse, 1981 and Sivaprasad *et al.*, 1984). VAM fungi have an intimate link between the roots of most crop plants and soils and thereby

affecting the development of host plants and soils (Schreiner and Bethlenfalvay, 1995).

Sivaprasad *et al.* (1984) collected root samples of cocoa from two gardens of Kollam district and reported that seven out of ten samples were mycorrhizal. The study revealed that VA mycorrhiza inoculation along with medium level phosphorus application was more effective. Cocoa seedlings inoculated with mycorrhizal spores looked more vigorous and had produced more leaves, reached greater height and had greater dry weight (Chulan and Ragu, 1986). Cuenca *et al.* (1990) reported that cocoa seedlings responded well to indigenous vesicular arbuscular mycorrhizae and exhibited significant increase in plant height and dry weight. Cheriyan (2001) also reported increased seedling height due to the application of native VAM.

The growth promotion obtained in cocoa seedlings was much lower than the values obtained in other tropical tree species (Ferrer *et al.*, 1986). Cuenca *et al.* (1990) suggested that in the case of cocoa seedlings large size of cotyledons and their permanence after germination might prevent the plants from becoming entirely dependent on the root absorption for nutrients and hence responding a lesser degree to VAM compared to other plants.

The growth and phosphorus uptake of cashew plants considerably improved with VAM colonization. (Sivaprasad *et al.*, 1992). Significant differences in plant height, stem girth and number of leaves per seedling and total plant biomass were observed over uninoculated control in VAM applied cashew seedlings (Remesh *et al.*, 1998). In VAM applied cashew seedlings, increased stem girth was observed 30 days after sowing. Other characters viz., leaf length, leaf breadth and number of leaves did not show any significant difference among the different treatments (Sridar *et al.*, 1990).

Inoculation of mulberry nursery beds with VAM increased growth, development and survival of mulberry saplings in comparison with uninoculated control (Das *et al.*, 1995).

Girija and Nair (1985) reported natural mycorrhizal association in grass like Paragrass, Gunea grass, Dinanath grass, Congo signal grass and Hybrid napier.

Azospirillum

In a survey conducted by Dobereiner *et al.* (1976), it was found that *Azospirillum* was a common inhabitant of the tropics. *Azospirillum lipoferum* was first found to be associated with the forage grass *Digitaria decumbens* (Doberiner and Day, 1976). The association of *Azospirillum* with the roots of several annual and perennial crops in coconut based farming systems of Kerala was reported by Ghai and Thomas (1989). The association of the nitrogen fixing associative bacterium, *Azospirillum* with root systems of many cereals and grasses was reported by Dobereiner and Day (1976) and Neyra and Dobereiner (1977).

Azospirillum was found to increase the growth and yield of many crops like rice, wheat, maize, sweet potato, fruit crops, vegetables, pulses, oil seeds and plantation crops (Venkateswarlu and Rao, 1983; Hill *et al.*, 1983 and Govindan and Purushothaman, 1985). One of the striking responses of crop plants upon inoculation with *Azospirillum* is the increased root and shoot growth and biomass accumulation (Smith *et al.*, 1978). Seed inoculation with *Azospirillum* increased dry weight of shoots in *Cenchrus ciliaris* and *Chrysopogon fulvus* (Rao *et al.*, 1979).

Azospirillum inoculation in cocoa seedlings increased the number of leaves, root biomass, shoot biomass and length over uninoculated control (Govindan and Nair, 1984). In a nursery experiment with coffee C X R seedlings, it was observed that *Azospirillum* treatment significantly increased plant height and

stem girth (Swarupa, 1996). Significant increase in plant height, stem girth, number of leaves per seedling and total plant biomass were observed in *Azospirillum* applied cashew seedlings (Remesh *et al.*, 1998). Cheriyan (2001) also reported increased height and number of leaves in *Azospirillum* inoculated cocoa seedlings.

Interaction of VAM and *Azospirillum*

Rao *et al.* (1985a&b) observed synergistic effect of vesicular arbuscular mycorrhiza and *Azospirillum* as evident by higher yield of barley and P uptake of pearl millet in comparison with either mycorrhizal or bacterial component alone. Contrary to this, Graham *et al.* (1981) reported that colonization by VAM fungi reduces root exudation and may reduce the release of malate and other organic acids from sorghum roots. These are preferred carbon sources for *Azospirillum brasilense*. The increased formation of vesicles, arbuscles and spores has been reported in eight grasses after dual inoculation with *Azospirillum* and VAM (Singh and Rao, 1987).

A nursery experiment conducted at Tamil Nadu Agricultural University (TNAU) for Arabica coffee indicated that addition of 500 g peat based *Azospirillum* along with 5 kg VAM to the nursery soil mixture significantly increased the shoot length, root length and dry weight of seedlings (Kumari and Balasubramanian, 1993).

Inoculation of VAM and *Azospirillum* enhanced dry matter of plant significantly over uninoculated control at all days of sampling in tea cuttings, combined inoculation of both giving better effect than individual inoculants or uninoculated control (Rajagopal and Ramreithinam, 1997).

Dual inoculation of VAM and *Azospirillum* increased the growth, yield and oil content of palmarosa over uninoculated control as well as inoculation with VAM alone (Neelima and Janardhanan, 1996).

Sansamma *et al.* (1998) reported that in a trial with inoculation of *Azospirillum* and VAM along with different doses of N, P, K in gunea grass, the yield was greatest in treatments with VAM followed by *Azospirillum.*

Biofertilizers and weed growth

Native VAM fungi can be encouraged in soils used for rice by allowing growth of preferred weeds during the off season and maintaining established mycelial net work by long term minimal tillage practices (Maiti *et al.*, 1996).

Among the 45-weed species secreened for the presence of VAM, the greatest colonization was recorded in members of Zygophyllaceae, Leguminosae, Malvaceae, Euphorbiaceae, Lilliaceae, Labiatae, Compositae and Gramineae (Lakshman, 1996).

In a study conducted in tea nursery, finely ground roots of the weed species *Ageratum conyzoides, Mimosa invisa* and *Borreria hispida* inoculated with VAM had been added to tea cuttings and after nine months it was observed that mycorrhiza enhanced the over all growth and dry weight of the tea shoots compared with control. Tea root dry weight was greatest in pots treated with *Ageratum conyzoides* (Deori *et al.*, 1998).

2.4   Pre-emergence herbicides in cocoa nursery

There are very few studies on the weed management aspects in cocoa nursery using herbicides. Related works on the herbicides included in the present study are also reviewed here.

2.4.1 Control of weeds

Laprade *et al.* (1989) reported from a trial for the evaluation of pre and post emergence herbicides in cocoa nursery that all the pre-emergence herbicides used gave good weed control. The pre-emergence herbicides included in the study were simazine (2.5 kg ha⁻¹), cynazine (2.5 kg ha⁻¹), diuron (1.5 kg ha⁻¹), oxyfluorfen (0.5 kg ha⁻¹) and terbutryin (1.5 kg ha⁻¹).

Use of diuron at 2 to 3 kg ha⁻¹ has been reported to control both monocot and dicot weeds for a period of 2 to 3 months in the rubber seedling nursery (Mathew and Punnoose, 1975). Diuron at the rate of 2 kg ha⁻¹ applied at pre-emergence or early post emergence stage controlled weeds effectively in nurseries of several fruit trees for 4 to 5 months (Challa, 1990). Lakshmanan *et al.* (1995) reported the control of weeds like *Digitaria sanguinalis, Panicum repens, Ischaemum indicum, Cyperus esculentus, Euphorbia hirta, Borreria aculeata, Cleome viscosa* and *Vernonia cineria* in a trial conducted with diuron 1.0, 2.0 and 2.5 kg ha⁻¹ in rubber seedling nursery. Diuron at the low dosage of 1.0 kg ha⁻¹ gave very good weed control during the first four months in rubber stock nurseries (Mangoensoekarjo and Nurdin, 1981).

In cashew polybag nursery, pre-emergence herbicides atrazine (1.25-2.5 g l⁻¹) and fluchloralin (2.7 g l⁻¹) gave control of the weeds like *Euphorbia hirta, Portulaca oleracea, Eragrostis minor, Cyperus rotundus, Cynodon dactylon* and *Amaranthus viridis*. Among the two, Fluchloralin (2.7 g l⁻¹) gave better control of weeds (Burondkar *et al.*, 1993).

Oxyfluorfen applied at the rate of 0.1-0.3 kg ha⁻¹ in potato gave poor control of *Cyperus rotundus* (Chauhan and Ramakrishnan, 1981). Oxyfluorfen (0.75 L/4200m²) reduced the growth of *Xanthium pungens* and *Euphorbia geniculata* in onion nursery (Farag and Koriem, 1995).

Clarkson and Van (1975) reported that metolachlor was effective on a wide variety of grasses and broad-leaved weeds in many crops. Weed management

studies by Dixon and Stroller (1982) showed moderate control of nut sedge through pre-emergence application of metolachlor.

A field trial in groundnut to know the efficacy of pre-emergence herbicides (fluchloralin, pendimethalin, alachlor, metolachor and oxyfluorfen) oxyfluorfen showed maximum weed control efficiency followed by pendimethalin. Weeds controlled were *Celosia argentea, Echinochloa crusgalli, E. colona, Cynodon dactylon* and *Cyperus rotundus* (Patel *et al.*, 1997).

2.4.2   Herbicidal effects on crop growth

There are reports of favourable effects of herbicides on the growth of many crops. In cashew polybag nursery, fluchloralin application (2.7 g l^{-1}) significantly increased seedling girth and number of functional leaves even though plant height showed no significant variation (Burondkar *et al.*, 1993). However, establishment of rubber seedlings was unaffected by the herbicide diuron (2 kg ha^{-1}) determined by either height or stem diameter measurements of rubber seedlings (Mangoensoekarjo and Nurdin, 1981; Lakshmanan *et al.*, 1995). Application of oxyfluorfen increased the potato yield appreciably over unweeded control (Chauhan and Ramakrishnan, 1981).

The application of atrazine (0.75 kg ha^{-1}) increased the growth and yield in maize compared to hand weeding (Dixit and Gautam, 1996). In a trial with herbicides, atrazine and alachlor in maize-pulse rotation the dry matter production of crop did not differ among the treatments and was significantly superior to unweeded check (Singh and Mani, 1981).

Oxyfluorfen (0.75 L/4200m^2) application in onion nursery increased onion plant growth parameters (number of leaves, bulb diameter, foliage dry weight and bulb dry weight) compared to hand weeding (Farag and Koriem, 1995).

2.4.3   Phytotoxicity due to herbicides

Diuron at 2 kg ha^{-1} cannot be used in nurseries even during its preparation since it is phytotoxic to rubber seedlings (Mangoensoekarjo and Kandan, 1974). Similar result was reported in Thailand by Boonsrirat and Paardekooper (1971) that diuron 3 kg ha^{-1} or higher may cause stunted growth though 1.8 kg ha^{-1} caused no apparent damage to rubber seedlings.

Mangoensoekarjo and Nurdin (1981) reported that low dosage of diruon 1.0 kg ha^{-1} showed no adverse effects on growth on rubber seedlings.

In cashew polybag nursery, use of atrazine (2.5 g l^{-1}) showed phytotoxicity as lower leaves of seedlings became brownish and gradualy dried up. This ultimately resulted in significant reduction in number of functional leaves. Nevertheless, lower dose of atrazine (1.2 g l^{-1}) did not affect adversely (Burondkar *et al.*, 1993). In true potato seed nursery use of fluchloralin (0.9 kg ha^{-1}) caused phytotoxity to potato seedlings (Trivedi *et al.*, 2001).

2.4.4   Herbicide effects on soil microflora

In a laboratory study, application of herbicide atrazine (1000 µg/L) diminished bacteria to almost one fourth of their original population and actinomycetes to 7 to 10 times. However, fungal flora remained unaffected (Rajoo and Ghonsikar, 1975). Sinha *et al.* (1980) reported that alachlor at 1.5 ppm did not produce any detrimental effect on soil fungi, bacteria and actinomycetes.

According to Mohammed (1984), majority of herbicides such as fluchloralin have no adverse effect on bacteria when applied at normal doses. Nalayini and Sankaran (1992) concluded that application of pendimethalin in sunflower plots at 1.0 kg ha^{-1} reduced bacterial and actinomycetes population over

unweeded control at 5 days after treatment but at 25 days after treatment there was no significant difference.

In a pre-emergence herbicide trial in sesame with fluchloralin (1.0 kg ha^{-1}), pendimethalin (0.5 kg ha^{-1}), oxyfluorfen (0.03 kg ha^{-1}), metolachlor (0.5 kg ha^{-1}), and alachlor (1.0 kg ha^{-1}), bacterial population was decreased by 11.5 to 70.2 per cent in all the treatments at 25 days after the treatment. The maximum decrease was in alachlor treated plots. The lost population recovered in plots treated with oxyfluorfen and metolachlor by 50 days after treatment. Maximum fungal population was recorded with unweeded control followed by pendimethalin. Actinomycetes population at 25 days after treatment increased in unweeded control and pendimethalin, compared with the initial population. All others reduced actinomycetes population (Nayak *et al.*, 1994).

Materials and Methods

3. MATERIALS AND METHODS

Experiments were conducted during 2000-2001 to suggest suitable weed management practices for cocoa nursery. The investigation consisted of two experiments involving soil solarization and fumigation with biofertilizers in one expriment and use of herbicides in another one. The details of materials and methods adopted for the study are described below.

3.1 GENERAL DETAILS

Location

The experiments were conducted in the nursery of Cadbury-KAU Co-operative Cocoa Research Project (CCRP) attached to the College of Horticulture, Vellanikkara, Thrissur. Vellanikkara is situated at 10°31' North lattitude, 76°13' East longitude and at an altitude of 40.3 m above MSL.

Soil

The soil of the experimental site was sandy clay loam in texture (Order: Ultisols). The important physical and chemical properties of the soil are presented in Table 1.

Potting mixture

The potting mixture was prepared using soil, sand and dried powdered cowdung in the ratio of 1:1:1. The chemical properties of the potting mixture are given in Table 2.

Seeds and seedlings

Seeds obtained from well matured pods collected from the field of CCRP were used for sowing. Seedlings were raised from uniform sized beans of well matured cocoa pods in polythene bags of size 20 x 10 cm filled with solarized, non-solarized or fumigated potting mixture.

Table 1. Important physical and chemical properties of the soil

Properties	Value	Methods used
(a) Mechanical composition		
Sand (%)	55.29	International pipette method
Silt (%)	13.39	(Piper, 1942)
Clay (%)	31.32	
Textural class	Sandy clay loam	
(b) Chemical properties		
Organic carbon (%)	0.57	Walkley and Black rapid titration method (Jackson, 1958)
Total nitrogen (%)	0.04	MicroKjeldahl method (Jackson,1958)
Available phosphorus (kg ha^{-1})	22.5	Ascorbic acid reduced molybdophosphoric blue color method (Watanabe and Olsen, 1965)
Available potassium (kg ha^{-1})	139.6	Flame photometry, Neutral normal ammonium acetate extraction (Jackson, 1958)

Table 2. Chemical properties of potting mixture used

Properties	Values	Procedure adopted
Organic carbon (%)	1.5	Walkley and Black rapid titration method (Jackson, 1958)
Total nitrogen(%)	0.126	MicroKjeldahl Method (Jackson, 1958)
Available phorphorus (kg ha^{-1})	99.59	Ascorbic acid reduced molybdophosphoric blue color method (Watanabe and Olsen, 1965)
Available potassium (kg ha^{-1})	235.00	Flame photometry, Neutral normal ammonium acetate extraction (Jackson, 1958)
Exchangeable calcium (m mol(1/2Ca^{++})Kg^{-1} soil)	9.7	EDTA titration (Jackson, 1958)
Exchangeable magnesium (m mol (1/2Mg^{++})Kg^{-1} soil)	4.8	EDTA titration (Jackson, 1958)

Meteorological data

Atmospheric temperature, sunshine hours and rainfall during the period of experiments were collected from the Department of Agricultural Meteorology, College of Horticulture, Vellanikkara and presented in Appendix I and II.

3.2   Experiment I

Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora.

3.2.1   Design and layout

The experiment details are given below:

a) Design   : 5x4 factorial experiment in CRD

b) Total treatments   : 20

c) Replication   : 3

d) Plot size   : 50 poly bags

Factor 1 Soil solarization (A)

A_0 - Untreated control

A_1 - Solarization for 15 days

A_2 - Solarization for 30 days

A_3 - Solarization for 45 days

A_4 - Fumigation with dazomet @ 30 g m^{-2}

Factor 2 Biofertilizer (B)

B_0 - No biofertilizer

B_1 - *Azospirillum*

B_2 - VAM

B_3 - *Azospirillum* + VAM

The factorial combinations are

Biofertilizer (B)

		B_0	B_1	B_2	B_3
Solarization (A)	A_0	A_0B_0	A_0B_1	A_0B_2	A_0B_3
	A_1	A_1B_0	A_1B_1	A_1B_2	A_1B_3
	A_2	A_2B_0	A_2B_1	A_2B_2	A_2B_3
	A_3	A_3B_0	A_3B_1	A_3B_2	A_3B_3
	A_4	A_4B_0	A_4B_1	A_4B_2	A_4B_3

3.2.2   Method of solarization

Transparent, polyethylene sheet of 150 guage (37.5 µm) was used for solarization. Mulching with polyethylene sheets was first done for the treatment, solarization for 45 days on 16-11-2000. After 15 days mulching with polyethylene for the 30 day treatment and again after 15 days for the 15 day treatment were done, so that all the treatments were opened on the same day. The potting mixture was made into raised beds of size 3.0 m length 1.0 m width and 20 cm height. The bed was leveled, compacted and watered thoroughly with a rose can. It was then mulched with 150 guage transparent polyethylene sheet as shown in plate No. 1. The sides of the sheet was covered with wet soil to keep the sheet in position. Adequate care was taken to keep the sheet in close contact with the soil to prevent formation of air pockets between the potting mixture and the sheet. The polyethylene sheets were removed 15, 30 and 45 days after mulching depending on the treatment.

For recording soil temperature soil thermometers were installed in the centre of the bed in both solarized and non-solarized soil at different depths (5, 10 and 15 cm). In the solarized beds the holes made for inserting the thermometer were perfectly sealed with cellophane tapes.

Plate 1. A view of solarization treatment of potting mixture

Diurnal variations of temperature in the solarized and control plots were recorded at 7.30 am and 2.30 pm.

3.2.3 Fumigation of potting mixture

Dazomet @ 30 g m^{-2} was used for fumigation in one treatment. Dazomet as Basamid granular, obtained from M/s BASF, was used. Chemically it is Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione. It has a broad spectrum of effectiveness against soil borne pests including nematodes, fungi and weed seeds.

Beds of 1.0 m length 1.0 m width and 15 cm height were prepared and slightly watered with a rose can. Dazomet at the rate of 30 g m^{-2} was spread on the top of the beds and mixed thoroughly so that it uniformly spreads to the entire 15 cm height of bed. These beds were then covered with transparent polyethylene sheets for one week. After one week, the polyethylene sheets were removed and the potting mixture was spread and kept as such for one week. This was done to facilitate escape of toxic gases.

3.2.4 Sowing seeds

The solarized, non-solarized and fumigated potting mixture were filled in polythene bags of size 20 x 10 cm. Uniform sized beans, collected from matured cocoa pods were sown in flat position for raising the seedlings and regularly watered. Two beans were sown in each bag. Two weeks after sowing, thinning to retain one healthy plant per polybag was done. The seedlings were maintained in green house under 50 per cent shade.

3.2.5 Vesicular arbuscular micorrhiza (VAM)

Vesicular arbuscular micorrhiza (VAM) was multiplied before the experiment and used for application as described below.

a) Isolation of spores of native VA mycorrhiza

Modified wet sieving and decanting method of Gerdemann and Nicolson (1963) was adopted for the isolation of VAM spores from soil. Soil (100 g) collected from the cocoa rhizosphere and was suspended in 1000 ml water. This was agitated vigorously to disperse all the soil clumps. The supernatant liquid was filtered after the heavier particles settled through a set of sieves of B.S.S.No.60 (250 micron), 150 (150 micron) and 350 (450 micron). The residue left behind was resuspended again in 1000 ml water. After settling down, the supernatent liquid was passed through the same set of sieves. This procedure was repeated three times in order to collect maximum number of spores from the soil. Finally, the materials present on each sieve were transferred to 100 ml beakers in a small volume of water and filtered through Whatman No.1 filter paper. The content of each filter paper was examined carefully under a stereomicroscope for the typical VAM spores. Spores of uniform size and shape were transferred to moistened filter paper in petridishes.

b) Mass multiplication of VA mycorrhiza

Mass multiplication of VA mycorrhiza was done by inoculating in the roots of maize (*Zea mays* L.) seedlings. Spores, that were isolated from the cocoa rhizosphere were used for inoculation. VA mycorrhizal spores were placed at a depth of 5 cm in sterilized potting mixture containing sand and soil in the ratio 1:1 in polythene bags. Over this, the maize seeds were sown. The maize plants were grown for 60 days for the proper development of infected roots. The soil and root samples of such infected maize plants were used for development of large quantity of inoculam. Infected roots of these maize plants were used as the mycorrhizal inoculum for the experiment conducted.

c) Application of VAM

VAM was applied to the soil before the sowing of seeds. The solarized, non-solarized and fumigated potting mixtures were filled in polythene bags according to the treatment. The polybags intended for VAM application were three-fourth filled. The roots of maize plants on which VAM was multiplied along with the rhizosphere soil at the rate of 50 g per polybag was applied. After, this the filling in of polybags was completed.

3.2.6   *Azospirillum*

Acid tolerant strain of *Azospirillum* obtained from Tamil Nadu Agricultural University (TNAU), Coimbatore was used.

Application of *Azospirillum*

Azospirillum was applied after the germination of seeds. After the thinning of seedlings to retain one per bag *Azospirillum* at the rate of 10 g per polybag containing about 1.5 Kg soil was applied according to treatment and incorporated in soil.

3.2.7   Chemical analysis of soil

Samples of potting mixture were collected before solarization and immediately after solarization period. These were used for the estimation of nutrients. Samples were also collected from fumigated soil before and after fumigation.

(1) Organic carbon

Organic carbon was estimated by Walkely and Black rapid titration method (Jackson, 1958).

purpose of estimation of microflora. Samples were also collected from fumigated soil, before and after fumigation. Subsequently, soil samples were collected at monthly intervals for three months, from all the polythene bags of a treatment in a replication and were mixed well. These samples were used for the estimation of microbial population.

The population of the fungi, bacteria and actinomycetes from the soil samples was estimated by serial dilution plate technique(Johnson and Curl,1972). Martin's rose bengal streptomycin agar, Thortan's standardised agar and Kenknight's agar were used for estimation of fungi, bacteria and actinomycetes respectively. The composition of the media used are given in Appendix 3.

3.2.9   Observations on weeds

Observations on weeds were taken at monthly intervals for three months.

(1) Weed count

Specieswise number of weeds were taken from each treatment.The weed intensity was counted from 50 polybags at 30 DAS,from 45 polybags at 60 DAS and from40 polybags at 90 DAS and expressed as count per 50 polybag, in order to maintain uniformity.

(2) Biomass of weeds (dry weight)

All the weeds from five polybags were collected along with roots, washed and dried under shade. Later they were oven dried at $80\pm5°C$ to constant weight. The dry weight of weeds was expressed as gram per polybag.

3.2.10   Observations on crop

Observations on growth parameters were taken from five tagged plant in each treatment at monthly intervals for three months.

(1) Height of the plant

The height was measured from the top of soil level in the cover to the growing point of the plant and mean plant height was expressed in cm.

(2) Girth of the plant

The collar girth of the plant were recorded monthly and mean girth was expressed in cm.

(3) Number of leaves

The number of leaves were recorded from five tagged plants and mean number of leaves was expressed.

(4) Leaf area per plant

As the leaves of cocoa seedlings were highly variable in their size and shape, they were divided into three groups, viz., small, medium and large, based on size. The maximum length and maximum width of all the leaves of the five tagged plants were recorded.

The leaf area of each leaf was calculated by using the formula l x b x k where l = length of leaves, b = breadth of leaves, k = factor. The factor k calculated separately for small, medium and large leaves from the leaves collected from the field by graphical method were used for calculation. The factors were

0.629,0.582,0.567 for small, medium and large leaves respectively. The sum of the leaf area of each plants were calculated to get the leaf area per plant.

(5) Dry matter production per plant

From each treatment, three plants were uprooted randomly as destructive sampling at monthly intervals. The samples were dried at $80\pm5°C$ until they recorded a constant dry weights. Leaf dry weight and total dry weight of the plants were recorded separately.

(6) Disease incidence

Disease incidence, if any, in each treatment were recorded.

(7) Earliness in reaching budding stage

The number of seedlings which reached budding stage was selected from each treatment at biweekly interval after three and half months and their numbers noted. The seedlings which reached pencil thickness was selected for budding.

3.3   Experiment II

Pre-emergence herbicides for the control of weeds in cocoa nursery.

3.3.1   Design and layout

The experiment was laid out in Completely Randomised Design. The details are given below.

Design   - Completely Randomised Design (CRD)

Total number of treatments - 9

Replication   - 3

Plot size   - 50 polybags

T_1 Diuron   - 2 kg ha^{-1}

T_2 Atrazine   - 2 kg ha^{-1}

T_3 Alachlor   - 2 kg ha^{-1}

T_4 Pendimethalin   - 1.5 kg ha^{-1}

T_5 Oxyfluorfen   - 0.3 kg ha^{-1}

T_6 Fluchloralin   - 1.5 kg ha^{-1}

T_7 Metolachlor   - 1.5 kg ha^{-1}

T_8 Untreated control

T_9 Weed free (hand weeding)

The required quantity of the commercial formulation of the herbicides were mixed with measured quantity of water (@ 700 l ha^{-1}) to spray in each plot. Spraying was done using a hand sprayer, one day after sowing. In the weed free plots hand weeding was done at biweekly intervals. In the unweeded control plots, no weed control measures were given and retained as such.

3.3.2   Information on herbicides

Pre-emergence herbicides were used for spraying.

(1) Diuron

Diuron is a substituted urea herbicide. Chemically it is 3-(3,4-dichlorophenyl)-1, 1-dimethyl-urea. Diuron formulated as wettable powder (Klass 80 WP, AgrEvo) was used in the study. It is used primarily to control annual grasses and broad leaved weeds before emergence and is recommended for weed control in pineapple, banana, papaya and several other tree crops.

(2) Atrazine

It is a triazine group of herbicide. The chemical name of atrazine is 2-chloro-4-(ethylamino)-6-isopropylamino)-S-triazine. The formulation was

wettable powder (Atrataf 50 WP, Rallis India). It is effective when applied as pre-emergence to control annual weeds. It is widely used to control annual grasses and broad leaved weeds in corn, pineapple, sugarcane etc.

(3) Alachlor

Alachlor is an acetamide herbicide containing the active ingredient 2-chloro-2',6'-diethyl-N-(methoxy-methyl) acetanilide. Lasso 50 EC, a product of Monsanto Ltd. in the form emulsifiable concentrate was used in the experiment. Alachlor is a pre-emergence herbicide with good efficiency for controlling annual grasses and broad leaved weeds.

(4) Pendimethalin

Pendimethalin is a dinitroaniline herbicide, chemical name being N-(1-ethyl propyl)-3,4-dimethyl-2,6 dinitrobenzenamine. Stomp 30 EC was the product used which is being produced by Cynamid India Ltd., with 30 per cent active ingredient. This is a pre-emergence herbicide for weed control of a wide spectrum of grasses and broad leaved weeds.

(5) Oxyfluorfen

Oxyfluorfen is a diphenyl ether herbicide. Chemically it is 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene. It effectively controls many annual weeds by pre-emergence application. Oxyfluorfen marketed as Goal 23.5 EC (Indofil chemicals) was used.

(6)Fluchloralin

It is a dinitroaniline herbicide. Chemically fluchloralin is N-(2-chloroethyl)-2,6-dinitro-N-propyl-4-(trifluoromethyl) aniline. It is a

pre-emergence herbicide which is absorbed via roots and shoots and affect many vital processes, weeds die off before or shortly after emergence. The product used was Basalin 45 EC by BASF, India.

(7) Metolachlor

It is an amide herbicide. Chemically it is 2-chloro-N-(2-ethyl-6-methyl-phenyl)-N-(2-methoxy-1-methyl ethyl) acetamide. It is a pre-emergence herbicide effective against many annual and perennial grasses. Metolachlor in the form of Duel 50 EC (Novartis Ltd.) was used.

3.3.3   Estimation of microflora

Samples of potting mixture were collected one day after application of herbicide and subsequently at 30, 60, 90 days. Each time, immediately after sampling, population of fungi, bacteria and actinomycetes were estimated by serial dilution plate technique (Johnson and Curl, 1972).

3.3.4   Observations on weeds

Observations on count and biomass of weeds were taken as in Experiment I.

Weed control efficiency

The weed control efficiency of was worked out monthly for three months on the basis of weed dry weight. The formula used for calculating weed control efficiency was as follows.

$$WCE = \frac{WDC - WDT}{WDC} \times 100$$

where,

WCE - Weed control efficiency

WDC - Weed dry weight in control plot

WDT - Weed dry weight in treated plot

3.3.5 Observations on crop

Five plants were selected at random from each plot. The observations on height, collar girth, number of leaves, leaf area per plant, leaf dry weight, dry matter production per plant, disease incidence and earliness in reaching budding stage were taken as in Experiment I.

Phytotoxicity

Phytotoxic symptoms appeared on the plants in the herbicides applied plots were recorded using a qualitative 0 to 10 point scale of visual symptoms (Rao, 2000).

3.4 Data analysis

Analysis of variance were performed on the data collected in various experiments, using the statistical package M STAT C (Freed, 1986). The data on weed count and weed dry matter production, which showed wide variations were subjected to square root transformations ($\sqrt{x}$ + 0.5) and logarithamic transformation [log (x + 1)] to make the analysis valid. The percentage values for experiment I were subjected to angular transformation (Gomez and Gomez, 1984). Comparisons among the treatment means, where the F-test was significant was done using LSD.

Results

4. RESULTS

The investigation on "Weed management in cocoa nursery" comprised of two separate experiments. These were (1) Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora; and (2) Pre-emergence herbicides for the control of weeds in cocoa nursery. The results obtained from these experiments are presented in this chapter.

4.1 Experiment I - Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora.

4.1.1 Effect of solarization on soil temperature

There were wide differences in soil temperatures in both solarized and non-solarized plots (Table 3). It was noticed that always the soil temperatures were higher than atmospheric temperature. However, the differences were greater for the values of maximum temperature than in the case of minimum temperature.

Table 3. Effect of solarization on soil temperature (highest recorded) at different depths

Depth (cm)	Solarized soil		Non-solarized soil	
	Max. Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)
5	48.00	28.00	38.50	24.40
10	40.00	27.00	36.00	25.00
15	37.10	27.00	34.10	25.00

Solarization increased both maximum and minimum temperature in the potting mixture and the effect was more pronounced in the top 5.0 cm layer. The difference in maximum temperature of solarized and non-solarized soil at the top 5 cm layer was 9.5°C (48°C and 38.5°C); whereas it was only 4°C (40°C and 36°C) and 3°C (37.1°C and 34.1°C) at 10 and 15 cm depths.

Table 4. Weekly mean temperature in solarized and non-solarized potting mixture

No. of weeks	Solarized potting mixture						Non-solarized potting mixture					
	Maximum temperature °C			Minimum temperature °C			Maximum temperature °C			Minimum temperature °C		
	Depth (cm)			Depth (cm)			Depth (cm)			Depth (cm)		
	5	10	15	5	10	15	5	10	15	5	10	15
1	42.50	36.00	33.21	29.21	28.21	28.07	34.43	32.29	29.79	25.00	25.64	25.93
2	43.71	38.07	34.93	29.86	28.93	28.39	36.80	33.46	29.59	24.29	26.34	26.41
3	44.79	37.61	34.67	30.04	29.07	28.93	35.57	34.17	30.76	25.29	25.93	25.74
4	45.60	38.46	35.30	29.51	28.11	28.43	35.94	33.24	31.00	25.16	25.73	25.93
5	45.54	37.11	35.20	29.41	27.94	28.27	36.22	33.14	30.00	24.93	25.59	25.84
6	44.70	38.36	35.10	28.79	28.20	28.54	35.07	32.71	29.84	24.87	25.79	25.86

Similarly the differences in minimum temperature of solarized and non-solarized soil at the top 5cm layer was 3.6°C (28°C and 24.4°C) whereas it was only 2°C (27°C and 25°C) at 10 and 15cm depths.

The weekly mean temperature in solarized and non-solarized potting mixture are presented in Table 4. The weekly mean in the case of maximum temperature differed from 42.5°C and 45.6°C and minimum temperature differed from 28.79°C and 30.04°C in the 5cm layer. The maximum mean temperature was in the fourth week of solarization (45.6°C) which was 9.7°C more than the temperature on non-solarized soil. The maximum weekly temperature at 10 and 15 cm depth were also recorded in the fourth week of solarization (38.46 and 35.3°C) which was 5.2°C and 4.3°C more than that in non-solarized plots. The minimum weekly temperature was noticed in the first week at different depths.

4.1.2   Effect of solarization on soil microflora

The microbial population estimated after the removal of polyethylene mulch are presented in Table 5. A significant reduction in the population of fungi, bacteria and actinomycetes, were observed as a result of solarization.

Table 5. Effect of solarization on soil microflora

Treatments	Fungi (10^3 cfu g^{-1})	Bacteria (10^4 cfu g^{-1})	Actinomycetes (10^4 cfu g^{-1})
Non-solarized	8.83	12.00	8.60
Solarization 15 days	4.93	8.17	7.90
Solarization 30 days	1.40	1.80	2.33
Solarization 45 days	1.87	1.07	1.93
Fumigation	1.50	1.90	1.13
SEm±	0.25	0.43	0.30
LSD (0.05)	0.78	1.34	0.94

The influence of solarization and fumigation on the population of fungi and bacteria was almost similar. Solarization for 30-day, 45-day and fumigation

with dazomet (without solarization) were almost equally efficient in reducing the population of fungi and baacteria. Solarization for 15days also reduced the population of fungi and bacteria significantly than non-solarization. The reduction in the actinomycetes population was the highest in fumigated plots, but it was on par with 45 day solarized plots. However, the population in 30 and 45 day solarized plots were not significantly different.

In all the cases, non-solarized potting mixture had the maximum microbial population.

4.1.3   Influence of solarization on nutrient availability

The data on the nutrient content of non-solarized and solarized potting mixture is given in Table 6.

A perusal of the data showed that organic carbon, total nitrogen, ammoniacal nitrogen and nitrate nitrogen were not significantly affected due to solarization.

Nevertheless, in the case of phosphorus, potassium, calcium and magnesium there were significant differences between treatments.

The maximum phosphorus, potassium, and calcium availability was noticed in 45-day solarized potting mixture. The quantity of exchangeable magnesium in 30 and 45-day solarized potting mixture were significantly superior to others.

4.1.4   Weed flora of the experimental field

The weed flora of the experimental field observed from the non-solarized plots are presented in Table 7.

Table 6. Influence of soil solarization on nutrient availability

Treatments	Organic carbon (%)	Total Nitrogen (%)	Ammonical - N (mg kg^{-1})	Nitrate - N (mg kg^{-1})	Available P (kg ha^{-1})	Exchange-able K (kg ha^{-1})	Exchange-able Ca (meq/100 g soil)	Exchange-able Mg (meq/100 g soil)
Non-solarized control	1.50	0.14	4.13	6.28	99.11	229.73	0.97	0.48
15 days solarization	1.57	0.12	4.20	6.33	99.58	231.53	1.04	0.49
30 days solarization	1.47	0.13	4.13	6.27	115.92	252.93	1.15	0.74
45 days solarization	1.57	0.13	4.17	6.33	126.42	281.14	1.34	0.71
Fumigation	1.56	0.13	4.20	6.37	106.48	238.73	0.97	0.49
SEm±	0.05	0.01	0.62	0.54	1.29	2.68	0.03	0.03
LSD (0.05)	NS	NS	NS	NS	4.08	8.43	0.12	0.12

Table 7. Weed flora of the experimental field

Sl.No.	Scientific name	Common name	Family
A. Grasses			
1	*Cynodon dactylon* (L.) Pers	Bermuda grass	Poaceae
2	*Dactyloctenium aegyptium* (L.) Beaur	Crow foot grass	,,
3	*Digitaria ciliaris* (Retz.) Koel	Crab grass	,,
4	*Eleusine indica* (L.) Gaertn.	Goose grass	,,
5	*Echinochloa colona* (L.) Link	Jungle rice	,,
6	*Eragrostis spp.*	Love grass	,,
B. Broad leaf weeds			
1	*Amaranthus viridis* L.	Slender amaranth	Amaranthaceae
2	*Ageratum conyzoides* L.	Goat weed	Asteraceae
3	*Borreria hispida* (L.) K. Schum	Button weed	Rubiaceae
4	*Cleome burmanii* Wt. & Arn.	Wild mustard	Capparidaceae
5	*Selaginella* sp.	Selaginella	Selaginellaceae
6	*Eclipta alba* (L.) Hassk.	False daisy	Asteraceae
7	*Emilia sonchifolia* (L.) DC	Red tassel flower	Asteraceae
8	*Euphorbia hirta* L.	Garden spurge	Euthorbiaceae
9	*Ludwigia perennis* L.	Water primrose	Onagraceae
10	*Mimosa pudica* L.	Touch-me-not	Fabaceae
11	*Mullugo pentaphylla* L.	Carpet weed	Mulluginaceae
12	*Mullugo disticha* (L.) Ser.	,,	,,
13	*Peperomia pellucida* (L.) HBK	-	Piperaceae
14	*Phyllanthus niruri* Auct.	Niruri	Euphorbiaceae
15	*Scoparia dulcis* L.	Sweet broom weed	Scrophulariaceae
16	*Vernonia cineria* (L.) Lees	Ash coloured flea bane	Asteraceae

In general, the weed flora were dominated by broad leaf weeds. Among them, *Ludwigia perennis, Borreria hispida, Amaranthus viridis, Cleome burmanii* were the major weeds. Other broad leaved weeds observed were *Ageratum conyzoides, Mullugo pentaphylla, Mullugo disticha, Peperomia pellucida* etc. *Digitaria ciliaris and Eleusine indica* were the major grasses. Other grasses were *Dactyloctenium aegyptium, Cynodon dactylon, Echinochloa colona* and *Eragrostis* spp. A fern, *Selaginella* sp. was also found.

4.1.5 Effect of soil solarization and biofertilizers on weed population

Total weed population

The observations on the count of weeds in various treatments are presented in Table 8. These observations were taken at monthly intervals for three months (30, 60 and 90 DAS).

The levels of solarization had significant effect on the total count of weeds at 30, 60 and 90 DAS. Fumigated plots and 45-day solarized plots recorded lower weed count and population of weeds in these two plots were on par at all the stages of observation followed by 30-day solarized plot at 30 and 60 DAS. Compared to non-solarized plots, the weed population in 15-day solarized plots were higher and significantly different at all the stages except at 90 DAS. At 90 DAS, the population under 30-day solarized plots were on par with 45-day solarized plots. At this stage, the weed count in control and 15-day solarized plot were also on par.

There were no significant differences in weed counts due to different levels of biofertilizers. Nevertheless, the biofertilizer treatments seem to favour a lower weed count at 30 DAS. *Azospirillum* + VAM showed the least count among them. Similarly, the interaction of levels of solarization and biofertilizers were significant at 60 DAS (Table 8a).

Table 8. Effect of levels of soil solarization and biofertilizers on total weed count (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	4.24* (17.48)	5.37 (28.34)	4.52 (19.93)
Solarization 15 days	5.63 (31.20)	6.35 (39.82)	5.10 (25.51)
Solarization 30 days	3.48 (11.61)	4.70 (21.59)	4.13 (16.56)
Solarization 45 days	2.82 (7.62)	3.87 (14.48)	3.69 (13.12)
Fumigation	2.60 (6.26)	3.80 (13.94)	3.28 (10.26)
SEm±	0.23	0.23	0.22
LSD (0.05)	0.65	0.65	0.62
Levels of biofertilizers (B)			
No biofertilizer	4.08 (16.15)	4.84 (22.93)	4.07 (16.06)
Azospirillum	3.89 (14.63)	5.14 (25.92)	4.53 (20.29)
VAM	3.61 (12.53)	4.72 (21.78)	4.15 (16.72)
Azospirillum + VAM	3.47 (11.54)	4.59 (20.57)	3.82 (14.09)
SEm±	0.35	0.32	0.24
LSD (0.05)	NS	NS	NS
Interaction A x B	NS	S	NS

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

Table 8a. Interaction effect of soil solarization and biofertilizers on total weed count at 60 DAS (number per 50 polybags)

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	5.10* (25.51)	4.84 (22.93)	6.0 (35.5)	5.55 (30.30)	5.37 (28.34)
15 days	6.59 (42.93)	7.72 (59.09)	5.43 (28.98)	5.67 (31.65)	6.35 (39.82)
30 days	4.62 (20.84)	4.55 (20.20)	4.97 (24.20)	4.74 (21.97)	4.70 (21.59)
45 days	3.76 (13.64)	4.28 (17.82)	3.98 (15.34)	3.44 (11.33)	3.87 (14.48)
Fumigation	4.10 (16.31)	4.34 (18.34)	3.19 (9.68)	3.57 (12.24)	3.80 (13.94)
Group mean	4.84 (22.93)	5.14 (25.14)	4.72 (21.78)	4.59 (20.57)	

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

SEm± for factor A - 0.23   LSD (0.05) - 0.65
SEm± for factor B - 0.32   LSD (0.05) - NS
SEm± for AB   - 0.40   LSD (0.05) - 1.13

At 60 DAS, a lower weed count was recorded in fumigation + VAM plots and the treatments 45-day solarized + *Azospirillum* + VAM, fumigation + *Azospirillum* + VAM, 45-day solarized + no biofertilizer, 45-day solarized + VAM applied and fumigation + no biofertilizer applied plots were on par with this. All the non-solarized and biofertilizer combinations and 15-day solarization and biofertilizer combinations were inferior to these.

Specieswise population of major weeds

(i) *Ludwigia perennis*

The data on the population of *Ludwigia perennis* are presented in Table 9. The data showed significant differences in the population of *Ludwigia perennis* at different levels of solarization.

Table 9. Effect of levels of soil solarization and biofertilizers on population of *Ludwigia perennis* (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	2.00*	2.28	2.25
	(3.50)	(4.70)	(4.56)
Solarization 15 days	2.33	2.94	2.30
	(4.93)	(8.14)	(4.79)
Solarization 30 days	1.27	1.68	1.22
	(1.11)	(2.32)	(0.98)
Solarization 45 days	1.28	1.43	1.25
	(1.4)	(1.54)	(1.06)
Fumigation	1.47	1.68	1.37
	(1.66)	(2.32)	(1.38)
SEm±	0.18	0.14	0.13
LSD (0.05)	0.51	0.39	0.37
Levels of biofertilizers (B)			
No biofertilizer	1.68	2.02	1.61
	(2.32)	(3.58)	(2.09)
Azospirillum	1.82	2.13	1.97
	(2.81)	(4.04)	(3.38)
VAM	1.43	1.92	1.54
	(1.54)	(3.19)	(1.87)
Azospirillum + VAM	1.50	1.93	1.58
	(1.75)	(3.22)	(2.00)
SEm±	0.19	0.19	0.17
LSD (0.05)	NS	NS	NS
Interaction A x B	NS	NS	NS

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

At 30 DAS, the weed count in 30-day solarized plots, 45-day solarized plots and fumigated plots were on par. However, the population in 15-day solarized plot and non-solarized plot were not significantly different. At 60 and 90 DAS, the weed count in 30 and 45-day solarized plots and fumigated plots were on par. However, at 60 DAS, higher count was observed in 15-day solarized plots though it is not significantly different from control plots.

The levels of biofertilizers did not have any effect on the count of *Ludwigia perennis*. There was no interaction between the levels of solarization and levels of biofertilizers.

(ii) *Borreria hispida*

There were significant differences in the population of *Borreria hispida* at different levels of solarization (Table 10).

At 30 DAS, the lowest population of *Borreria* was observed in fumigated plots followed by 45 and 30-day solarized plots which were on par. The population in 15-day solarized plots and control plots were on par.

The lowest population of *Borreria hispida* at 60 DAS was noticed in 45 day solarized followed by fumigated plots. The counts in fumigated plots and 30-day solarized plots were on par.

At 90 DAS, the population in 45 and 30-day solarized plot and fumigated plot were on par.

The levels of biofertilizer did not make any difference on the count of *Borreria hispida* at different stages. There was no interaction between levels of solarization and levels of biofertilizers.

Table 10. Effect of levels of soil solarization and biofertilizers on population of *Borreria hispida* (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	1.87*	2.07	1.79
	(2.3)	(3.78)	(2.70)
Solarization 15 days	1.94	2.25	1.77
	(3.26)	(4.56)	(2.63)
Solarization 30 days	1.27	1.24	1.08
	(1.11)	(1.04)	(0.67)
Solarization 45 days	0.98	0.82	0.78
	(0.46)	(0.17)	(0.11)
Fumigation	0.87	1.11	1.08
	(0.26)	(0.73)	(0.67)
SEm±	0.13	0.11	0.11
LSD (0.05)	0.36	0.30	0.30
Levels of biofertilizers (B)			
No biofertilizer	1.58	1.48	1.24
	(2.00)	(1.69)	(1.04)
Azospirillum	1.23	1.56	1.36
	(1.01)	(1.93)	(1.35)
VAM	1.33	1.56	1.37
	(1.27)	(1.93)	(1.38)
Azospirillum + VAM	1.40	1.39	1.24
	(1.46)	(1.43)	(1.04)
SEm±	0.16	0.17	0.14
LSD (0.05)	NS	NS	NS
Interaction A x B	NS	NS	NS

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

Table 11. Effect of levels of soil solarization and biofertilizers on population of *Amaranthus viridis* (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	1.79* (2.7)	1.93 (3.22)	1.67 (2.29)
Solarization 15 days	2.50 (5.75)	2.57 (6.10)	1.36 (1.35)
Solarization 30 days	0.88 (0.27)	0.87 (0.26)	0.82 (0.17)
Solarization 45 days	0.79 (0.12)	0.78 (0.11)	0.75 (0.06)
Fumigation	0.71 (0.00)	0.71 (0.00)	0.89 (0.29)
SEm±	0.12	0.10	0.12
LSD (0.05)	0.35	0.28	0.33
Levels of biofertilizers (B)			
No biofertilizer	1.41 (1.49)	1.36 (1.35)	1.20 (0.94)
Azospirillum	1.44 (1.57)	1.43 (1.54)	1.36 (1.35)
VAM	1.25 (1.06)	1.41 (1.49)	1.28 (1.14)
Azospirillum + VAM	1.23 (1.01)	1.29 (1.16)	1.16 (0.85)
SEm±	0.22	0.22	0.18
LSD (0.05)	NS	NS	NS
Interaction A x B	NS	S	NS

*$\sqrt{x}$ + 0.5 transformed values. Values in parenthesis are original values

(iii) *Amaranthus viridis*

A perusal of the data in Table 11 showed that there were significant differences in the count of *Amaranthus viridis* due to different levels of solarization.

At 30 DAS and 60 DAS, no *Amaranthus viridis* plants were noted in fumigated plots and 45 and 30-day solarized plots. The population was more in 15-day solarized plot compared to non-solarized plot.

The count of *Amaranthus viridis* in 45 and 30-day solarized plots and fumigated plots were on par at 90 DAS. At this stage, the population in 15-day solarized plot and fumigated plots were also on par.

The biofertilizers did not have any effect on the density of *Amaranthus viridis* at any of the stages. Interaction between levels of solarization and biofertilizers, had significant effect on the population of *Amaranthus viridis* at 60 DAS (Table 11a).

Table 11a. Interaction effect of soil solarization and biofertilizers on population of *Amaranthus viridis* at 60 DAS (number per 50 polybags)

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum +* VAM	
Non-solarized	2.24* (4.52)	1.86 (3.00)	2.10 (3.91)	1.56 (1.93)	1.93 (3.22)
15 days	2.26 (4.60)	3.16 (9.49)	2.39 (5.21)	2.48 (5.65)	2.57 (6.10)
30 days	0.88 (0.27)	0.71 (0.00)	0.88 (0.27)	1.00 (0.50)	0.87 (0.26)
45 days	0.71 (0.00)	0.71 (0.00)	1.00 (0.50)	0.71 (0.00)	0.78 (0.11)
Fumigation	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Group mean	1.36 (1.35)	1.43 (1.54)	1.41 (1.49)	1.29 (1.16)	

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values
SEm± for factor A - 0.10   LSD (0.05) - 0.28
SEm± for factor B - 0.22   LSD (0.05) - NS
SEm± for AB   - 0.18   LSD (0.05) - 0.51

At this stage, all the treatment combinations except the combinations with 15-day solarized plot and non-solarized plots were on par and resulted in complete control of weeds.

(iv) *Digitaria ciliaris*

There were significant differences among the count of *Digitaria ciliaris* due to the levels of solarization (Table 12) at different stages.

The population of *Digitaria ciliaris* in treatments, 45-day solarization, 30-day solarization and fumigation were on par at 30, 60 and 90 DAS. At 30 and 60 DAS, the population in 15-day solarized plot and non-solarized plots were almost similar. At 90 DAS, the maximum population was in 15 days solarized plot compared to non-solarized plot.

The levels of biofertilizers had significant effect on the population of *Digitaria ciliaris* at 30 DAS. At this stage, the population in VAM applied plot were less than the control plots. Interaction between solarization and biofertilizers was significant at 30 DAS (Table 12a).

All the levels of biofertilizer with 30 or 45-day solarization, the treatment combinations with 15-day solarization + VAM, 15-day solarization + *Azospirillum* + VAM, fumigation + no biofertilizer, fumigation + VAM and fumigation + *Azospirillum* + VAM were on par.

(v) *Eleusine indica*

The data on the population of *Eleusine indica* are presented in Table 13. The levels of solarization had significant effect on the population of *Eleusine indica* at different stages. The population in 45 and 30-day solarized plots were on par at 30 DAS. The minimum population was in fumigated plots which was on par

Table 12. Effect of levels of soil solarization and biofertilizers on population of *Digitaria ciliaris* (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	1.80* (2.74)	1.73 (2.49)	1.46 (1.63)
Solarization 15 days	1.64 (2.19)	2.00 (3.50)	1.77 (2.63)
Solarization 30 days	0.85 (0.22)	1.07 (0.64)	1.01 (0.52)
Solarization 45 days	0.79 (0.12)	0.91 (0.33)	0.87 (0.26)
Fumigation	1.07 (0.64)	0.88 (0.27)	0.82 (0.17)
SEm±	0.16	0.11	0.10
LSD (0.05)	0.44	0.32	0.29
Levels of biofertilizers (B)			
No biofertilizer	1.46* (1.63)	1.35 (1.32)	1.22 (1.00)
Azospirillum	1.40 (1.46)	1.35 (1.32)	1.21 (0.96)
VAM	0.97 (0.44)	1.31 (1.22)	1.19 (0.92)
Azospirillum + VAM	1.10 (0.71)	1.25 (1.06)	1.12 (0.75)
SEm±	0.17	0.16	0.13
LSD (0.05)	0.48	NS	NS
Interaction A x B	S	NS	NS

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

Table 12a. Interaction effect of soil solarization and biofertilizers on population of *Digitaria ciliaris* at 30 DAS (number per 50 polybags)

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	2.22* (4.43)	1.67 (2.29)	1.29 (1.16)	2.02 (3.28)	1.80 (2.74)
15 days	2.47 (5.60)	2.21 (4.38)	0.88 (0.27)	1.00 (0.71)	1.64 (2.19)
30 days	0.71 (0.00)	0.88 (0.27)	1.10 (0.71)	0.71 (0.00)	0.85 (0.22)
45 days	0.88 (0.27)	0.71 (0.00)	0.88 (0.27)	0.71 (0.00)	0.79 (0.12)
Fumigation	1.00 (0.50)	1.52 (1.81)	0.71 (0.00)	1.05 (0.60)	1.07 (0.64)
Group mean	1.46 (1.63)	1.40 (1.46)	0.97 (0.44)	1.10 (0.71)	

*$\sqrt{x + 0.5}$ transformed values. Values in parenthesis are original values

SEm± for factor A - 0.16   LSD (0.05) - 0.44
SEm± for factor B - 0.17   LSD (0.05) - 0.48
SEm± for AB   - 0.24   LSD (0.05) - 0.70

Table 13. Effect of levels of soil solarization and biofertilizers on population of *Eleusine indica* (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	1.50* (1.75)	1.78 (2.67)	1.53 (1.84)
Solarization 15 days	2.30 (4.79)	2.32 (4.88)	2.09 (3.87)
Solarization 30 days	1.30 (1.19)	1.49 (1.72)	1.41 (1.49)
Solarization 45 days	0.95 (0.40)	0.84 (0.21)	0.96 (0.42)
Fumigation	0.75 (0.06)	0.79 (0.12)	0.84 (0.21)
SEm±	0.16	0.13	0.13
LSD (0.05)	0.45	0.36	0.37
Levels of biofertilizers (B)			
No biofertilizer	1.57* (1.96)	1.46 (1.63)	1.42 (1.52)
Azospirillum	1.20 (0.94)	1.48 (1.69)	1.31 (1.22)
VAM	1.38 (1.40)	1.42 (1.52)	1.47 (1.66)
Azospirillum + VAM	1.35 (1.32)	1.42 (1.52)	1.27 (1.11)
SEm±	0.20	0.19	0.16
LSD (0.05)	NS	NS	NS
Interaction A x B	NS	NS	S

*$\sqrt{x+0.5}$ transformed values. Values in parenthesis are original values

with 45-day solarized plot. The maximum population was found in 15-day solarized plots followed by population in non-solarized plots.

At 60 and 90 DAS, the population in 45-day solarized plots and fumigated plots was on par. At both stages, the maximum population was in 15-day solarized plots.

The levels of biofertilizers did not have any significant effect on the population of *Eleusine indica* at different stages. Interaction between treatments was found significant at 90 DAS   (Table 13a).

Table 13a. Interaction effect of soil solarization and biofertilizers on population of *Eleusine indica* at 90 DAS (number per 50 polybags)

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	1.74* (2.53)	1.27 (1.11)	1.77 (2.63)	1.35 (1.32)	1.53 (1.84)
15 days	1.77 (2.63)	2.70 (6.79)	1.94 (3.26)	1.93 (3.22)	2.09 (3.87)
30 days	2.02 (3.58)	1.00 (0.50)	1.46 (1.63)	1.17 (0.87)	1.41 (1.49)
45 days	0.71 (0.00)	0.88 (0.27)	1.27 (1.11)	1.00 (0.50)	0.96 (0.42)
Fumigation	0.88 (0.27)	0.71 (0.00)	0.88 (0.27)	0.88 (0.27)	0.84 (0.21)
Group mean	1.42 (1.52)	1.31 (1.22)	1.47 (1.66)	1.27 (1.11)	

*$\sqrt{x} + 0.5$ transformed values. Values in parenthesis are original values

SEm± for factor A - 0.13   LSD (0.05) - 0.37
SEm± for factor B - 0.16   LSD (0.05) - NS
SEm± for AB   - 0.19   LSD (0.05) - 0.67

Among them the treatment combinations 45-day solarization + no biofertilizer, fumigation + *Azospirillum*, 45-day solarization + *Azospirillum*, fumigation + no biofertilizer, fumigation + VAM, fumigation + *Azospirillum* +

VAM, 30-day solarization + *Azospirillum*, 45-day solarization + *Azospirillum* + VAM, 30-day solarization + *Azospirillum* + VAM, 45-day solarization + VAM, non-solarized + *Azospirillum* and non-solarized + *Azospirillum* + VAM showed lower population of *Eleusine indica* compared to others and were on par.

4.1.6   Effect of soil solarization and biofertilizers on weed dry matter production (WDP)

The data on the dry matter production of weeds at monthly intervals are presented in Table 14. A perusal of the data shows that the different levels of solarization differed significantly in weed dry matter production at different stages.

At 30 DAS, the minimum WDP was in 45-day solarized plots followed by fumigated plots which were on par, and recorded significantly lower WDP than the 30-day solarized plots.

At 60 and 90 DAS, the lowest WDP was in 45-day solarized plots and the WDP in 30-day solarized plots and fumigated plots were on par. Similarly, the WDP in 15-day solarized plots and non-solarized plots were on par.

The levels of biofertilizers had significant effect on the dry matter production of weeds at 30 DAS. At this stage, *Azospirillum* + VAM and VAM applied plots were on par and had significantly lower WDP than all others. All the biofertilizer applied plots have less WDP compared to control. No significant interaction effects among the treatment combinations were noticed in the case of weed dry matter production.

Table 14. Effect of levels of soil solarization and biofertilizers on weed dry matter production (g polybag^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	0.28*	1.02	1.28
	(0.32)	(1.77)	(2.60)
Solarization 15 days	0.31	1.22	1.29
	(0.36)	(2.39)	(2.63)
Solarization 30 days	0.14	0.49	0.82
	(0.15)	(0.63)	(1.27)
Solarization 45 days	0.04	0.17	0.39
	(0.041)	(0.19)	(0.48)
Fumigation	0.06	0.25	0.51
	(0.062)	(0.28)	(0.67)
SEm±	0.02	0.09	0.07
LSD (0.05)	0.06	0.25	0.19
Levels of biofertilizers (B)			
No biofertilizer	0.24	0.81	0.96
	(0.22)	(1.25)	(1.61)
Azospirillum	0.17	0.64	0.81
	(0.19)	(0.90)	(1.25)
VAM	0.16	0.57	0.84
	(0.17)	(0.77)	(1.32)
Azospirillum + VAM	0.11	0.49	0.81
	(0.12)	(0.63)	(1.25)
SEm±	0.02	0.14	0.12
LSD (0.05)	0.05	NS	NS
Interaction A x B	NS	NS	NS

* Log (x+1) transformed values. Values in parenthesis are original values

4.1.7   Growth parameters of cocoa seedlings as affected by solarization and biofertilizers

Height

The data on the height of cocoa seedlings as affected by solarization and biofertilizer treatments are presented in Table 15. The levels of solarization had significant influence on the height of cocoa seedlings at 30 days after sowing (DAS), 60 DAS and 90 DAS. At 30 DAS, the maximum height of seedlings was observed in 45-day solarized plot. The height of the seedlings in 30-day solarized plots and fumigated plots were on par. Similarly, the height of seedlings in non-solarized control plots and 15 day solarized plots were on par.

Table 15. Height of cocoa seedlings as affected by different levels of soil solarization and biofertilizers (cm)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	15.52	17.53	26.13
Solarization 15 days	15.86	18.67	28.59
Solarization 30 days	17.45	22.81	35.25
Solarization 45 days	18.15	23.48	37.54
Fumigation	17.32	22.65	32.73
SEm±	0.187	0.416	0.65
LSD	0.54	1.18	1.85
Levels of biofertilizers (B)			
No biofertilizer	16.37	20.13	30.09
Azospirillum	16.98	20.64	32.23
VAM	16.86	21.32	32.65
Azospirillum + VAM	17.24	22.03	33.23
SEm±	0.30	0.72	1.219
LSD	0.86	NS	NS
Interaction A x B	NS	NS	NS

DAS – Days after sowing

The height of cocoa seedlings in 45 and 30 day solarized plots and in fumigated plots were on par at 60 DAS. The height of the seedlings in control plots and 15-day solarized plots were on par and significantly lower to these.

At 90 DAS, the maximum height of seedlings was observed in 45 days solarized plot which was significantly higher than that in 30-day solarized plots. The height of seedlings in fumigated plots and 15-day solarized plots were higher than control plots.

Biofertilizers included in the study showed significant effects on the height of seedlings at 30 DAS. At 30 DAS, the height was the maximum in the treatment, *Azospirillum* + VAM, but was on par with other biofertilizer treatments. However the treatments no-biofertilizer, *Azospirillum*, and VAM were also on par.

No interaction between solarization levels and biofertilizers were observed.

Collar girth

The levels of solarization had significant effect on the collar girth of seedlings at 30, 60 and 90 DAS (Table 16a). The treatment solarization for 45 days showed the maximum collar girth at all the stages.

Table 16a. Collar girth of cocoa seedlings as affected by different levels of soil solarization and biofertilizers at 30 DAS (cm)

Solarization (A)	Biofertilizer (B)				Group means
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized control	1.51	1.53	1.54	1.60	1.55
15 days	1.52	1.62	1.61	1.63	1.60
30 days	1.61	1.69	1.70	1.77	1.69
45 days	166	1.73	1.77	1.83	1.75
Fumigation	1.67	1.70	1.63	1.67	1.67
Group means	1.59	1.66	1.65	1.70	

SEm± for factor A – 0.02   LSD (0.05) – 0.05
SEm± for factor B – 0.02   LSD (0.05) – 0.06
SEm± for AB   – 0.02   LSD (0.05) – 0.07

However, at 30 DAS the collar girth of seedlings in 45-day and 30-day solarized plots were on par, followed by fumigated plots. There were no significant differences in the girth of seedlings between non-solarized plots and 15-day solarized plot.

At 60 DAS and 90 DAS, (Table 16b and 16c) the girth of seedlings in 45-day solarized plot and fumigated plot were on par, followed by seedlings in 30-day solarized plot. The girth of seedlings in all the solarized plots were higher than non-solarized plots at 90 DAS.

The levels of biofertilizers also had significant effect on the collar girth of seedlings except at 60 DAS. At 30 DAS and 90 DAS the maximum values were in *Azospirillum* + VAM. However, the collar girth of seedlings in all the biofertilizer treatments were on par. Though not significantly different at 60 DAS too, *Azospirillum* + VAM showed the maximum collar girth.

Interaction between solarization and biofertilizer treatments was also found significant in the case of collar girth at 30, 60 and 90 DAS.

A perusal of data (Table 16a) at 30 DAS showed that the treatment combinations, 45-day solarization + (*Azospirillum* + VAM), 45 day solarization + VAM, 45 day solarization + *Azospirillum* and 30-day solarization + (*Azospirillum* + VAM) were superior to other combinations and were on par.

At 60 DAS, the collar girth of 45-day solarization + (*Azospirillum* + VAM) and 45-day solarization + VAM combinations were found superior to others and were on par.

AT 90 DAS, the combinations 45-day solarization + (*Azospirillum* + VAM) and fumigation + *Azospirillum* were found superior and were on par.

Table 16b. Collar girth of cocoa seedlings as affected by different levels of soil solarization and biofertilizers at 60 DAS (cm)

Solarization (A)	Biofertilizer (B)				Group means
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized control	1.68	1.69	1.67	1.66	1.68
15 days	1.75	1.71	1.68	1.74	1.72
30 days	1.78	1.85	1.86	1.95	1.86
45 days	1.83	1.94	2.00	2.06	1.96
Fumigation	1.91	1.89	1.89	1.93	1.91
Group means	1.79	1.82	1.82	1.87	

SEm± for factor A – 0.02   LSD (0.05) – 0.05
SEm± for factor B – 0.3   LSD (0.05) – NS
SEm± for AB   – 0.02   LSD (0.05) – 0.07

Table 16c. Collar girth of cocoa seedlings as affected by different levels of soil solarization and biofertilizers at 90 DAS (cm)

Solarization (A)	Biofertilizer (B)				Group means
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized control	1.77	1.78	1.84	1.84	1.80
15 days	2.03	2.06	2.07	2.07	2.06
30 days	2.03	2.21	2.22	2.41	2.22
45 days	2.16	2.34	2.40	2.55	2.36
Fumigation	2.26	2.44	2.30	2.41	2.35
Group means	2.05	2.17	2.17	2.26	

SEm± for factor A – 0.04   LSD (0.05) – 0.09
SEm± for factor B – 0.06   LSD (0.05) – 0.17
SEm± for AB   – 0.06   LSD (0.05) – 0.13

Number of leaves per plant

The data on the effect of levels of solarization and biofertilizers on the number of leaves are presented in Table 17. There were significant differences in the number of leaves at 30, 60 and 90 DAS due to different levels of solarization. The number of leaves were higher in 45-day solarized plots at all stages.

Table 17. Effect of levels of soil solarization and biofertilizers on number of leaves of cocoa seedlings (Number plant^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	4.28	7.75	12.63
Solarization 15 days	4.36	7.48	11.73
Solarization 30 days	4.82	8.35	13.40
Solarization 45 days	4.87	8.78	14.28
Fumigation	4.47	8.07	13.03
SEm±	0.11	0.17	0.290
LSD	0.32	0.48	0.463
Levels of biofertilizers (B)			
No biofertilizer	4.20	7.82	12.50
Azospirillum	4.55	8.08	12.77
VAM	4.57	8.13	13.27
Azospirillum + VAM	4.83	8.30	13.45
SEm±	0.109	0.186	0.329
LSD	0.30	NS	0.932
Interaction A x B	NS	S	NS

DAS – Days after sowing

However, the number of leaves in 45-day solarized plots and 30-day solarized plots were on par at 30 DAS and 60 DAS. All the other treatments were inferior to these treatments.

At 90 DAS, the highest number of leaves were seen in the seedlings of 45-day solarized plots. The number of leaves per plant in 30 day solarized plot and fumigated plot were on par. Others were inferior to the above treatments.

The effect of levels of biofertilizers on the number of leaves was found to be significant at 30 DAS and 90 DAS. The number of leaves were more in all the biofertilizer applied plot than in control. However, *Azospirillum* + VAM had maximum number of leaves at all the stages.

The number of leaves at 60 DAS due to interaction of solarization and biofertilizers were also found significant (Table 17a). At this stage, the treatment combinations, 45-day solarization + (*Azospirillum* + VAM), 45 day solarization + VAM, 45 day solarization + *Azospirillum* and 30 day solarization + (*Azospirillum* + VAM) were superior and were on par.

Table 17a. Interaction effect of soil solarization and biofertilizers on number of leaves of cocoa seedlings at 60 DAS (Number plant^{-1})

Solarization (A)	Biofertilizer (B)				Group means
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized control	7.33	7.87	8.47	7.33	7.75
15 days	7.47	7.67	7.27	7.53	7.48
30 days	7.60	8.57	8.47	8.76	8.35
45 days	8.23	8.60	8.87	9.40	8.78
Fumigation	8.47	7.73	7.60	8.47	8.07
Group means	7.82	8.08	8.13	8.30	

SEm± for factor A – 0.17 LSD (0.05) – 0.48
SEm± for factor B – 0.186 LSD (0.05) – NS
SEm± for AB – 0.29 LSD (0.05) – 0.813

Leaf area per plant

The levels of solarization had significant effect on the leaf area per plant (Table 18). At all the stages, 45-day solarized plots showed the maximum leaf area per plant. At 30 DAS the leaf area of 30-day solarized plots and fumigated plots were on par and inferior to 45-day solarized plots. The leaf area of non-solarized plots and 15-day solarized plots were on par and were inferior to others.

Table 18. Effect of levels of soil solarization and biofertilizers on leaf area of cocoa seedlings (cm² plant⁻¹)

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	125.11	347.94	716.74
Solarization 15 days	130.00	348.73	709.14
Solarization 30 days	160.27	490.97	886.58
Solarization 45 days	177.73	532.10	939.59
Fumigation	155.75	461.45	884.50
SEm±	3.28	15.17	17.39
LSD (0.05)	9.28	42.95	49.27
Levels of biofertilizers (B)			
No biofertilizer	141.95	418.71	776.16
Azospirillum	147.80	436.42	818.73
VAM	148.62	421.50	837.68
Azospirillum + VAM	158.71	468.30	876.68
SEm±	5.814	23.59	28.20
LSD (0.05)	16.47	NS	79.83
Interaction A x B	NS	NS	NS

DAS – Days after sowing

At 60 DAS, the leaf area of 45 day solarized plot and 30 days solarized plot were on par, followed by fumigation. At 90 DAS also, the maximum leaf area was noted in 45-day solarized plots. Leaf area of seedlings in 30 day solarized plots and fumigated plots were on par.

The levels of biofertilizer had significant effect on the leaf area of seedlings at 30 and 90 DAS. The leaf area of all the biofertilizer applied plots were found significantly different from non-biofertilizer plots.

Leaf dry weight

The effect of the levels of solarization and levels of biofertilizers on the leaf dry weight of seedlings are presented in Table 19.

Table 19. Effect of levels of soil solarization and biofertilizers on leaf dry weight of cocoa seedlings (g plant^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	0.35	1.37	2.38
Solarization 15 days	0.35	1.44	2.44
Solarization 30 days	0.41	1.92	3.41
Solarization 45 days	0.45	2.12	4.07
Fumigation	0.44	2.12	3.85
SEm±	0.02	0.08	0.16
LSD (0.05)	0.06	0.22	0.46
Levels of biofertilizers (B)			
No biofertilizer	0.40	1.71	2.87
Azospirillum	0.40	1.77	3.26
VAM	0.39	1.77	3.20
Azospirillum + VAM	0.40	1.92	3.59
SEm±	0.02	0.11	0.23
LSD (0.05)	NS	NS	0.64
Interaction A x B	NS	NS	NS

DAS – Days after sowing

The leaf dry weight in 45 and 30-day solarized plots and in fumigated plots were on par at 30 and 60 DAS.

At 90 DAS, the leaf dry weight in 45 day solarized plot and fumigated plots were on par followed by in 30-day solarized plots.

The effect of levels of biofertilizers on the leaf dry weight was significant only at 90 DAS. The leaf dry weight of seedlings were on par in all the biofertilizer applied plots and superior to no- biofertilizer plots.

Total plant dry weight

Total dry weight of plants were found to be significantly affected by the levels of solarization at 30, 60 and 90 DAS (Table 20). Plant dry weight was

maximum in 45-day solarized plots at all the stages. At 30 DAS, this was followed by 30-day solarized plots and fumigated plots which were on par.

Table 20. Effect of levels of soil solarization and biofertilizers on total plant dry weight of cocoa seedling (g plant^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Levels of solarization (A)			
Non-solarized control	0.98	2.03	3.96
Solarization 15 days	0.86	2.09	4.04
Solarization 30 days	1.25	2.90	5.24
Solarization 45 days	1.47	3.21	6.34
Fumigation	1.31	3.15	6.01
SEm±	0.04	0.11	0.23
LSD (0.05)	0.11	0.31	0.66
Levels of biofertilizers (B)			
No biofertilizer	1.17	2.55	4.65
Azospirillum	1.18	2.57	5.09
VAM	1.20	2.65	5.11
Azospirillum + VAM	1.14	2.95	5.64
SEm±	0.06	0.16	0.32
LSD (0.05)	NS	NS	0.90
Interaction A x B	NS	NS	NS

DAS – Days after sowing

The plant dry weight in 45-day solarized plots, 30-day solarized plots and fumigated plots were on par at 60 DAS.

At 90 DAS, the plant dry weight in 45 day solarized plot and fumigated plot were on par followed by plant dry weight in 30 day solarized plots.

The effect of the levels of biofertilizers were found significant only at 90 DAS. At this stage, the plant dry weight in no biofertilizer plots was much inferior to that in biofertilizer applied plots.

4.1.8   Earliness in reaching budding stage

The number of plants removed for budding at different stages in percentage are given in Table 21. The selection of plants for budding started three and half month after sowing when the plants reached pencil thickness. First removal for budding was done on 24-4-2001. Subsequently plants were removed on 6-5-2001, 16-5-2001, 24-5-2001 until more than 95 per cent of the plants were removed for budding.

The levels of solarization had significant influence on the number of plants selected for budding. On 24-4-2001 higher percentage of plants were selected from 45 and 30 days solarized plot followed by fumigated plot. There was progressive increase in the number of plants selected. On 24-5-2001 the progressive total of plants selected from 45 and 30 days solarized plot and from fumigated plots were on par. All the biofertilizer applied plots showed higher progressive total on the last date compared to control. The minimum progressive total was noted in non-solarized control.

Biofertilizers had significant effect on the number of plants selected on 24-4-2001 and at this stage the maximum percentage of budded plants were selected from the treatment, *Azospirillum* + VAM, but it was on par with the treatments *Azospirillum* and VAM.

Table 21. Number of plants selected for budding at different intervals in percentage (earliness in reaching budding stage)

Treatments	17/4/01 (107 DAS)	1/5/01 (122 DAS)	Progre- ssive total	16/5/01 (137 DAS)	Progre- ssive total	24/5/01 (145 DAS)	Progre- ssive total
Level of solarization (A)							
Non solarized control	0.05*	0.12	0.17	0.17	0.35	0.26	0.65
	(4.99)	(11.97)	(16.91)	(16.91)	(34.27)	(25.70)	(60.49)
Solarization 15 days	0.06	0.14	0.20	0.23	0.44	0.26	0.76
	(5.99)	(13.95)	(19.86)	(22.79)	(42.58)	(25.10)	(68.87)
Solarization 30 days	0.28	0.30	0.62	0.25	0.97	0.16	1.37
	(27.62)	(29.54)	(58.08)	(24.73)	(82.46)	(15.92)	(97.98)
Solarization 45 days	0.33	0.31	0.69	0.24	1.07	0.12	1.40
	(32.39)	(30.49)	(63.63)	(23.76)	(87.70)	(11.97)	(98.53)
Fumigation	0.26	0.34	0.63	0.24	0.97	0.15	1.35
	(25.70)	(33.33)	(58.89)	(23.76)	(82.46)	(14.94)	(97.56)
SEm±	0.02	0.02	0.03	0.02	0.03	0.02	0.02
LSD (0.05)	0.05	0.05	0.09	0.05	0.09	0.04	0.07
Levels of biofertilizers (B)							
No biofertilizer	0.16	0.23	0.41	0.22	0.68	0.21	0.95
	(15.92)	(22.79)	(39.84)	(21.81)	(62.86)	(20.84)	(81.36)
Azospirillum	0.18	0.26	0.46	0.22	0.75	0.19	1.00
	(17.89)	(25.70)	(44.38)	(21.81)	(68.14)	(18.88)	(84.28)
VAM	0.19	0.25	0.47	0.23	0.78	0.19	1.03
	(18.88)	(24.73)	(45.27)	(22.79)	(70.30)	(18.88)	(85.71)
Azospirillum + VAM	0.24	0.24	0.52	0.23	0.84	0.16	1.04
	(23.76)	(23.76)	(49.67)	(22.79)	(74.44)	(15.92)	(86.23)
SEm±	0.02	0.03	0.07	0.01	0.08	0.02	0.01
LSD (0.05)	0.07	NS	NS	NS	NS	NS	0.03
Interaction A x B	NS	S	NS	NS	S	S	NS

*Angular transformed values. Values in parenthesis are original values. DAS - Days after sowing
DAS-Days after sowing

4.1.9   Soil microflora in the nursery after biofertilizer application and sowing seeds.

Population of soil fungi at 30 DAS

The levels of solarization had significant effect on the population of fungi at 30 DAS (Table 22a). The highest population was in non-solarized control plots (11.6 x 10^3 cfu g^{-1}) and fumigated plots recorded lower (3.2 x 10^3 cfu g^{-1}) and this was on par with 30-day solarized plots. The population in 30 and 45-day solarized plots were on par. The population in 15-day solarized plots were higher compared to 30 and 45-day solarized plots and fumigated plots.

Table 22a. Effect of levels of soil solarization and biofertilizers on population of soil fungi at 30 DAS (10^3 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized control	12.60	13.26	10.27	10.3	11.60
15 days	9.17	6.47	7.07	5.37	7.02
30 days	4.13	4.40	3.17	3.30	3.75
45 days	5.23	5.17	3.67	3.67	4.43
Fumigation	2.63	3.03	3.43	3.73	3.20
Group mean	6.75	6.47	5.52	5.27	

SEm± for factor A - 0.33   LSD (0.05) - 0.93
SEm± for factor B - 0.86   LSD (0.05) - NS
SEm± for AB   - 0.35   LSD (0.05) - 0.99

The levels of biofertilizers did not show any effect on the population of fungi at 30 DAS. Interaction was however, found significant at this stage. The highest population was in the treatment combination, non-solarized + *Azospirillum* followed by control (non-solarized + no biofertilizer) and these two treatments were on par. Lesser population was noticed in combinations with fumigation + no biofertilizer, fumigation + *Azospirillum* and fumigation with VAM, which were on par.

Population of soil fungi at 60 DAS

The levels of solarization had significant effect on the population of fungi at 60 DAS (Table 22b). The maximum population was in non-solarized plots followed by 15 day solarized plots. The minimum population was noticed in 30-day solarized plots followed by fumigated plots and these were on par. The population in 30 and 45-day solarized plots were on par.

Table 22b. Effect of levels of soil solarization and biofertilizers on population of soil fungi at 60 DAS (10^3 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	16.47	14.20	11.55	12.50	13.68
15 days	12.33	9.00	5.53	5.00	7.97
30 days	6.67	5.30	3.87	3.87	4.93
45 days	7.80	5.83	4.67	5.67	5.99
Fumigation	3.13	4.10	4.50	4.07	3.95
Group mean	9.28	7.69	6.02	6.22	

SEm± for factor A - 0.54 LSD (0.05) - 1.54
SEm± for factor B - 0.98 LSD (0.05) - 2.78
SEm± for AB   - 0.34 LSD (0.05) - 0.98

Biofertilizers at different levels also had significant effect on the population of fungi at 60 DAS. The maximum population was in control (no biofertilizer) followed by *Azospirillum* applied plots and these were on par. Similarly, the population in VAM applied plots, *Azospirillum* + VAM applied plots and *Azospirillum* applied plots were on par.

The interaction effects were also found significant at this stage. The control plots (non-solarized + no biofertilizer) recorded the highest population followed by non-solarized + *Azospirillum* applied plots. The combination with fumigation + no biofertilizer had minimum population and combinations with 30-

day solarization + VAM, 30-day solarization + *Azospirillum* + VAM, fumigation + *Azospirillum* + VAM and fumigation + *Azospirillum* were on par with this.

Population of soil fungi at 90 DAS

A perusal of the data in Table 22c showed that there were significant differences in population of fungi at 90 DAS. The levels of solarization, levels of biofertilizer and interaction of both were found significant.

Table 22c. Effect of levels of soil solarization and biofertilizers on population of soil fungi at 90 DAS (10^3 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	17.30	16.10	12.27	12.73	14.60
15 days	10.80	7.17	6.67	5.83	7.62
30 days	9.93	6.27	4.13	4.83	6.29
45 days	11.30	7.03	5.97	7.10	7.85
Fumigation	4.10	5.30	5.47	4.83	4.93
Group mean	10.69	8.37	6.90	7.06	

SEm± for factor A - 0.60   LSD (0.05) - 1.68
SEm± for factor B - 1.07   LSD (0.05) - 2.70
SEm± for AB   - 0.21   LSD (0.05) - 1.20

Among the different levels of solarization, the maximum population was in non-solarized plots. The population in 15-day solarized plots, 30 day solarized plots and 45-day solarized plots were on par. Similarly, the population in fumigated plots recorded the minimum, but it was on par with the population in 30-day solarized plots.

The treatments without biofertilizer and *Azospirillum* application was superior in the population of fungi. The population in VAM applied plots and *Azospirillum* + VAM applied plots was on par but significantly lower to these two mentioned treatments.

In the case of interaction effects, the highest population was in control plots followed by non-solarized and *Azospirillum* applied plots. The combinations, fumigation + no biofertilizer, 30-day solarization + VAM, 30-day solarization + *Azospirillum* + VAM, fumigation + *Azospirillum* + VAM and fumigation + *Azospirillum*, had significantly lower population.

Population of soil bacteria at 30 DAS

The levels of solarization had significant effect on population of bacteria (Table 23a). The maximum population was in non-solarized plots followed by 15-day solarized plots. The population in 30 and 45-day solarization and fumigated plots were on par. Biofertilizers had no significant effect on bacterial population.

Table 23a. Effect of levels of soil solarization and biofertilizers on population of soil bacteria at 30 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	20.50	22.30	18.67	20.57	20.51
15 days	17.90	9.73	9.47	11.17	12.07
30 days	3.67	5.03	4.00	4.93	4.41
45 days	3.13	5.30	3.63	3.37	3.86
Fumigation	2.60	3.83	3.03	3.23	3.17
Group mean	9.56	9.24	7.76	8.65	

SEm± for factor A - 0.50   LSD (0.05) - 1.57
SEm± for factor B - 1.85   LSD (0.05) - NS
SEm± for AB   - 0.48   LSD (0.05) - 1.36

The interaction of levels of solarization and biofertilizers on bacterial population was found significant at this stage. The maximum population was in non-solarized + *Azospirillum* applied plots. The combinations with fumigation + no biofertilizer, fumigation + *Azospirillum*, fumigation + VAM, fumigation + *Azospirillum* + VAM, 45 day solarization + no biofertilizer, 45 day solarization +

Azospirillum + VAM and 30 day solarization + no biofertilier recorded lower bacterial population and were on par.

Population of soil bacteria at 60 DAS

The levels of solarization had significant effect on the population of bacteria at 60 DAS (Table 23b). The maximum population was in non-solarized control followed by 15-day solarized plot. The population in 30-day and 45-day solarized and fumigated plots were on par.

Table 23b. Effect of levels of soil solarization and biofertilizers on population of soil bacteria at 60 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	23.80	27.73	23.57	23.93	24.76
15 days	20.50	14.50	12.90	9.97	14.47
30 days	5.37	6.47	4.60	4.30	5.18
45 days	3.50	6.03	4.70	4.90	4.78
Fumigation	4.00	3.37	4.23	3.67	3.82
Group mean	11.43	11.62	10.00	9.35	

SEm± for factor A - 0.62   LSD (0.05) - 1.77
SEm± for factor B - 2.28   LSD (0.05) - NS
SEm± for AB   - 0.46   LSD (0.05) - 1.31

The effect of levels of biofertilizer on bacterial population was not significantly different at 60 DAS. However, significant effects were noticed due to the interaction of levels of solarization and levels of biofertilizers. The maximum population was in non-solarized + *Azospirillum* applied plots (27.73 x 10^3 cfu g^{-1}) followed by control (non-solarized + no biofertilizer), non-solarized + VAM, non-solarized + *Azospirillum* + VAM which were on par. Bacterial population noticed at 60 DAS in treatments with fumigation + no biofertilizer, fumigation + *Azospirillum*, fumigation + VAM, fumigation + *Azospirillum* + VAM, 30-day

solarization + VAM, 30-day solarization + *Azospirillum* + VAM, 45-day solarization + no biofertilizer were similar and significantly lower.

Population of soil bacteria at 90 DAS

The data on bacterial population at 90 DAS are presented in Table 23c. Different levels of solarization had significant effect on the population of bacteria at this stage. Non-solarized and 15-day solarized plots recorded higher population than other treatments. The lowest population was in fumigated plot, but the population in 45-day solarized plot was on par with it.

Table 23c. Effect of levels of soil solarization and biofertilizers on population of soil bacteria at 90 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	25.37	29.00	22.56	23.70	25.16
15 days	22.47	19.07	12.10	12.23	16.47
30 days	6.47	7.03	6.93	6.30	6.68
45 days	4.43	5.20	5.80	5.83	5.32
Fumigation	3.17	2.70	4.27	3.57	3.43
Group mean	12.38	12.60	10.33	10.33	

SEm± for factor A - 0.75   LSD (0.05) - 2.12
SEm± for factor B - 2.27   LSD (0.05) - NS
SEm± for AB   - 0.65   LSD (0.05) - 1.84

The levels of biofertilizer did not have any effect on bacterial population at 90 DAS, but the interaction was significant. The highest bacterial population was in combinations of non-solarized + *Azospirillum* applied plots. All the combinations of fumigation and biofertilizers were inferior to others.

Population of actinomycetes at 30 DAS

The data on actinomycetes population at 30 DAS are presented in Table 24a. Significant differences were observed in actinomycetes population at different

levels of solarization. The highest number was in non-solarized plot followed by 15-day solarized plot. Actinomycetes population was the lowest in fumigated plots. The populations in 30 and 45-day solarized plots showed intermediate value and were on par.

Table 24a. Effect of levels of soil solarization and biofertilizers on actinomycetes population at 30 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	8.27	8.10	8.80	7.37	8.13
15 days	6.46	5.97	7.13	7.37	6.73
30 days	3.23	4.87	4.07	3.77	3.98
45 days	3.67	4.10	4.33	5.20	4.33
Fumigation	2.83	2.27	3.20	2.93	2.80
Group mean	4.89	5.06	5.50	5.33	

SEm± for factor A - 0.21   LSD (0.05) - 0.6
SEm± for factor B - 0.55   LSD (0.05) - NS
SEm± for AB   - 0.34   LSD (0.05) - 0.95

The levels of biofertilizers did not have any effect on actinomycetes population but the interaction was significant. The treatments control (non-solarized + no biofertilizer), non-solarized + *Azospirillum* and non-solarized + VAM recorded higher population of actinomycetes and were on par. All the fumigated treatments with biofertilizer combinations showed lower number of actinomycetes.

Population of actinomycetes at 60 DAS

The data on the population of actinomycetes at 60 DAS are presented in Table 24b. The population of actinomycetes differed significantly due to different levels of solarization. Non-solarized and 15-day solarized plots recorded higher population and were on par. The minimum population was in fumigated plots followed by 30-day solarized plots.

Table 24b. Effect of levels of soil solarization and biofertilizers on actinomycetes population at 60 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	8.20	6.87	8.53	6.37	7.49
15 days	8.40	6.83	7.37	8.57	7.79
30 days	5.47	6.13	4.73	5.27	5.40
45 days	6.53	5.73	6.50	7.03	6.45
Fumigation	3.03	3.87	4.53	5.30	4.18
Group mean	6.33	5.89	.6.33	6.51	

SEm± for factor A - 0.26 LSD (0.05) - 0.73
SEm± for factor B - 0.42 LSD (0.05) - NS
SEm± for AB   - 0.35 LSD (0.05) - 0.99

The levels of biofertilizers did not have any effect on the population of actinomycetes. Nevertheless, the interaction of levels of solarization and biofertilizers was significant. The treatments control (non-solarized + no biofertilizer), 15-day solarization + no biofertilizer, non-solarized + VAM and 15 day solarization + *Azospirillum* + VAM showed higher population and were on par. Fumigation + no biofertilizer and fumigation + *Azospirillum* recorded lower population of actinomycetes and were on par.

Population of actinomycetes at 90 DAS

The data on the population of actinomycetes at 90 DAS are presented in Table 24c. The levels of solarization, levels of biofertilizers and interaction of both differed significantly at 90 DAS.

Among the levels of solarization, non-solarized and 15-day solarized plots showed higher population and were on par. The minimum population was in fumigated plots.

Table 24c. Effect of levels of soil solarization and biofertilizers on actinomycetes population at 90 DAS (10^4 cfu g^{-1})

Solarization (A)	Biofertilizers (B)				Group mean
	No biofertilizer	*Azospirillum*	VAM	*Azospirillum* + VAM	
Non-solarized	9.80	6.03	7.80	5.97	7.40
15 days	6.17	7.43	8.40	6.30	7.08
30 days	4.57	7.33	6.53	6.57	6.25
45 days	5.13	5.93	7.13	7.13	6.33
Fumigation	2.83	5.30	5.83	5.97	4.98
Group mean	5.70	6.40	7.14	6.39	

SEm± for factor A - 0.38   LSD (0.05) - 1.06
SEm± for factor B - 0.38   LSD (0.05) - 1.06
SEm± for AB   - 0.32   LSD (0.05) - 0.93

Among the different biofertilizers used, *Azospirillum* + VAM, *Azospirillum* and VAM applied plots recorded higher population and were on par. The population of actinomycetes was found to be the highest in control plots (non-solarized + no biofertilizer), due to interaction effects. The minimum count was noticed in the treatment, fumigation + no biofertilizer.

4.2   Experiment II - Pre-emergence herbicides for the control of weeds in cocoa nursery

4.2.1.   Weed flora of the experimental field

The weed flora of experimental nursery observed from the untreated control plots are presented in Table 25.

Most of the weeds in the field were broad leaf weeds. Among them *Ludwigia perennis, Borreria hispida* and *Mullugo pentaphylla* were the important ones. Important grasses observed included *Digitaria ciliaris* and *Eleusine indica.* Other weeds like, *Alternanthera echinata, Amaranthus viridis, Cleome burmanii, Peperomia pellucida, Commelina benghalensis* etc. were also observed. A fern *Selaginella* sp. was also found especially in the later stages.

Table 25. Weed flora of the experimental field

Sl.No.	Scientific name	Common name	Family
A. Grasses			
1	*Dactyloctenium aegyptium* (L.) Beauv	Crow foot grass	Poaceae
2	*Digitaria ciliaris* (Retz.) Koel	Crab grass	,,
3	*Eleusine indica* (L.) Gaertn	Goose grass	,,
B. Broad leaf weeds			
1	*Alternanthera echinata* L.	Kaki weed	Amaranthaceae
2	*Amaranthus viridis* L.	Slender amaranth	Amaranthaceae
3	*Borreria hispida* (L.) K. Schum	Butten weed	Rubiaceae
4	*Cleome burmanii* Wt. & Arn	Wild mustard	Capparidaceae
5	*Commelina benghalensis* L.	Tropical spiderwort	Commelinaceae
6	*Curculigo orchioides* Gaertn.	.Black musale	Amaryllidaceae
7	*Eclipta alba* (L.) Hassk.	False daisy	Asteraceae
8	*Emilia sonchifolia* (L.) DC .	Red tassel flower	Asteraceae
9	*Euphorbia hirta* L.	Garden spurge	Euphorbiaceae
10	*Ludwigia perennis* L.	Water primrose	Onagraceae
11	*Mullugo pentaphylla* L.	Carpet weed	Mulluginaceae
12	*Peperomia pellucida* (L.) HBK	Peporomia	Piperaceae
13	*Selaginella* sp.	Selaginella	Selaginellaceae
14	*Vernonia cineria* (L.) Lees	Ash coloured fleabane	Asteraceae

4.2.2   Effects on weeds

Total weed count

The data on the total weed count are presented in Table 26. All the treatments significantly reduced the weed population compared to unweeded plot. All the herbicide treatments resulted in complete (100 per cent) control of weeds for 30 days. The herbicide treatments, diuron, pendimethalin and oxyfluorfen did not allow germination of weeds even after 90 DAS. Among other herbicides atrazine showed minimum number at 60 DAS and alachlor at 90 DAS, which were significantly lower than untreated control.

Dry matter production of weeds (Biomass of weeds)

At 30 DAS, there were no weeds in treated plots except in unweeded control (Table 27). However, at 60 DAS and 90 DAS weeds emerged in some treatments and the weed dry matter production was significantly different. At 60 DAS and 90 DAS, the treatments with diuron, pendimethalin and oxyfluorfen as well as handweeded plot recorded zero value. Weed dry matter was the lowest in unweeded control.

Weed control efficiency (WCE)

Weed control efficiency was 100 per cent in all the treatments except unweeded control at 30 DAS. However, it was found non-significant at 60 DAS (Table 28).

There was significant difference in WCE between treatments at 90 DAS. The WCE of diuron, pendimethalin, oxyfluorfen and hand weeded plots were on par followed by atrazine and alachlor applied plots.

Table 26. Effect of pre-emergence herbicides on total weed count (number per 50 polybags)

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	0.00	0.707*(0.00)	0.707(0.00)
Atrazine 2 kg ha^{-1}	0.00	2.339(5.00)	5.147(26.00)
Alachlor 2 kg ha^{-1}	0.00	4.636(21.00)	3.238(10.00)
Pendimethalin 1.5 kg ha^{-1}	0.00	0.707(0.00)	0.707(0.00)
Oxyfluorfen 0.3 kg ha^{-1}	0.00	0.707(0.00)	0.707(0.00)
Fluchloralin 1.5 kg ha^{-1}	0.00	4.527(20.00)	5.307(28.00)
Metolachlor 1.5 kg ha^{-1}	0.00	4.527(20.00)	4.847(23.00)
Untreated control	77.00	11.424(130.00)	10.416(108.00)
Weed free	0.00	0.707(0.00)	0.707(0.00)
SEm±	0.00	0.08	0.07
LSD (0.05)	0.00	0.241	0.203

DAS - Days after sowing.
* √x+0.5 transformed values .Values in parenthesis are original values.

Table 27. Effect of pre-emergence herbicides on weed dry matter production (g polybag^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	0.00	0.00	0.00
Atrazine 2 kg ha^{-1}	0.00	0.16(0.179)*	0.28(0.324)
Alachlor 2 kg ha^{-1}	0.00	0.15(0.177)	0.43(0.540)
Pendimethalin 1.5 kg ha^{-1}	0.00	0.00	0.00
Oxyfluorfen 0.3 kg ha^{-1}	0.00	0.00	0.00
Fluchloralin 1.5 kg ha^{-1}	0.00	0.26(0.311)	0.69(1.015)
Metolachlor 1.5 kg ha^{-1}	0.00	0.28(0.379)	0.63(0.895)
Untreated control	0.649	0.81(1.256)	1.48(3.54)
Weed free	0.00	0.00	0.00
SEm±	0.00	0.157	0.135
LSD (0.05)	0.00	0.34	0.294

DAS - Days after sowing.
* log(x+1) tansformed values. Values in parenthesis are original values.
Treatments with zero values are excluded from statistical analysis.

Table 28a. Weed control efficiency in cocoa nursery as influenced by pre-emergence herbicides

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	100.00	100.00	100.00
Atrazine 2 kg ha^{-1}	100.00	85.48	84.72
Alachlor 2 kg ha^{-1}	100.00	85.90	83.66
Pendimethalin 1.5 kg ha^{-1}	100.00	100.00	100.00
Oxyfluorfen 0.3 kg ha^{-1}	100.00	100.00	100.00
Fluchloralin 1.5 kg ha^{-1}	100.00	73.94	70.58
Metolachlor 1.5 kg ha^{-1}	100.00	73.38	73.89
Untreated control	0.00	0.00	0.00
Weed free	100.00	100.00	100.00
SEm±		9.08	2.65
LSD (0.05)		NS	7.15

Zero values are excluded from statistical analysis.

Table 28b. Visual rating of phytotoxicity symptoms on cocoa seedlings at 30 DAS on a 0-10 scale

Treatments	Rating	Crop description
Diuron 2 kg ha^{-1}	0	No injury, normal
Atrazine 2 kg ha^{-1}	0	No injury, normal
Alachlor 2 kg ha^{-1}	1	Slight stunding, injury or discolouration
Pendimethalin 1.5 kg ha^{-1}	0	No injury, normal
Oxyfluorfen 0.3 kg ha^{-1}	0	No injury, normal
Fluchloralin 1.5 kg ha^{-1}	3	Injury more pronounced but not persistent
Metolachlor 1.5 kg ha^{-1}	1	Slight stunding, injury or discolouration
Untreated control	0	No injury, normal
Weed free	0	No injury, normal

4.2.3 Effects on cocoa seedlings

Phytotoxic effects

Phytotoxic symptoms were observed in fluchloralin, alachlor and metolachlor applied plots (Table 28b). In fluchloralin applied plots, there was 100 per cent germination, but there was delay in the formation of leaves. Even after one month, there was no leaves in some seedlings. Crinkling of leaves were also noticed. Leaf size was also small compared to unsprayed controls. This affected the growth throughout the period of observation.

In the case of alachlor and metolachlor, crinkling of leaves was noticed in the early stages of seedlings. Eventhough there was phytotoxicity in early stage, the seedlings recovered to normal growth, in the later stages of seedling growth.

Height of seedlings

The height of cocoa plants at different stages are presented in Table 29. The differences in plant height between hand weeding and other treatments were not significant at 30 and 90 days after sowing (DAS), though the height in untreated control was the lowest. However, the treatments showed significant differences at 60 DAS. Herbicide treatments atrazine, pendimethalin and oxyfluorfen recorded higher plant height and were on par with diuron, metolachlor and hand weeding treatments.

Collar girth

The data on seedling collar girth was taken at monthly intervals for 3 months are presented in Table 30. The collar girth was found to differ significantly at all stages. At 30 DAS, the seedling collar girth in weed management treatments were found higher than unweeded control, but there was not much differences in

Table 29. Height of cocoa seedlings as influenced by pre-emergence herbicides (cm)

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	18.12	25.33	41.90
Atrazine 2 kg ha^{-1}	18.60	27.70	47.10
Alachlor 2 kg ha^{-1}	17.07	23.58	40.83
Pendimethalin 1.5 kg ha^{-1}	17.95	27.48	49.56
Oxyfluorfen 0.3 kg ha^{-1}	17.93	27.56	44.40
Fluchloralin 1.5 kg ha^{-1}	15.64	22.60	39.40
Metolachlor 1.5 kg ha^{-1}	17.24	25.40	44.73
Untreated control	15.71	20.60	38.73
Weed free	16.68	23.76	41.20
SEm±	0.69	1.38	2.42
LSD (0.05)	NS	4.1	NS

DAS - Days after sowing

Table 30. Collar girth of cocoa seedlings as influenced by pre-emergence herbicides (cm)

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	1.48	1.94	2.44
Atrazine 2 kg ha^{-1}	1.55	1.92	2.48
Alachlor 2 kg ha^{-1}	1.54	1.90	2.36
Pendimethalin 1.5 kg ha^{-1}	1.53	1.92	2.42
Oxyfluorfen 0.3 kg ha^{-1}	1.54	1.92	2.42
Fluchloralin 1.5 kg ha^{-1}	1.46	1.79	2.27
Metolachlor 1.5 kg ha^{-1}	1.54	1.93	2.36
Untreated control	1.23	1.56	1.89
Weed free	1.52	1.90	2.40
SEm±	0.03	0.05	0.06
LSD (0.05)	0.108	0.14	0.17

DAS - Days after sowing

collar girth among herbicide applied treatments and handweeding. Among herbicides, fluchloralin had the lowest collar girth.

At 60 DAS and 90 DAS all the herbicide treatments were found superior to unweeded plots. Among herbicides, fluchloralin applied plots showed significantly lower values.

Number of leaves

The data on mean number of leaves per plant is shown in Table 31. The mean number of leaves of seedlings were not significantly different between the treatments at 30 DAS and 60 DAS. However, the number of leaves at 90 DAS was significantly different between treatments. All the treatments except diuron and unweeded control were on par and superior to the above treatments.

Table 31. Number of leaves of cocoa seedlings as influenced by pre-emergence herbicides (number plant^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	4.26	8.13	15.46
Atrazine 2 kg ha^{-1}	4.66	9.53	17.73
Alachlor 2 kg ha^{-1}	4.53	9.53	17.53
Pendimethalin 1.5 kg ha^{-1}	4.40	8.93	17.06
Oxyfluorfen 0.3 kg ha^{-1}	4.60	9.26	18.20
Fluchloralin 1.5 kg ha^{-1}	4.00	8.06	17.53
Metolachlor 1.5 kg ha^{-1}	4.33	8.80	18.33
Untreated control	3.90	7.73	14.33
Weed free	4.10	8.20	17.60
SEm±	0.20	0.43	0.71
LSD (0.05)	NS	NS	2.11

DAS - Days after sowing

Leaf area per plant

The leaf area per plant was found to differ significantly between the treatments at 30 DAS and 60 DAS (Table 32). The leaf area of atrazine applied

plots was the highest at 30 DAS. However, the treatments atrazine, pendimethalin and oxyfluorfen were on par and showed superiority over fluchloralin, untreated control and hand weeding. The leaf area of fluchloralin applied plots was inferior to all other herbicide applied treatments.

Table 32. Leaf area of cocoa seedlings as influenced by pre-emergence herbicides (cm^2 plant^{-1})

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	150.71	422.73	961.52
Atrazine 2 kg ha^{-1}	167.54	525.50	1052.98
Alachlor 2 kg ha^{-1}	144.61	445.13	943.64
Pendimethalin 1.5 kg ha^{-1}	160.36	510.85	1034.54
Oxyfluorfen 0.3 kg ha^{-1}	153.59	516.01	1019.13
Fluchloralin 1.5 kg ha^{-1}	111.96	329.10	766.75
Metolachlor 1.5 kg ha^{-1}	148.73	396.86	782.61
Untreated control	115.74	365.19	716.14
Weed free	122.90	434.63	856.16
SEm±	10.89	28.49	89.44
LSD (0.05)	32.35	84.65	NS

DAS - Days after sowing

Sixty days after sowing, herbicide treatments atrazine, oxyfluorfen, pendimethalin and alachlor were on par in terms of leaf area, followed by diuron, metolachlor and hand weeded plots. The leaf area of fluchloralin and unweeded, plots were also on par, but the lowest

Leaf dry weight per plant

Leaf dry weight per plant was significantly different among treatments at 30 and 90 days after sowing (Table 33). The leaf dry weights of all the herbicide applied treatments, except fluchloralin, were on par at 30 DAS. There were no differences in leaf dry weight among fluchloralin, hand weeded and unweeded control.

Table 33. Leaf dry weight of cocoa seedlings as influenced by pre-emergence herbicides (g plant $^{-1}$)

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	0.43	1.58	2.88
Atrazine 2 kg ha^{-1}	0.42	1.75	3.35
Alachlor 2 kg ha^{-1}	0.39	1.31	2.34
Pendimethalin 1.5 kg ha^{-1}	0.44	1.29	2.76
Oxyfluorfen 0.3 kg ha^{-1}	0.42	1.44	3.21
Fluchloralin 1.5 kg ha^{-1}	0.23	1.01	2.19
Metolachlor 1.5 kg ha^{-1}	0.36	1.08	2.42
Untreated control	0.24	0.98	1.63
Weed free	0.26	1.32	2.36
SEm±	0.05	0.17	0.30
LSD (0.05)	0.13	NS	0.89

DAS - Days after sowing

At 90 DAS, the leaf dry weight of treatments, atrazine, oxyfluorfen, diuron and pendimethalin were on par and superior to unweeded control.

Total dry weight per plant

The data on the total dry weight per plant are presented in Table 34. The total dry weight was significantly different between the treatments at 30, 60 and 90 days after sowing.

Table 34. Total dry weight of cocoa seedlings as influenced by pre-emergence herbicides (g plant $^{-1}$)

Treatments	30 DAS	60 DAS	90 DAS
Diuron 2 kg ha^{-1}	1.10	2.37	4.34
Atrazine 2 kg ha^{-1}	1.26	2.35	5.31
Alachlor 2 kg ha^{-1}	1.02	1.98	3.91
Pendimethalin 1.5 kg ha^{-1}	1.18	2.13	4.26
Oxyfluorfen 0.3 kg ha^{-1}	1.17	2.39	4.88
Fluchloralin 1.5 kg ha^{-1}	0.90	1.60	3.58
Metolachlor 1.5 kg ha^{-1}	1.07	1.84	3.70
Untreated control	0.80	1.50	2.79
Weed free	1.16	1.96	3.89
SEm±	0.07	0.16	0.36
LSD (0.05)	0.21	0.47	1.07

DAS - Days after sowing

At 30 DAS, the total dry weight of all the treatments except fluchloralin and unweeded control were similar. The total dry weight in fluchloralin and unweeded plots were inferior to others.

At 60 DAS, the treatments oxyfluorfen diuron, atrazine, pendimethalin, hand weeding and alachlor were on par and superior to other treatments. The dry weight was the lowest in unweeded plots. Among the herbicide applied treatments the dry weight of fluchloralin and metolachlor were inferior to others.

At 90 DAS, the total dry weight of the treatments atrazine, oxyfluorfen, diuron and pendimethalin were on par followed by alachlor, hand weeding, fluchloralin and metolachlor. Atrazine was significantly superior to hand weeded plots. The total dry weight in all the treatments were higher than that of unweeded treatment.

4.2.4 Earliness in reaching budding stage

The number of plants selected for budding at different stages in percentage are given in Table 35.

Selection of plants for budding started three and half months after sowing, when the plants reached pencil thickness. The first selection of seedlings for budding was done on 6-5-2001 (110 days after sowing). Subsequently, plants were selected on 16-5-2001, 24-5-2001, 5-6-2001 until more than 95 per cent of the plants were selected for budding. On 6-5-2001, the maximum percentage of plants were removed from pendimethalin and oxyfluorfen applied plots followed by hand weeded plot.

The maximum percentage of plants were selected on 16-5-2001 from all treatments. There was significant difference between treatments in percentage of plants selected for budding. Higher number of plants were selected from atrazine

Table 35. Number of plants selected for budding at different intervals in percentage (earliness in reaching budding stage)

Treatments	6/5/01 (110 DAS)	16/5/01 (120 DAS)	Progressive total	24/5/01 (128 DAS)	Progressive total	5/6/01 (140 DAS)	Progressive total
Diuron 2 kg ha^{-1}	21.14	39.84	60.97	18.70	79.67	7.00	96.75
Atrazine 2 kg ha^{-1}	19.51	45.53	65.04	25.20	90.24	3.33	98.31
Alachlor 2 kg ha^{-1}	19.51	35.78	55.29	26.83	82.12	6.33	97.57
Pendimethalin 1.5 kg ha^{-1}	39.84	39.84	79.66	14.63	94.29	2.00	99.19
Oxyfluorfen 0.3 kg ha^{-1}	34.96	45.53	80.49	13.82	94.31	2.33	100.00
Fluchloralin 1.5 kg ha^{-1}	12.20	25.20	37.40·	21.14	58.54	21.14	79.67
Metolachlor 1.5 kg ha^{-1}	16.26	34.15	50.40	23.58	73.98	8.00	93.49
Untreated control	6.50	18.70	25.20	26.02	51.22	11.33	78.86
Weed free (hand weeding)	30.08	30.08	60.17	24.39	84.56	5.33	97.57
SEm±	2.61	2.61	3.36	2.61	3.29	0.72	2.20
LSD (0.05)	7.75	7.75	9.98	7.75	9.77	2.14	6.54

DAS-Days after sowing

and oxyfluorfen applied plots and treatments with diuron and pendimethalin were on par with this. Lower number of plants were selected from fluchloralin applied plots and untreated control was on par with this.

The pregressive total of plants selected at this stage was maximum in oxyfluorfen applied treatments and number of plants selected from pendimethalin applied plots was on par with this. Beyond this date the percentage of plants selected for budding decreased in all the treatments except in untreated control.

The progressive total of percentage of plants selected on 5-6-2001 was maximum on oxyfluorfen applied plots (100 per cent) closely followed by pendimethalin (99.2 per cent), atrazine (98.3 per cent), alachlor and hand weeding (97.6 per cent). The lowest percentage was noted in untreated control (78.9 per cent) and fluchloralin (79.7 per cent) was on par with this.

4.2.5   Effect on soil microflora

The effects of herbicide application on the population of soil microflora viz., fungi, bacteria and actinomycetes in the potting mixture were studied. Population estimates of these microorganisms, done one day after application (1 DAA) and subsequently at 30, 60 and 90 DAA are presented in Table 36a, b&c respectively.

Soil fungi

Herbicide application affected the population of fungi adversely. There was reduction in the population of fungi one day after the application of herbicide. However, there was not much reduction in the treatments atrazine, oxyfluorfen, metolachlor and hand weeding, which were on par with untreated control. The count in untreated control was 9.8×10^3 cfu g^{-1}. The reduction of fungal population

was highest in diuron (6.1 x 10^3 cfu g^{-1}) applied plots and alachlor, pendimethalin and fluchloralin applied plots were not significantly different from this.

Table 36a. Population of soil fungi as affected by pre-emergence herbicide application (10^3 cfu g^{-1})

Treatments	1 DAA	30 DAA	60 DAA	90 DAA
Diuron 2 kg ha^{-1}	6.10	6.20	8.30	8.80
Atrazine 2 kg ha^{-1}	8.50	8.60	8.70	7.60
Alachlor 2 kg ha^{-1}	6.32	5.80	6.60	6.80
Pendimethalin 1.5 kg ha^{-1}	7.60	7.90	8.50	8.70
Oxyfluorfen 0.3 kg ha^{-1}	8.60	8.90	9.30	9.90
Fluchloralin 1.5 kg ha^{-1}	7.80	8.10	8.80	9.10
Metolachlor 1.5 kg ha^{-1}	8.10	6.50	6.80	7.60
Untreated control	9.80	10.20	13.50	13.2
Weed free	9.00	9.90	10.83	9.30
SEm±	0.58	0.56	0.56	0.58
LSD (0.05)	1.715	1.66	1.65	1.71

DAA - Days after application

A change in the pattern of population build up of fungi was observed 30 days after application of herbicide. While there was slight increase in the population of fungi in some treatments; there was reduction in some other treatments compared to the population at 1 DAA. Still fungi population was the highest in unweeded control but on par with hand weeded plot. The population increased in unweeded plot and hand weeded plots. The count of fungi in treatments atrazine and oxyfluorfen were on par with these also. Lower count was observed in alachlor, diuron and metolachlor applied plots. However, alachlor and metolachlor applied plots showed a reduction in population compared to previous observation at 1 DAA.

At 60 DAA, in general, there was an increase in the population of fungi in all the treatments compared to 30 DAA. Differences between the treatments

were also 'significant. At this stage (60 DAA) too, the maximum population of fungi was in untreated control (13.5 x 10^3 cfu g^{-1}) followed by hand weeded plots (10.83 x 10^3 cfu g^{-1}). Among the herbicide treatments, the maximum population was in oxyfluorfen applied plots (9.3 x 10^3 cfu g^{-1}) which was on par with fluchloralin, atrazine, pendimethalin and diuron. Herbicide applied treatments, alachlor and metolachlor, however, showed the least count of fungi.

At 90 DAA also, the population was the maximum in unweeded control (13.2 x 10^3 cfu g^{-1}) and the differences were significant. The lowest count was noted in alachlor (6.8 x 10^3 cfu g^{-1}) and it was not significantly different from metolachlor.

In all the other herbicide applied plots, the population of fungi was on par with the population in hand weeded plots (9.3 x 10^3 cfu g^{-1}).

Soil bacteria

Among the different soil microflora, in general, the maximum reduction due to herbicide application was in the bacterial population.

Table 36b. Population of soil bacteria as affected by pre-emergence herbicide application (10^4 cfu g^{-1})

Treatments	1 DAA	30 DAA	60 DAA	90 DAA
Diuron 2 kg ha^{-1}	3.81	7.19	10.2	18.1
Atrazine 2 kg ha^{-1}	6.43	10.50	12.1	18.8
Alachlor 2 kg ha^{-1}	2.43	9.51	14.0	19.8
Pendimethalin 1.5 kg ha^{-1}	6.45	10.10	12.20	20.1
Oxyfluorfen 0.3 kg ha^{-1}	9.10	12.10	15.10	21.17
Fluchloralin 1.5 kg ha^{-1}	4.53	9.60	14.20	19.2
Metolachlor 1.5 kg ha^{-1}	2.86	8.10	10.10	17.8
Untreated control	12.1	20.37	23.30	26.5
Weed free	11.6	15.76	18.10	22.5
SEm±	0.58	0.56	0.58	0.58
LSD (0.05)	1.71	1.65	1.71	1.72

DAA - Days after application

The maximum population was observed in untreated control at different stages (1, 30, 60 and 90 DAA) followed by hand weeded plots. All the herbicide applied treatments showed reduction in bacterial counts when the samples were analysed one day after application, compared to untreated control (12.1 x 10^3 cfu g^{-1}). Differences were significant between treatments. The maximum reduction was noted in alachlor applied plots (2.43 x 10^4 cfu g^{-1}) and the minimum reduction was in oxyfluorfen applied plots (9.2 x 10^4 cfu g^{-1}).

There was substantial increase in the population of bacteria one month after application (30 DAA) of herbicide in all the treatments. Significant differences in bacterial population was observed between herbicide applied plots and untreated control. The maximum population was in untreated control (20.37 x 10^4 cfu g^{-1}) followed by hand weeded plots. Among the herbicide applied plots, highest bacterial population was noticed in oxyfluorfen applied plots and atrazine applied plots were on par with these. The lowest bacterial count was in diuron applied plots (7.19 x 10^4 cfu g^{-1}).

At the end of second month (60 DAA), there was an increase in bacterial population compared to previous observation. The treatments differed significantly. The maximum population was in untreated control followed by hand weeded plot. Among the herbicide applied plots, the highest population was in oxyfluorfen applied plots, but it was on par with the treatments alachlor and fluchloralin. Lower population was noticed in metolachlor and diuron applied. plots.

By the end of the third month (90 DAA), the population of bacteria in oxyfluorfen applied plots (21.17 x 10^4 cfu g^{-1}) was on par with the bacterial population in hand weeded plot (22.5 x 10^4 cfu g^{-1}). The population in treatments atrazine, alachlor, pendimethalin and fluchloralin were on par but were less than other treatments.

In general, there was a gradual build up of population of bacteria in all the herbicide applied plots compared to the previous bacterial count at different stages. By the third month, the population was coming to the normal level, eventhough there were significant differences between control and other treatments.

Actinomycetes

The maximum population of actinomycetes was found in the untreated control plots followed by hand weeded plots in all the stages of observation. A significant reduction in the population of actinomycetes was observed in all the herbicide applied treatments except oxyfluorfen, when the population was estimated one day after application of herbicide. The population of actinomycetes in untreated control, hand weeded plot and oxyfluorfen applied plots were similar. The population reduction was more pronounced in alachlor applied plots followed by metolachlor treated plots.

Table 36c. Population of soil actinomycetes as affected by pre-emergence herbicide application (10^4 cfu g^{-1})

Treatments	1 DAA	30 DAA	60 DAA	90 DAA
Diuron 2 kg ha^{-1}	7.03	8.30	8.77	10.40
Atrazine 2 kg ha^{-1}	5.13	6.40	8.60	10.87
Alachlor 2 kg ha^{-1}	3.63	6.10	7.53	8.70
Pendimethalin 1.5 kg ha^{-1}	8.18	9.10	9.77	13.47
Oxyfluorfen 0.3 kg ha^{-1}	9.33	10.37	11.47	14.20
Fluchloralin 1.5 kg ha^{-1}	6.37	9.33	10.23	11.80
Metolachlor 1.5 kg ha^{-1}	4.51	6.20	8.27	9.43
Untreated control	10.20	12.17	14.17	15.43
Weed free	10.21	11.27	12.20	13.93
SEm±	0.59	0.56	0.60	0.58
LSD (0.05)	1.75	1.66	1.78	1.72

DAA - Days after application

As in the case of bacterial population, actinomycetes population also showed an increase over the previous count. At the stage of 30 DAA also, there

were significant differences in actinomycetes population between treatments. The population in untreated control and hand weeded plots were on par. Among the herbicide applied plots, the maximum population was in oxyfluorfen treated plots and the treatment, pendimethalin and fluchloralin were on par with this. The lowest count was noticed in alachlor and metolachlor applied plots.

Actinomycetes population noted at 60 DAA also showed that there were significant differences in the count between treatments. The maximum population was in untreated control. The population in hand weeded plot and oxyfluorfen applied plot were on par. Here also, the lowest population was noted in alachlor applied plots.

At 90 DAA, the population of actinomycetes in untreated control, hand weeded plot and oxyfluorfen applied plots were on par. The minimum population was observed in alachlor applied plots.

Discussion

5. DISCUSSION

The investigation to develop suitable weed management practices in cocoa seedling nursery using soil solarization, fumigation, biofertilizers and herbicides brought out several useful findings. The results presented in the previous chapter are discussed below experiment-wise.

5.1   Experiment I - Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora

5.1.1   Solarization effects on soil temperature

It is a proven fact that many beneficial effects of solarization are due to an increase in soil temperature. Reported increase in temperature ranges from 3-18°C over non-solarized soil (Katan *et al.* 1976; Chen and Katan, 1980; Katan, 1980, 1981; Mayers *et al.*, 1983; Benjamin and Rubin, 1982; Kumar and Yaduraju, 1992; Kurian, 1992; Vilasini, 1996 and Bhasker and Nanjappa, 1997). In the present experiment the highest temperature obtained on a single day was 48°C at 5 cm depth under solarized condition and the temperature difference was 9.5°C than that in the non-solarized soil (Table 3). The increase in soil temperature in plastic mulched soil has been reported to be due to the green house effect caused by polyethylene film and prevention of evaporation (Mahrer, 1979; Avissar *et al.*, 1986). Polyethylene reduces heat convection and water evaporation from the soil to the atmosphere. Because of the formation of water droplets on the inner surface of the polyethylene film, its transmissivity to incoming short wave solar radiation is increased but prevented the escape of outgoing long wave radiation from the soil resulting in better heating.

Soil temperature fluctuations in solarized and non-solarized soil depend on several factors like atmospheric temperature, thickness of polyethylene film, moisture content of the soil etc. (Katan, 1981). The highest maximum temperature
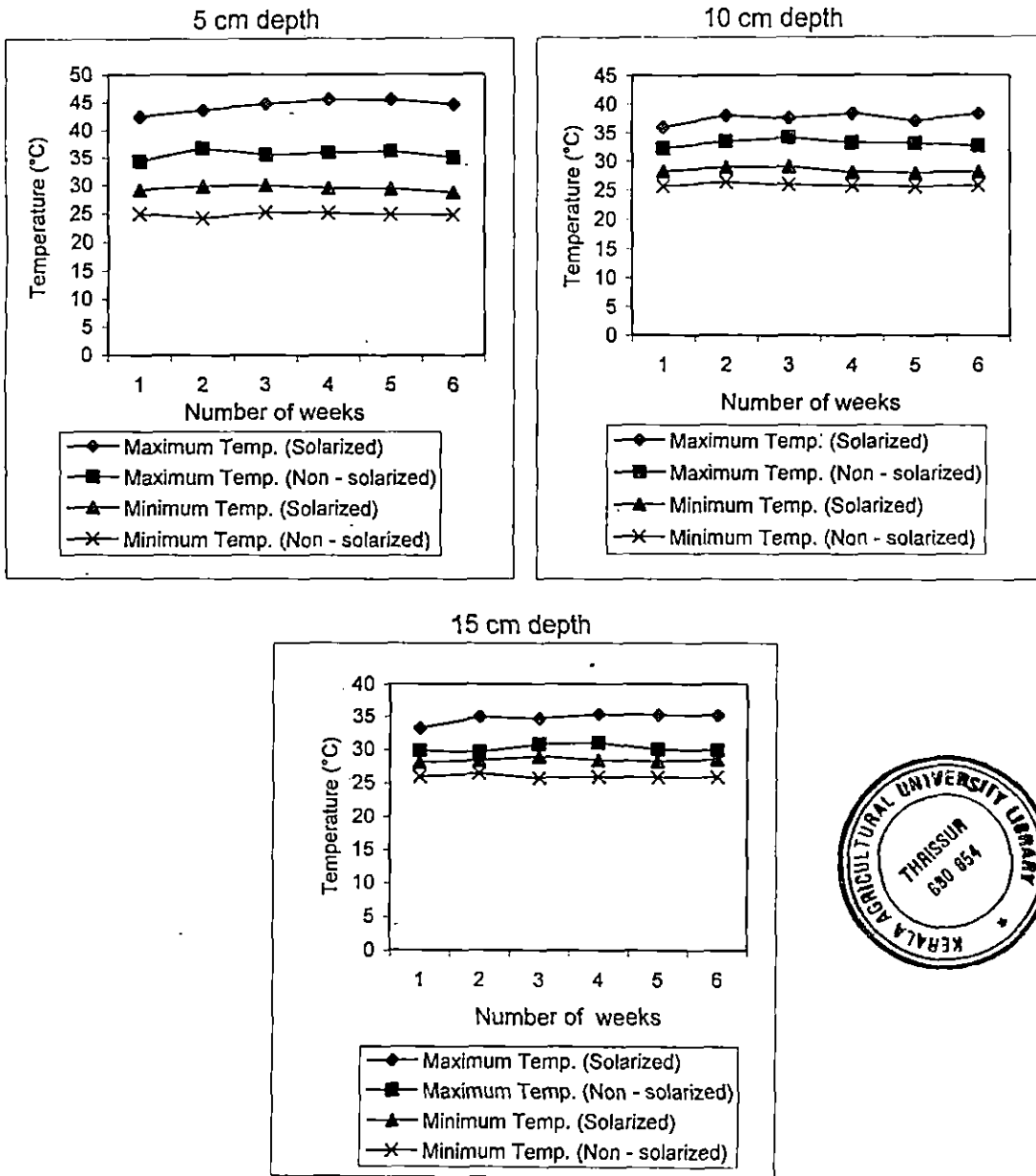
Fig. 1. Maximum and minimum temperature in solarized and non-solarized potting mixture at different depths

recorded in the solarized soil on a single day at 5, 10 and 15 cm depth were 48°C, 40°C and 37.1°C respectively as compared to 38.5°C, 36°C and 34.1°C in non-solarized soil. Thus, with an increase in soil depth there was a corresponding decrease in the soil temperature too. Weekly mean temperature also followed same trend (Table 4; Fig.1). As Mehrer (1979) and Katan (1981) reported, this is due to an increase in the thermal capacity and decrease in the heat conductivity of soil with increase in depth.

5.1.2   Solarization effects on soil microflora

Solarization inhibited the population of fungi, bacteria and actinomycetes in soil (Table 5; Fig.2)). There was a corresponding reduction in microbial population as the period of solarization increased from 15 to 45 days. Solarization causes increase in temperature and at higher temperature only a few species would be able to survive close to the upper limit of temperature to that group (Katan, 1981). Sublethal heating also created problems. It decreases the ability of the propagules to withstand stress (Pullman et al., 1981). Presence of moisture, in addition, increases the heat sensitivity of fungal structures (Katan, 1981). Soil under plastic mulch retained moisture during the entire period of solarization and this enhanced killing of fungal propagules as observed in the present study. Even temperatures near to 45°C was reported to be lethal if maintained for longer periods (Grooshevoy, 1939).

Reduction in fungi as a result of solarization was reported by many researchers (Dwivedi and Dubey, 1987; Cartia et al., 1987; Meron et al., 1989; Chandran, 1989; Kurian, 1992 and Vilasini, 1996 and Binimol, 2000). There are conflicting versions in the literature on the effect of solarization on the population of bacteria and actinomycetes. Chandran (1989) reported no change in the bacterial population as a result of solarization. In the case of actinomycetes, he reported a slight increase in population. Stapleton and DeVay (1982) and Kaewrung et al.

(1989a) from other countries could not observe any significant changes in actinomycetes population. Nevertheless; Kurian (1992), Vilasini (1996) and Binimol (2000) reported a reduction in the population of bacteria and actinomycetes as observed in the present experiment. Probably, the types of bacteria and actinomycetes present in the soil which are highly sensitive to temperature were responsible for this type of differential response. It is obvious that thermophilic organisms will escape the effect of heating.

Fig. 2. Effect of solarization on soil microflora
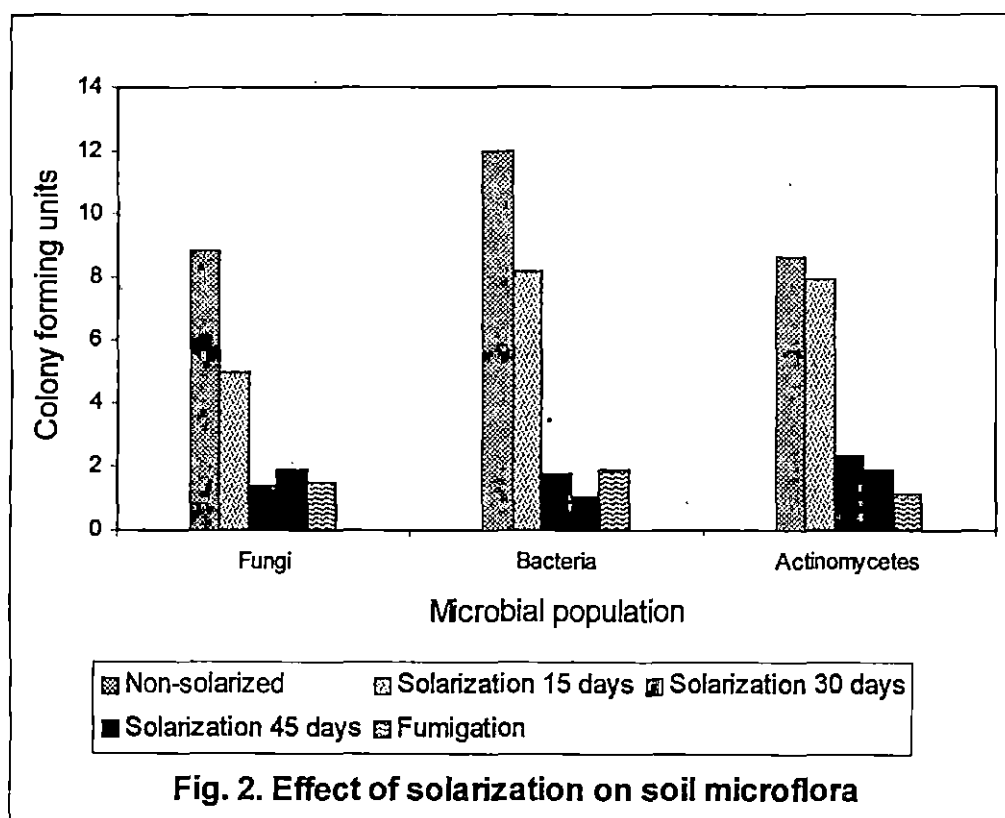
Polyethylene mulch increases soil temperature and soil respiration and serves as a barrier to oxygen diffusion into the soil, and carbon dioxide out of it. Under normal situations, free exchange of gases take place in soil and whatever type of gases are produced escape into the atmosphere. However, permeability of polyethylene to gases is low, and volatile gases including some poisonous gases are thus trapped inside. This accumulation of volatiles under polyethylene mulch might have also helped in inactivating or killing micro-organisms. In addition to

thermal death of microflora effect of sublethal heating were also documented (Lifshitz,1983). Sublethal heating delays the germination of propagules, reduces growth rate, increases sensitivity to soil fumigants and possible induced biological control of several phytopathogenic fungi. In a way, solarization mimic the effects of soil flooding to reduce the soil microflora. The treatment becomes more effective as temperature of moist soil is increased (Stapleton and DeVay, 1982).

Fumigation with dazomet also reduced the population of fungi, bacteria and actinomycetes, similar to 45-day solarized plots. The active ingredient in the product, methyl isothiocyanate, is responsible for the effects. BASF (1984) claims that it is effective against soil fungi as well in addition to weed seeds, nematodes and soil insects. McElroy (1985) reported a drastic reduction in the population of *Phytophthora* due to fumigation with dazomet. In the case of fungi, the reduction was from 8.83×10^3 cfu g^{-1} to 1.5×10^3 cfu g^{-1} (83 per cent reduction). In the case of bacteria and actinomycetes too, dazomet caused substantial reduction. The decrease was of the order of 84 per cent and 87 per cent in the case of bacteria and actinomycetes population. It is clear that methyl isocyanate is toxic to bacteria and actinomycetes as well.

5.1.3 Solarization effects on nutrient availability

Solarization effects on the nutrients tested, organic carbon, total nitrogen, ammoniacal nitrogen nitrate nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium, were not uniform. In the experiment, solarization increased the amount of available phosphorus, exchangeable potassium, calcium and magnesium. Nevertheless, organic carbon, total nitrogen and nitrate nitrogen were unaffected (Table 6).

There is a general agreement that availability of phosphorus was increased by solarization (Stapleton *et al.*, 1985; Chandran, 1989; Vilasini, 1996

and Binimol, 2000). The observations of Tisdale *et al.* (1993) supports this. The mechanisms resulting in increased P availability following moist situation as in the present experiment might include dissolution of occluded P, hydrolysis of iron phosphate, increased mineralization of organic phosphorus in acid soils and greater diffusion of phosphorus. Increased temperature of the moist soil may have some acceleratory effects on these physical mechanisms.

Solarization has marked influence on the exchangeable cations studied. In the case of exchangeable potassium, reported results are not uniform. According to Stapleton *et al.* (1985) and Chandran (1989) there was no change in the exchangeable potassium content. However, Kaewruang (1989a); Kurian (1992) Vilasini (1996) and Binimol(2000) reported increase in exchangeable potassium. The increased exchangeable potassium observed here can be explained. Tisdale *et al.* (1993) reported that the capacity of the soil to supply potassium to roots is reduced by the effect of low temperature on diffusion. Increasing the temperature increases potassium accumulation. In other words, effective diffusion co-efficient increases with an increase in temperature. Similar reasons can be attributed to the presence of increased amounts of exchangeable Ca and Mg in solarized soils.

An increase in moisture availability and temperature should naturally have its effects on organic matter decomposition, carbondioxide formation and loss of carbon and ammonification and nitrification processes. However, in the present experiment there were no changes in the above parameters. This can be attributed to the reduction of micro-organism as a result of solarization. Solarization reduced the population of fungi, bacteria and actinomycetes. That means breakdown of organic matter and consequent ammonification and nitrification are also affected. This ultimately resulted in a comparable status of organic carbon, total nitrogen, ammoniacal nitrogen and nitrate nitrogen in both solarized and non-solarized plots. According to Yaduraju (1993), the increases in the ammoniacal and nitrate nitrogen reported by several workers were not uniform to all soils and it happened

in some soils only. The status of organic carbon is also not similar. Chandran (1989) and Kurian (1992) reported an increase in organic carbon content in solarized plots; while Vilasini (1996) reported no change in the organic carbon status.

5.1.4   Solarization, fumigation and biofertilizer effects on weeds

Solarization had a profound suppressive effect on weed population (Table 8; Plate 2). Solarization for 45 days gave good control of weeds followed by 30-day solarized plot.

The higher level of weed control obtained by solarization in the current studies can be related to the increased soil temperature at various depths (5, 10 and 15 cm). Solarization has two complementary effects: (1) inducing the emergence of dormant propagules and foliar scorching of emerged plants under plastic cover and (2) decreased weed emergence after removal of the polyethlene sheets (Horowitz et al., 1983). Heating seeds to a temperature above optimum for germination causes a reduction of the germination rate possibly due to denaturation of functional protein (Taylorson and Hendricks, 1977; Levitt, 1980). The mean 'maximum' temperature recorded in the upper layer of the solarized soil was 8.81°C higher than that of unmulched soil (44.41°C and 35.6°C) and this caused a reduction of germination rate of weed seeds. Hendricks and Taylorson (1976) reported that heating weed seeds from 30-35°C modified the membrane permeability resulting in the leakage of endogenous amino acids. This might have attracted soil microflora and reduced the germination rate of weed seeds. Another possible cause of reduced germination of weed seeds is the increased susceptibility of hydrated weed seeds to high temperature and its effects on heat resistance of seeds (Yaduraju and Ahuja, 1990). In the presence of moisture, less energy is required to change the peptide chain configuration of protein; for decreasing the heat resistance of seeds (Katan, 1981). The mean 'maximum' temperature of 44.41°C in the upper 5 cm layer throughout the period of solarization reduced the

Plate 2. Two month old cocoa seedlings in solarized and fumigated potting mixture

A_0 – Non-solarized potting mixture A_2 – Solarization for 30 days
A_3 – Solarization for 45 days A_4 – Fumigated potting mixture

heat resistance of hydrated seeds. The above changes occurred due to solarization can be cited as the reasons for the reduction in weed density under plastic mulching.

Excellent weed control with solarization was reported from many countries (Benjamin and Rubin, 1982; Chandran, 1989; Kurian, 1992; Vilasini, 1996; Binimol, 2000 and Sainudheen, 2000).

Fumigation with dazomet also reduced the weed growth similar to 45-day solarization. When applied to moist soil the active ingredient in dazomet breaks down into methyl isothiocynate and has a broad spectrum of effectiveness against weeds and other soil borne pests (McElroy, 1985). The results reported by Figuerou and Kogan (1995) corroborate this.

The major broad leaf weeds in the nursery were *Ludwigia perennis, Borreria hispida* and *Amaranthus viridis*. Solarization for 45 days, 30 days and fumigation reduced the population of these weeds. Effective control of broad leaved weeds by solarization was reported by many researchers (eg. Chandran, 1986; Kurian, 1992; Vilasini, 1996; Bhasker and Nanjappa, 1997 and Mudalagiriyappa, 1999).

The population of grasses were practically zero in 45-day solarized plots and fumigated plots. *Digitaria ciliaris* and *Eleusine indica* were the major grasses observed in the area and were controlled effectively by solarization. Excellent control of grasses by solarization was also reported by Katan (1980), Standifer *et al.* (1984); Braun *et al.* (1987); Ragone and Wilson (1988) and Yaduraju and Ahuja (1990).

Contrary to the results obtained in 45 and 30-day solarized plots, the population of weeds in 15-day solarized plots were significantly higher compared

to non-solarized control at 30 and 60 DAS. Solarization for a short period might have helped to break the dormancy of weed seeds which germinated with greater vigour afterwards. Yaduraju and Ahuja (1990) reported a similar case of enhanced weed population due to short-term solarization.

The results suggest that biofertilizers have not much effect on the germination of weed seeds, though in some cases interaction effects were significant when combined with solarization.

5.1.5   Solarization and biofertilizer effects on crop growth

Growth parameters of cocoa seedlings

Solarization at different intervals (15, 30 and 45 days) and fumigation had significant effect on growth parameters of cocoa seedlings (height (Fig.3), collar girth, number of leaves, leaf area (Fig.4), leaf dry weight and total plant dry weight). Seedlings in 45 and 30 day solarized plants and fumigated plots showed superiority at all the stages of observation. It is natural to assume that weed free conditions during germination have provided a better start for the crop.

According to Yaduraju (1993), increased growth response following soil solarization is likely to result from reductions of major factors limiting plant growth such as fungal or bacterial pathogens, soil borne insects and weeds rather than an increased availability of mineral nutrients. It has been shown from extensive studies in different soil types and nutrient sources that increase in levels of soil nutrient due to solarization are transient and do not persists for long. Increased plant growth parameters as a result of solarization was reported in many crops, for instance, peach seedling (Stapleton and DeVay, 1982), sorghum (Habeeburrahaman, 1992), sunflower (Bhasker and Nanjappa, 1997), tobacco (Meti, 1993), chillies (Kurian, 1992) and ginger (Vilasini, 1996).
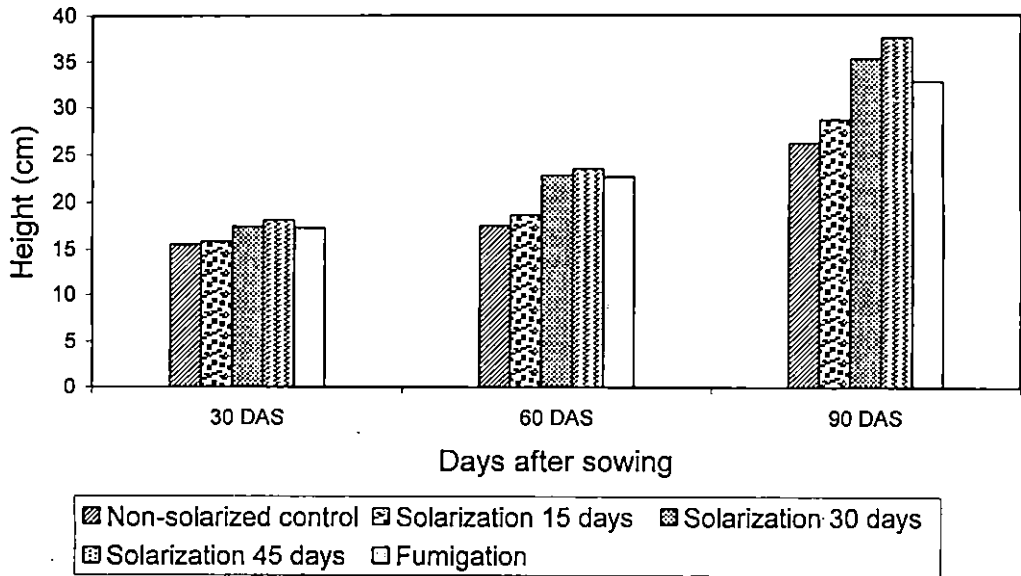
Fig. 3. Effect of soil solarization on height of cocoa seedlings
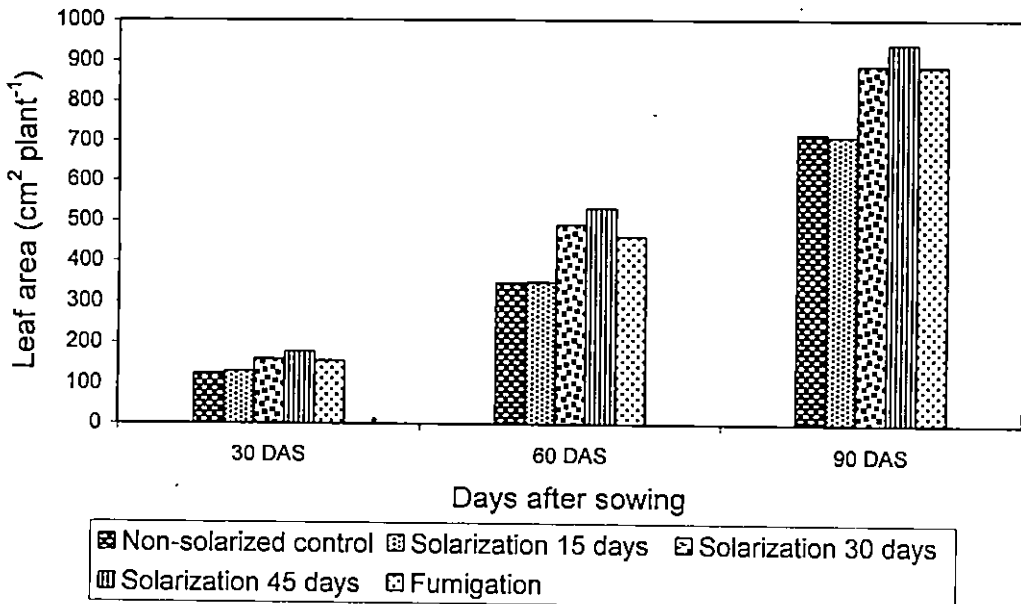
Fig. 4. Effect of soil solarization on leaf area of cocoa seedlings

Biofertilizer application also had significant effect on growth characters like leaf area (Table 18), leaf dry weight (90 DAS) and total plant dry weight (90 DAS). There were significant differences in growth characters between biofertilizer applied and control plots. Nevertheless, there were not much differences between different biofertilizer treatments.

Favourable growth of inoculated plants over un-inoculated control could be attributed to many reasons viz., increased nutrient uptake, hormonal effects of indole acetic acid, gibberellines and cytokinenes released by microorganisms or indirectly affecting the balance between harmful and beneficial organisms in the rhizosphere or by production of antibiotics and quinones which are known to give protection to plants against plant pathogens (Sivaprasad *et al.*, 1984 and Cuenca *et al.*, 1990). All the biofertilizers used in the study were positively influenced one or other characters which in turn, influenced the overall growth of seedlings. Increased plant growth due to biofertilizer application (VAM and *Azosporillum*) was reported by many workers in cocoa (Govindan and Nair, 1984; Cuenca, 1990), cashew (Sivaprasad *et al.*, 1992; Remesh *et al.*, 1998), coffee (Swarupa, 1996) and mulberry seedlings (Das *et al.*, 1995).

The significant interaction effect of solarization and biofertilizers noticed in the case of collar girth (Table 16a, b&c) and number of leaves (60 DAS), showed that the combination had some added effects than individual effects. The treatment 45-day solarization + biofertilizer (*Azospirillum* + VAM) application was found to be the superior combination compared to others. Thirty day solarization + *Azospirillum* + VAM was also found better. Kurian (1992) suggested that VAM combined with soil solarization could be one of the approaches to increase plant growth as a non-chemical method because solarization inhibits deleterious micro-organisms which inhibit VAM infection.

Earliness in reaching budding stage

The overall growth improvement due to solarization and biofertilizer application helped in attaining early budding stage in seedlings (Table 21). In this experiment attempt to select seedlings which reached buddable stage was first done after 107 days of sowing. This continued upto 38 days and stopped when more than 90 per cent of the seedlings were selected and also when no further selection was not possible due to poor growth. The treatment 45 and 30-day solarization and fumigation showed the highest early removal of seedlings. A progressive total of 98.53 per cent, 97.98 per cent and 97.51 per cent of seedlings could be selected for budding by 144 days in these treatments whereas only 60.49 per cent could be taken for budding on non-solarized plots by this time. The weed free conditions from germination onwards created a competition free environment which is conducive for early vigorous growth of seedlings in all the above promising treatments. The increased collar girth observed at 30, 60 and 90 DAS is a clear indication of vigorous growth of seedlings for early budding. At all the stages the collar girth was significantly higher in solarized and fumigated plots.

Earliness in attaining buddable girth of seedlings is important as it reduces the total nursery period. This ultimately gives vigorous and healthy seedlings or budlings for planting in the shortest time. The results indicated that the application of biofertilizers had its influence on attaining earliness for budding. This is to be expected as any effects on the over all growth of seedlings as seen in the case of collar girth, height, number of leaves, leaf area, leaf dry weight and total plant dry weight of seedlings at different stages of growth will have a bearing on attaining earliness in budding. The effects of biofertilizers were more apparent at the first removal of seedlings for budding. Progressive total at the last date was also significant in biofertilizer applied plots.

5.1.6   Post-solarization effects with biofertilizers on the soil microflora in the nursery

After subjecting the potting mixture to various solarization treatments and fumigation, cocoa nursery was set up and biofertilizers were applied. In the post-solarization scenario also, the simple effects of solarization and fumigation were apparent. The fumigated soil continue to be with the least count of micro-organisms even after 90 DAS (Table 22a to 24c). In other solarized treatments, there were substantial improvements in the count of organisms. Nevertheless, upon the passage of time, recolonization occurs in various plots and except in fumigated plots, the count almost reached as that of 15-day solarized plots by 90 DAS.

Simple effects of biofertilizers were not significant by 30 DAS on soil microflora. However, by 60 DAS and 90 DAS, it also showed positive influence in the count of fungi. Actinomycets showed any effects only at 90 DAS. Nevertheless, bacterial count was unaffected. In the case of fungi at 60 and 90 DAS, the treatments VAM and *Azospirillum* + VAM showed significantly lower count than no-biofertilizer treatment. The count in *Azospirillum* applied (alone) plots were higher than VAM and VAM + *Azospirillum* but on par with no-biofertilizer treatment. This effect can be attributed to the effect of VAM on several disease causing fungi (Rao, 1977; Nair and Peethambaran, 2000). Nair and Peethambaran (2000) reported reduction in *Fusarium, Phytophthora* and *Thielaviopsis* due to the inoculation of VAM. Reported mechanisms include higher concentrations of phenolic compounds in mycorrhizal roots and enhanced enzymatic activity detrimental to soil borne fungi.

By 90 DAS, an increased actinomycetes population was observed in VAM applied plots than no-biofertilizer plots. Most probably, the toxic effect of VAM on disease causing fungi, may have favoured the growth of actinomycetes.

At all the stages, solarization treatments and biofertilizers interacted. The effects of biofertilizers were more apparent in 30 day and 45 day solarized plots. As expected in fumigated plots, interaction was not apparent probably because of the persistance of toxic residues in the soil. It is persumed that microorganisms from the biofertilizers could not establish in fumigated soil because of its toxic effects.

5.2 Experiment II – Pre-emergence herbicides for the control of weeds in cocoa nursery

5.2.1 Effect on weeds

All the herbicides included in the study were effective in reducing the population (Table 26; Plate 3) and dry matter production (Table 27) of weeds upto 30 days. In the herbicide applied plots, no weeds emerged upto 30 DAS. However, the treatments pendimethalin (1.5 kg ha^{-1}), oxyfluorfen (0.3 kg ha^{-1}) and diuron (2 kg ha^{-1}) were able to keep the fields weed free for 90 days, the last stage of observation tried in the present experiment. Laprade *et al.* (1989) reported good control of weeds in cocoa nursery using diuron 1.5 kg ha^{-1} and oxyfluorfen 0.5 kg ha^{-1}. Lakshmanan *et al.* (1995) reported that diuron @ 2.5 kg ha^{-1} could control weeds for a period of 120 days in rubber nursery. Rao (2000) reported that diuron is ideal for the control of emerging weeds in tea, cotton, coffee, grapes, pineapple, apples, pears and many other tree crops, at the rate of 0.8-2.5 kg ha^{-1} as pre-emergence spray. It has a field half life of 90 days. Oxyfluorfen is also recommended in several crops at 0.25-2.0 kg ha^{-1} including soybean, groundnut, cassava, pulses, tea, rubber, oil palm, vegetable and rice. Its field life is 35 days. Pendimethalin is registered for use in cotton, maize, tobacco, sorghum, wheat groundnut, sun flower, rice, sugarcane, fruit crops, vegetables, potato etc. at 0.5-2 kg ha^{-1}. Pendimethalin has a field half life of 44 days (Rao, 2000).

3a

3b

3c

3d

Plate 3. One month old cocoa seedlings in potting mixture treated with
pre-emergence herbicides

3a – Unweeded control   3b – Fluchloralin 1.5 kg ha^{-1} (Note the phytotoxicity)
3c – Oxyfluorfen 0.3 kg ha^{-1} 3d – Pendimethalin 1.5 kg ha^{-1}

The weed control efficiency of 100 per cent even after 90 days shows that the dosages tried here – diuron 2 kg ha^{-1}, oxyfluorfen 0.3 kg ha^{-1} and pendimethalin 1.5 kg ha^{-1} – are enough to have a weed free nursery upto 90 days. In normal circumstances, this much weed free period, is enough as budding starts by this time and any further germination of weeds is not likely to take place because of the shading effects (Table 28).

The application of atrazine (2 kg ha^{-1}), alachlor (2 kg ha^{-1}), metolachlor (1.5 kg ha^{-1}) and fluchloralin (1.5 kg ha^{-1}) were not as effective as that of the above mentioned promising herbicides in controlling weeds beyond 30 days.

5.2.2   Effects on growth parameters of cocoa seedlings

The plant growth parameters (height (Fig.5), collar girth, number of leaves, leaf area per plant (Fig.6), leaf dry weight and total plant dry weight) in all the herbicide treatments were found superior to unweeded control. Among the herbicide applied plots, seedlings in oxyfluorfen (0.3 kg ha^{-1}), pendimethalin (1.5 kg ha^{-1}) and atrazine (2 kg ha^{-1}) applied plots showed superiority over others in growth characters like height, leaf area per plant, and leaf dry weight. These treatments were superior even to hand weeded plot. Fluchloralin applied plots showed inferiority in growth characters compared to others.

It is obvious that the low growth parameters of cocoa seedlings in unweeded plots is due to the weed competition from germination, and thus the initial growth suffered. The growth reduction in fluchloralin applied plots is apparently not due to weed competition but due to phytotoxicity of the herbicide on seedlings at the applied dosage - 1.5 kg ha^{-1} (Plate 3). Phytotoxic symptoms due to application of fluchloralin (0.9 kg ha^{-1}) was reported in potato (Trivedi *et al.*, 2001).

Fig. 5. Effect of pre-emergence herbicides on height of cocoa seedlings

Legend:
- Diuron 2 kg ha-1
- Alachlor 2 kg ha-1
- Oxyfluorfen 0.3 kg ha-1
- Metolachlor 1.5 kg ha-1
- Weed free
- Atrazine 2 kg ha-1
- Pendimethalin 1.5 kg ha-1
- Fluchloralin 1.5 kg ha-1
- Untreated control

Fig. 6. Effect of pre-emergence herbicides on leaf area on cocoa seedlings ht of cocoa seedlings

Legend:
- Diuron 2 kg ha-1
- Alachlor 2 kg ha-1
- Oxyfluorfen 0.3 kg ha-1
- Metolachlor 1.5 kg ha-1
- Weed free
- Atrazine 2 kg ha-1
- Pendimethalin 1.5 kg ha-1
- Fluchloralin 1.5 kg ha-1
- Untreated control

Most of the growth characters of cocoa seedlings were lower in weed free control than in the herbicide applied plots. Ries (1976) reported cases of increased growth and yield of crops, due to the application of herbicides. He reported several cases involving 2,4-D, simazine, atrazine, terbacil, diuron, DNOC, bensulide etc. The mechanisms behind the observed increase in growth is still unclear. Nevertheless, Ries (1976) attribute the increase in growth to increased nitrogen absorption or metabolism. Another possible reason is the complete elimination of competition from weeds from the germination time onwards. In the present experiment weed free control was maintained by hand weeding once in 14 days. Chances of some weed germination and competition for resources with young cocoa seedlings though on a lower degree would be likely in this situation.

5.2.3   Earliness in reaching budding stage

Earnliness in reaching budding stage is an indication of efficient nursery management. In the present experiment, attempts to select seedlings which reached buddable stage was first done after 110 days after sowing. This continued for 30 days (6-5-2001 to 5-6-2001) and stopped when more than 90 per cent of the seedlings were selected and also when no further selection of seedlings was possible due to poor growth. The herbicide treatments, oxyfluorfen, pendimethalin and atrazine, were efficient in attaining the maximum number of buddable seedlings early (Table 35). These treatments produced the maximum number of total buddable seedlings at the end of the experiment. This is to be expected as weed free conditions maintained in the treatments with no apparent phytotoxicity (but with some beneficial effects on growth) favourably influenced almost all the growth parameters especially height, collar girth, number of leaves per plant, leaf area, total dry matter production etc.

5.2.4   Effects of herbicides on soil microflora

Herbicides are known to influence the biological life in the soil which in turn affect many complex beneficial biochemical transformations in soil. In the present experiment, application of herbicides, in general, reduced the population of soil fungi, bacteria and actinomycetes.

The population of fungi was affected by the application of most of the herbicides even one day after application (Table 36a; Fig.7).

Fig. 7. Effect of pre-emergence herbicides on population of soil fungi
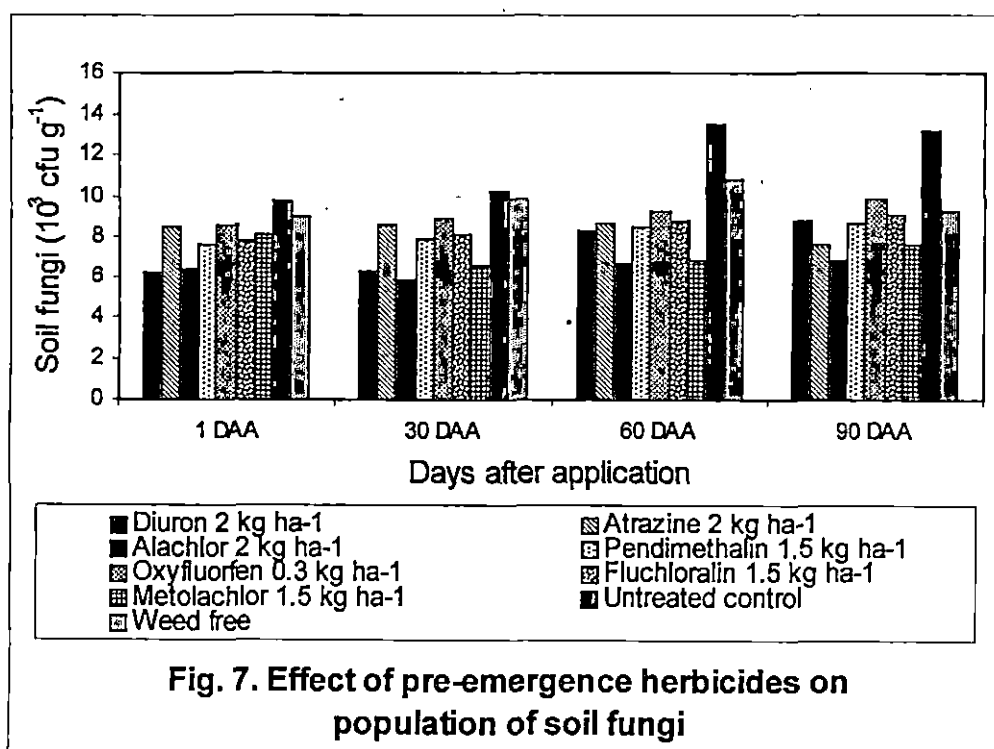
Diuron applied plots were the worst affected (6.1 x 10^3 cfu g^{-1}) and alachlor, pendimethalin and fluchloralin applied plots were similar to these. However, there were not much reduction in oxyfluorfen and atrazine applied plots compared to untreated control indicating that these two are relatively safe to fungi. A change in the pattern of population build up of fungi was observed 30 DAA of herbicide. While there was increase in the population in some treatments there was

reduction in some other treatments, compared to previous count. At 60 and 90 DAA in general, there was an increase in population of fungi compared to 30 DAA. Still, maximum population of fungi was noted in untreated control followed by hand weeded plots showing the residual effects of herbicides even at 90 DAA.

Compared to fungi and actinomycetes, bacteria was the most affected due to herbicide application. Herbicides differed in their effects on bacteria (Table 36b; Fig.8).

Fig. 8. Effect of pre-emergence herbicides on population of soil bacteria
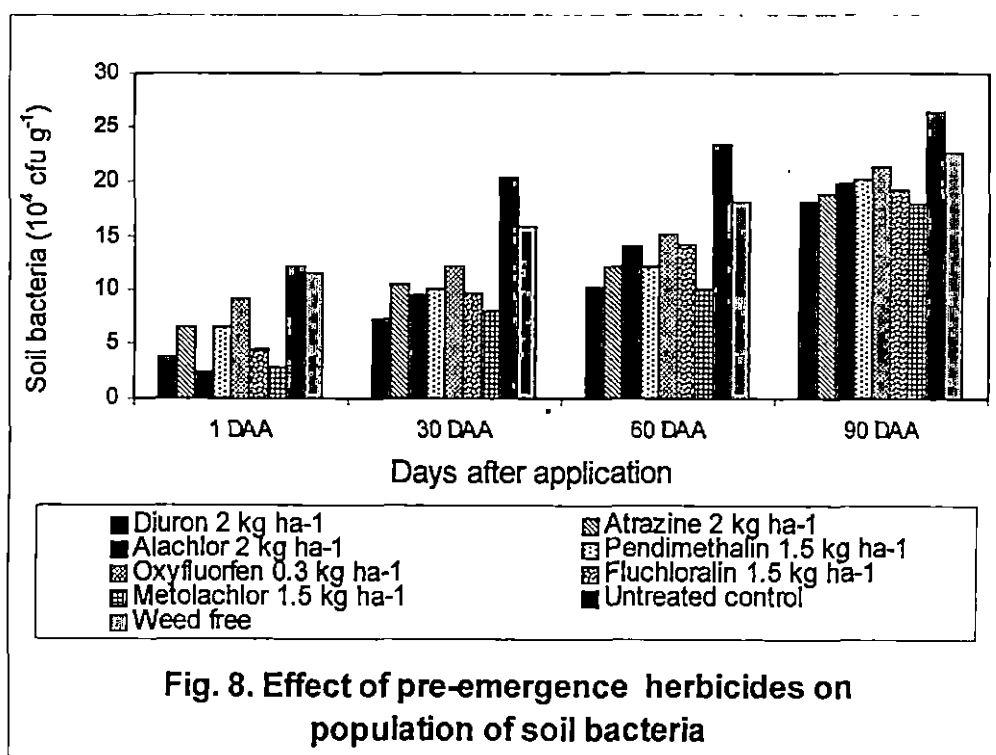
Alachlor, metolachlor and diuron applied plots showed the maximum reduction on bacterial population at one DAA. Oxyfluorfen applied plots showed the minimum reduction. Still, the population was significantly lower than untreated control. There was a substantial increase in the population of bacteria when the population was estimated at 30, 60 and 90 DAA compared to previous count. Among the herbicide .applied plots, oxfluorfen showed rapid build up of bacteria and by 90 DAA the population was on par with the hand weeded plot.

Nevertheless, the herbicides, metolachlor, atrazine, diuron and fluchloralin still showed lower bacterial population than untreated control at 90 DAA.

The herbicidal effects on actinomycetes population were almost similar to bacteria (Table 36c; Fig.9).

Fig. 9. Effect of pre-emergence herbicides on population of actinomycetes
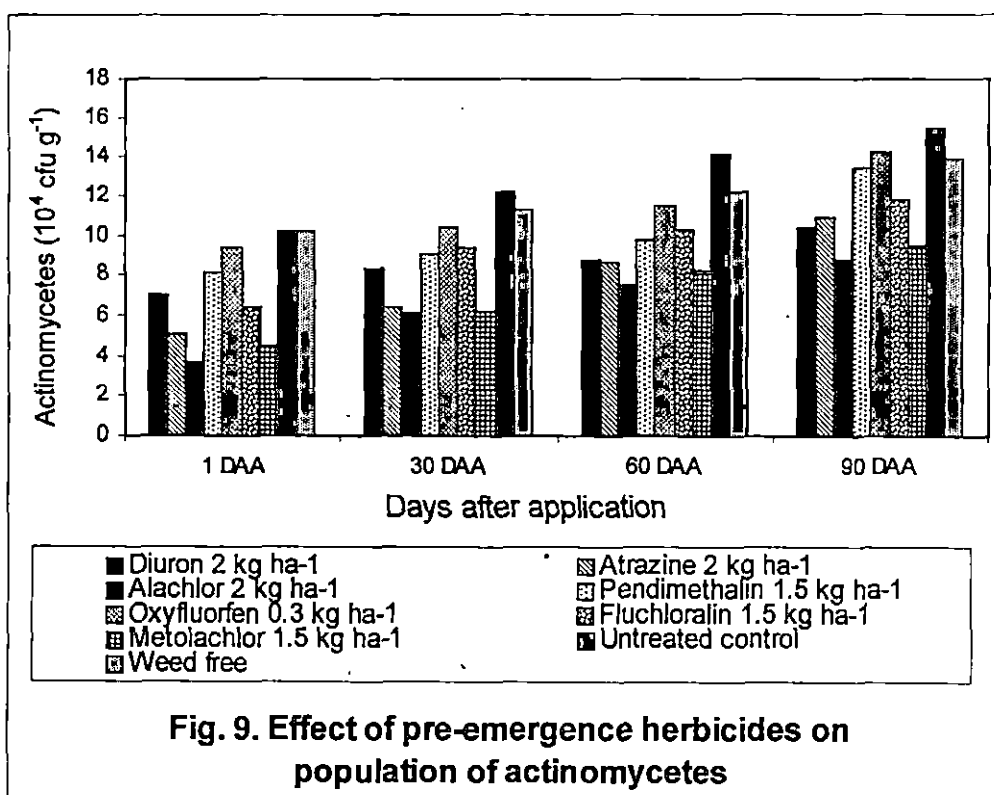
A significant reduction in actinomycetes population was observed in all the herbicide applied plots except oxyfluorfen at one day after application of herbicides. The population reduction was more prominent in alachlor applied plots followed by metolachlor applied plots. There was an increase in population when estimated at 30, 60 and 90 DAA. However, the differences among the treatments were significant during these stages too. At 60 DAA, the population in oxyfluorfen applied plots were on par with hand weeded plot and at 90 DAA, it was on par with unweeded control. The herbicides alachlor, metolachlor and diuron were the worst affected which showed adverse effect even at 90 DAA.

From the results, it is clear that all the herbicides included have adverse effects on the population of fungi, actinomycetes, and bacteria. A reduction in the microbial population due to the application of herbicides had been reported by many workers (Kumar *et al.*, 1987; Jaryal *et al.*, 1989; Nalayini and Sankaran, 1991 and Nayak *et al.*, 1994). The results obtained in the present experiment are also in similar lines. However, the differences in the toxic effects of different herbicides on microbial population was quite apparent. Herbicides belonging to the group, chloroacetamides - alachlor and metolachlor, were the worst herbicides in terms of reduction in microbial population. Oxyfluorfen was found to be relatively safe to all the microorganisms studied. Eventhough in course of time, the effects of herbicides seems to be vanishing, still lower count was observed compared to untreated control even at 90 days after application. It is inferred that many of the herbicides used are inhibitory to soil microorganisms and microbial activity and biological equilibrium in the soil is disturbed upon its application. As Jaryal *et al.* (1989) suggested the toxic effects of the herbicides might be nullified due to their degradation in soil. However, it is gradual and takes considerable time to regain the original status. The finding stressed the point that while suggesting herbicides for large scale use, in addition to their economic viability and effectiveness on target weed and their effect on the soil ecosystem shall also be taken into consideration.

6. SUMMARY

Experiments were conducted during 2000-2001 at the cocoa nursery of Cadbury-KAU Co-operative Cocoa Research Project attached to the College of Horticulture, Kerala Agricultural University, Thrissur to develop appropriate weed management strategies for cocoa nursery. The main objectives of the investigation were to test the feasibility of solarization and fumigation as measures of weed control in cocoa nursery and to determine the effects of *Azospirillum* and VAM inoculation in nurseries coupled with solarization and fumigation on the growth of cocoa seedlings and weed growth. Another objective of the investigation was to suggest a suitable pre-emergence herbicide for preventing germination of weeds in the nursery.

The investigation consisted of two experiments (1) Influence of soil solarization and biofertilizers on the growth of cocoa seedlings and weed flora. (2) Pre-emergence herbicides for the control of weeds in cocoa nursery.

The experiment on solarization and biofertilizers (Experiment I) was laid out in 5 x 4 factorial in CRD with three replications. Solarization at different intervals (15, 30 and 45 days) and fumigation were compared together with biofertilizers (*Azospirillum*, VAM, *Azospirillum* + VAM). The experiment on pre-emergence herbicides (Experiment II) was laid out in completely randomised design with 9 treatments and three replications. The treatments included diuron (2 kg ha^{-1}), alachlor (2 kg ha^{-1}), atrazine (2 kg ha^{-1}), pendimethalin (1.5 kg ha^{-1}), oxyfluorfen (0.3 kg ha^{-1}), fluchloralin (1.5 kg ha^{-1}), metolachlor (1.5 kg ha^{-1}), untreated control and weed free situation maintained by handweeding fortnightly. The salient findings of the study are summarised below.

(1)   The weed flora of cocoa nursery was dominated by broad leaf weeds, predominant being *Borreria hispida, Ludwigia perennis, Amaranthus viridis* and *Mullugo pentaphylla. Digitaria ciliaris* and *Eleusine indica* were the major grasses observed in the nursery.

(2)   Solarization increased the soil temperature. The soil temperature difference at 5 cm depth ranged from 7°C to 9.5°C higher than the temperature in non-solarized plots. The highest weekly mean temperature in solarized plot was 45.6°C and the highest maximum temperature observed on a single day was 48°C, whereas the respective temperature for non-solarized plots were 35.94°C and 38.5°C.

(3)   Solarization reduced the population of fungi, bacteria and actinomycetes in potting mixture. The reduction varied with period of solarization. The highest reduction was in 45 day solarized plots.

(4)   Fumigation with dazomet (@ 30 g m^{-2}) also reduced the soil microbial population considerably.

(5)   Solarization increased the availability of certain nutrients in 30 and 45 day solarized plots. There were improvements in available phosphorus, exchangeable potassium, calcium and magnesium status where as there were no changes in organic carbon, total nitrogen, ammoniacal nitrogen and nitrate nitrogen.

(6)   Solarization for 45 and 30 days and fumigation reduced the weed population and weed biomass considerably. However, 15 day solarization increased weed growth.

(7)   Biofertilizers do not have much effect on the germination of weed seeds, though in some cases interaction with solarization and biofertilizer was significant.

(8)   There were improvements in the growth parameters of seedlings in 45 and 30 day solarized and fumigated plots, whereas the response to biofertilizer application was comparatively less eventhough there were differences

among control and biofertilizer applied plots. All the biofertilizer applied plots had improved the characters like height, collar girth, number of leaves, leaf area, leaf dry weight and total plant dry weight. Nevertheless, certain characters showed interaction between solarization and biofertilizers. Solarization for 45 days with application of *Azospirillum* + VAM was found to be superior to other combinations in the case of important growth parameters of cocoa such as collar girth and number of leaves per plant.

(9)   In the cocoa nursery, in the post-solarization and fumigation phase, the population of soil microflora continue to be the lowest in fumigated plots even after 90 days. However, there were substantial improvement in the population of microorganisms in solarized plots from 30 DAS to 90 DAS.

(10)   The overall growth improvement due to solarization and biofertilizer application helped in attaining in early budding stage of cocoa seedlings. The treatments, 45 and 30-day solarization and fumigation had higher selection of seedlings for budding. In the above treatments 98.53, 97.98 and 97.56 per cent seedlings could be removed for budding by 144 days; whereas only 60.49 per cent could be taken for budding in non-solarized plots by this time.

(11)   All the pre-emergence herbicides tried in the experiment and weed free control gave 100 per cent weed control for the first month. However, oxyfluorfen, pendimethalin and diuron maintained this condition even after 90 DAS. Herbicide application reduced the weed biomass also.

(12)   The plant growth parameters of cocoa seedlings in all the herbicide applied treatments except fluchloralin applied plots, were improved over unweeded control; the treatment with atrazine was superior to weed free control, but on par with oxyfluorfen and pendimethalin.

(13)   The highest number of buddable seedlings and also earliness in attaining buddable collar girth were observed in oxyfluorfen, pendimethalin and atrazine herbicides applied plots.

(14)   All the herbicides tried in this study affected the microbial population (fungi, bacteria and actinomycetes). Herbicides belonging to the group chloroacetamides (alachlor and metolachlor) were the worst herbicides in terms of reduction in microbial population. Oxyfluorfen was found to be a relatively safe herbicide for maintaining microorganisms population.

Conclusion

The results clearly shows that solarization for 30-45 days is a promising non-chemical method for preventing germination and growth of weeds in cocoa nursery. Fumigation with dazomet (30 g m^{-2}) is also very effective in weed control on par with solarization. Solarization influenced the nutrient dynamics of soil by increasing the available P, exchangeable K, Ca and Mg. The solarization (30-45 days) and fumigation also had their influence on the growth of cocoa seedlings and they yielded the maximum number of seedlings for budding besides attaining buddable girth earlier. Biofertilizer application, though had not much effect on weed control, influenced cocoa seedling growth. The combination of 45 days solarizaion with VAM + *Azospirillum* application was more effective not only in controlling weeds but also increasing the growth of cocoa seedlings.

Pre-emergence herbicides such as oxyfluorfen (0.3 kg ha^{-1}) pendimethalin (1.5 kg ha^{-1}) and diuron (2.0 kg ha^{-1}) were effective in maintaining a weed free condition up to 90 days after sowing. However, the application of atrazine, oxyfluorfen and pendimethalin showed some phytotonic effect on cocoa seedlings. This effect was helpful to the cocoa seedlings to attain required buddable collar girth earlier. The herbicides, in general, reduced the population of microorganisms considerably. However, oxyfluorfen was relatively safe to

microorganisms. Taking into consideration the herbicide effects on the control of weeds, growth of cocoa seedlings and maintenance of microbial population oxyfluorfen (0.3 kg ha^{-1}) and pendimethalin (1.5 kg ha^{-1}) can be recommended for weed control in cocoa nursery.

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* Originals not seen

Appendices

APPENDIX-1

Maximum and minimum atmospheric temperature, soil temperature, sunshine hours and rainfall during the solarization period
(16-11-2000 to 31-12-2000)

Date	Atmospheric temperature		Soil temperature (°C) at 5, 10 and 15 cm depth)												Sunshine (Hours)	Rainfall (mm)
	Maximum	Minimum	Solarized soil						Non-solarized soil							
			5 cm		10 cm		15 cm		5 cm		10 cm		15 cm			
			7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30		
16-11-2000	33.0	25.5	30.0	46.0	28.5	39.0	28.5	35.5	24.5	37.0	26.0	32.5	26.0	30.5	9.8	0
17-11-2000	32.4	25.5	29.0	43.0	28.0	36.0	28.5	34.0	25.0	35.0	25.5	32.5	26.0	30.5	5.6	0
18-11-2000	30.0	22.6	28.0	41.0	27.5	36.0	27.5	33.0	24.5	35.0	25.0	32.0	25.0	30.0	8.4	0
19-11-2000	31.2	25.0	30.0	38.0	28.0	35.0	28.5	31.0	25.5	32.0	25.5	30.0	25.5	29.0	8.0	0
20-11-2000	27.6	24.0	28.0	38.0	28.0	33.0	27.5	31.0	25.5	31.0	26.5	30.0	26.5	28.5	5.5	4
21-11-2000	31.6	22.4	29.5	45.5	29.0	36.0	28.0	34.0	25.0	34.0	25.5	36.0	26.5	30.0	6.2	2.3
22-11-2000	31.6	23.4	20.0	46.0	28.5	37.0	28.0	34.0	25.0	37.0	25.5	33.0	26.0	30.0	6.4	0
23-11-2000	31.5	25.5	30.0	42.8	29.0	36.0	28.5	33.0	25.5	35.0	26.0	32.0	26.5	29.5	6.8	5.3
24-11-2000	31.5	24.0	30.0	42.0	29.0	35.7	28.0	33.2	25.0	35.6	26.0	33.0	26.0	29.5	5.3	0
25-11-2000	33.0	22.7	30.0	43.0	28.5	40.0	28.0	37.1	25.2	38.0	26.3	33.0	26.5	30.0	9.1	0
26-11-2000	32.2	22.2	29.0	45.0	28.5	39.2	28.5	36.0	25.4	38.5	26.2	34.0	26.5	30.0	9.7	0
27-11-2000	32.6	21.5	31.0	46.0	30.0	40.0	29.0	36.2	25.5	37.0	27.0	35.7	26.2	29.6	8.8	0
28-11-2000	32.0	21.8	20.0	45.0	29.0	38.6	28.2	35.0	25.6	37.5	26.4	33.5	26.5	30.0	7.5	3.2
29-11-2000	32.0	21.8	29.0	43.0	28.5	37.0	28.5	34.0	24.8	36.0	26.5	33.0	26.2	28.5	6.4	3.4
30-11-2000	30.4	22.6	31.0	43.2	28.5	36.5	28.0	33.0	25.0	34.2	26.0	32.5	26.0	30.0	5.6	0
1-12-2000	31.8	21.0	29.0	43.0	28.5	36.2	27.0	34.0	25.0	34.3	25.5	32.0	25.0	29.4	6.2	3.3
2-12-2000	31.4	21.4	30.2	44.3	29.0	38.4	28.0	35.0	25.0	36.5	25.5	36.0	25.0	32.1	6.8	0
3-12-2000	31.8	24.0	29.0	45.0	29.0	38.2	30.0	35.0	25.5	36.0	26.0	34.0	25.0	30.0	9.6	0
4-12-2000	32.6	22.3	30.0	48.0	29.5	39.0	28.0	35.0	25.0	37.0	27.0	35.0	26.0	34.1	9.6	0
5-12-2000	31.4	24.5	31.0	44.0	30.0	37.0	31.0	35.4	26.0	35.0	26.0	33.7	27.0	30.0	9.6	0
6-12-2000	29.8	24.4	30.1	46.0	29.0	38.0	30.0	35.2	25.5	36.0	25.1	36.0	26.2	29.8	5.5	0
7-12-2000	30.0	22.4	29.2	45.0	28.2	38.2	28.0	35.0	25.5	35.5	26.0	34.1	25.2	30.0	8.3	0
8-12-2000	30.8	22.4	29.1	45.4	28.2	38.0	28.0	35.1	25.1	35.6	26.0	32.0	25.7	29.0	9.6	0
9-12-2000	31.2	22.8	30.0	47.0	28.0	39.1	29.8	35.2	25.0	36.0	26.0	33.0	27.0	31.0	9.5	0
10-12-2000	30.6	23.0	29.2	44.0	28.2	37.3	27.5	35.2	25.5	35.0	25.5	34.0	26.0	30.0	9.5	0
11-12-2000	31.0	22.0	30.0	45.2	29.0	38.5	29.0	35.1	25.0	36.0	25.5	33.0	25.5	30.0	9.6	0
12-12-2000	30.6	21.2	30.0	45.1	28.2	39.0	28.5	35.5	25.5	37.0	26.0	33.1	25.6	30.0	9.6	0

Date	Atmospheric temperature		Soil temperature (°C) at 5, 10 and 15 cm depth)												Sunshine (Hours)	Rainfall (mm)
			Solarized soil						Non-solarized soil							
	Maximum	Minimum	5 cm		10 cm		15 cm		5 cm		10 cm		15 cm			
			7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30	7.30	2.30		
13-12-2000	31.6	21.6	29.1	45.5	27.0	39.1	29.0	38.0	25.0	36.5	26.0	33.5	26.5	30.0	9.6	0
14-12-2000	31.6	20.6	30.0	46.0	28.0	39.5	29.0	35.5	24.7	36.7	26.0	33.5	26.0	31.0	9.7	0
15-12-2000	31.4	19.4	29.2	45.5	27.0	39.1	28.0	35.0	24.8	36.0	25.6	33.6	26.0	29.0	9.7	0
16-12-2000	31.0	21.5	29.1	45.0	27.5	38.5	28.0	35.5	25.1	36.0	25.2	33.0	2.58	29.0	9.8	0
17-12-2000	30.6	23.2	30.0	46.0	28.0	40.0	28.5	35.6	25.0	36.5	25.5	33.5	2.60	30.5	9.9	0
18-12-2000	31.8	22.8	29.1	45.0	28.4	38.1	28.0	35.2	25.1	35.4	25.5	32.0	2.60	30.4	8.8	0
19-12-2000	32.0	22.7	29.5	45.1	28.5	40.1	28.1	36.0	25.0	36.0	25.6	33.0	25.7	30.1	6.8	0
20-12-2000	31.8	22.4	29.0	46.2	28.2	38.5	28.3	35.2	24.8	37.0	25.7	34.0	25.4	30.0	6.2	0
21-12-2000	31.2	22.4	28.4	44.5	28.5	39.0	28.3	34.5	24.7	35.8	25.6	33.0	25.3	29.1	8.8	0
22-12-2000	31.0	22.8	29.0	43.2	28.8	39.1	27.5	35.2	25.0	36.0	25.3	33.0	26.0	29.2	8.4	0
23-12-2000	32.0	22.0	29.0	45.3	28.1	38.7	29.0	35.0	25.1	34.7	26.5	32.8	26.0	30.1	6.6	0
24-12-2000	32.4	23.0	29.4	46.1	28.4	39.1	29.2	36.0	25.2	35.1	26.3	33.0	26.2	31.0	5.6	0
25-12-2000	32.6	19.5	29.0	45.2	28.0	38.6	29.0	35.8	25.0	34.9	26.0	32.8	26.0	30.5	7.6	0
26-12-2000	32.2	19.0	28.7	45.0	58.1	38.0	28.8	35.0	24.7	35.0	25.8	32.4	26.1	30.0	8.6	0
27-12-2000	29.2	22.2	28.4	43.0	27.5	36.8	28.0	34.2	24.4	34.0	25.0	32.0	25.4	29.0	9.5	0
28-12-2000	28.2	21.0	28.0	43.2	27.8	36.5	28.5	34.5	24.8	34.5	25.0	32.5	25.2	29.5	7.0	3.2
29-12-2000	30.2	23.5	28.5	43.5	28.0	37.1	28.7	34.6	25.1	34.7	25.3	33.0	25.5	29.6	5.5	0
30-12-2000	31.8	22.8	28.2	44.0	27.8	36.0	28.6	34.7	25.3	35.1	25.1	32.5	25.7	29.4	7.4	2.0
31-12-2000	31.8	22.0	28.6	45.1	27.9	36.5	29.0	35.0	24.8	35.0	25.2	32.6	25.8	29.7	8.5	2.8

APPENDIX-2

Weekly distribution of weather parameters (1-1-2001 to 31-5-2001)

Meteorological week	Temperature (°C)		Rainfall (mm)	Sunshine (h day^{-1})	Relative humidity	
	Maximum	Minimum			Morning	Afternoon
1	32.1	23.1	0	8.4	80	49
2	37.5	22.9	0	9.0	75	40
3	32.6	23.0	0	8.8	63.	34
4	33.5	23.4	0-	8.1	69	39
5	31.9	23.3	12.2	4.3	77	52
6	34.3	22.1	0	7.7	81	44
7	34.9	22.4	0	9.1	82	37
8	35.1	23.5	0	8.7	90	52
9	35.2	23.7	0 ·	8.7	85	49
10	35.0	23.5	2.2	8.1	89	57
11	35.2	23.4	0	8.6	88	57
12	34.3	24.2	0	7.2	85	54
13	34.3	25.2	2.2	8.0	87	54
14	35.7	25.3	7.1	6.3	85	62
15	33.1	23.4	190.6	53	90	64
16	33.7	24.8	44	8.4	89	65
17 (6/5)	34.3	25.5	1.4	6.3	90	63
18	33.5	25.4	13.0	6.0	78	65
19	33.0	25.5	0	7.1	88	62
20	32.8	25.0	18.1	8.4	89	64
21	31.4	23.5 ·	102.9	4.7	91	76
22	30.8	23.7	44.8	4.7	92	71

APPENDIX-3

Composition of media used in microbial studies

1. Martins Rose Bengal Agar (for fungus)

Dextrose	-	10.00 g
Petone	-	5.0 g
KH_2PO_4	-	0.5 g
$MgSO_4 7H_2O$	-	0.2 g
Rose Bengal dye	-	0.032 g
Streptomycin	-	0.025 g
Agar	-	20.00 g
Distilled water	-	1000 ml

2. Thortan's Standard Agar (for bacteria)

Mannitol	-	1 gm
Asparagine	-	0.5 g
$K_2H PO_4$	-	1 g
KNO_3	-	0.5 g
$MgSO_4$	-	0.2 g
$CaCl_2$	-	0.1 g
NaCl	-	0.1 g
Ferric chloride	-	0.002 g
Agar	-	20 g
Distilled water	-	1000 ml

3. Kenknight's Agar (for actinomycetes)

Glucose	-	1 g
KH_2PO_4	-	0.1 g
$NaNO_3$	-	0.1 g
KCl	-	0.1 g
$MgSO_4 7H_2O$	-	0.1 g
Agar	-	20 g
Distilled water	-	1000 ml

WEED MANAGEMENT IN COCOA NURSERY

By
P. V. SHYLAJA

ABSTRACT OF THE THESIS

**Submitted in partial fulfilment of the
requirement for the degree of**

Master of Science in Agriculture

**Faculty of Agriculture
Kerala Agricultural University**

**Department of Agronomy
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA
2001**

ABSTRACT

Experiments were conducted during 2000-2001 at the College of Horticulture, Kerala Agricultural University, Thrissur with the objective of suggesting appropriate weed management strategies involving solarization, fumigation, biofertilizers and herbicides for cocoa nursery. The investigation consisted of two experiments. In the first experiment, solarization at different intervals (15, 30 and 45 day) and fumigation were compared together with biofertilizers (*Azospirillum,* VAM, *Azospirillum* + VAM). Seven pre-emergence herbicides were screened in the second experiment along with weed free and untreated control.

The major weeds of the nursery area were broad leaf weeds. Solarization for 30 and 45 days and fumigation were very effective in controlling weed growth and biomass of weeds. The temperature at 5 cm depth was 7-9.5°C more than the non-solarized soil. Solarization for 30 and 45 days and fumigation reduced the population of fungi, bacteria and actinomycetes considerably. Increases in the availability of some nutrients - available P, exchangeable K, Ca and Mg - were also observed as a result of solarization for 30 and 45 days. Organic carbon, total nitrogen, ammoniacal nitrogen, nitrate nitrogen were unaffected.

Biofertilizers seems to have no appreciable effect on weed population and growth.

Solarization for 30 and 45 days and fumigation increased the growth of cocoa seedlings. Increased growth of seedlings resulted in early selection of seedlings for budding from this treatments. Biofertilizers also had significant influences on growth parameters of cocoa and earliness in attaining collar girth of buddable size. Certain growth characters showed interaction effects between

solarization and biofertilizers. Solarization for 45 days and *Azospirillum* + VAM was found to be a superior combination influencing collar girth at all the stages.

Among the pre-emergence herbicides tried, diuron (2.0 kg ha^{-1}), oxyfluorfen (0.3 kg ha^{-1}) and pendimethalin (1.5 kg ha^{-1}) were the most effective in weed control. Atrazine (2.0 kg ha^{-1}), oxyfluorfen and pendimethalin had effect on better growth of seedlings. The maximum number of recovery of stock seedling was from oxfluorfen applied plots; and it also had least effect on soil microorganisms. Alachlor (2.0 kg ha^{-1}) and metolachlor (1.5 kg ha^{-1}) were the worst in terms of reduction in microbial population.