INTEGRATED WEED MANAGEMENT IN OKRA

(*Abelmoschus esculentus* [L.] Moench.)

By

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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

2000

DECLARATION

I hereby declare that this thesis entitled **"Integrated Weed Management in Okra (*Abelmoschus esculentus* [L.] Moench.)"** 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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We, the undersigned members of the Advisory Committee of **Mr.K.Sainudheen,** a candidate for the degree of **Master of Science in Agriculture**, agree that the thesis entitled **"Integrated Weed Management in Okra (*Abelmoschus esculentus* [L.] Moench.)"** may be submitted by Mr.K.Sainudheen, in partial fulfilment of the requirement for the degree.

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ACKNOWLEDGEMENT

*I am deeply indebted to **Dr.C.T.Abraham**, Associate Professor, AICRP on Weed Control, College of Horticulture, Vellanikkara and chairman of my advisory committee for his constructive criticism, valuable advice and encouragement throughout the course of this investigation. I consider myself fortunate in having had the privilege of being guided by him.*

*My profound sense of gratitude is due to **Dr.N.N.Potty**, Professor and Head, Department of Agronomy and member of my advisory committee for his valuable suggestions and help rendered with understanding and forbearance.*

*I am indebted to **Dr.P.S.John**, Associate Professor, Department of Agronomy, College of Horticulture and member of my advisory committee for his solid and timely support at all stages of the thesis preparation.*

*My deep felt gratitude are also due to **Dr.S.Rajan**, Associate Professor and Head, Department of Olericulture, College of Horticulture, Vellanikkara and member of my advisory committee for his valuable suggestions.*

I wish to acknowledge the assistance and advice provided by Dr.R.Vikraman Nair, Associate Director of Research, Southern Zone, College of Agriculture, Vellayani, Dr.Mercy George, Dr.K.E.Savithri, Dr.Jose Mathew and Dr.C.George Thomas, Associate Professors, Department of Agronomy, College of Horticulture, Vellanikkara.

I wish to acknowledge Dr.P.V.Prabhakaran, Associate Dean (i/c), College of Horticulture, Vellanikkara, for the help rendered throughout the course of my project work.

The help received from Mr.Nandakumar and Mr.Paul, AICRP on Weed Control is remembered with gratitude.

I wish to express my gratitude to Smt.Joyce, Technical Assistant, College of Horticulture for the help in statistical analysis.

A special word of thanks Sri.Joy, J.M.J. Computers, Thottapadi for the neat and prompt typing of the manuscript.

I wish to express my gratitude to my seniors Deepa, Mini and Lency, my classmates Divya, Renu and my juniors Karthik, Lakshmi and Senthil and Sonia for their encouragement and help.

I also express cordial thanks to my friends, both post and undergraduates. More personally I would like to thank the sincere help and inspiration from Ajith (CB, K and Kumar), Murali, Sunil (Kumar, KM and Dutt), Sherin, Ashith, Mash, Pattabi, Subash, Sajnu, Renjith, Biju, Sanjeev, Shibu, Rajeev, Sreeja, Annie, Maya, Renu and Priya.

No words can explain the affection and gratitude to my beloved parents and family members who provided me the soothing shoulders in time of need.

Above all, I bow before God, the almighty for his bountiful blessings without which I could not have completed this endeavour successfully.

6-9-2000

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Dedicated to my beloved parents

INTRODUCTION

INTRODUCTION

Weeds are usually more adapted to any agroclimatic situation than the crop plants. Both share the same space and resources and if the crops are not protected, the weeds will invade, compete and take over the field.

Among all the pests (insects, animals, diseases and weeds) in India, weeds alone are responsible for one-third loss in crop production. Rao (1983) estimated 45 per cent loss of agricultural produce by weeds, 30 per cent by insects, 20 per cent by disease and 5 per cent by other pests. Estimates showed that weeds in India cause an annual monetary loss of Rs.19800 million (Mukhopadhyay, 1992). Besides reduction in grain yield, weeds remove large amount of nutrients from the soil and indirectly reduce the yield potential by serving as alternate hosts to a number of crop pests.

The magnitude of damage due to weeds vary with the crop and also with the nature of weeds. Vegetables are, in general, highly susceptible to weed infestation. Singh *et al.* (1993) reviewed the losses caused by weeds in vegetable crops and reported yield losses ranging from 6-82 per cent.

Okra (*Abelmoschus esculentus* L. Moench) commonly known as bhindi is one of the important vegetable crops in India and is grown in 4,20,000 ha with an annual production of four million tones. Okra is largely preferred on account of its tender green fruits, short duration and easiness in cultivation under wide range of growing conditions. Fruits of okra are rich in protein, fibre, mineral matter and fat. They are also good source of vitamins like A, B and C and minerals like calcium, magnesium and phosphorus.

Reduction in yield of okra due to weed competition has been reported to range from 59 to 90 pr cent (Singh *et al.*, 1982). Weed flora of the vegetable ecosystem include perennial and annual weeds. The perennials are reported to cause more economic loss, the important among them being *Cynodon dactylon* and *Cyperus rotundus*. These weeds are grouped under world's worst weeds, because of their fast spreading and highly competitive nature. Rattan *et al.* (1981) noticed that 75 per cent of the weed flora was shared by *Cynodon* and *Cyperus* along with *Echinochloa crusgalli* in an okra field.

In situation where both perennial and annual weeds are problematic for successful vegetable cultivation, only an integrated weed management system (IWMS) will be workable, because problematic weeds require judicious integration of the different components of weed management such as chemical, physical and cultural methods.

Solarization is a novel and ecofriendly method of weed control which is based on the principle that covering the soil with transparent polyethylene (TPE) films would trap the heat inside, resulting in raise in soil temperature to a level lethal to living plant tissues including weed seeds. Effectiveness of solarization for the control of most annual and perennial weeds has been reported by Katan (1980).

Ecofriendly weed management technique like smother cropping with cowpea and traditional methods like digging in the summer season or application of systemic herbicide glyphosate against *Cynodon* and *Cyperus* have been reported. Further annual weeds can be controlled by pre-emergence herbicides along with one hand weeding in the kharif season. Black polyethylene mulching is also a choice for supressing broad spectrum of weeds apart from modifying the bio-physico-chemical characters of the rhizosphere. Keeping these points in mind the current investigation was planned with the following objectives:

1. to study the effect of solarization on control of weeds especially *Cynodon dactylon* and *Cyperus rotundus*.
2. to compare the efficiency of glyphosate, smother cropping and monthly digging for weed control during the summer season and their effects in the subsequent okra crop.

3. to compare the efficiency of different pre-emergence herbicides and black polyethylene mulching for weed control in okra crop.
4. to develop an integrated method for managing the weeds, including perennial weeds like *Cynodon dactylon* and *Cyperus rotundus*, in the okra crop and
5. to study the crop-weed competition for major nutrients in okra crop.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

In an ecosystem where perennial and annual weeds are equally problematic, an integrated approach of two or more methods will be required for successful crop production. Perennial weeds like *Cynodon dactylon* and *Cyperus rotundus* and a number of annual weeds have been reported to be problematic for successful vegetable cultivation in major vegetable ecosystems of India and abroad. Literature showing the problems and management strategies of perennial and annual weeds in vegetables with special reference to okra are reviewed here.

2.1 Dominance of perennial weeds in vegetable crops

Dominance and competition of perennial weeds especially *Cynodon dactylon* and *Cyperus rotundus* in the vegetable ecosystems has been reported by many workers in India and abroad. Rattan *et al.* (1981) noticed that 75 per cent of the weed flora was shared by *Cynodon dactylon, Cyperus rotundus* and *Echinochloa crusgalli* in an okra field in Himachal Pradesh. In Madhya Pradesh, at Jabalpur, the dominance of *Cynodon dactylon* and *Cyperus rotundus* in the garlic fields was documented by Sharma *et al.* (1983). At Almora in Uttar Pradesh, Vishnoi *et al.* (1983) listed the major weeds in pea fields as *Cynodon dactylon, Cyperus rotundus, Chenopodium album, Fumaria indica, Eclipta alba* and *Vicia sativa*. Kumar and Singh (1985) observed that *Cyperus rotundus, Echinochloa colonum* and *Celosia spp*. contributed 80 per cent of weeds in the okra field.

Cyperus rotundus and *Cynodon dactylon* were reported as the major weeds in mungbean fields of Punjab by Kolar and Dhingra (1986),while Saimbhi *et al.* (1994) reported dominance of *Cyperus rotundus, Eleusine aegypticum, Chenopodium album, Tribulus terrestris, Trianthema portulacastrum, Celosia argentia* and *Portulaca spp.* in the vegetable fields at Jalandhar.

In the field experiments of AICVIP, conducted in Kerala at College of Horticulture, Vellanikkara, the major weeds observed in chilli and okra fields were *Cynodon dactylon, Cyperus rotundus, Digitaria ciliaris, Brachiaria distachya, Eleusine indica, Ludwigia parviflora, Cleome viscosa* and *Ageratum conyzoides* (KAU, 1992). In Karnataka, Leela (1993) observed *Cyperus rotundus, Cyperus iria, Cynodon dactylon, Lagasca mollis, Acanthospermum hispidum, Euphorbia spp., Mollugo pentaphylla* and *Portulacca oleracea* as the major weeds in vegetables like tomato, bean, okra and radish. Lal (1998) listed *Cynodon dactylon, Cyperus rotundus, Amaranthus viridis, Anagallis arvensis* and *Chenopodium album* as the major weeds of potato fields in India.

Cynodon dactylon, Datura fastuosa, Cyperus rotundus, Schonwia thebaica, Convolvulus arvensis, Echinochloa colonum and *Tribulus terrestris* were identified as the major weeds of vegetable fields of Yemen by Al-Kathiri (1994).

The literature indicates the dominance of perennial weeds in the weed flora of vegetable ecosystem

2.1.1 Bermuda grass

Twenty seven countries including several countries in South Africa, consider *Cynodon dactylon* as a principal or serious weed. The perennial grass has been identified as the most problematic grass weed of the arable lands of Botswana (Philips, 1993). A drastic reduction in yield of *Lucerne* due to *Cynodon dactylon* infestation was documented by Butler (1982). Similar findings were noticed by Gambhir *et al.* (1983) in radish and Adejonwo *et al.* (1990) in okra. Philips (1993) reported a 125 per cent yield increase in sorghum by controlling Bermuda grass alone, at Gaborone in Botswana. It was also found that pre-emergent herbicides are not effective against this grass.

2.1.2 Nutsedge

The purple nutsedge has been listed as one of the world's worst weeds. It occur both in cultivated and uncultivated lands in tropical, subtropical and Mediterranean climate between 35°N and 35°S latitude. It is a highly competitive weed with a C_4 pathway for CO_2 fixation. Ramamoorthy and Lakshmanachary (1995) had made an attempt to compare its competitive ability. The biomass production of black gram was 8.090 $gm^{-2}.day^{-1}$ under weed free conditions, while it was only 5.893 gm^{-2} day^{-1} from a field infested with nutsedge.

Ranade and Buru (1975) estimated that nutsedge could reduce crop yields by 25-35 per cent in groundnut. A drastic reduction in yield of upland rice due to nutsedge infestation was documented by Okafer and Datta (1976). Similar findings were reported in urdbean, cassava, okra and sugarcane by Kumar and Singh (1985), Villamayor and Reona (1987), Adejonwo (1990), Sathyavelu *et al.* (1992), respectively.

In Ludhiana, Saimbhi *et al.* (1994) had reported that the control of *Cyperus rotundus* resulted in higher yields of okra. Srinivasan (1995) also noticed results in line with this finding in taro.

A study was undertaken at Varanasi in Uttar Pradesh in 1988 in a field with inceptisol (clay loam) soil, which was heavily infested with *Cyperus rotundus*. The field was dug to a depth of 40 cm and the stolons, rhizomes and bulbs of this weed and any other weeds present were removed. The field was levelled and any *Cyperus rotundus* which subsequently emerged again, was removed. It was estimated from the *Cyperus rotundus* material removed, that there was 1.49×10^6 stolons per hectare which weighed 2040 kg/ha. Also it was estimated to remove 36.5 kg ha^{-1} N, 3.88 kg ha^{-1} P and 43.45 kg ha^{-1} K from the soil (Sanoria *et al.*, 1989).

2.2 Associated weed flora

Detailed information regarding the existence and dynamics of the associated weed flora of the crop ecosystem is helpful in formulating appropriate weed management programme.

Bhalla and Parmar (1982) listed *Commelina benghalensis, Setaria glauca, Ageratum conyzoides, Physalis minima, Amaranthus viridis* and *Cyperus rotundus* as the major weeds of okra in Madhya Pradesh. Adejonwo *et al.* (1990) reported the dominance of *Eleusine indica, Digitaria horizontalis, Cynodon dactylon, Dactyloctenium aegyptium, Solanum nigrum, Acanthospermum hispidum, Commelina benghalensis, Amaranthus spinosus, Ageratum conyzoides* and *Cyperus rotundus* in the okra fields of Nigeria. Saghir *et al.* (1993) reported that the most problematic weeds of vegetable fields of UAE are *Convolvulus arvensis, Cynodon dactylon, Cyperus rotundus* and *Sorghum halepense*.

Chenopodium album, Ageratum conzoides, Medicago spp., Cynodon dactylon, Digitaria sanguinalis, Echinochloa colonum, Setaria glauca, Elensiue indica, Commelina nudiflora and *Cyperus rotundus* were the major weeds of tomato fields of Solan (Kalia *et al.*, 1982). Singh *et al.* (1982) in Haryana observed the dominance of *Trianthema portulacastrum, Cyperus rotundus, Eclipta alba, Echinochloa crusgalli* and *Euphorbia thymifolia* in Brinjal. Ali (1985) noticed *Amaranthus polygamous, Flaveria australasica, Parthenium hysterophorus, Echinochloa colonum, Dactyloctenium aegyptium, Cynodon dactylon, Cyperus rotundus, Trianthema portulucastrum, Amaranthus viridis, Cyanandropsis pentaphylla* and *Portulaca quadrifida* as the major weeds of brinjal, in Tamil Nadu.

From the above literature, it is clear that apart from perennial weeds, annual weeds are also a major problem in the vegetable fields.

2.3 Crop weed competition

Weeds are competitive and adaptable to all adverse environments. It is the largest single factor which impairs agricultural production. Rao (1983) estimated that loss of agricultural produce accounts to 45 per cent by weeds, 30 per cent by insects, 20 per cent by diseases and 5 per cent by other pests. However, the losses due to weeds vary with the crop.

Singh *et al.* (1993) reviewed that the losses due to weeds in vegetable crops ranged from 6 to 82 per cent. In okra, the loss of yield, due to weed infestation is estimated to be between 50 and 90 per cent (Singh *et al.*, 1982; Amma and Ramdas, 1991), whereas in tomato, it ranged from 42-71 per cent (Singh *et al.*, 1993).

2.3.1 Critical period of crop weed competition

Critical period of weed competition is that part in the life cycle of a crop plant wherein weeding results in highest economic returns.

Maintaining weed free environment has resulted in maximum yields in tomato (Beste, 1979), okra (Singh *et al.*, 1982), radish (Gambhir *et al.*, 1983) and summer squash (Ponchio JA-de *et al.*, 1984). However, assessing the critical stages of weed competition and containing the weeds during this period was proved to be effective and economical (Singh *et al.*, 1982). It has been also reported that the critical period was 15-30 days for okra, while it ranged from 30-45 days for chilli.

2.4 Approaches in weed management in vegetable crops

2.4.1 Weed management in off-season

The important off-season weed management practices like non-selective herbicide application (sequential), solarization, smother cropping and monthly digging are reviewed here under.

2.4.1.1 Glyphosate

It is a non-selective translocative post emergence herbicide capable of controlling the perennial weeds, with complex underground vegetative system. Muller *et al.* (1984) stated the success of glyphosate 2-4 lb acre^{-1} against *Cynodon dactylon, Cyperus rotundus* and *Convolvulus arvensis* in the Asparagus fields of U.S.A. Andino (1989) reported the success of glyphosate against *Cyperus rotundus* in the tomato fields of Costa-Rica. In USA, sponge wiper application of glyphosate was effective, economical and less time consuming in vegetable fields (Harrison, 1982). Satisfactory control of Bermuda grass and nut grass with glyphosate has been reported by Ahuja and Yaduraju (1995) under non-crop situations in India.

In Trinidad, Hammerton (1974) suggested alternate use of glyphosate with 2,4-D and MSMA for better control of nutsedge. However, Mangoensoekarjo (1979) suggested that tank mixing of 2 kg glyphosate with 0.75 kg 2,4-D amine ha^{-1} was better than glyphosate alone. Grubben (1974) found that split application of glyphosate at 3 litres ha^{-1} with an interval of one month between treatments would give 95 per cent control of nutsedge tubers. Sandhu and Bhatia (1992) found that split application of glyphosate twice @ 1 kg ha^{-1} of commercial product was effective on nutsedge. Similar results with initial spraying of 2-3.5 kg ha^{-1} of glyphosate were documented by Hawton *et al.* (1992). Kandasamy *et al.* (1998) observed very good control of *Cynodon dactylon* with sequential application of glyphosate at monthly interval. Seventy five per cent control was observed after first spray itself, under non crop situation.

Effective nutsedge control could be attained by applying 2 kg ha^{-1} of glyphosate commercial product along with 50 ppm NAA. Similarly Manickam and Gnanamurthy (1992) noticed significant reduction of nutgrass biomass through spraying 1.0 per cent glyphosate with 0.05 per cent 2,4-D sodium salt or 1 per cent ammonium sulphate.

The results of trials undertaken in Mauritius showed that glyphosate was very quickly absorbed by *Cyperus rotundus* and that a dry period as short as one hour after spraying was sufficient for adequate weed control. Although satisfactory control was obtained, when spraying was followed by tillage 24 hrs later, better results were achieved when the interval between spraying and tillage was lengthened to one week; longer intervals did not substantially increase the level of weed control. Glyphosate was sprayed @ 1 kg ai ha^{-1} (Mc-Intyre and Barbe, 1995).

Madhavi *et al.* (1992) observed no residual toxicity on succeeding green gram from application of glyphosate @ 1.5 kg ai ha^{-1} along with 2 per cent ammonium sulphate. Similar results in succeeding cereals was noticed by Kumar and Singh (1992).

In trials on a clay loam soil of pH 5, glyphosate was applied before sowing or transplanting tomatoes. Tomatoes sown immediately after glyphosate suffered no injury but transplanted tomatoes showed various symptoms, even when 15 days elapsed between the herbicide application and transplanting (Andino *et al.*, 1989).

The above literature shows the effectiveness of glyphosate against a broad spectrum of weeds.

2.4.1.2 Solarization

Soil solarization is a novel technique for controlling soil borne pests including weeds by heating the surface soil using transparent plastic sheets spread on moist soil, which traps the solar radiation. Solarization is non-hazardous to the user as well as to the environment.

In the present review an attempt has been made to collect information on the effects of solarization on soil temperature, weeds and growth and yield of crops.

a) Soil temperature

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 the toxic products resulting from rapid organic matter decomposition (Benjamin and Rubin, 1982). Biradar *et al.* (1997) also reported that higher soil temperature under the treatment was responsible for the death or damage of weeds.

Benjamin and Rubin (1982) reported an increase in soil temperature by 10-15°C in the top 5-10 cm, by solarization in Israel while, Egley (1983) noticed maximum temperature of 65-69°C for 3-4 hrs of the afternoon on clear days compared with 43-50°C in the uncovered soils, in USA. In New Zealand, Alexander (1990) reported peak soil temperatures of 55, 51, 47 and 43°C at 13, 38, 63 and 99 mm depths.

Peak soil temperatures of 63°C and 59°C in the solarised soil at 5 and 10cm depth, was observed by Vilasini (1996) at Kerala Agricultural University, Vellanikkara, when the atmospheric temperature of the exprerimental area ranged from 23°C to 39.4°C.Bhaskar and Nanjappa (1997) observed highest temperatures of 50.1°C and 42.8°C at 5 and 10 cm depths compared to 43.6 and 39.8°C in the uncovered plots in Bangalore.

b) Weed control

Most annual and perennial weeds were effectively controlled by solarization (Katan, 1980). Solarization by covering the soil with clear polyethylene sheets has been found to reduce the weed problems in the subsequent crop of broccoli, tomato, melon (Elmore and Heefketh, 1984) and in other vegetables (Ismaileh, 1991).

Egley (1983) reported 64-98 per cent weed control by solarization for 1-4 weeks. Significant reduction in weed emergence was obtained in case of *Sida spinosa, Amaranthus spp., Xanthium pensylvanicum, Abutilon theophrasti* and

Anoda cristata. Solarization for one week significantly reduced the number of viable buried seeds of *Sida spinosa, Xanthium pensylvanicum, Abutilon theophrasti* and *Anoda cristata.*

Horowitz *et al.* (1983) reported that the effectiveness, was different for different weed species. Annual weeds like *Portulaca olerecea* and *Lamium amplexicaule* were controlled very well. However, *Conyza canadensis* and *Malva nicaensis* were relatively resistant. Perennials escaped due to its deep below ground systems.

Standifer *et al.* (1984) observed that *Commelina communis* seed was killed to a depth of 11 cm after 40 days of solarization. But *Cyperus* spp. and *Echinochloa crusgalli* succumbed only in the upper 3-4 cm only. After 3 weeks *Eleusine indica* seeds remained viable only at depths more than 5 cm.

Braun *et al.* (1987) found that solarization considerably increased the soil temperature in the upper layers and resulted in significant reduction in the number of emerged weeds including *Echinochloa crusgalli, Digitaria sauguinalis, Chenopodium album, Polygonum persicaria* by a total of 90 per cent. A solarisation period of 30 days caused 71.2 and 77.7 per cent mortality of *Chenopodium album* and *Polygonum persicaria,* in Germany.

Ragone and Wilson (1988) noted that soil solarization with 4 mm thick, clear polythene sheets for 6 weeks increased the maximum temperature by 9°C, 5°C and 4°C at depths of 5, 15 and 30 cm of soil, and controlled grass weeds like *Paspalum conjugatum, Panicum maxima, Brachiaria mutica* and *Digitaria horizontalis* for 3 months and broad leaved weeds like *Euphorbia hirta, Cleome viscosa, Ludwigia octovalvis* and *Phyllanthus niruri* were reduced. However, control of *Cyperus rotundus* was inconsistent.

From Jordan, Ismaileh (1991) reported that weed reduction varied from 41 to 100 per cent during seven months after termination of solarization, but was less effective, when the soil was disturbed after solarization.

Yaduraju and Ahuja (1990) reported the effectiveness of solarization against *Cynodon dactylon* and 100 per cent control of *Sorghum halapense*, whereas it was less effective against *Convolvulus arvensis*. Emergence of *Dactyloctenium aegyptium*, *Acrachne racemosa*, *Trianthema portulacastrum* and *Cyperus rotundus* was decreased due to solarization for 32 days, in Karnataka (Kumar *et al.*, 1993).

Ninety five and 99 per cent reduction of *Cyperus rotundus* was reported by Lopez and Gonzalez (1995) by solarization for 2 and 3 months respectively. Solarization for 30 days controlled dicot weeds effectively (Bhaskar and Nanjappa, 1997). Mudalagiriyappa *et al.* (1999) reported a significant reduction of monocots, dicots and sedges by 86-96, 81-94 and 30-40 per cent over control by solarization for 45 days with 0.05 mm polythene sheets.

Survival of *Cyperus rotundus* tubers in the soil even after solarization has been reported by several workers (Horowitz *et al.*, 1983). It has been attributed to the heat resistance of tubers. Another reason for escape of *Cyperus rotundus* may be attributed to the tuber formation in deeper layers. Hauser (1962) reported that, irrespective of soil texture, most of the tubers were found in 10-15 cm depth followed by 5-10 cm depth of soil. Enhanced germination of *Cyperus rotundus* after solarization was reported by Egley (1983). Enhanced germination o *Digitaria sanguinalis* in Netherlands was reported by Braun *et al.* (1988).

Elmore (1991) suggested that winter annual weeds were more susceptible to solarization than summer annuals, which were comparatively resistant.

c) Combinations with solarization

Ismaileh (1991) suggested that solarization followed by black polythene mulching resulted in better yield of tomato. He also reported that solarization without further mulching was not better than the standard farmers practice of hand weeding.

Combined solarization and pre emergence application of pendimethalin gave control of most of the weeds and higher lettuce yield (Cabello and Verdu, 1995). Soil solarization for 40 days along with one hand weeding 45 days after sowing of sunflower resulted in effective control of weeds and better yield (Bhaskar and Najappa, 1997).

d) Growth and yield of crops

In New Zealand, Alexander (1990) reported increased plant growth and head weight of broccoli by solarization. Enhanced tomato yield followed by solarization for 6 weeks, prior to planting of tomato was reported by Ismaileh (1991) in Jordhan.

An yield response by 100-125 per cent for onion, 52 per cent for groundnut and 72 per cent for sesamum were reported by Singh *et al.* (1993). Yield increment of 34-64 per cent was observed in okra by solarization alone (Bawazir *et al.*, 1995). Biradar *et al.* (1997) reported that yield response by solarization in groundnut was statistically similar to the pod yield obtained under weed free conditions.

e) Economics

Mansour and Sultan (1991) reported that use of solarization in onion-maize-onion rotation was economically feasible in the long term. This was in contrast to the results of earlier trials with a broad bean-maize-bean rotation in Egypt.

The above literature shows contrasting results from solarization for control of perennial weeds like *Cynodon dactylon* and *Cyperus rotundus*. However the control of annual weeds was much consistent. In many crops positive yield response was also observed.

2.4.1.3 Smother cropping

Raising plants that grow fast and develop high leaf area is found to adversely affect many weeds especially those like *Cynodon dactylon* and *Cyperus rotundus,* which follows C_4 pathway for Co_2 fixation.

Patterson (1982) pointed out that the weed competition especially of nutsedge, was maximum during first 20 days after sowing of crops, due to it's early germination and vigorous growth. Later on it tends to decline, since nutsedge was highly sensitive to shading.

Cowpea is a crop which is very suitable to grow as a smother crop. Growing cowpea, green gram and soybean as intercrop in maize could exert suppressing effects on weeds (Tosh, 1979). Reduction in weed growth by raising cowpea, in the coconut-banana cropping system was reported by Savithri (1990). Bhan and Sushilkumar (1998) reported that growing cowpea as an intercrop in banana resulted in development of a dense canopy covering entire ground area and suppressed weed growth completely for a period of 70 days.

Thakur *et al.* (1989) also, concluded that cropping systems incorporating smother crops and or intercropping with cover crops greatly reduced the weed problems of *Cynodon dactylon, Cyperus rotundus* and other species seen on the sandy loam soils of Dholi in Bihar.

Pritts *et al.* (1993) reported that growing a cover crop in the year prior to planting strawberry significantly reduced weed population in the establishment year compared to fallowing. Marigolds (*Tagetes* spp.) suppressed grasses and nut sedge, while sudan grass (*Sorghum sudanense*) suppressed broad leaved weeds. The other pre-plant cover crops used in the trial were rye grass (Lolium spp.) and buckwheat, which also did not affect the strawberry yields. Similar results were obtained by Pritts and Kelley (1993).

Intercropping of sorghum with cowpea smothered weeds and reduced hand weeding cost without affecting sorghum yield (Rao and Shetty, 1981). Smother crop also improve soil fertility by adding organic matter and preventing soil erosion. Moreover it is an ecofriendly method of weed control.

Above literature shows the superiority of cowpea as a smother crop and success of other smother crops for effective weed control.

2.4.1.4 Digging

It is a kind of mechanical weed management which can be done by any unskilled labour and is non-polluting, without residual problems and relatively safe to the operators.

McCue and Sweet (1982) tested various tillage programmes, combined with the use of herbicide to control foliage, in fields infested with yellow nutsedge. Tuber samples were taken, counted and incubated at 25°C to encourage sprouting. The number of newly formed tubers was decreased by 40 per cent with late cultivation and by 98 per cent with season long foliage control. Old tubers were unaffected. Tuber numbers decreased with increasing number of cultivation; 3 cultivations at monthly intervals gave a reduction equal to that obtained with season long foliage control. Sanoria *et al.* (1989) also proved the effectiveness of repeated ploughing for long lasting results.

Combination of cultural and chemical weed control methods were used against *Cyperus rotundus* in a potato (cv. Kufri Sinduri) and Maize (cv. T-41) cropping system on sandy loam at Kanpur in 1987-89 by Tewari and Singh (1991).

Exposure of underground tubers of the weed to the sun by deep ploughing twice in April and May gave the best *Cyperus rotundus* control (65.39, 70.08 and 69.0 per cent reduction in aerial shoots, tubers and rhizomes respectively). The control of *Cyperus rotundus* by summer ploughing increased the grain yield of maize and the tuber yields of potatoes by 13.75 and 3.40 per cent respectively.

In trials over 3 years at two sites in South Eastern Botswana, by mouldboard ploughing in winter, when the soil was dry, and then in spring before planting or twice in spring after the first rain and again before planting, were compared with single ploughing before planting sorghum for their effects on the regrowth of the perennial grass *Cynodon dactylon* and sorghum grain yield (Philips, 1993). The effect of tine cultivation just before planting was also measured in combination with the ploughing regimes. On average the winter and spring double-ploughing treatment reduced grass regrowth during that season by 60 per cent and double spring ploughing by 33 per cent compared with a single pass.

The potential advantage from summer ploughing for the perennial weeds comes from the prolonged exposure of propagating structures to desiccation in the dry season. It was observed that the decline in tuber germination was ten fold when the tubers were exposed 72 hours to bright sunshine (Raju and Reddy, 1999).

2.4.2 Weed management in crop

2.4.2.1 Herbicides

a) Pendimethalin

It is a pre-emergence herbicide used for the selective control of a wide spectrum of grasses and broad leaved weeds. Good control of grasses and some broad leaved weeds have been reported (MMRS, 1980) with Pendimethalin.

Ali (1985) reported effectiveness of pendimethalin in brinjal, against a broad spectrum of weeds other than *Flaveria australasica* and *Portulaca quadrifida*. Kumar and Singh (1985) reported significantly higher yield in urd bean than weedy control but less than that under weed free conditions, with the application of pendimethalin @ 1.5 kg ha^{-1}. Pendimethalin 1 kg ha^{-1} gave best crop yield in black gram but did not control *Cyperus rotundus* (Venkateswarlu *et al.*, 1988).

Leela (1993) suggested pendimethalin for short duration crops like bean, peas and amaranthus because she observed good weed control up to 30 days only.

Saimbhi *et al.* (1994) reported that pendimethalin 0.75 kg ha^{-1} resulted in good weed control efficiency in okra.

i) Pendimethalin in combination with hand weeding

Adejonwo *et al.* (1990) noticed that pre-emergence application of pendimethalin followed by manual weeding 3 weeks after sowing was effective in controlling all the weeds in okra. The treatment resulted in an average yield of 7 t ha^{-1} compared to 0.58 to 0.67 t ha^{-1} in unweeded plots. Leela (1993) suggested pendimethalin followed by one hand weeding for long duration vegetable crops. Field trials at Jabalpur and Jalandhar indicated that pendimethalin 0.75 kg ha^{-1} followed by hand weeding at 35 DAS was the best method for weed control in okra (Saimbhi *et al.*, 1994).

Maximum pod yield of 3682 kg ha^{-1} was obtained with minimum weed population of 12 m^{-2} through pre-emergence application of pendimethalin @ 1 kg ha^{-1} along with one hand weeding at 35 DAS in groundnut. Similar results were obtained when hand weeding was done on 20 DAS in red gram also (Itnal *et al.*, 1993).

The above literature shows the importance of integrated weed management as pendimethalin alone was not sufficient for broad spectrum weed control in medium and long duration vegetable crops.

b) Metolachlor

Clarkson and Van (1975) reported that metolachlor was effective on a wide variety of grasses and broad leaved weeds as well as *Cyperus esculentus* either as a pre-sowing incorporated or a pre-emergence herbicide in vegetable crops. Similar results were reported by Brown and Swingle (1977) except for control of *Portulaca oleracea* and Henne (1977), in tomato. Satisfactory weed control in okra was obtained through pre-emergence application of metolachlor @ 1 kg ha^{-1} (AICVIP, 1998).

Weed management studies by Dixon and Stroller (1982) showed a moderate control of nutsedge through pre-emergence application of metolachlor @ 1.0 kg ha^{-1}.

i) Metolachlor in combination with hand weeding

Application of metolachlor @ 1.0 kg ha^{-1} with one hand weeding on 45 DAS significantly improved the yield attributes and oil content in groundnuts (Suresh, 1984). Maximum groundnut pod yield of 1452 kg ha^{-1} with least weed dry weight of 675 kg ha^{-1} were found to be attributed with pre-emergence application of metolachlor @ 1 kg ha^{-1} with one hand weeding on 35 DAS (Guggari *et al.*, 1995). Adejonwo *et al.* (1990) noticed that pre-emergence application of metolachlor followed by manual weeding three weeks after sowing was effective in controlling all the weeds in okra.

Highest okra yield (64.3 q ha^{-1}) was resulted by metolachlor 1.0 kg ha^{-1} followed by hand weeding at 45 DAS through maximum weed control efficiency of 73.2 per cent (AICVIP, 1998).

Field testing throughout U.S. indicated crop tolerance to metolachlor at herbicidal rates on several vegetable crops (Clarkson and Van, 1975). However, phytotoxicity to tomato was reported, due to metolachlor application (MMRS, 1980).

c) Fluchloralin

Control of grasses and broad leaved weeds with fluchloralin was reported by Sandhu and Randhava (1979) and Pandey and Singh (1983) in okra, Ali (1985) in brinjal and Kumar and Singh (1985) in urdbean.

Best weed control and highest seed yield of okra (2048-2719 kg ha^{-1}) was obtained in plots treated with fluchloralin @ 1.5 kg ha^{-1} (Singh *et al.*, 1985). Leela (1993) also reported similar findings.

i) Fluchloralin in combination with hand weeding

Fluchloralin @ 0.48 l ha^{-1} followed by one hand weeding gave the lowest fresh and dry weight of weeds, highest seed yield and highest net profit ratio in okra (Bhalla and Parmar, 1982). This finding was supported by Singh *et al.* (1982). Application of fluchloralin @ 1.0 kg ha^{-1} with supplementary weeding gave highest fruit numbers and yield of green pods of okra per hectare (Pandey and Singh, 1983). This was in agreement with the findings of Tiwari *et al.* (1985), Bhalla and Parmar (1986) and Leela (1993) in many vegetable crops.

Pannu *et al.* (1991) obtained maximum weed control efficiency through soil incorporation of fluchloralin 1.5 kg ha^{-1} with one hand weeding 25 DAS. Gogoi *et al.* (1997) suggested Fluchloralin followed by hand weeding in okra for highest average seed yield (1.67 t ha^{-1}) and maximum cost benefit ratio (1:1.42).

Okra yields and quality were not affected by fluchloralin application for the selective control of weeds (Sandhu and Randhawa, 1979). On the contrary moderate yield reduction in tomato was reported by Brown and Swingle (1977).

d) Economics

In tomato and okra, integrating fluchloralin (0.75-1.0 kg) or pendimethalin (0.5-1.0 kg) with one hand weeding 40 days after sowing was found more economical than hand weeding twice (Leela, 1993).

Highest cost benefit ratio of 1:1.42 was obtained from the treatment fluchloralin 0.5-1 kg ai ha^{-1} followed by one hand weeding 40 days after sowing of okra (Gogoi *et al.*, 1997).

2.4.2.2 Polyethylene mulching

Paller *et al.* (1979) observed that mulching with rice straw 5 cm deep and hand weeding at 30 days after transplanting was not sufficient for the successful control of weeds especially *Cyperus rotundus* and *Rottboellia exaltata* in tomato.

A comparative study of black, silver white or transparent plastic mulch on Kohlrab (*Brassica oleracea* var. *gongylodes* L.) cv. Azur by Zengerk (1981) revealed that, there was increase in yield, quality and earliness due to mulching irrespective of the mulch material. Silvestri *et al.* (1985) observed higher yields of tomato when plastic soil mulching was adopted in both direct seedling and transplanting and also that black plastic was more efficient than transparent plastic.

An experiment conducted in Juanadiaz, Pereuroto Rico revealed that the highest marketable yield (64.5 t ha^{-1}) of tomato and net income were obtained from plastic mulching in combination with handweeding. In case of sweet pepper highest yield of 29.5 t ha^{-1} was obtained with plastic mulching in combination with directed spray of paraquat (Liu *et al.*, 1987). Red pepper (*Capsicum annum* L.) cv. Shinhong gave the highest yields of 900 kg ha^{-1} in Korea, when mulched with black polythene sheet compared to transparent polythene film and white PVC film (Kwon *et al.*, 1988).

Black plastic mulch increased early yields of grade I fruits by 0.5 lb $plant^{-1}$ and total yield was increased by 1.7 lb $plant^{-1}$ of bell pepper cv. Skipper capsicums (Call and Courtar, 1989). Similar results were reported by El-Sayed and El-Fadaly (1991) in tomato and Birge *et al.* (1996) in pumpkin. Aranjo *et al.* (1992) observed that harvesting 'Vista Alerge' cucumbers (*Cucumis sativus* L.) could be brought forward by 7 days by mulching either with red or black plastic sheet.

Gutal *et al.* (1992) observed that polythene mulch films increased soil temperature by 5-7°C, which facilitated faster germination and better root proliferation. At the same time weed growth was checked and soil moisture was retained preserving soil structure. It was further observed that CO_2 around the plant was increased. Results of three years experiments with 25 μ black LDPE film as mulch indicated that tomato yield could be increased by 55 per cent and weed growth was reduced by 90 cent and soil moisture conserved was 28 per cent more than that without mulch.

According to Konys and Konys (1992) tomato cv. Najwezensniejzy (intermediate) and New Yorker (dwarfing) produced the highest total and commercial yields of 43.2 and 19.7 t ha^{-1} when mulched with black plastic sheet. Mashingaidze (1996) noticed that, the harvesting period of tomato was extended by black polythene mulching and subsequently the total yield. The enhanced growth and yield was attributed to the changed temperature and light micro-environment around the plants. Saikia *et al.* (1997) obtained the maximum weed control efficiency of 96.5 per cent in okra by mulching with black polythene. The higher yield was attributed to the high moisture and temperature regimes in the soil.

a) Economics of mulching

According to Djigma and Diemkouma (1986), cost analysis in egg plant and tomatoes showed that saving in water use due to weed control and higher productivity with the use of black polythene mulching in these crops justified the investment in mulching during cool season. However an experiment conducted at Margahayu Experimental Farm on capsicum cv. Barito revealed that the unmulched, unshaded control crop produced only 1.25 t of fruits ha^{-1} and this was more profitable than the crop mulched with black polyethylene and shaded which yielded 5.0 t ha^{-1} (Basuki and Asaudhi, 1987).

Gutal *et al.* (1992) observed that a 20 per cent saving in weeding cost could be achieved by the use of black LDPE film mulching in brinjal. Saikia *et al.* (1997) reported that mulching with black LDPE promoted okra growth and resulted in yields of 223 q ha^{-1} compared with 31.1 q ha^{-1} for control and highest cost benefit ratio of 1:3.1.

2.5 Nutrient uptake by weeds and crops

Setty and Hosmani (1977) observed negative correlation coefficient between weeds and crops regarding nutrient uptake. Doubling of nutrient uptake by groundnut with weed free conditions compared to unweeded check was reported by Soundararajan *et al.* (1981).

In a field trial at Khandwa in Madhya Pradesh, maximum concentration of NPK in straw of okra at harvest was obtained with the application of fluchloralin @ 0.48 l ha^{-1} followed by one hand weeding (Bhalla and Parmar, 1982). Similarly, the nutrient removal by weeds under unweeded check was found to be 5-10 times higher than weed control treatments (Suresh, 1984).

The uptake studies by Satao *et al.* (1995) in hariyali, under non cropped situations revealed that the NPK uptake was higher in unweeded check compared to treated plots.

Vethamani and Balakrishnan (1990) found that highest uptake of N, P and K occurred in okra plants, treated with fluchloralin at 2 kg ha^{-1} and receiving N at 50 kg ha^{-1} as well as mulching with polyethylene. This treatment also gave good quality fruits with high ascorbic acid content and low fibre content.

Pannu *et al.* (1991) showed that integrating one hand weeding on 40 DAS with pre-emergence application of fluchloralin @ 1 kg ai ha^{-1} facilitates the maximum uptake of 183.6, 27.4 and 106.7 kg NPK ha^{-1} in groudnut.

Kundra *et al.* (1993) reported that application of pendimethalin resulted in the uptake of 83.6 kg N and 11.8 kg P by *Pisum sativum* while only 8.0 kg N and 0.6 kg P by weeds.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation was carried out to develop an integrated method for management of weeds, especially perennial weeds like *Cynodon dactylon* (L.) Pers and *Cyperus rotundus* L. in vegetable crops. The experiment was planned with a set of treatments, like application of broad spectrum herbicide, solarization, smother cropping and monthly digging in the summer seasons of 1998 and 1999, mainly to reduce the infestation of above perennial weeds. In the second phase, in kharif season, weed management practices like plastic mulching, application of pre-emergence herbicides and hand weeding were compared with weedy check in okra crop. The details of materials used and methods adopted for the study are described below.

3.1 Experimental site

3.1.1 Location

The experiment was conducted in the vegetable research farm of Department of Olericulture, College of Horticulture, Thrissur. The field is located at an altitude of 22.25 m above MSL, 10° 32" latitude and 76° 16" longitude. This place enjoys a warm humid tropical climate.

The field had almost uniform and high incidence of perennial weeds like *Cynodon dactylon* (L.) Pers, *Cyperus rotundus* (L.) Pers and many summer annual weeds.

3.1.2 Soil

Texturally the soil of the experimental site is sandy clay loam. The mechanical composition as well as physical and chemical properties of the soil are presented in Table 1.

Table 1. Soil characteristics of the experimental site

Character	Per cent Composition/ Value	Procedure adopted
1. Mechanical composition		
Course sand	16.18	Robinson international pipette method
Fine sand	27.10	
Silt	10.00	
Clay	36.20	
Textural class	Sandy clay loam	I.S.S.S. System
2. Physical constants of the soil		
Field capacity (0.3 hrs)	19.23	Pressure Plate apparatus
Moisture percentage a 15 bars	10.90	Pressure Plate apparatus
Bulk density (g cm^{-3})	1.41	Core Method
Particle density (g cm^{-3})	2.18	Pyeno meter method
3. Chemical properties		
Organic carbon (%)	0.47	Walkley and Black rapid titration method
Available Nitrogen (%)	0.008	Alkaline permanganate method
Available Phosphorus (%)	0.0003	Chlorostannus reduced molyb-dophosphorus blue colour method in hydrochloric acid system
Available Potassium (%)	0.008	Flame photometry, Neutral normal ammonium acetate extraction
Soil reaction (pH)	5.4	Soil water suspension of 1:2.5
Electrical conductivity (mmhos cm^{-1})	0.35	Soil water extract of 1:2.5

3.1.3 Weather conditions

Mean weekly weather data during the period of experiment, recorded at the meteorological observatory of the College of Horticulture, Vellanikkara, are presented in Appendix-I.

3.1.4 Season

The experiment was conducted during the summer and kharif seasons of 1998 and 1999.

3.1.5 Cropping history

The experimental site was under bulk cultivation of vegetables like okra, tomato and chilli for the last few years.

3.2 Materials

3.2.1 Crop varieties

a. Cowpea

In the summer season cowpea var Kanakamony was used as smother crop. Kanakamony is a medium duration, semi trailing variety and forms good canopy. It is a moderate to high yielding dual purpose variety. The variety is photo-sensitive and moderately drought tolerant.

b. Okra

In the kharif season okra var. Arka Anamika was raised. It is a variety resistant to Yellow Vein Mosaic virus disease. The plants are medium tall of (about 100 cm height) with short internodal length and non-branching habit. It takes about 50 days from sowing to first flowering and about 55 days for first picking. Fruits are medium sized and green in colour.

3.2.2 Fertilizers

Factomphos (20:20:0:15), urea (45.6%) and muriate of potash (60%) were used as the source of N, P and K.

3.2.3 Herbicides

a. Glyphosate (Round-up 41% SL)

It is a broad spectrum, systemic, post emergence herbicide. It is effective against perennial weeds also, as it will be translocated to the underground propagating structures. Glyphosate is a glycine derivative, chemically it is [N (phosphonomethyl) glycine].

b. Pendimethalin(Stomp 30% EC)

It is a dinitroaniline group herbicide [N-(1-ethyl propyl)-3,4-dimetheyl-2,6 dinitro benzenamine]. This is a pre-emergence herbicide used for selective control of a wide spectrum of grasses and broad leaved weeds in vegetables ,pulses and oil seed crops .

c. Metolachlor (Dual 50% EC)

It is an amide herbicide [2-chloro-N (2-etheyl-6- metheyl phenyl)-N-(2-methoxy-1-metheyl ether acetamide]. It is a pre-emergence herbicide effective against annual and perennial grasses and recommended for vegetables, pulses and oilseed crops.

d. Fluchloralin (Basalin 45% EC)

It is a dinitro aniline herbicide.Chemically, fluchloralin is [N-(2-chloro ethyl)-2,6 dinitro-N-propyl-4-(trifluoromethyl) benzenamine].

It is a pre-emergence herbicide, which is absorbed via roots and shoots and affect vital processes, weeds die off before or shortly after emergence. It is recommended for pulses, vegetables and oil seed crops.

3.3 Methods

3.3.1 Design and layout

The experiment was laid out in split-plot design with the summer season weed management practices as main plot treatments and the different weed control methods during the kharif season as sub plot treatments. The layout plan of the experiment is given in Figure 1.

The details of treatments are given below:

a) Design: Split-plot

b) Replication: 3

c) Main plot treatments (given in summer season before planting okra in the kharif season)

Number of treatments : 6

1. Glyphosate 0.8 kg ha^{-1} (two applications at 45 days interval)
2. Glyphosate 1.2 kg ha^{-1} (two applications at 45 days interval)
3. Covering the field with transparent polyethylene sheet, after digging the field (solarization)
4. Raising cowpea (cv. Kanakamony)
5. Digging the field twice at monthly interval and removing underground portions of weeds
6. Unweeded control

d) Subplot treatments (given in kharif season)

No. of treatments : 6

1. Mulching with black polyethylene (leaving the base of okra plant)
2. Handweeded control (at 15, 30 and 45 DAS)
3. Pendimethalin 1.0 kg ha^{-1} (pre-emergence) + HW at 45 DAS)
4. Metolachlor 1.0 kg ha^{-1} (pre-emergence) + HW at 45 DAS
5. Fluchloralin 1.5 kg ha^{-1} (Pre-emergence) + HW at 45 DAS
6. Unweeded control

e) Plot size

1. Main plot: 19.25 m x 4.5 m

N

W E

S

Fig.1. Layout of the experimental field

0.25m 3m 4.5 m 0.5 m 0.6 m

Replication	Main plot						
	M_2	S_3	S_4	S_2	S_5	S_1	S_6
	M_1	S_5	S_1	S_3	S_2	S_6	S_4
R_1	M_6	S_1	S_6	S_5	S_3	S_2	S_4
	M_4	S_2	S_1	S_3	S_4	S_6	S_5
	M_5	S_1	S_3	S_4	S_6	S_5	S_2
	M_6	S_5	S_1	S_2	S_3	S_6	S_4
	M_4	S_4	S_2	S_6	S_1	S_3	S_5
	M_3	S_2	S_1	S_4	S_5	S_3	S_6
R_2	M_6	S_6	S_1	S_5	S_2	S_4	S_3
	M_1	S_1	S_4	S_3	S_2	S_5	S_6
	M_5	S_6	S_5	S_2	S_1	S_6	S_5
	M_2	S_4	S_1	S_3	S_5	S_2	S_6
	M_4	S_1	S_6	S_3	S_5	S_2	S_4
	M_3	S_3	S_4	S_2	S_1	S_5	S_6
R_3	M_5	S_6	S_1	S_3	S_5	S_4	S_2
	M_6	S_3	S_5	S_1	S_4	S_2	S_6
	M_1	S_1	S_3	S_6	S_2	S_5	S_4
	M_2	S_5	S_6	S_2	S_4	S_3	S_1

19.25 cm

Main plots

M_1. Glyphosphate 0.8 kg ha^{-1}

M_2. Glyphosphate 1.2 kg ha^{-1}

M_3. Solarization

M_4. Cowpea

M_5. Digging

M_6. UWC

Sub plots

S_1. Polyethylene mulching

S_2. Hand weeding

S_3. Pendimethalin 1.0 kg ha^{-1} + HW

S_4. Metolachlor 1.0 kg ha^{-1} + HW

S_5. Fluchloralin 1.5 kg ha^{-1} + HW

S_6. UWC

2. Sub plot

i) Gross plot size: 3.0 m x 4.5 m

ii) Border: 0.5 m on all sides

iii) Sampling area: one metre strip along the 4.5 m side inside the border area

iv) Net plot size: 1.0 m x 3.5 m

3.4 Field culture

3.4.1 Land preparation

a. Main plot

The experimental area was measured and laid out for main plots according to the design of the experiment. The plots were separated by bunds of 50 cm and blocks by bunds of 60 cm.

Plots requiring solarization, smother cropping and digging were ploughed with a tractor, clods were broken and weeds and stubbles of previous crops were removed.

i. Glyphosate application

Required quantity of the commercial formulation of glyphosate (Round-up) as per treatments (0.8 and 1.2 kg ha^{-1}) were mixed with water to spray the plot(@500 l per ha).An ASPEE back pack sprayer fitted with flood jet nozzle was used for spraying the herbicide.

ii. Solarization

The plots allotted for this treatment were formed in to beds of 4.5 m width,19.25 m length and 25 cm height. After levelling the beds, they were irigated well and mulched with transparent polythene sheets of 125 guage thickness. The edges of the sheets were sealed with soil to keep the sheets in position and to prevent movement of air. Adequate care was taken to keep the sheets in close contact with the soil to prevent the formation of air pockets between soil and the sheets. Soil thermometers at depths of 5, 10 and 20 cm were installed at the centre of the bed.

iii. Smother cropping

The plots for raising smother crop were made into a fine tilth and seeds of cowpea variety Kanakamony was broadcasted at high seed rate of 40 kg ha^{-1}. Irrigations were given as and when required.

iv. Monthly digging

Two diggings at monthly interval (one digging at the beginning and another one month later) were given to the plots.

v. Weedy control

The plots randomly selected as weedy check were kept as such after marking the boundaries.

b. Sub plot

At the beginning of the kharif season, each main plot was ploughed separately after slashing cowpea and weeds from all plots. Bunds were kept intact and adequate care was taken not to mix the soil from different treatments. Each main plot was divided into six sub plots by forming bunds of 25 cm width. Ridges for sowing okra were formed 60 cm apart after broadcasting basal dose of fertilizers.

i. Fertilizer application

The fertilizers, viz. factomphos, urea and muriate of potash were used to supply required quantities of N, P and K (NPK @ 50:8:25 kg ha^{-1}). P and K were applied basally as single dose. However, N was applied in two split doses, half as basal and the other half at 30 days after sowing.

ii. Seeds and Sowing

Three okra seeds per hill were dibbled 45 cm apart on the ridges formed at 60 cm interval (spacing: 60 x 45 cm). Seed rate was 7 kg ha^{-1}. In black polyethylene mulching treatment, the field was mulched first and seeds were dibbled through the holes made at 45 cm apart on the positions above the ridge.

iii. Thinning and gap filling

Thinning to retain one plant per hill and gap filling were done one week after sowing.

iv. Hand weeding

Hand weeding was done on 15, 30 and 45 DAS in the hand weeding treatments and only on 45 DAS in the treatments where herbicide and hand weeding are combined. In polyethylene mulched plots, weed growth observed through the holes made for planting okra, was also removed periodically.

v. Pre-emergence herbicides

Required quantity of the commercial formulations of pendimethalin, metolachlor and fluchloralin were mixed with measured quantity of water (@ 500 l ha^{-1}) to spray in each plot with an ASPEE back pack sprayer fitted with a flood jet nozzle.

vi. Unweeded control

No weed control measure was given in these plots.

vii. Plant protection

Minor infestation of fruit borer was noticed during both years and the infested fruits were removed and destroyed. No chemical spray was required.

viii. Harvest

Picking was started on 28th July in 1998 and 15th July in 1999. Okra harvesting was done once in three days and continued up to 13th September and 28th August.

3.5 Observations

3.5.1 Observations on weeds

a) Weed count

Weed counts were recorded using an iron quadrat of 0.25 m^2 (50 cm x 50 cm) from three randomly selected points in the main plots just before land preparation and from two points per sub plot at 30 and 60 days after sowing.

For the perennial weeds, the count of underground propagating structures was recorded after slashing the weeds and digging an area of 50 cm x 50 cm upto a depth of 50 cm in three spots each in the main plots and expressed as number of underground propagules of *Cynodon dactylon, Cyperus rotundus* and total per m^2 at 50 cm depth.

b) Weed dry weight

All weeds inside the quadrates from the observation points were cut along the ground surface, washed and dried under shade. Later they were oven dried at 80±5°C to a constant weight. The dry weight of weeds are expressed as kg ha^{-1}. Weight of underground structures are expressed as kg ha^{-1} after the above procedure.

c) Weed control efficiency

Weed control efficiency was worked out on the basis of weed dry weight at 30 DAS. The formula used for the calculation of weed control efficiency was as follows:

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

where,

WCE - Weed control efficiency
WDC – Weed dry weight in the control plot
WDT – Weed dry weight in the treated plot

3.5.2 Observations on crop

Five plants were selected at random from each plot. The following observations were recorded and the mean values are worked out.

a) Phytotoxicity

Phytotoxic symptoms appeared on the plants in the herbicides applied plots were recorded.

b) Incidence of Yellow Vein Mosaic

The incidence of yellow vein mosaic was recorded.

c) Number of leaves plant^{-1}

The number of existing leaves were recorded from the sample plants at 30 and 60 day after sowing and the mean is reported.

d) Height of the plant

Height of the plant was measured from the ground level to the tip of the longest leaf on 30 and 60 day after sowing and the mean values are expressed in cm.

e) Dry matter production

Dry matter production was recorded during 30 and 60 day after sowing. The plants were uprooted from the destructive sampling area. The plants were dried under shade and oven dried at 80±5°C till consecutive weights agreed. The dry weight of the plants are expressed as kg ha^{-1}.

f) Number of fruits plant^{-1}

The total number of fruits produced on the sample plants were recorded and the mean was worked out.

g) Total fruit yield

The weight of fruits from each harvest was added and the total fruit yield was expressed as t ha^{-1}.

h) Weed Index

Weed index was computed by using the formula,

$$WI = \frac{(x-y) \times 100}{x}$$

where

WI – Weed Index

x – Yield from weed free plot or the treatment which recorded minimum weeds

y – Yield from the treatment for which WI is to be worked out

3.5.3 Soil temperature

Soil temperatures at depths of 5, 10 and 20 cm from solarized and nonsolarized soils were recorded daily at 8.00 am and 2.30 pm..

3.6 Chemical analysis

3.6.1 Plant analysis

The whole plants of okra and composite sample of weeds, collected at 30 and 60 days after sowing were analysed for nitrogen, phosphorus and potassium. The samples were dried to constant weight in an electric hot air oven at 80±5°C, ground in to fine powder using Wiley mill and used for chemical studies.

a) Total nitrogen

Total nitrogen content was estimated by modified microkjeldahl method (Jackson, 1958).

b) Total phosphorus

Total phosphorus content was estimated by vanado-molybdophosphoric yellow colour method, after extraction with triple acid. The yellow colour was read in a Klette- Summerson photo electric colorimeter at 470 nm (Jackson, 1958).

c) Total potassium

The extract used for phosphorus estimation was used for estimation of total potassium using flamephotometer method (Jackson, 1958).

d) Uptake of nutrients

The total uptake of nitrogen, phosphorus and potassium by weeds and crop at 30 and 60 day after sowing were calculated by multiplying the content of nutrients in the plant sample and the respective dry weight and was expressed in kg ha^{-1}.

3.6.2 Soil analysis

Soil analysis was done before the experiment. A representative soil sample of the field, obtained by mixing the soil samples collected from different parts of field, was used for the determination of organic carbon, available nitrogen, phosphorus and potassium.

3.7 Economics of cultivation

The relative economics of different weed control treatments given in the okra crop was compared by calculating the additional cost for weed control operations and additional returns over and above the unweeded control and working out the return per Rupee invested.

3.8 Statistical analysis

Analyses of variance were performed on the data collected in various experiments, using the statistical package 'MSTAT' (Freed, 1986). Data on weed count and weed dry matter production that showed wide variation were subjected to square root transformations ($\sqrt{x+0.5}$ or $\sqrt{x+1}$) and logarithmic transformation [log (x+1)] respectively to make the analysis of variance valid. Treatments had only zero values were excluded from statistical analysis. Multiple comparisons among treatment means where the F-test was significant (at 5 per cent level of significance) were done using DMRT.

RESULTS

4. RESULTS

The results of the experiments conducted during 1998 and 1999, to evaluate different weed management techniques like application of systemic herbicide, solarization, smother cropping and monthly digging in the summer season, followed by weed management in okra by polyethylene mulching, hand weeding and application of pre-emergence herbicides are presented in this chapter.

Results are presented under the following heads:

4.1 Weed management during summer season
4.1.1 Weed flora
4.1.2 Weed population
4.1.3 Count of propagating structures
4.1.4 Dry matter production
4.1.5 Soil temperature
4.2 Weed management in okra crop
4.2.1 Observations on weeds
4.2.1.1 Weed flora
4.2.1.2 Weed population
4.2.1.3 Dry matter production by weeds
4.2.1.4 Weed control efficiency
4.2.2 Observations on okra
4.2.2.1 Establishment of crop
4.2.2.2 Growth characters
4.2.2.3 Yield attributes
4.2.2.4 Yield
4.2.2.5 Weed Index
4.3 Nutrient uptake studies
4.3.1 Uptake by weeds
4.3.2 Uptake by crop
4.4 Economics of weed control treatments

4.1 Weed management during summer season (main plot treatments)

4.1.1 Weed flora

The weed flora of the trial field are presented in Table 2.

The weed flora in the trial field was dominated by grasses. Among them, *Cynodon dactylon, Digitaria ciliaris, Dactyloctenium aegyptium* and *Eleusine indica* were the important ones. *Cyperus rotundus* and *Cyperus iria* were the sedges observed in the control plots. Dicot weed population was moderate in the summer, *Ludwigia parviflora, Synedrella nodiflora, Cleome viscosa* and *Ageratum conyzoides* being the major ones. Seventy eight per cent of the total weed population was constituted by perennial weeds like *Cynodon dactylon* and *Cyperus rotundus*.

4.1.2 Weed population

Observations on the count of weeds in various treatment plots are presented as count of *Cynodon dactylon, Cyperus rotundus, Cyperus iria,* other annual weeds and total weeds. The observations were taken just before land preparation for sowing okra, in the kharif season. No weed growth was observed in the solarized plots as all the weeds which were present at the start of the trial and those which germinated later were killed, under polyethylene sheets.

Data on the effect of summer season (main plot) treatments on the population of major weeds of the field are presented in Tables 3a and 3b.

During 1998 and 1999, solarization treatment resulted in complete control of all the weeds in the field. The systemic herbicide glyphosate applied at 1.2 kg ha^{-1} was the next best treatment and resulted in very low population of all the weeds. This treatment proved it's superiority over the lower dose of glyphosate (0.8 kg ha^{-1}) on the control of *Cynodon dactylon* in both the years of study. In general, the weed population of *Cyperus rotundus, Cyperus iria* and other weeds were lower in glyphosate 1.2 than in glyphosate 0.8 kg though the differences were

Table 2. Weed flora of the experimental field

Sl. No.	Scientific name	Common name	Family	% of total weeds	
				Summer	Kharif
A. Monocots					
1	*Cyperus rotundus* (L.)	Nutgrass	Cyperaceae	6.6	14.1
2	*Cyperus iria* L.	yellow nutsedge	Cyperaceae	3.7	9.6
3	*Cynodon dactylon* (L.) Pers	Bermuda grass	Poaceae	71.5	42.6
4	*Digitaria ciliaris* (Retz.) Koel	Crab grass	Poaceae	3.4	4.8
5	*Dactyloctenium aegyptium* (L.) Beauv	Crow foot grass	,,	3.0	3.4
6	*Eleusine indica* (L.) Gaertn.	Goose grass	,,	2.8	3.2
7	*Ischaemum rugosum* Salisb.	Wringle grass	,,	2.0	2.5
8	*Echinochloa colona* (L.) Link	Jungle rice	,,	-	1.6
9	*Panicum repens* L.	Torpedo grass	,,	0.5	0.2
10	*Brachiaria distachya* stapf.	Signal grass	,,	0.8	1.9
11	*Brachiaria mutica* (forsk.) Stapf.	Para grass	,,	0.4	0.2
B. Broad leaved weeds					
1	*Ludwigia parviflora* Roxb.	Water primrose	Onagraceae	0.8	3.4
2	*Ageratum conyzoides* L.	Goat weed	Asteraceae	0.9	2.0
3	*Synedrella nodiflora* Gaertn.	Venapachha(M)	Asteraceae	0.8	2.2
4	*Euphorbia hirta* L.	Garden spurge	Euphorbiaceae	0.2	1.0
5	*Cleome viscosa* L.	Wild mustard	Capparidaceae	0.4	1.4
6	*Emilia sonchifolia* (L.) DC	Red tassel flower	Asteraceae	0.6	1.2
7	*Physalis minima* L.	Ground cherry	Solanaceae	-	0.4
8	*Phyllanthus niruri* Auct.	Niruri	Euphorbiaceae	0.3	1.3
9	*Scoparia dulcis* L.	Sweet brown weed	Scrophu-lariaceae	0.3	0.5
10	*Cleome pentaphylla* L.	Cleome	Capparidacea	0.3	0.5
11	*Mollugo pentaphylla* L.	Carpet weed	Molluginaceae	-	0.4
12	*Leucas aspera* (willd) Spreng.	Leucas	Apiaceae	0.3	0.8
13	*Borreria hispida* (L.) Schum	Button weed	Rubiaceae	0.2	0.6
14	*Sida acuta* Burm.f	Southern sida	Malvaceae	0.2	0.2

(M) – Malayalam Name

Table 3. Effect of treatments on weed population during 1998 and 1999 (No. m^{-2})

a. 1998

Treatments	*Cynodon dactylon*	*Cyperus rotundus*	*Cyperus iria*	*Panicum repens*	Other weeds	Total
Gly 0.8 kg ha^{-1}	*6.69 [d] (44.00)	3.29 [c] (10.00)	3.49 [c] (11.30)	2.95 [bc] (8.00)	3.95 [c] (14.70)	9.47 [d] (88.00)
Gly 1.2 kg ha^{-1}	2.49 [e] (5.30)	2.07 [d] (3.30)	2.75 [c] (6.70)	2.50 [cd] (5.30)	3.78 [c] (13.30)	5.91 [e] (34.00)
Solarization	-	-	-	-	-	-
Cowpea	11.38 [c] (130.70)	4.49 [b] (19.30)	6.46 [b] (41.30)	2.10 [d] (4.00)	8.59 [b] (73.30)	16.39 [c] (268.00)
Digging	14.39 [b] (206.70)	3.85 [bc] (14.00)	8.60 [a] (73.30)	3.48 [ab] (11.33)	13.69 [a] (188.70)	22.24 [b] (495.30)
UWC	32.33 [a] (1046.70)	8.22 [a] (66.70)	8.41 [a] (70.700)	3.58 [a] (12.00)	14.68 [a] (215.30)	37.53 [a] (1410.70)
SEm±	0.388	0.224	0.294	0.182	0.592	0.506
LSD	1.918	0.737	0.960	0.592	1.931	1.651

b. 1999

Treatments	*Cynodon dactylon*	*Cyperus rotundus*	*Cyperus iria*	Other weeds	Total	
					1999	Pooled
Gly 0.8 kg ha^{-1}	8.83 [b] (77.30)	4.32 [b] (18.70)	6.81 [a] (46.00)	10.03 [b] (100.00)	15.68 [b] (245.30)	12.53 [c] (166.67)
Gly 1.2 kg ha^{-1}	3.90 [c] (14.70)	3.40 [b] (10.70)	4.43 [b] (18.70)	3.87 [d] (14.70)	7.72 [c] (58.70)	6.78 [d] (46.33
Solarization	-	-	-	-	-	-
Cowpea	2.49 [c] (5.30)	4.49 [b] (20.00)	2.75 [c] (6.70)	6.36 [c] (40.00)	8.09 [c] (65.30)	12.22 [c] (166.67)
Digging	3.93 [c] (14.70)	4.70 [b] (21.30)	3.95 [b] (14.70)	15.73 [a] (246.70)	17.26 [b] (297.30)	19.74 [b] (396.30)
UWC	27.17 [a] (746.70)	9.89 [a] (97.30)	4.85 [b] (22.70)	15.14 [a] (229.30)	33.07 [a] (1096.00)	35.30 [a] (1253.30)
SEm±	1.042	0.427	0.278	0.519	0.777	2.019
LSD	3.397	1.391	0.907	1.694	2.534	6.053

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

not statistically significant in both the years. Raising cowpea resulted in significant reduction of all the weeds in both the years. This treatment was the best one for the control of *Cyperus iria* and was on par with glyphosate 1.2 for control of *Cynodon dactylon* and *Cyperus rotundus* in 1999. The digging treatment also resulted in significant reduction in the population of *Cynodon dactylon* and *Cyperus rotundus*. However, it could not effectively control *Cyperus iria* and other annual weeds wherein the population was on par with weedy check. Thus in the total weed count also, the digging treatment had higher population than the treatments solarization, glyphosate and smother cropping.

Pooled analysis for total weed count also supported the superiority of solarization. This was followed by glyphosate 1.2 kg ha^{-1}. Glyphosate 0.8 kg ha^{-1} was statistically on par with smother cropping. Digging treatment was inferior but had significantly lower weed count than control.

4.1.3 Count of propagating structures

Data on the effect of main plot treatments on the count of underground propagating structures of problem weeds are presented in Table 4.

Solarization was the most successful in bringing down the underground propagating structures of the *Cynodon dactylon* and *Cyperus rotundus* in both the years. Eventhough glyphosate 1.2 was inferior to solarization in reducing *Cynodon dactylon* in both years and total propagating structures in 1999, these treatments were statistically on par for the total propagating structures in 1998 and *Cyperus rotundus* tubers in both years of study. The next best treatments were glyphosate 0.8 kg ha^{-1} during 1998 and smother cropping in 1999. Eventhough digging significantly reduced the count of propagating structures in both years, it was not as efficient as other treatments. Pooled data revealed that solarization was the best followed by glyphosate 1.2 and glyphosate 0.8 kg ha^{-1}. Smother cropping and digging treatments were statistically on par and were superior to the weedy check.

Table 4. Effect of treatments on count of propagating structures of weeds at 50 cm depth (No. m^{-2})

Treatments	*Cynodon dactylon*		*Cyperus rotundus*		Total		
	1998	1999	1998	1999	1998	1999	Pooled
Gly 0.8 kg ha^{-1}	*4.57[c] (20.00)	5.74[b] (32.00)	6.80[b] (45.3)	5.62[b] (30.70)	8.14[c] (65.30)	7.98[b] (62.70)	8.06[c] (63.96)
Gly 1.2 kg ha^{-1}	3.78[d] (13.30)	3.20[d] (9.30)	4.57[c] (20.00)	3.48[cd] (11.30)	5.86[d] (33.30)	4.65[c] (20.70)	5.25[d] (21.56)
Solarization	2.75[e] (6.70)	1.90[e] (2.70)	4.72[c] (21.30)	2.08[d] (4.00)	5.28[d] (28.00)	2.73[d] (6.70)	4.05[e] (15.40)
Cowpea	8.19[b] (66.70)	4.84[c] (22.70)	7.76[b] (60.00)	4.78[bc] (22.70)	11.24[b] (126.70)	6.75[b] (45.70)	7.00[b] (20.00)
Digging	8.54[b] (92.00)	3.37[d] (10.70)	6.74[b] (45.30)	6.12[b] (37.30)	10.84[b] (117.3)	6.92[b] (48.00)	8.80[bc] (76.44)
UWC	11.46[a] (130.70)	10.49[a] (109.30)	11.17[a] (124.00)	10.55[a] (110.70)	15.98[a] (254.70)	14.86[a] (226.00)	15.42[a] (236.78)
SEm±	0.211	0.224	0.378	0.538	0.377	0.442	0.292
LSD	0.664	0.707	1.298	1.697	1.189	1.394	0.860

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

4.1.4 Dry matter production (DMP)

4.1.4.1 Dry matter production by weeds

Data pertaining to the effect of main plot treatments on the dry matter production by weeds are presented in Table 5a and 5b.

Solarization was the most efficient treatment which recorded no dry matter production during 1998 and 1999. Glyphosate 1.2 was the next best by bringing down the DMP to a very low level in the case of all the weeds in both years. In general, glyphosate at low concentration was on par or slightly inferior to glyphosate 1.2 kg ha^{-1}. Smother cropping was found next best after glyphosate 1.2 and was most effective against *Cyperus iria* during 1999. Even though digging treatment significantly reduced dry matter production by *Cynodon dactylon* and *Cyperus rotundus* in both the years, the dry matter production in this treatment by *Cyperus iria* in 1998 and other weeds in 1999 were on par with the control. The pooled data for total weed DMP also highlighted the superiority of glyphosate 1.2 kg ha^{-1} after solarization. This treatment was statistically on par with glyphosate 0.8 kg during 1999. Smother cropping and monthly digging were on par and superior to weedy check.

4.1.4.2 Dry matter production by propagating structures

Data showing the effect of treatments on dry matter production by the underground propagating structures are presented in Table 6.

Solarization was the best treatment in bringing down the DMP by *Cynodon dactylon* and *Cyperus rotundus* as well as the total underground propagating structures, in both the years. However, glyphosate 1.2 kg ha^{-1} was on par with solarization to reduce the DMP by *Cyperus rotundus* and total propagating structures during 1998. Glyphosate 0.8 kg ha^{-1} was on par with smother cropping except for *Cynodon dactylon* and total propagating structures during 1998, where in glyphosate 0.8 kg ha^{-1} was statistically superior to smother

Table 5. Effect of treatments on weed dry matter production during 1998 and 1999 (kg ha^{-1})

a. 1998

Treatments	*Cynodon dactylon*	*Cyperus rotundus*	*Cyperus iria*	*Panicum repens*	Other weeds	Total
Gly 0.8 kg ha^{-1}	*2.33^{c} (215.30)	1.49^{c} (30.67)	1.74^{c} (54.70)	1.53^{ab} (37.30)	1.94^{d} (88.00)	2.63^{d} (426.00)
Gly 1.2 kg ha^{-1}	1.38^{d} (23.30)	1.38^{c} (23.33)	1.63^{c} (46.70)	1.36^{ab} (24.00)	1.95^{d} (92.00)	2.30^{e} (199.30)
Solarization	-	-	-	-	-	-
Cowpea	2.66^{bc} (474.70)	1.85^{b} (76.33)	2.34^{b} (216.00)	1.20^{b} (20.70)	2.73^{c} (536.70)	3.12^{c} (1234.00)
Digging	2.92^{b} (825.30)	1.82^{b} (66.67)	2.61^{a} (410.70)	1.94^{a} (86.70)	3.09^{b} (1253.30)	3.42^{b} (2642.70)
UWC	4.02^{a} (4865.30)	2.85^{a} (716.67)	2.61^{a} (405.30)	2.03^{a} (106.00)	3.45^{a} (2871.30)	3.95^{a} (8964.70)
Sem±	0.155	0.085	0.0753	0.050	0.068	0.036
LSD	0.505	0.279	0.245	0.652	0.223	0.119

b. 1999

Treatments	*Cynodon dactylon*	*Cyperus rotundus*	*Cyperus iria*	Other weeds	Total weeds
Gly 0.8 kg ha^{-1}	*2.53^{b} (338.70)	2.26^{b} (184.00)	2.41^{a} (266.70)	2.88^{b} (765.30)	3.19^{c} (1554.70)
Gly 1.2 kg ha^{-1}	1.61^{cd} (46.70)	1.97^{c} (102.70)	2.11^{b} (129.30)	2.07^{c} (129.30)	2.61^{e} (406.70)
Solarization	-	-	-	-	-
Cowpea	1.39^{d} (24.00)	2.16^{bc} (146.70)	1.62^{d} (42.70)	2.64^{b} (450.70)	2.81^{d} (664.00)
Digging	1.76^{c} (58.70)	1.99^{c} (98.70)	1.85^{c} (74.70)	3.31^{a} (2033.30)	3.36^{b} (2272.70)
UWC	3.47^{a} (3040.00)	3.09^{a} (1248.00)	2.31^{a} (212.70)	3.37^{a} (2362.70)	3.82^{a} (6532.00)
SEm±	0.100	0.079	0.061	0.079	0.036
LSD	0.326	0.259	0.198	0.259	0.119

* log (x+1) transformed value. Values in paranthesis are the original values

Table 6. Effect of treatments on dry matter production of propagating structures of weeds (kg ha^{-1})

Treatments	*Cynodon dactylon*		*Cyperus rotundus*		Total	
	1998	1999	1998	1999	1998	1999
Gly 0.8 kg ha^{-1}	*2.13^{c} (137.30)	2.18^{b} (150.70)	2.51^{b} (325.30)	2.24^{ab} (174.70)	2.67^{c} (462.70)	2.51^{b} (325.30)
Gly 1.2 kg ha^{-1}	1.91^{d} (80.00)	1.73^{c} (53.30)	2.13^{c} (134.70)	1.92^{b} (84.00)	2.33^{d} (214.70)	2.14^{c} (137.30)
Solarization	1.70^{e} (50.70)	1.18^{d} (14.70)	2.17^{c} (149.30)	1.10^{c} (30.70)	2.30^{d} (200.00)	1.61^{d} (45.30)
Cowpea	2.51^{b} (319.30)	2.10^{b} (127.00)	2.63^{b} (441.30)	2.21^{ab} (176.00)	2.88^{b} (760.70)	2.47^{b} (303.00)
Digging	2.46^{b} (287.30)	1.82^{c} (66.70)	2.55^{b} (362.70)	2.41^{ab} (269.30)	2.81^{b} (647.3)	2.51^{b} (336.00)
UWC	2.97^{a} (922.70)	2.84^{a} (694.70)	3.01^{a} (1030.70)	2.87^{a} (742.7)	3.29^{a} (1955.30)	3.16^{a} (1437.00)
SEm±	0.048	0.048	0.045	0.244	0.026	0.088
LSD	0.152	0.152	0.142	0.768	0.081	0.027

* log (x+1) transformed value. Values in paranthesis are the original values

crop. However, the pooled data for total count showed that these treatments were on par. Digging treatment also brought down the DMP significantly in both the years. The pooled data for total count also reflected the superiority of solarization as the best treatment and glyphosate as the next.

4.1.5 Soil temperature

The atmospheric temperature was higher during April than in May (Tables 7a and 7b). This difference was seen in the soil temperatures also (both solarized as well as non solarized soils). It is noticed that always the soil temperatures were higher than the atmospheric temperature and that the magnitude of the differences were higher for the values of maximum temperature than in the case of minimum temperature.

The solarization has effected increase in both maximum and minimum temperature in the soil and the effect was more pronounced at the top 5 cm layer. During April 1998 the difference in maximum temperature of solarized and non-solarized soil at the top 5 cm layer was 8.5°C (56.9°C and 48.4°C) whereas it was only 6.7°C and 1.2°C at 10 cm and 20 cm depths. Similar differences were noticed for the observations on temperature during May 1998 also.

4.2 Weed management in okra (subplot treatments)

4.2.1 Observations on weeds

4.2.1.1 Weed flora

The weed flora in okra crop during the Kharif season was more diverse than the flora found in the summer season. In addition to the main weeds of summer season viz. *Cynodon dactylon*, *Cyperus rotundus*, *Cyperus iria*, *Digitaria ciliaris*, *Dactyloctenium aegyptium*, *Ludwigia parviflora* etc., a number of annual weeds were seen in the okra crop (Table 2). The percentage population of *Cyperus iria*, *Ludwigia parviflora*, *Digitaria ciliaris*, *Dactyloctenium aegyptium* and *Ischaemum rugosum* were considerably higher and that of *Cynodon dactylon* was

Table 7. Effect of solarization on soil temperature at different depths

a. April 1998

Depth (cm)	Solarized soil		Non solarized soil	
	Max. temp. (°C)	Min. temp. (°C)	Max. temp. (°C)	Min. temp. (°C)
5	56.9	34.3	48.4	31.7
10	48.8	34.6	42.1	32.7
20	38.6	34.8	37.4	33.2

Mean air temperature : Max:36.5°C
Min: 25.6°C

b. May 1998

Depth (cm)	Solarized soil		Non solarized soil	
	Max. temp. (°C)	Min. temp. (°C)	Max. temp. (°C)	Min. temp. (°C)
5	49.0	32.1	40.8	29.9
10	44.2	33.4	37.2	29.9
20	36.0	33.5	35.6	30.2

Mean air temperature : Max:34.1°C
Min: 25.2°C

lower in the okra crop. In addition to these weeds, *Echinochloa colona, Phyllanthus niruri* and *Physalis minima* were also seen in the Kharif season. However, practically no weed growth was recorded in polyethylene mulched plots, as any weed was germinated through the holes made for planting okra, was removed periodically. So which can be considered as weed free check.

4.2.1.2 Weed population

a) *Cynodon dactylon*

Residual effect of the summer season (main plot) treatments was seen during the okra crop (Kharif season. All the summer season treatments resulted in lower *Cynodon dactylon* count in okra crop during both years of the study (Table 8). During 1998, the treatment glyphosate 1.2 kg ha^{-1} applied in summer resulted in the least population of *Cynodon* in okra, closely followed by solarization which was on par. In 1999, solarization treatment resulted in significantly lower values than all other treatments at 30 and 60 DAS stages (3.11 and 4.00 No. m^{-2}). This was followed by glyphosate 1.2 kg and 0.8 kg ha^{-1} which were statistically on par. Smother cropping and monthly digging were on par and better than the control in both years.

The weed control treatments given to okra crop during Kharif season (sub plot treatments) did not result in appreciable reduction in the *Cynodon* population, during both years of study, eventhough the pre-emergence herbicides resulted in statistically lower values.

b) *Cyperus rotundus*

In general, only glyphosate 1.2 kg ha^{-1} applied (in the summer) plots showed consistent and significant reduction in *Cyperus rotundus* in both the years (Table 9). In 1999, all the treatments had significantly lower *Cyperus rotundus* population compared to weedy check at 30 and 60 DAS (34.27 and 25.6 No. m^{-2}). Glyphosate 1.2 kg ha^{-1} resulted in maximum reduction (10.00 and 13.00 No. m^{-2})

Table 8. Effect of treatments on population of *Cynodon dactylon* at various growth stages of okra

Treatments	*Cynodon dactylon* (No. m^{-2})			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Glyphosate 0.8 kg ha^{-1}	*5.42^{b} (29.87)	6.85^{c} (46.67)	2.88^{b} (9.07)	3.04^{b} (9.33)
Glyphosate 1.2 kg ha^{-1}	3.37^{c} (11.73)	4.75^{d} (22.40)	2.32^{b} (6.27)	2.67^{b} (7.47)
Solarization	3.90^{c} (15.60)	4.79^{d} (22.53)	1.75^{c} (3.11)	1.91^{c} (4.00)
Cowpea	6.68^{b} (44.40)	8.16^{b} (67.20)	2.91^{b} (9.33)	2.61^{b} (6.93)
Digging	6.69^{b} (44.93)	8.73^{b} (77.33)	3.21^{b} (11.60)	3.26^{b} (11.73)
UWC	10.04^{a} (100.08)	11.00^{a} (121.07)	9.36^{a} (89.87)	7.71^{a} (61.87)
SEm±	0.416	0.245	0.265	0.192
LSD	1.310	0.773	0.834	0.606
Subplots				
Poly Mulching	-	-	-	-
H.W.	5.70 (38.11)	7.66^{b} (61.78)	3.04^{b} (13.00)	3.04^{a} (13.33)
Pendimethalin + HW	6.23 (43.22)	6.72^{c} (50.67)	3.62^{b} (20.00)	2.67^{ab} (12.00)
Metolachlor + HW	5.92 (43.22)	7.11^{bc} (55.56)	3.64^{b} (24.44)	1.91^{b} (16.89)
Fluchloralin + HW	4.89 (37.78)	7.11^{c} (54.44)	3.33^{b} (17.11)	2.61^{ab} (13.30)
UWC	6.35 (43.78)	8.31^{a} (75.22)	4.44^{a} (30.56)	3.26^{a} (28.89)
SEm±	0.225	0.187	0.230	0.259
LSD	NS	0.530	0.653	0.737

*$\sqrt{x+1}$ transformed value. Values in paranthesis are the original values

Table 9. Effect of treatments on the population of *Cyperus rotundus* at various growth stages of okra

Treatments	*Cyperus rotundus* (No. m^{-2})			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Glyphosate 0.8 kg ha^{-1}	*4.12^{c} (17.33)	4.56^{ab} (20.13)	3.69^{bc} (13.73)	3.96^{b} (15.73)
Glyphosate 1.2 kg ha^{-1}	3.14^{d} (10.00)	3.72^{c} (13.33)	2.82^{d} (7.33)	2.86^{c} (8.27)
Solarization	6.34^{a} (39.47)	5.22^{a} (27.33)	4.17^{b} (17.07)	3.73^{b} (13.33)
Cowpea	6.03^{ab} (36.13)	4.94^{ab} (24.00)	3.34^{cd} (18.40)	3.37^{bc} (10.67)
Digging	5.40^{b} (28.80)	4.83^{ab} (23.60)	3.20^{cd} (10.40)	3.45^{bc} (11.47)
UWC	6.28^{a} (38.67)	4.07^{bc} (16.80)	5.90^{a} (34.27)	4.97^{a} (25.60)
SEm±	0.234	0.298	0.159	0.218
LSD	0.738	0.939	0.503	0.689
Subplots				
Poly Mulching	-	-	-	-
H.W.	5.95^{a} (36.11)	4.39^{b} (19.56)	4.14^{b} (16.89)	3.29^{cd} (10.67)
Pendimethalin + HW	5.18^{b} (28.00)	4.35^{b} (18.56)	3.45^{c} (13.22)	3.09^{d} (9.33)
Metolachlor + HW	5.03^{b} (26.00)	4.25^{b} (17.89)	3.53^{c} (13.22)	3.65^{bc} (13.11)
Fluchloralin + HW	4.88^{b} (25.67)	4.40^{b} (19.11)	3.61^{c} (14.00)	4.00^{b} (15.78)
UWC	5.05^{b} (26.22)	5.39^{a} (29.22)	4.53^{a} (20.33)	4.58^{a} (22.00)
SEm±	0.144	0.182	0.126	0.156
LSD	0.408	0.517	0.357	0.443

*$\sqrt{x+1}$ transformed value. Values in paranthesis are the original values

in the first and second year (7.33 and 8.27 No. m^{-2}) followed by glyphosate 0.8 kg ha^{-1} and smother cropping.

Only slight reduction in count of *Cyperus rotundus* was observed due to weed management treatments given to crop, except for black polyethylene mulching treatment.

c) *Cyperus iria*

In general, the various summer season weed management practices other than solarization had no significant influence on the population of *Cyperus iria* (Table 10). Solarization resulted in considerable reduction of this weed at all the stages of crop in both years of study.

All the weed management practices given to okra crop resulted in significant reduction in *Cyperus iria* population, except pendimethalin at 30 DAS in 1999, which recorded higher values than even unweeded control. Metolachlor was the best pre emergence herbicide against *Cyperus iria*.

d) Broad leaved weeds

Data are presented in Table 11. Among the main plot treatments, solarization was most successful in both years though the differences were not statistically significant in 1998. Glyphosate treatments had little impact on the population of broad leaved weeds in both the years. These treatments along with digging and smother cropping were on par with weedy check at 30 DAS, during 1998. Generally a higher infestation of broad leaved weeds especially *Ludwigia parviflora* was observed in 1999.

Various sub plot treatments significantly reduced weed population at 30 and 60 DAS in both the years. Hand weeding was statistically inferior to pre-emergence herbicides. Pendimethalin resulted in significant reduction of broad leaved weeds in both the years. Metolachlor was on par with pendimethalin at 30

Table 10. Effect of treatments on count of *Cyperus iria* at various growth stages of okra

Treatments	*Cyperus iria* (No. m^{-2})			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Glyphosate 0.8 kg ha^{-1}	*4.61 [a] (23.87)	2.78 (10.67)	6.16 [a] (37.90)	4.49 [a] (19.73)
Glyphosate 1.2 kg ha^{-1}	5.17 [a] (27.90)	3.24 (15.73)	5.68 [ab] (32.40)	4.08 [ab] (16.00)
Solarization	2.23 [c] (5.50)	2.95 (9.73)	2.94 [c] (8.80)	2.73 [c] (8.30)
Cowpea	3.77 [b] (16.53)	2.73 (10.70)	6.05 [a] (36.93)	3.68 [b] (13.07)
Digging	4.69 [a] (24.53)	2.26 (7.20)	5.99 [a] (36.40)	4.47 [a] (19.50)
UWC	4.59 [a] (22.30)	3.03 (10.13)	5.13 [b] (26.93)	4.19 [ab] (17.60)
SEm± LSD	0.185 0.584	0.297 NS	0.183 0.578	0.170 0.534
Sub plots				
Poly. mulching	-	-	-	-
H.W.	3.11 [c] (9.56)	1.75 [c] (3.11)	4.18 [d] (16.67)	3.59 [b] (12.44)
Pendimethalin + HW	4.56 [b] (22.11)	2.57 [b] (7.11)	6.22 [a] (40.44)	3.77 [b] (14.22)
Metolachlor + HW	2.16 [d] (4.44)	1.47 [c] (1.78)	5.27 [c] (29.56)	3.62 [b] (13.80)
Fluchloralin + HW	5.04 [b] (27.56)	2.47 [b] (6.22)	5.70 [b] (34.67)	3.89 [b] (14.67)
UWC	6.01 [a] (36.78)	5.89 [a] (35.22)	5.25 [c] (28.11)	4.84 [a] (22.33)
SEm± LSD	0.206 0.587	0.215 0.612	0.134 0.382	0.146 0.414

*$\sqrt{x}$ + 1 transformed value. Values in paranthesis are the original values

Table 11. Effect of treatments on count of broad leaved weeds at various growth stages of okra

Treatments	Broad leaved weeds (No. m^{-2})			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Glyphosate 0.8 kg ha^{-1}	*3.28 ^{a} (12.80)	3.67 ^{b} (14.53)	7.98 ^{b} (64.80)	7.34 ^{a} (53.90)
Glyphosate 1.2 kg ha^{-1}	2.96 ^{ab} (11.10)	3.82 ^{b} (16.13)	7.45 ^{c} (56.00)	6.80 ^{abc} (45.60)
Solarization	2.13 ^{b} (4.90)	3.54 ^{b} (13.20)	5.08 ^{e} (25.33)	5.32 ^{d} (29.10)
Cowpea	2.87 ^{ab} (8.53)	3.95 ^{b} (16.80)	7.83 ^{b} (62.93)	6.23 ^{c} (38.40)
Digging	2.52 ^{ab} (8.00)	3.55 ^{b} (13.90)	9.01 ^{a} (82.13)	6.61 ^{bc} (45.60)
UWC	3.47 ^{a} (14.13)	4.54 ^{a} (20.40)	6.74 ^{d} (47.90)	6.83 ^{ab} (46.67)
SEm± LSD	0.288 0.909	0.172 0.542	0.109 0.344	0.174 0.549
Subplots				
Poly. mulching	-	-	-	-
H.W.	3.34 ^{b} (11.22)	4.33 ^{b} (18.56)	7.80 ^{b} (64.00)	6.89 ^{b} (47.33)
Pendimethalin + HW	1.79 ^{c} (3.11)	2.36 ^{d} (6.00)	5.96 ^{d} (36.22)	5.10 ^{d} (26.44)
Metolachlor + HW	2.17 ^{c} (5.33)	3.39 ^{c} (11.90)	6.69 ^{c} (45.22)	6.34 ^{c} (39.80)
Fluchloralin + HW	2.04 ^{c} (4.22)	3.77 ^{bc} (14.11)	7.41 ^{b} (55.60)	6.39 ^{c} (40.44)
UWC	5.02 ^{a} (25.67)	5.39 ^{a} (28.60)	8.88 ^{a} (81.60)	7.90 ^{a} (62.00)
SEm± LSD	0.252 0.716	0.231 0.714	0.165 0.470	0.091 0.258

*$\sqrt{x+1}$ transformed value. Values in paranthesis are the original values

DAS, during 1998. No weed growth was observed in the polyethylene mulched plots.

e) Other grass weeds

Data on the population of other grasses (*Digitaria ciliaris, Eleusine indica, Dactyloctenium aegyptium, Brachiaria distachya, Ischaemum rugosum, Echinochloa colona* and *Brachiaria mutica*) are presented in Table 12.

Among the various summer season weed management practices, glyphosate treatments and solarization showed consistent and significant reduction of other grass weeds in the subsequent crop of okra. In 1998, glyphosate 1.2 kg ha^{-1} was the best but was on par with solarization.

Among the treatments given to okra, polyethylene mulching recorded no weed growth in both years of study, which was followed by metolachlor in 1998 and hand weeding in 1999. Application of all pre-emergence herbicides resulted in significant reduction in the count of other grass weeds.

f) Total weed count

The data on total weed count are presented in Table 13a and 13b.

All the summer season weed management practices significantly reduced total weed population in the subsequent okra crop, in both years. In general, Glyphosate 1.2 kg ha^{-1} and solarization were the best treatments, followed by glyphosate 0.8 kg ha^{-1}. The cover cropping and monthly digging were statistically better than UWC but were inferior to the earlier mentioned treatments.

Black polyethylene mulching resulted in complete suppression of all weeds. Metolachlor was the best (87.70 and 99.90 weeds m^{-2}) at 30 and 60 DAS in 1998 and pendimethalin (131.80 and 81.56 weeds m^{-2}) in 1999. But pendimethalin was on par with hand weeding at 30 DAS.

Table 12. Effect of treatments on count of other grass weeds at various growth stages of okra

Treatments	Other grass weeds (No. m^{-2})			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Glyphosate 0.8 kg ha^{-1}	*3.22^{bc} (11.73)	4.49^{bc} (20.27)	5.48^{b} (29.90)	5.50^{c} (31.50)
Glyphosate 1.2 kg ha^{-1}	2.56^{c} (6.93)	4.36^{c} (19.33)	4.65^{c} (21.60)	5.34^{c} (30.67)
Solarization	3.32^{bc} (11.60)	5.19^{abc} (28.33)	3.31^{d} (12.30)	4.04^{d} (16.53)
Cowpea	3.72^{ab} (15.20)	5.23^{ab} (27.90)	6.21^{a} (38.67)	6.05^{b} (37.87)
Digging	4.36^{a} (20.80)	5.06^{abc} (28.67)	5.81^{ab} (34.67)	5.46^{c} (31.20)
UWC	4.19^{a} (20.00)	5.54^{a} (32.93)	5.74^{ab} (34.00)	6.58^{a} (43.40)
SEm±	0.253	0.245	0.144	0.147
LSD	0.798	0.771	0.453	0.463
Subplots				
Poly mulching	-	-	-	-
H.W.	3.04^{b} (9.11)	4.67^{b} (21.67)	4.18^{c} (18.44)	4.06^{d} (16.44)
Pendimethalin + HW	3.07^{b} (9.80)	5.24^{b} (27.22)	4.34^{c} (19.67)	4.58^{c} (21.80)
Metolachlor + HW	2.83^{b} (8.70)	4.01^{c} (16.70)	5.10^{b} (27.22)	5.46^{b} (29.56)
Fluchloralin + HW	3.04^{b} (9.11)	3.95^{c} (15.70)	6.23^{a} (40.11)	5.74^{b} (33.33)
UWC	5.83^{a} (35.22)	7.03^{a} (49.94)	6.14^{a} (37.11)	7.63^{a} (58.44)
SEm±	0.229	0.218	0.157	0.157
LSD	0.651	0.621	0.446	0.477

*$\sqrt{x+1}$ transformed value. Values in paranthesis are the original values

Table 13. Total weed count in okra at 30 DAS as influenced by main plot (summer season) and sub plot (kharif season) treatments during 1998 and 1999 (No. m^{-2})

a. 1998

Main plot Treatments	Subplot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	-	9.06 (81.33)	8.64 (75.33)	7.79 (60.00)	9.98 (99.33)	10.54 (148.00)	9.20 [c] (92.80)
Gly 1.2 kg ha^{-1}	-	7.96 (62.67)	8.75 (76.00)	6.30 (41.33)	8.18 (66.67)	10.61 (112.00)	8.24 [c] (70.93)
Solarization	-	7.81 (60.67)	8.75 (76.67)	8.25 (68.67)	8.34 (68.67)	10.54 (110.67)	8.74 [c] (77.10)
Cowpea	-	10.72 (114.00)	10.55 (110.67)	9.92 (98.00)	10.63 (112.00)	12.52 (156.67)	10.87 [b] (118.30)
Digging	-	10.99 (120.00)	10.50 (109.33)	10.0 (99.33)	10.59 (112.00)	13.91 (192.67)	11.20 [b] (126.70)
UWC	-	13.64 (186.00)	13.61 (184.67)	13.17 (172.67)	13.18 (172.67)	16.43 (269.33)	14.01 [a] (197.07)
Sub plot mean	-	10.03 [b] (104.11)	10.13 [b] (105.44)	9.07 [c] (90.00)	10.15 [b] (105.20)	12.43 [a] (164.90)	

Interaction is not significant

b. 1999

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	-	11.45 [ghi] (130.67)	12.09 [fgh] (145.33)	11.58 [ghi] (133.33)	11.81 [fgh] (138.67)	15.24 [bc] (231.33)	12.43 [c] (155.90)
Gly 1.2 kg ha^{-1}	-	9.28 [kl] (85.33)	10.75 [ij] (114.67)	10.67 [ij] (113.33)	12.17 [fg] (148.00)	12.48 [fg] (154.33)	11.07 [d] (123.20)
Solarization	-	8.54 [lm] (72.00)	6.71 [n] (44.00)	7.09 [n] (49.33)	8.12 [m] (65.33)	10.01 [jk] (99.33)	8.09 [e] (66.00)
Cowpea	-	11.64 [ghi] (13.67)	11.06 [hi] (122.00)	12.03 [fgh] (144.67)	13.59 [de] (184.67)	14.41 [cd] (206.67)	12.55 [c] (158.53)
Digging	-	11.87 [fgh] (140.00)	11.92 [fgh] (141.33)	12.84 [ef] (164.00)	13.79 [de] (189.33)	15.56 [ab] (241.33)	13.20 [b] (175.00)
UWC	-	14.59 [bcd] (212.00)	14.98 [be] (223.33)	15.26 [bc] (232.00)	15.60 [bc] (242.67)	16.44 [a] (269.33)	15.37 [a] (235.87)
Sub plot mean	-	11.23 [c] (129.11)	11.25 [c] (131.80)	11.58 [c] (131.44)	12.51 [b] (161.44)	14.02 [a] (200.44)	

*$\sqrt{x+1}$ transformed value. Values in paranthesis are the original values

Table 13c. Effect of treatments on total weed count in okra at 60 DAS

Treatments	Total weed count (No. m^{-2})	
	1998	1999
Main plots		
Glyphosate 0.8	10.53 [c] (112.40)	11.19 [b] (127.47)
Glyphosate 1.2	9.16 [e] (86.93)	10.32 [c] (108.00)
Solarization	9.92 [d] (100.50)	8.33 [d] (72.00)
Cowpea	12.00 [b] (146.53)	10.35 [c] (107.50)
Digging	12.06 [b] (180.67)	10.80 [bc] (119.47)
UWC	14.11 [a] (201.33)	13.87 [a] (197.33)
SEm±	0.159	0.154
LSD	0.500	0.486
Sub plots		
Poly. mulching	-	-
H.W.	11.12 [b] (124.70)	9.95 [c] (99.91)
Pendimethalin + HW	10.34 [c] (109.56)	8.86 [d] (81.56)
Metolachlor + HW	9.82 [d] (99.90)	10.59 [b] (115.80)
Fluchloralin + HW	10.42 [c] (109.70)	10.80 [b] (117.56)
U.W.C.	14.80 [a] (221.61)	13.85 [a] (195.80)
SEm±	0.158	0.144
LSD	0.450	0.409

*$\sqrt{x + 1}$ transformed value. Values in paranthesis are the original values

Interaction was significant at 30 DAS stage in 1999 solarization during summer followed by pre-emergence application of pendimethalin 1.0 kg ha^{-1} (44.00 No. m^{-2}) in okra was the best treatment after the mulching combinations. Maximum weed count (269.33 No. m^{-2}) was observed in the control (Table 13b).

4.2.1.3 Dry matter production by weeds

Data on dry matter production by weeds are given in Table 14a, 14b and 14c.

Application of glyphosate 1.2 kg ha^{-1} during the summer season significantly reduced weed dry matter production in the subsequent okra crop, during 1998. Solarization was statistically on par with glyphosate 0.8 kg ha^{-1} but was inferior to glyphosate 1.2 kg ha^{-1}. Solarization was the superior one in 1999, followed by glyphosate 1.2 kg ha^{-1} at 30 DAS. However, at 60 DAS glyphosate treatments were on par. Smother cropping and monthly digging also produced significantly lower weed dry matter compared to the control.

No weed DMP was recorded in the plots which received polyethylene mulching. Among the other weed control measures in okra, metolachlor along with hand weeding at 45 DAS was the best throughout the cropping period, though it was slightly below hand weeding at 30 DAS, during 1998. Pendimethalin + Hand weeding was the most successful in 1999, followed by metolachlor and hand weeding.

Interaction was significant at 30 DAS. After polyethylene mulching combinations, glyphosate 1.2 kg ha^{-1} during summer followed by metolachlor in okra recorded lowest DMP (100.18 kg ha^{-1}) in 1998. During 1999, solarization followed by pendimethalin (265.13 kg ha^{-1}) produced the lowest weed dry matter.

Table 14. Total weed dry matter production in okra at 30 DAS as influenced by main plot (summer season) and sub plot (kharif season) treatments during 1998 and 1999 (kg ha^{-1})

a. 1998

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	-	2.45^{no} (282.80)	2.64^{ijkl} (433.24)	2.40^{op} (250.53)	2.78^{efgh} (605.31)	2.91^{cd} (811.62)	2.64^{c} (432.29)
Gly 1.2 kg ha^{-1}	-	2.42^{op} (264.63)	2.56^{klm} (366.35)	2.01^{q} (100.18)	2.50^{mno} (316.62)	2.80^{defg} (630.50)	2.46^{d} (285.82)
Solarization	-	2.33^{p} (214.00)	2.66^{ijkl} (454.00)	2.59^{jklm} (388.60)	2.62^{ijklm} (412.42)	3.00^{bc} (989.11)	2.64^{c} (434.15)
Cowpea	-	2.57^{klm} (371.83)	2.82^{def} (664.35)	2.68^{hijk} (475.25)	2.71^{fghij} (511.54)	3.01^{b} (1060.44)	2.76^{b} (576.57)
Digging	-	2.54^{lm} (347.67)	2.73^{efghi} (536.89)	2.70^{hgij} (503.06)	2.66^{ijkl} (451.44)	3.05^{b} (1122.18)	2.74^{b} (543.90)
UWC	-	2.63^{ijkl} (428.27)	2.85^{de} (704.78)	2.84^{de} (683.44)	2.81^{defg} (646.11)	3.18^{a} (1516.65)	2.86^{a} (726.41)
Sub plot mean	-	2.49^{c} (309.98)	2.71^{b} (512.51)	2.53^{c} (340.88)	2.68^{b} (477.13)	2.99^{a} (985.07)	

b. 1999

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	-	2.67^{def} (468.01)	2.58^{ghi} (381.09)	2.61^{fgh} (409.49)	2.64^{efg} (432.93)	2.84^{c} (685.46)	2.67^{c} (464.73)
Gly 1.2 kg ha^{-1}	-	2.56^{hij} (359.84)	2.51^{jkl} (325.30)	2.52^{jkl} (327.79)	2.58^{ghi} (380.82)	2.80^{c} (626.98)	2.59^{d} (3.91.22)
Solarization	-	2.46^{lm} (290.27)	2.43^{m} (265.13)	2.50^{kl} (311.67)	2.53^{ijk} (334.58)	2.66^{def} (454.53)	2.51^{e} (325.40)
Cowpea	-	2.70^{d} (500.91)	2.63^{fg} (420.52)	2.68^{de} (481.47)	2.83^{c} (689.35)	2.91^{b} (808.91)	2.75^{b} (561.36)
Digging	-	2.71^{d} (507.48)	2.62^{fg} (419.74)	2.71^{d} (507.60)	2.80^{c} (627.68)	2.97^{a} (938.44)	2.76^{b} (576.56)
UWC	-	2.84^{c} (683.42)	2.80^{c} (626.38)	2.83^{c} (671.61)	2.83^{c} (675.78)	3.01^{a} (1019.80)	2.86^{a} (723.44)
Sub plot mean	-	2.66^{c} (451.73)	2.60^{d} (392.13)	2.64^{c} (436.00)	2.70^{b} (501.47)	2.86^{a} (729.95)	

*$\sqrt{x + 1}$ transformed value. Values in paranthesis are the original values

Table 14c. Effect of treatments on total weed dry matter production (DMP) in okra at 60 DAS

Treatments	Weed DMP (kg ha^{-1})	
	1998	1999
Main plots		
Glyphosate 0.8 kg ha^{-1}	2.66 [d] (454.89)	2.78 [c] (605.70)
Glyphosate 1.2 kg ha^{-1}	2.56 [e] (363.38)	2.75 [c] (561.14)
Solarization	2.66 [d] (459.01)	2.63 [d] (426.30)
Cowpea	2.78 [b] (597.64)	2.83 [b] (670.89)
Digging	2.72 [c] (524.84)	2.84 [b] (686.27)
UWC	2.88 [a] (762.02)	3.00 [a] (999.60)
SEm±	0.012	0.012
LSD	0.036	0.036
Subplots		
Poly. mulching	-	-
H.W.	2.62 [b] (413.63)	2.72 [c] (525.32)
Pendimethalin + HW	2.59 [c] (384.19)	2.66 [d] (456.09)
Metolachlor + HW	2.44 [d] (273.15)	2.74 [bc] (541.81)
Fluchloralin + HW	2.58 [c] (375.63)	2.75 [b] (556.15)
UWC	3.34 [a] (2166.07)	3.16 [a] (1449.92)
SEm±	0.0105	0.0075
LSD	0.0300	0.0212

*$\sqrt{x}$ + 1 transformed value. Values in paranthesis are the original values

4.2.1.4 Weed Control Efficiency (WCE)

Weed control efficiency was highest in glyphosate 1.2 kg ha^{-1} (78.11%) during 1998 and in solarization (67.46%) in 1999 (Table 15). These two treatments were followed by glyphosate 0.8 kg ha^{-1} in both the years of study. Other summer season treatments also had higher weed control efficiency compared to the weedy check.

Hand weeding had the highest WCE (78.78%), followed by metolachlor in 1998. During 1999, metolachlor was on par with hand weeding but inferior to pendimethalin (60.13%), which was the best.

Interaction was significant in both the years. After all mulching combinations, highest WCE efficiency was resulted in glyphosate 1.2 kg ha^{-1} – metolachlor combination (1998) and solarization - pendimethalin combination in 1999.

4.2.2 Observations on okra crop

4.2.2.1 Establishment of crop

During 1998, no phytotoxicity was noticed for any of the herbicides. However, during 1999 in metolachlor sprayed plots there was phytotoxicity and poor establishment of okra. Ill developed root system and stunted appearance were the symptoms noticed on these plants. Even after replanting, the establishment was poor due to the continuous rains during the period.

4.2.2.2 Growth characters

a) Number of leaves

All the summer season weed management practices significantly increased the number of leaves per plant compared to control, in both years (Table 16). Eventhough solarization (7.79 leaves $plant^{-1}$) and glyphosate 1.2 kg ha^{-1} were on par in 1998, solarization (9.04 leaves $plant^{-1}$) was significantly superior

Table 15. Weed control efficiency in okra at 30 DAS as influenced by main plot (summer season) and sub plot (kharif season) treatments during 1998 and 1999

a. 1998

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. Mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	100.00^{a}	80.83^{bcde}	69.80^{ghijkl}	83.47^{bc}	59.99^{mno}	46.40^{p}	68.10^{b}
Gly 1.2 kg ha^{-1}	100.00^{a}	82.17^{bcd}	77.61^{cdefg}	93.44^{a}	78.94^{bcdef}	58.37^{no}	78.11^{a}
Solarization	100.00^{a}	85.88^{b}	69.54^{hijkl}	74.18^{efghij}	72.68^{fghijk}	34.50^{q}	67.36^{b}
Cowpea	100.00^{a}	75.43^{defghi}	56.11^{o}	68.21^{ijkl}	65.87^{klm}	29.76^{qr}	59.08^{c}
Digging	100.00^{a}	76.64^{cdefgh}	64.57^{lmn}	66.76^{jklm}	70.23^{ghijkl}	25.99^{r}	60.84^{c}
UWC	100.00^{a}	71.73^{fghijkl}	53.51^{o}	54.47^{o}	57.15^{o}	0.00^{s}	47.37^{d}
Sub plot mean	100.00^{a}	78.78^{a}	65.19^{c}	73.42^{b}	67.48^{c}	32.50^{d}	

b. 1999

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	100.00^{a}	53.57^{ghi}	62.62^{cdef}	59.77^{efg}	57.50^{fgh}	32.72^{j}	53.24^{c}
Gly 1.2 kg ha^{-1}	100.00^{a}	64.58^{cde}	68.10^{abcd}	67.84^{abcd}	62.64^{def}	38.48^{j}	60.33^{b}
Solarization	100.00^{a}	71.52^{ab}	73.96^{a}	69.40^{abc}	67.19^{bcd}	55.22^{ghi}	67.46^{a}
Cowpea	100.00^{a}	50.39^{i}	58.72^{efgh}	52.55^{hi}	33.28^{j}	20.66^{k}	43.12^{d}
Digging	100.00^{a}	49.80^{i}	58.83^{efgh}	50.20^{i}	38.37^{j}	7.91^{l}	41.02^{d}
UWC	100.00^{a}	32.73^{j}	38.55^{j}	34.15^{j}	33.73^{j}	0.00^{m}	27.82^{e}
Sub plot mean	100.00^{a}	53.76^{b}	60.13^{a}	55.65^{b}	48.78^{c}	25.83^{d}	

than all other treatments in 1999. Glyphosate 0.8 kg ha^{-1} was also on par with above treatments during 1998.

Plastic mulching confirmed its superiority with maximum number of leaves (8.87 and 10.04 leaves $plant^{-1}$), followed by hand weeding in both years. The next best was metolachlor in 1998 and pendimethalin during 1999.

b) Plant height

Glyphosate concentrations were superior to all other main plot treatments in both the years. Solarization was on par with monthly digging in 1998 and with glyphosate concentrations in 1999 (Table 16).

The okra plants in the polyethylene mulched plots, were taller than those from other treatments (88.97 and 95.80 cm). Hand weeding in both years, metolachlor (1998) and pendimethalin (1999) were the other better treatments. Minimum plant height was noticed in the control plots.

c) Dry matter production (DMP) by okra

The data on dry matter production by okra at different stages are presented in Table 17.

Among the summer season treatments, glyphosate 1.2 kg ha^{-1} recorded maximum DMP by okra at all the stages during both years of study (9.11, 29.38 and 8.94, 27.24 g $plant^{-1}$ at 30 and 60 DAS respectively). Solarization was on par with glyphosate 0.8 kg ha^{-1} (30 DAS) during 1998, and with glyphosate 1.2 kg ha^{-1} in 1999. Digging and raising cowpea during summer season also resulted in increased DMP of okra, compared to control.

Polyethylene mulching (12.29, 35.41 and 13.08, 34.50 g $plant^{-1}$) was superior to all other treatments at both stages of observation (30 and 60 DAS) in both years of study. Metolachlor (1998) and pendimethalin (1999) were the better

Table 16. Effect of treatments on number of leaves and height of okra at 60 DAS

Treatments	No. of leaves (No. plant^{-1})		Plant height (cm)	
	1998	1999	1998	1999
Main plots				
Gly 0.8 kg ha^{-1}	7.67 ^{ab}	8.57 ^{b}	84.10 ^{a}	83.54 ^{a}
Gly 1.2 kg ha^{-1}	7.96 ^{a}	8.59 ^{b}	85.89 ^{a}	83.57 ^{a}
Solarization	7.79 ^{a}	9.04 ^{a}	78.28 ^{b}	86.28 ^{a}
Cowpea	7.26 ^{bc}	7.80 ^{c}	73.20 ^{c}	72.23 ^{b}
Digging	7.16 ^{c}	7.99 ^{c}	77.09 ^{b}	71.41 ^{b}
UWC	5.91 ^{d}	6.50 ^{d}	68.52 ^{d}	59.32 ^{c}
SEm±	0.136	0.110	0.701	1.092
LSD	0.428	0.347	0.207	3.442
Subplots				
Poly. mulching	8.87 ^{a}	10.04 ^{a}	88.97 ^{a}	95.80 ^{a}
H.W.	7.76 ^{b}	8.69 ^{b}	80.01 ^{b}	87.11 ^{b}
Pendi + HW	7.07 ^{c}	8.32 ^{c}	74.12 ^{d}	75.84 ^{c}
Meto + HW	7.56 ^{b}	7.18 ^{e}	78.66 ^{bc}	62.32 ^{e}
Flu + HW	7.06 ^{cb}	7.41 ^{d}	77.00 ^{c}	66.70 ^{d}
UWC	5.44 ^{d}	6.84 ^{f}	68.33 ^{e}	68.65 ^{d}
SEm±	0.073	0.080	0.587	0.730
LSD	0.206	0.227	1.661	2.066

Table 17. Effect of treatments on dry matter production by okra at various growth stages

Treatments	Dry matter production (g $plant^{-1}$)			
	1998		1999	
	30 DAS	60 DAS	30 DAS	60 DAS
Main plots				
Gly 0.8 kg ha^{-1}	8.93^{b}	28.01^{b}	8.58^{b}	26.04^{b}
Gly 1.2 kg ha^{-1}	9.11^{a}	29.38^{a}	8.94^{a}	27.24^{a}
Solarization	8.91^{b}	26.29^{c}	8.92^{a}	27.35^{a}
Cowpea	8.46^{c}	26.51^{c}	8.57^{b}	25.37^{b}
Digging	8.16^{d}	25.36^{d}	8.34^{c}	25.29^{b}
UWC	7.73^{e}	22.50^{e}	7.57^{d}	21.65^{c}
SEm±	0.058	0.131	0.054	0.267
LSD	0.182	0.413	0.171	0.842
Subplots				
Poly. mulching	12.29^{a}	35.41^{a}	13.08^{a}	34.50^{a}
H.W	8.30^{c}	26.55^{c}	7.98^{bc}	26.53^{b}
Pendi + HW	8.09^{d}	26.13^{cd}	8.03^{b}	26.57^{b}
Meto + HW	8.55^{b}	27.77^{b}	7.77^{c}	24.67^{c}
Flu + HW	7.95^{d}	25.58^{d}	7.74^{c}	24.52^{c}
UWC	6.11^{e}	16.61^{e}	6.32^{d}	16.17^{d}
SEm±	0.053	0.216	0.089	0.268
LSD	0.149	0.610	0.252	0.758

treatments among the pre-emergence herbicides. However, all the treatments resulted in significantly higher DMP by okra compared to control (6.11, 16.61 and 6.32, 16.17 g plant^{-1}).

4.2.2.3 Yield attributes

a) Number of fruits per plant

The data revealed that, all the summer season weed management practices had significant influence on increasing fruit production of okra (Table 18). Solarization resulted in maximum fruit production per plant (6.11 No. plant^{-1}), which was significantly higher than all other treatments in 1999. During 1998, glyphosate treatments were on par with solarization.

Among the sub plot treatments, polyethylene mulching (10.73 and 10.22 fruits plant^{-1}) significantly increased the fruit production in both years. Metolachlor and hand weeding were the other better treatments in 1998 while pendimethalin and hand weeding were so in the second year.

4.2.2.4 Yield

The data on yield of okra are presented in Tables 19a & 19b.

Various summer season weed management practices resulted in significant increase in yield of okra, in both years. Among them, glyphosate 1.2 kg ha^{-1} was the superior one (3.07 t ha^{-1}) in 1998, followed by glyphosate 0.8 kg ha^{-1} and solarization. In 1999, solarization (2.02 t ha^{-1}) was the best followed by glyphosate treatments. Other treatments also resulted in higher yields than control.

Among sub plot treatments, polyethylene mulching (4.54 and 4.24 t ha^{-1}) was significantly better than all other treatments and control (0.95 and 0.72 t ha^{-1}). Hand weeding (2.57 t ha^{-1}) and metolachlor (2.40 t ha^{-1}) during 1998 and pendimethalin (1.79 t ha^{-1}) in 1999 were the next better ones. Fluchloralin also performed better in both years than the control.

Table 18. Effect of treatments on fruit production by okra

Treatments	Fruit production (No. plant^{-1})	
	1998	1999
Main plots		
Glyphosate 0.8 kg ha^{-1}	7.71 ^{a}	5.60 ^{cd}
Glyphosate 1.2 kg ha^{-1}	7.87 ^{a}	5.97 ^{b}
Solarization	7.89 ^{a}	6.11 ^{a}
Cowpea	7.22 ^{b}	5.71 ^{c}
Digging	6.83 ^{c}	5.50 ^{d}
UWC	4.26 ^{d}	4.28 ^{e}
Sem±	0.074	0.127
LSD	0.233	0.040
Subplots		
Poly. mulching	10.73 ^{a}	10.22 ^{a}
H.W.	6.97 ^{c}	6.28 ^{b}
Pendimethalin + HW	6.74 ^{d}	6.37 ^{b}
Metolachlor + HW	7.19 ^{b}	3.46 ^{d}
Fluchloralin + HW	6.36 ^{e}	3.77 ^{c}
UWC	3.79 ^{f}	3.08 ^{e}
Sem±	0.053	0.121
LSD	0.151	0.043

Table 19. Yield of okra as influenced by main plot (summer season) and sub plot (kharif season) treatments during 1998 and 1999 (t ha^{-1})

a. 1998

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	5.15^{a}	2.89^{e}	2.37^{gh}	2.96^{e}	2.53^{fg}	1.05^{lmn}	2.82^{b}
Gly 1.2 kg ha^{-1}	5.28^{a}	2.94^{e}	2.85^{e}	3.31^{d}	2.77^{ef}	1.28^{l}	3.07^{a}
Solarization	5.10^{a}	2.54^{fg}	2.02^{ij}	2.93^{e}	1.96^{ijk}	1.01^{lmn}	2.60^{c}
Cowpea	4.44^{b}	2.88^{e}	1.88^{ijk}	2.14^{hi}	2.10^{ij}	0.95^{mn}	2.40^{d}
Digging	3.98^{c}	2.49^{fg}	1.83^{jk}	1.90^{ijk}	1.90^{ijk}	0.77^{no}	2.14^{e}
UWC	3.31^{d}	1.70^{k}	0.95^{mn}	1.15^{lm}	1.04^{lmn}	0.66^{o}	1.47^{f}
Sub plot mean	4.54^{a}	2.57^{b}	1.98^{d}	2.40^{c}	2.05^{d}	0.95^{e}	

b. 1999

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	4.26^{c}	1.74^{fgh}	1.85^{efg}	0.72^{opqr}	1.20^{k}	0.72^{opqr}	1.75^{c}
Gly 1.2 kg ha^{-1}	4.49^{b}	1.93^{ef}	1.95^{ef}	0.90^{mno}	1.28^{k}	0.72^{opqr}	1.88^{b}
Solarization	4.75^{a}	1.97^{e}	2.01^{e}	0.95^{lm}	1.48^{ij}	0.95^{lmn}	2.02^{a}
Cowpea	4.54^{b}	1.65^{hi}	1.94^{ef}	0.79^{mnop}	1.33^{jk}	0.74^{nopq}	1.83^{b}
Digging	4.35^{bc}	1.68^{ghi}	1.89^{ef}	0.76^{mnopq}	1.24^{k}	0.65^{pqr}	1.76^{c}
UWC	3.04^{d}	1.13^{kl}	1.12^{kl}	0.57^{qr}	0.90^{mno}	0.52^{r}	1.21^{d}
Sub plot mean	4.24^{a}	1.68^{c}	1.79^{b}	0.78^{e}	1.24^{d}	0.72^{e}	

The interaction effect was also found to be significant. During 1998, the yield ranged from 5.28 t ha^{-1} for the treatment where glyphosate 1.2 kg ha^{-1} applied in summer season followed by black polyethylene mulching in the okra crop to as low as 0.66 t ha^{-1} in the absolute control treatment, where no weed control treatment was given in both summer season and kharif season. During 1999, the best combination was solarization in summer season followed by mulching with black polyethylene in okra crop (4.75 t ha^{-1}). Here also, the absolute control (UWC in both seasons) recorded the lowest yield of 0.52 t ha^{-1}.

All the treatment combinations involving polyethylene mulching in okra crop (including the control in summer season) resulted in higher okra yields, indicating the crop stimulatory and weed control effect. In general, during 1998, the combinations of solarization and glyphosate treatments (1.2 and 0.8 kg ha^{-1}) with metolachlor 1.0 kg ha^{-1} gave comparatively higher yields, though statistically lower than the combinations with polyethylene mulching. This was followed by combinations of the above main plot treatments with hand weeding and pendimethalin. However, in 1999, the combinations with metolachlor were inferior to those with hand weeding, pendimethalin and even fluchloralin, as it caused phytotoxicity to the crop.

4.2.2.5 Weed Index (WI)

Generally all main plot treatments showed a lower weed index value compared to control (72.24 and 74.47%) during both years indicating the superiority of those treatments (Table 20a & 20b). However, glyphosate 1.2 kg ha^{-1} (41.85%) and solarization (57.50%) were the best ones in 1998 and 1999 respectively.

Among the sub plot treatments, it was polyethylene mulching which resulted in very low WI values in both years (14.17 and 10.74%). Hand weeding and metolachlor were the succeeding ones in 1998 and pendimethalin in 1999.

Table 20. Weed index in okra as influenced by main plot (summer season) and sub plot (kharif season) treatments during 1998 and 1999 (%)

a. 1998

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	2.58^{o}	45.32^{k}	55.16^{hi}	44.08^{k}	52.09^{ij}	80.13^{cd}	46.56^{e}
Gly 1.2 kg ha^{-1}	0.00^{o}	44.35^{k}	46.02^{k}	37.37^{l}	47.62^{jk}	75.72^{d}	41.85^{f}
Solarization	3.53^{o}	51.78^{ij}	61.67^{fg}	44.58^{k}	62.82^{efg}	80.82^{bcd}	50.87^{d}
Cowpea	15.90^{n}	45.50^{k}	64.48^{efg}	59.56^{gh}	60.25^{fg}	82.00^{bc}	54.62^{c}
Digging	25.70^{m}	52.81^{i}	65.42^{ef}	64.03^{efg}	64.00^{efg}	85.55^{ab}	59.58^{b}
UWC	37.33^{l}	67.80^{e}	82.01^{bc}	78.26^{cd}	80.39^{cd}	87.62^{a}	72.24^{a}
Sub plot mean	14.17^{e}	51.26^{d}	62.46^{b}	54.65^{c}	61.20^{b}	81.97^{a}	

b. 1999

Main plot treatments	Sub plot treatments						Main plot mean
	Poly. mul.	H.W.	Pendi	Meto	Flu	U.W.C.	
Gly 0.8 kg ha^{-1}	10.35^{p}	63.34^{klm}	60.95^{lmn}	84.82^{abcd}	74.70^{h}	84.88^{abcd}	63.17^{b}
Gly 1.2 kg ha^{-1}	5.55^{q}	59.40^{mn}	58.96^{mn}	81.18^{def}	72.96^{h}	84.82^{abcd}	60.48^{d}
Solarization	0.00^{r}	58.45^{n}	57.72^{n}	79.92^{fg}	68.78^{ij}	80.14^{efg}	57.50^{e}
Cowpea	4.32^{q}	65.24^{jk}	59.60^{mn}	83.27^{cdef}	72.11^{hi}	84.47^{bcde}	61.50^{cd}
Digging	8.20^{pq}	64.72^{jkl}	60.24^{mn}	84.06^{bcdef}	73.99^{h}	86.42^{abc}	62.94^{bc}
UWC	36.00^{o}	76.24^{gh}	76.38^{gh}	88.02^{ab}	81.15^{def}	89.02^{a}	74.47^{a}
Sub plot mean	10.74^{e}	64.56^{c}	62.31^{d}	83.55^{a}	73.95^{b}	84.96^{a}	

Interaction was significant in both years. Combinations of polyethylene mulching with glyphosate treatments and solarization were the superior ones, which was nil in the combinations with glyphosate 1.2 kg ha^{-1} in 1998 and with solarization in 1999. Glyphosate 1.2 kg ha^{-1} with metolachlor 1.0 kg ha^{-1} and solarization followed by pendimethalin 1.0 kg ha^{-1} were the best pre-emergence herbicides, in the respective years.

4.3 Studies on nutrient uptake

4.3.1 Nutrient removal by weeds

The data on uptake of nitrogen, phosphorus and potassium by weeds at different stages in 1998 are presented in Table 21 and the corresponding N, P and K content in Appendix-II.

a) Nitrogen

The effect of the main plot treatments applied during the summer season was reflected in the uptake of nutrients by weeds in the okra crop in the kharif season. Glyphosate 1.2 kg ha^{-1} recorded minimum N removal (6.87 and 9.12 kg ha^{-1}), followed by glyphosate 0.8 kg ha^{-1} and solarization which were on par. Cowpea and monthly digging were on par but significantly higher than the control (14.79 and 17.28 kg ha^{-1}).

In the okra crop, no nutrients removal by weeds was recorded in the polyethylene mulched plots, as there was no weed growth. Hand weeded plots recorded minimum N removal by weeds at 30 DAS (6.30 kg ha^{-1}), but metolachlor had the least values (5.65 kg ha^{-1}) towards 60 DAS. Hand weeding was on par with other pre-emergence herbicides at 60 DAS. Control had maximum uptake by weeds (19.04 and 40.03 kg ha^{-1}).

b) Phosphorus

Glyphosate treatments (1.2 and 0.8 kg ha^{-1}) recorded minimum P uptake by weeds among the main plot treatments (0.79, 1.10 and 0.94, 1.22 kg ha^{-1}). This

Table 21. Effect of treatments on nutrient removal by weeds at various growth stages of okra during 1998 (kg ha^{-1})

Treatments	Nitrogen		Phosphorus		Potassium	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Mainplots						
Gly 0.8 kg ha^{-1}	9.71 ^{c}	11.84 ^{c}	0.94 ^{c}	1.22 ^{d}	10.26 ^{c}	12.57 ^{c}
Gly 1.2 kg ha^{-1}	6.87 ^{d}	9.12 ^{d}	0.79 ^{c}	1.10 ^{d}	7.06 ^{d}	9.95 ^{d}
Solarization	9.87 ^{c}	12.80 ^{c}	1.20 ^{b}	1.48 ^{c}	9.88 ^{c}	12.40 ^{c}
Cowpea	12.15 ^{b}	15.05 ^{b}	1.36 ^{b}	1.81 ^{b}	12.27 ^{b}	15.73 ^{b}
Digging	11.03 ^{bc}	14.62 ^{b}	1.21 ^{b}	1.53 ^{c}	11.83 ^{b}	14.73 ^{b}
UWC	14.79 ^{a}	17.28 ^{a}	1.56 ^{a}	2.03 ^{a}	15.87 ^{a}	17.70 ^{a}
SEm±	0.417	0.399	0.059	0.845	0.430	0.397
LSD	1.314	1.259	0.186	0.141	1.356	1.251
Subplots						
Poly. Mulching	-	-	-	-	-	-
H.W.	6.30 ^{d}	7.55 ^{b}	0.81 ^{d}	1.00 ^{b}	6.62 ^{e}	7.98 ^{b}
Pendi + HW	10.38 ^{b}	6.96 ^{b}	1.19 ^{b}	0.89 ^{c}	10.91 ^{b}	7.43 ^{b}
Meto + HW	8.33 ^{c}	5.65 ^{c}	0.94 ^{c}	0.67 ^{e}	8.64 ^{d}	5.79 ^{c}
Flu + HW	9.64 ^{b}	7.07 ^{b}	0.99 ^{c}	0.77 ^{d}	9.89 ^{c}	7.24 ^{b}
UWC	19.04 ^{a}	40.03 ^{a}	1.96 ^{a}	4.31 ^{a}	19.90 ^{a}	40.78 ^{a}
SEm±	0.300	0.344	0.036	0.035	0.336	0.374
LSD	0.852	0.977	0.102	0.099	0.954	1.064

was followed by solarization, which was on par with other treatments except, smother crop at 60 DAS. All the treatments had lower P removal than the control at all stages.

Among the weed control methods in okra crop, the superiority achieved by hand weeding at 30 DAS was lost at 60 DAS and metolachlor emerged as the superior one (0.94 and 0.67 kg ha^{-1}). Hand weeding had higher P uptake than the pre-emergence herbicides at 60 DAS. However, all the treatments resulted in significantly lower P uptake at all stages compared to control (1.96 and 4.31 kg ha^{-1}).

c) Potassium

Among the main plot treatments, all the treatments significantly reduced K removal by weeds and glyphosate 1.2 kg ha^{-1} had the lowest uptake at all stages (7.06 and 9.95 kg ha^{-1}). This was followed by solarization and glyphosate 0.8 kg ha^{-1}. Cowpea and digging treatments were on par and statistically superior to control (15.87 and 17.70 kg ha^{-1}).

In the okra crop, after polyethylene mulching, hand weeding (6.62 kg ha^{-1}) was the next best at 30 DAS, but metolachlor 1.0 kg ha^{-1} was so at 60 DAS. However, other treatments were also superior to weedy check (19.90 and 40.78 kg ha^{-1}) at both stages of observation.

4.3.2 Nutrient removal by okra

The data on uptake of nitrogen, phosphorus and potassium by okra at different stages in 1998 are presented in Table 22 and the corresponding N, P and K content in Appendix-III.

a) Nitrogen

Okra crop in the glyphosate 1.2 kg ha^{-1} treatment had maximum uptake of N (7.98 and 23.12 kg ha^{-1}) at both the stages. This was followed by glyphosate 0.8 kg ha^{-1} and solarization. Raising cowpea and monthly digging were on par and statistically superior to weedy check at 30 DAS.

Table 22. Effect of treatments on nutrient removal by okra at various growth stages during 1998 (kg ha^{-1})

Treatments	Nitrogen		Phosphorus		Potassium	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Mainplots						
Gly 0.8kg ha^{-1}	7.71 ^{b}	22.05 ^{b}	2.75 ^{a}	5.66 ^{b}	7.24 ^{b}	20.58 ^{b}
Gly 1.2kg ha^{-1}	7.98 ^{a}	23.12 ^{a}	2.80 ^{a}	6.09 ^{a}	7.75 ^{a}	22.88 ^{a}
Solarization	7.60 ^{b}	20.83 ^{c}	2.77 ^{a}	5.45 ^{c}	7.70 ^{a}	20.79 ^{b}
Cowpea	7.02 ^{c}	20.99 ^{c}	2.60 ^{b}	5.48 ^{c}	6.98 ^{c}	20.56 ^{b}
Digging	6.98 ^{c}	19.82 ^{d}	2.47 ^{c}	5.31 ^{d}	6.31 ^{d}	18.95 ^{c}
UWC	6.18 ^{d}	16.66 ^{e}	2.29 ^{d}	4.55 ^{e}	5.74 ^{e}	16.64 ^{d}
SEm±	0.069	0.172	0.224	0.034	0.067	0.231
LSD	0.218	0.543	0.071	0.108	0.210	0.727
Subplots						
Poly. mulching	10.67 ^{a}	28.61 ^{a}	3.92 ^{a}	7.57 ^{a}	10..37 ^{a}	28.26 ^{a}
H.W.	7.03 ^{c}	20.94 ^{c}	2.53 ^{c}	5.49 ^{c}	6.84 ^{b}	20.23 ^{c}
Pendi + HW	6.89 ^{c}	20.28 ^{cd}	2.46 ^{d}	5.29 ^{d}	6.58 ^{c}	19.64 ^{cd}
Meto + HW	7.33 ^{b}	21.73 ^{b}	2.61 ^{b}	5.64 ^{b}	6.94 ^{b}	21.30 ^{b}
Flu + HW	6.67 ^{d}	19.65 ^{d}	2.36 ^{e}	5.22 ^{d}	6.34 ^{d}	19.23 ^{d}
UWC	4.88 ^{e}	12.27 ^{e}	1.80 ^{f}	3.34 ^{e}	4.64 ^{e}	11.73 ^{c}
SEm±	0.068	0.235	0.018	0.052	0.055	0.233
LSD	0.193	0.664	0.052	0.148	0.155	0.658

Polyethylene mulching had maximum uptake of N (10.67 and 28.61 kg ha^{-1}), followed by metolachlor, among the subplot treatments. Other treatments were also significantly superior to the weedy check.

b) Phosphorus

Among the summer season (main plot) treatments glyphosate 1.2 kg ha^{-1} had maximum uptake of P at both the stages (2.80 and 6.09 kg ha^{-1}). However, at 30 DAS, glyphosate 0.8 kg ha^{-1} and solarization were on par with glyphosate 1.2 kg ha^{-1}. Though lower, the uptake in cowpea and digging was higher than the weedy check (2.29 and 4.55 kg ha^{-1}).

Polyethylene mulching was the best treatment (3.92 and 7.57 kg ha^{-1}) among the weed control practices in okra. Among the pre-emergence herbicides, metolachlor 1.0 kg ha^{-1} had highest P uptake (Table 22).

c) Potassium

Glyphosate 1.2 kg ha^{-1} (7.75 and 22.88 kg ha^{-1}) was the most successful summer season treatment, which permitted maximum uptake of K by okra at both stages. Glyphosate 0.8 kg ha^{-1} and solarization were on par at 60 DAS, and were superior to control (Table 22).

Among the sub plot treatments, polyethylene mulching (10.37 and 28.26 kg ha^{-1}) was the best, followed by metolachlor 1.0 kg ha^{-1}. However, other treatments also significantly increased K uptake compared to control (4.64 and 11.73 kg ha^{-1}).

4.4 Economics of weed control treatments

The data on the economics of different treatments given to okra are presented in Table 23 and the details on cost of cultivation and polyethylene mulching in Appendix-IVa and IVb.

Table 23. Effect of treatments given to okra crop on additional returns. (Rs. ha^{-1})

Treatments	Total return	Cost of the weed control operations in okra	Additional return due to weed control	Return per rupee invested on weed control
Glyphosate 0.8 + pl.mul	30888	13938	24594	1.76
Glyphosate 0.8 + H.W.	17334	9870	11040	1.12
Glyphosate 0.8 + Pendi	14220	5440	7926	1.46
Glyphosate 0.8 + Meto	17736	5050	11442	2.27
Glyphosate 0.8 + Flu	15186	5066	8892	1.76
Glyphosate 0.8 + UWC	6294	-	-	-
Glyphosate 1.2 + pl.mul	31704	13938	24006	1.72
Glyphosate 1.2 + H.W.	17628	9870	9930	1.01
Glyphosate 1.2 + Pendi	17112	5440	9414	1.73
Glyphosate 1.2 + Meto	19848	5050	12150	2.41
Glyphosate 1.2 + Flu	16596	5066	8898	1.76
Glyphosate 1.2 + UWC	7698	-	-	-
Solarization + pl.mul	30594	13938	24522	1.76
Solarization + H.W.	15258	9870	9186	0.93
Solarization + Pendi	12150	5440	6078	1.12
Solarization + Meto	17562	5050	11490	2.28
Solarization + Flu	11778	5066	5706	1.13
Solarization + UWC	6072	-	-	-
Cowpea + pl.mul	26664	13938	209581	1.50
Cowpea + H.W.	17262	9870	11556	1.17
Cowpea + Pendi	11262	5440	5556	1.02
Cowpea + Meto	12816	5050	7110	1.41
Cowpea + Flu	12594	5066	6888	1.36
Cowpea + UWC	5706	-	-	-
Digging + pl.mul	23868	13938	19278	1.38
Digging + H.W.	14964	9870	10374	1.05
Digging + Pendi	10962	5440	6372	1.17
Digging + Meto	11406	5050	6816	1.35
Digging + Flu	11406	5066	6816	1.35
Digging + UWC	4590	-	-	-
Control + pl.mul	19878	13938	15948	1.14
UWC + H.W.	10224	9870	6294	0.63
UWC + Pendi	5706	5440	1866	0.34
UWC + Meto	6888	5050	2958	0.59
UWC + Flu	6222	5066	2292	0.45
UWC + UWC	3930	-	-	-

Uptake of major nutrients (N, P and K) by okra was higher whereas the uptake by weeds was lower, in these treatments.

Black polyethylene mulching given after solarization or glyphosate 1.2 kg ha^{-1} resulted in better vegetative growth, yield attributes and yield in okra. However, return per rupee invested on weed control was the highest from combinations of metolachlor 1.0 kg ha^{-1} + HW at 45 DAS or pendimethalin 1.5 kg ha^{-1} + HW at 45 DAS with solarization or glyphosate 1.2 kg ha^{-1}. This was due to the higher cost for mulching operation.

DISCUSSION

5. DISCUSSION

The results of experiments conducted to develop an integrated method for management of weeds in vegetable ecosystems, with special reference to okra are discussed in this chapter.

5.1 Weed management during summer season

Weed flora in the trial field was dominated by grasses in both years of study. In the control plots, *Cynodon dactylon* and *Cyperus rotundus* together constituted 78 per cent of the total weeds. The count of *Cynodon dactylon* and total weeds were reduced from 1046.70 and 1410.70 No. m^{-2} in 1998 to 746.70 and 1096.00 No. m^{-2} in 1999 respectively. Such reductions were observed in other treatments also. However, the population of *Cyperus rotundus* remained almost the same in both years (Table 3a and 3b).

5.1.1 Effect of summer season treatments

The results showed that all the treatments experimented significantly reduced total weed population, including that of *Cynodon dactylon* and *Cyperus rotundus* (Table 3). No weed growth was recorded in the solarized plots as any weed germinated was killed, due to the hot condition under the polyethylene sheets (Plate 2). Observations were taken immediately after removing polyethylene sheets after solarization for 60 days.

After solarization, glyphosate 1.2 kg ha^{-1} applied twice at 45 days gap, was the most successful and gave consistent results in controlling weeds (Fig.2 and Plate 1) especially *Cynodon dactylon* and *Cyperus rotundus*. The efficacy of systemic herbicide glyphosate needs no emphasis. The effectiveness of glyphosate against nutgrass - a perennial sedge with deep ground vegetative propagules, has been reported by Grubben (1974) and Sandhu and Bhatia (1992). Good control of *Cynodon dactylon* obtained in the current experiment is in line with the

Plate 1. Complete drying of weeds in glyphosate 1.2 kg ha^{-1}(right) compared with profuse growth in control (left)

Plate 2. Weed smothering by cowpea (left) compared with weed suppression in solarization (right)

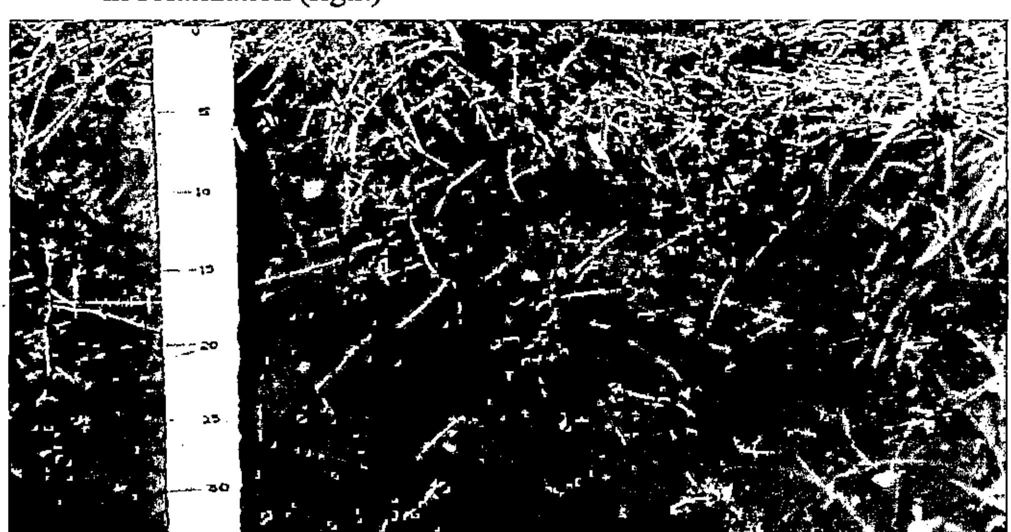


Plate 3. Distribution and regeneration of underground propagules of *Cynodon dactylon*

Fig. 2. Effect of summer season treatments on total weed count

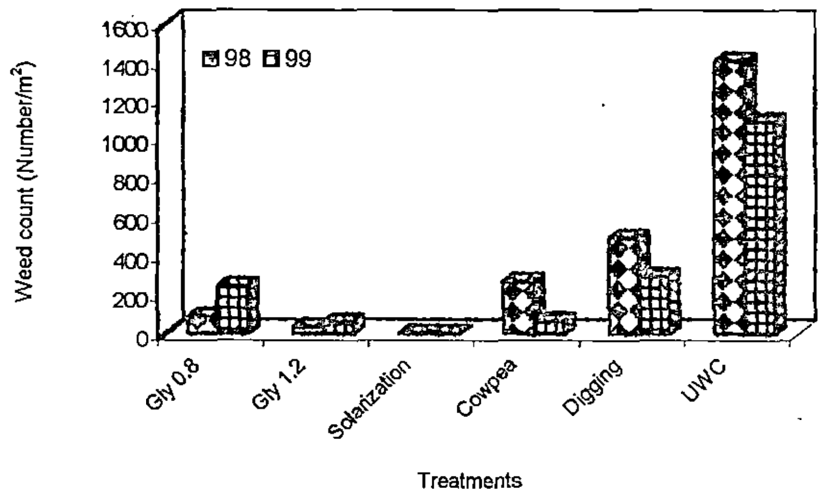
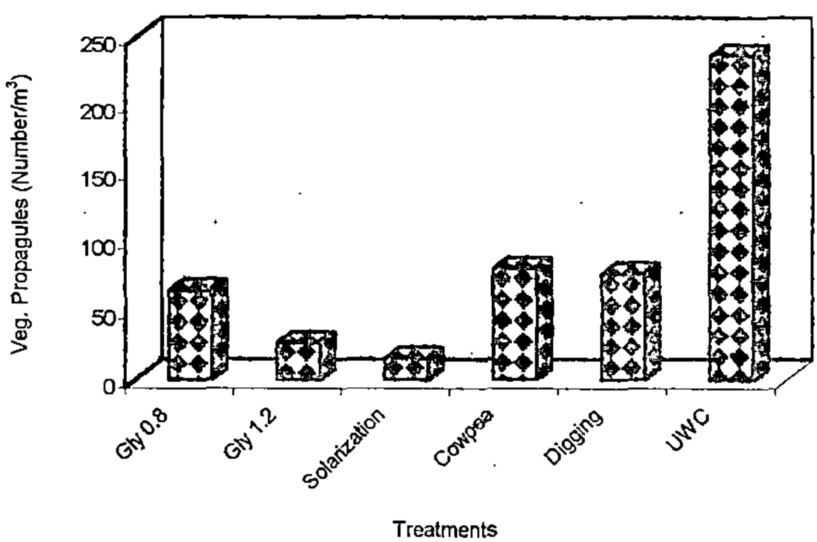


Fig. 3. Effect of treatments on total underground vegetative propagules



observations of Muller *et al.* (1985) and Kandasamy *et al.* (1998), under non crop situations. The trial also revealed that glyphosate 1.2 kg ha^{-1} was superior, in both years, for the control of bermuda grass (5.30 and 14.70 No. m^{-2}) and nutgrass (3.30 and 10.70 No. m^{-2}), than glyphosate at lower concentration (0.8 kg ha^{-1}). Better control with higher concentration of glyphosate (upto 1.25 kg ha^{-1}) was earlier reported by Singh *et al.* (1993). Glyphosate being a systemic herbicide, will be translocated to the underground vegetative propagules and can kill the whole plant. It was also observed that the effectiveness of glyphosate at lower concentration (0.8 kg ha^{-1}) was not much effective in the second year as the previous year, may be due to the influence of environment.

Smother cropping with cowpea resulted in satisfactory control of all types of weeds during 1998, and was on par with glyphosate application of 1.2 kg ha^{-1}. The weed control effect of the smother cropping could be attributed to the better canopy formation of cowpea crop resulting in a smothering effect on the ground, which is fatal to weeds like *Cynodon* and *Cyperus* which have a C_4 pathway for Co_2 fixation. The shade sensitiveness has been reported by workers like Patterson (1982) for nutgrass and Thakur *et al.* (1989) for bermuda grass. Cowpea var. Kanakamony was selected as the smother crop, because of its fast growing and forming good canopy over the area. These qualities of cowpea and broad spectrum suppression of weeds by cowpea growing in coconut-banana cropping system was reported by Savithri (1990). Bhan and Sushilkumar (1998) also recommended cowpea as an intercrop in banana for weed suppression upto 70 days.

Monthly digging reduced perennial weeds significantly in both the years. This effect was pronounced in 1999 where in it was on par with the best treatment (Table 3b). The reduction in count of *Cynodon dactylon* and *Cyperus rotundus* may be attributed to the continuous exposure of the vegetative propagules of these weeds to the hot sun in summer season. This is line with the observations of Philips (1993) who recommended repeated ploughing to reduce the problems of

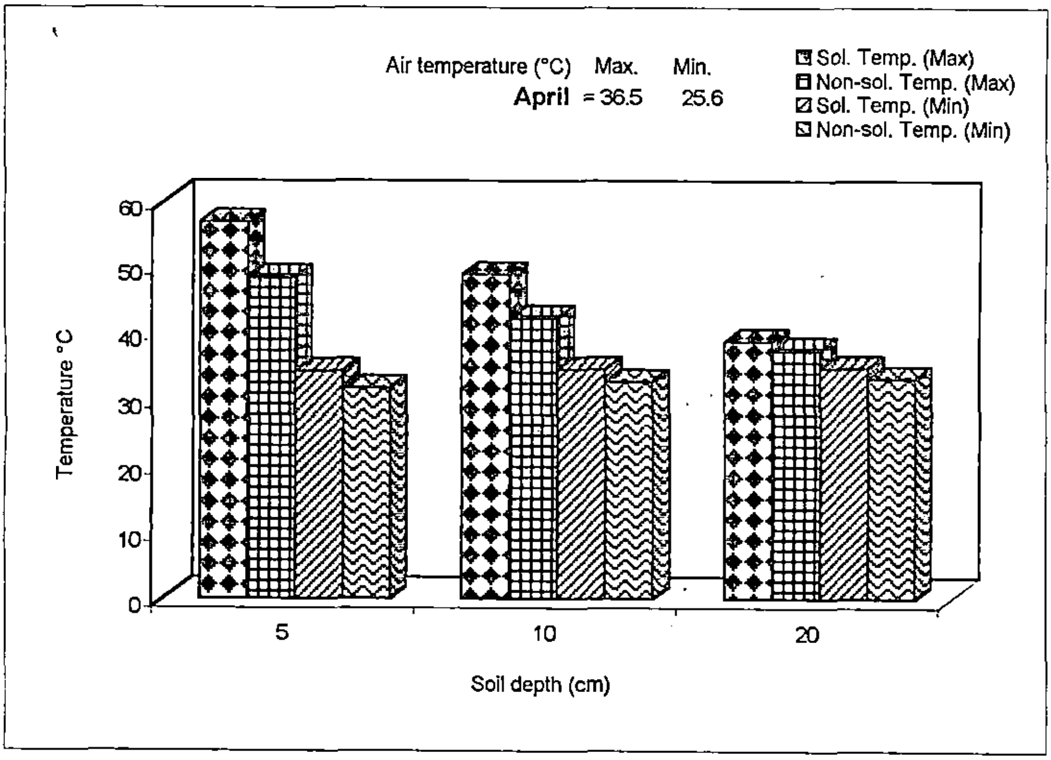
Cynodon dactylon. However, regeneration of Bermuda grass even from a depth of 35 cm from the ground level was observed in the current study (Plate 3). Raju and Reddy (1999) observed that the decline in tuber germination of *Cyperus rotundus* was ten-fold when the tubers were exposed 72 hrs to bright sunshine. However, control of *Cyperus iria* and other annual weeds was not satisfactory in this treatment. A higher population of these weeds in digging treatment may be due to the exposure of burried seeds to the upper layers due to the frequent soil distrubances (Dyer, 1995) supported by less competition from perennial weeds.

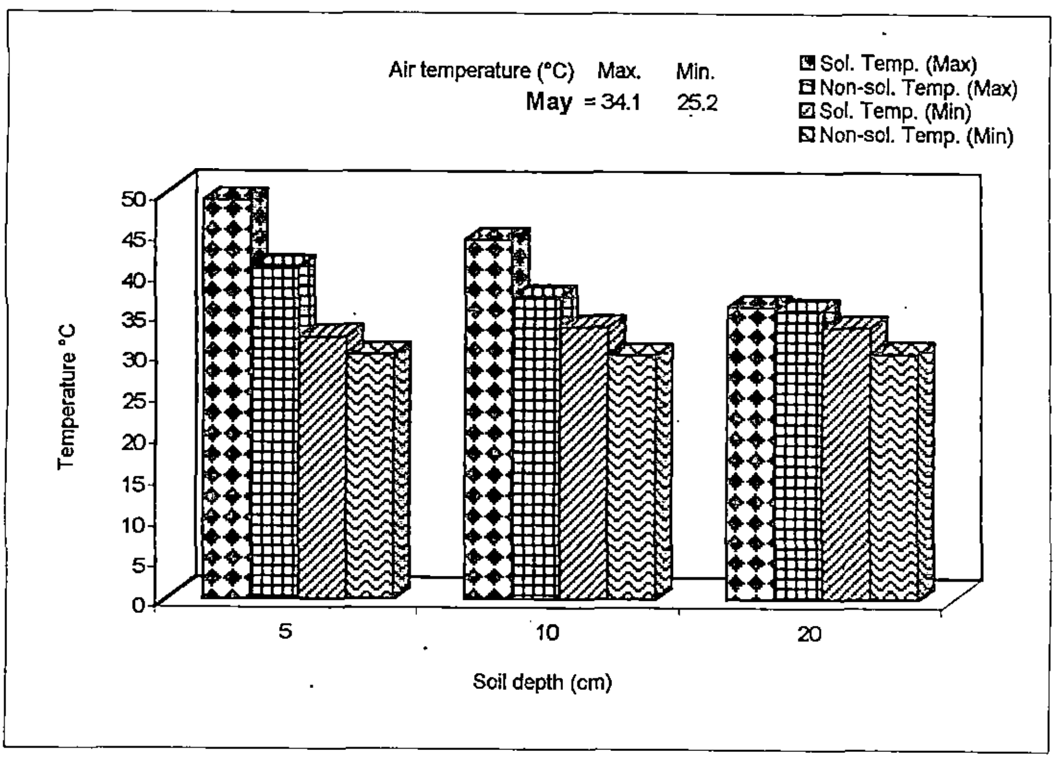
Significant reduction in the count of underground vegetative propagules of the perennial weeds was observed in all treatments. Solarization was the most successful against bermuda grass but closely followed by glyphosate (1.2 kg ha^{-1}) application and both treatments were on par for count of nut grass propagules. Increased temperature in the solarized plots, in April (56.9 and 48.8°C at 5 and 10 cm depth) and in May (49.0 and 44.2°C respectively) (Table 7 and Fig.4) may be the reason for this reduction of underground vegetative propagules. Higher soil temperature due to solarization has been reported by Katan (1980), Vilasini (1996) and Bhaskar and Nanjappa (1997).

The systemic action of glyphosate is capable of desiccating and killing these structures under the soil. Reduction of vegetative propagules after smother cropping and monthly digging was also significant especially in 1999. Shaded and smothered condition resulting from the canopy of cowpea, might have prevented photosynthesis and subsequent multiplication of propagules, while monthly digging in the summer season had exposed the propagules to the hot sun leading to desiccation and drying of propagules has already been reported by Raju and Reddy (1999). These aspects are discussed in detail under weed management in okra crop (Section 5.2.1).

The dry matter production of weeds also followed the same pattern as observed in the case of population of weeds (Table 5a and 5b) and propagating

Fig. 4. Effect of solarisation on soil temperature





structures (Table 6). Glyphosate 1.2 kg ha^{-1} was the best treatment in reducing weed DMP, in both years. Reduction in DMP by weeds after glyphosate application has been reported by Grubben (1974). The superiority of glyphosate may be due to the broad spectrum control of weeds. The DMP by underground vegetative propagules (Table 6) also followed the same trend as that of the count of above structures. The total DMP by both perennial weeds was the least in solarization.

5.2 Weed management in okra crop

5.2.1 Effect of summer season treatments in okra

Effect of solarization for two months in the summer season (April and May) was seen reflected in the weed count and weed dry matter production in the succeeding okra crop especially in the case of *Cynodon dactylon* and *Cyperus rotundus* (Tables 8 and 9). *Cynodon dactylon* which accounted for 71 per cent of the total weed flora in the experimental field during the summer season, was reduced to 21.33 No. m^{-2} (85% reduction) during 1998 and by 100 per cent in 1999 in the okra crop at 30 DAS (Fig.5). Effectiveness of solarization to control *Cynodon* was earlier reported by Yaduraju and Ahuja (1990) and Elmore *et.al.* (1993). Control of *Cyperus rotundus* in okra crop due to solarization was not appreciable in both the years of study, though its count was reduced to 17.07 No. m^{-2} (50%) during 1999. Less effectiveness of solarization for nutgrass may be due to the heat resistance of tubers or tuber formation in the deeper soil layers. This was earlier reported by Horowitz *et al.* (1983). However, improvement in effectiveness in the second year may be due to the cumulative effect. Inconsistent control of nutgrass was reported by Ragone and wilson (1988) also. Control of *Cyperus rotundus* only up to 3-4 cm depth of soil was reported by Standifer (1984), whereas Raju and Reddy (1999) noticed distribution of *Cyperus tubers* up to 45 cm depth in a well aerated soil. Poor effectiveness of solarization after soil disturbance was found by Ismaileh (1991) also.

Fig. 5. Effect of summer season treatments on count of *Cynodon dactylon* in okra at 30 DAS

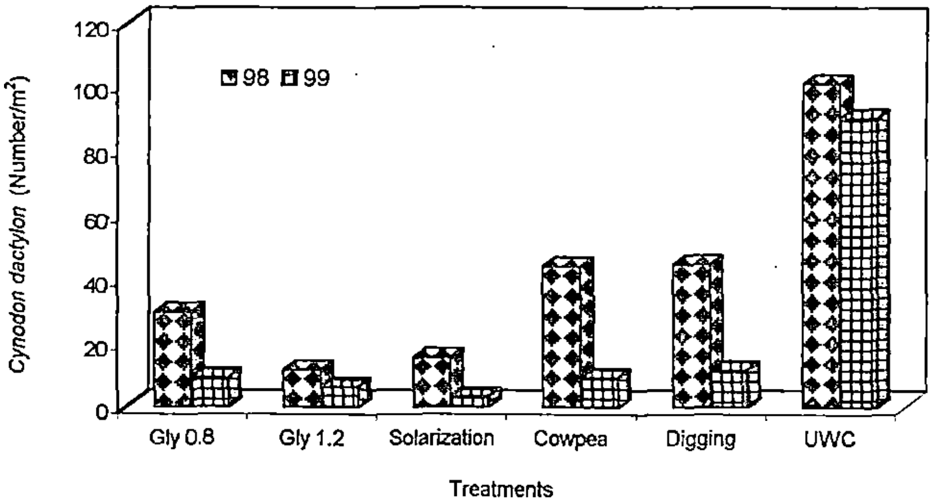
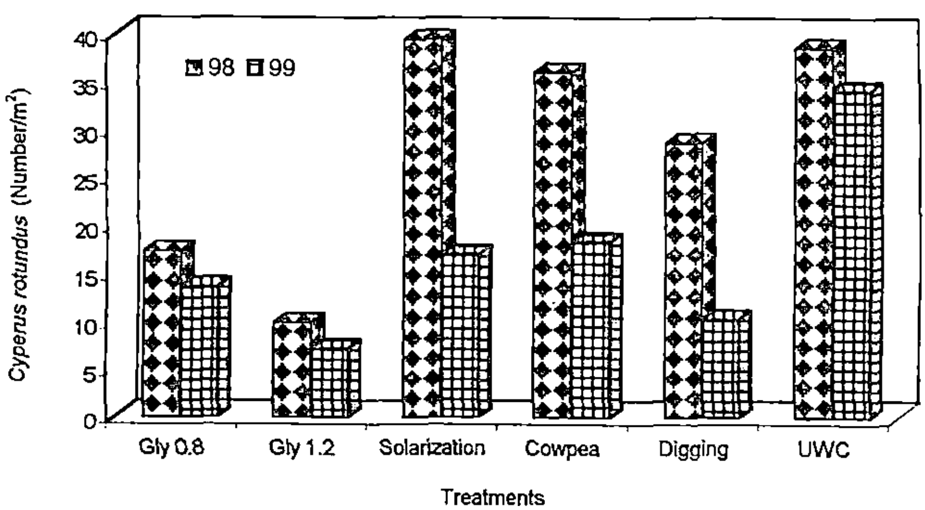


Fig. 6. Effect of summer season treatments on count of *Cyperus rotundus* in okra at 30 DAS

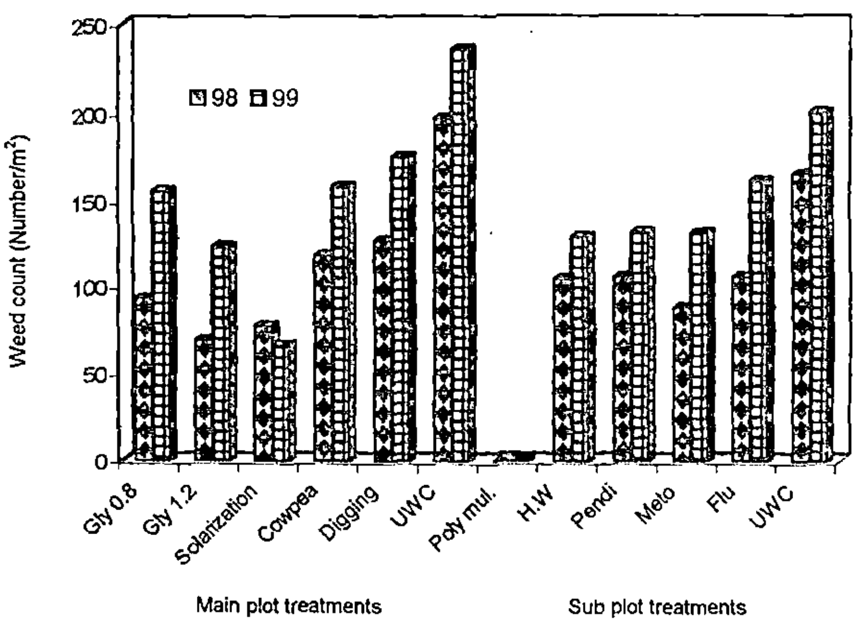


There was significant reduction in the count of *Cyperus iria* (Table 10) broad leaved weeds (Table 11) and other grass weeds (Table 12) due to solarization. Sixty one and 72 per cent reduction in total weed count in okra during 1998 and 1999 was observed in the current studies (Table 13 and Fig.7). Solarization effect was significant in okra at 60 DAS also in the total weed count. The weed DMP also followed the pattern of total weed count. It was 60 and 65 per cent in the respective years at 30 DAS of okra. Bavazir *et al.* (1995) observed 65-97 per cent reduction of weed DMP in the subsequent okra crop, grown in the solarized field. Count of grasses, sedges and broad leaved weeds were reduced by 76, 36 and 57 per cent in okra crop at 30 Das, due to solarization alone. Eighty, 55 and 40 per cent control of broad leaved, grassy and sedge weeds due to soil solarization were reported by Reddy *et al.* (1998) in brinjal, tomato and chilli nurseries at 30 DAS. Effective control of broad leaved weeds in sunflower by solarization was observed by Bhaskar and Nanjappa (1997). Reduction of monocots, dicots and sedges by 86-96, 81-94 and 30-40 per cent over control by solarization was noticed by Mudalagiriyappa (1999).

The higher level of weed control obtained by solarization in the current studies can be ascribed to the increased soil temperatures at various depths (5, 10 and 20 cm) in these plots (Table 7). According to Muzik (1970), thermo-death of most plant tissues happens due to coagulation of protoplasm, between 45-50°C. Increase in maximum temperature by 8.5°C in April 1998 and 8.2°C in May 1998 at 5 cm depth was recorded in the solarized plots (56.9 and 49.0°C). A few rains obtained in May was responsible for the lower temperature in this month. However, at 20 cm depth the increase in temperature in solarized soil was negligible (Fig.4). Higher soil temperature by solarization has been reported by Katan (1980), Horowitz (1983) and Ragone and Wilson (1988).

As stated by Biradar *et al.* (1997), the supremacy of transparent polyethylene in raising soil temperature to higher magnitudes could be due to the maximum transmittance of the incoming short wave radiation.

Fig. 7. Effect of treatments on total weed count in okra at 30 DAS



Residual effect of glyphosate treatments (0.8 and 1.2 kg ha^{-1}) was observed in okra crop, which was more pronounced during 1998 when it was on par with solarization in total weed count and weed DMP. Glyphosate at higher concentration (1.2 kg ha^{-1}) was superior to its lower concentration (0.8 kg ha^{-1}) especially for the control of *Cynodon dactylon* (Fig.5) and *Cyperus rotundus* (Fig.6). This is in line with the observations of Singh *et al.* (1993), who noticed increase in per cent suppression of weeds and weed DMP with increase in rate of glyphosate up to 1.25 kg ha^{-1}. The effectiveness of sequential application of glyphosate against *Cynodon* was earlier reported by Muller *et al.* (1985) and Kandasamy *et al.* (1998), under non-crop situations. Good control of *Cyperus rotundus* was observed by Grubben (1971) and Sandhu and Bhatia (1992) by split application of glyphosate. Glyphosate is a systemic herbicide which can be translocated to the underground vegetative propagules and kill the whole system. The effect of glyphosate was significant in the case of other annual weeds also (Tables 11 and 12) in okra crop, in the kharif season. Sequential application of glyphosate might have prevented annual weeds from producing seeds in the summer season. Broad spectrum control of weeds by glyphosate application was reported by Grubben (1974). The weed DMP in the okra crop also followed the pattern of total weed count. Reduction in weed DMP in tomato crop after glyphophate application (before sowing), was reported by Andino *et al.* (1989).

Satisfactory weed control was obtained by smother cropping (Table 13). The DMP by weeds in this treatment was also significantly lower than the control, in both years of study. Savithri (1990) noticed reduction in total weed count and weed DMP by smother cropping with cowpea. Pritts *et al.* (1993) and Pritts and Kelley (1993) observed reduced weed population in strawberry, by smother cropping in the previous year. Analysis of results also revealed that the reduction in total weed count was mainly attributed to the reduction in count of *Cynodon dactylon* by smother cropping with cowpea in the summer season (Table 8). *Cynodon* population in the smother cropping was almost similar to that in the glyphosate treatments in 1999 (Fig.5). The shade sensitiveness of *Cynodon* having a C_4 pathway for Co_2 fixation has been reported by Thakur *et al.* (1989).

The reduction of *Cynodon* and *Cyperus* count by monthly digging observed in the current study is in agreement with the observations of Sanoria *et al.* (1989), who suggested repeated ploughing for long lasting weed control. However, digging was not much effective on the control of annual weeds especially grasses (Table 12) at 30 DAS. As Dyer (1995) stated, tillage might have stimulated germination of weed seeds, by redistributing seeds to positions favourable for germination, seed scarification or breaking of dormancy followed by exposure to light in the summer.

5.2.2 Effect of treatments given in okra crop

Weed management in okra crop had significant influence on the total weed count and weed DMP at all stages (30 and 60 DAS) in both the years of study. Black polyethylene mulching, irrespective of the main plot treatments, managed all types of weeds throughout the cropping season. However, weed growth through the holes made for planting okra was noticed though it was negligible in solarization and glyphosate treatments. Higher level of weed control in this treatment is in line with the observations of Gutal *et al.* (1992) in brinjal (90%), Saikia *et al.* (1997) in okra, Mashingaidze *et al.* (1996) and Liu *et al.* (1989) in tomato. Saikia *et al.* (1997) reported 96.5 per cent WCE by black polyethylene mulching in okra. Hand weeding treatment (at 15, 30 and 45 DAS) had poor response on control of *Cynodon*, *Cyperus* and even on the annual weeds. However, in combinations with solarization and glyphosate treatments, the total weed count and weed DMP was similar to the premergence herbicides. Land disturbance and moist conditions might have enhanced seed germination. Nai-Kin (1996) suggested that chemical methods were superior to cultural methods as chemical methods would not bring weed seeds to the soil surface. The reduction in total weed count by hand weeding is in agreement with Kalia *et al.* (1982) who observed hand weeding thrice was similar to the pre-emergence herbicidal weed control. Bhaskar and Nanjappa (1997) suggested hand weeding in the okra, after solarization for effective weed control.

Pendimethalin 1.0 kg ha^{-1} followed by hand weeding at 45 DAS was most consistent. Metolachlor 1.0 kg ha^{-1} + HW at 45 DAS in combination with glyphosate 1.2 kg ha^{-1} was the best in 1998 (Table 13). During 1999, metolachlor 1.0 kg ha^{-1} + HW at 45 DAS and pendimethalin 1.0 kg ha^{-1} + HW at 45 Das showed similar trends in reduction of total weeds (Fig. 7) and weed DMP in combination with solarization. Solarization and pendimethalin combination was earlier reported by Cabello and Verdu (1995) for best weed suppression in lettuce. The total weed count and weed DMP was almost similar at 30 and 60 DAS, probably due to the hand weeding given at 45 DAS. Research reports by Adejonwo *et al.* (1990) and Sainbhi *et al.* (1994) also favoured one hand weeding after pre-emergence application of pendimethalin to get better weed control in okra. Adejonwo *et al.* (1990) also recommended metolachlor + HW for okra. After mulching, metolachlor and pendimethalin resulted in higher WCE, during 1998 and 1999 respectively (Table 15). This is in line with the observations of Sainbhi *et al.* (1994) with pendimethalin and AICVIP (1998) with metolachlor, in okra.

5.3 Crop growth

The weed management techniques during summer months affected various crop growth characters studied. Taller okra plants with more number of leaves (Table 16) and higher DMP (Table 17) were observed in glyphosate 1.2 kg ha^{-1} during 1998. However, during 1999, solarization treatment resulted in the highest vegetative growth and was on par with glyphosate 1.2 kg ha^{-1} in plant height and crop DMP. Increased plant growth by solarization has been reported by Alexander (1990) in broccoli and Mudalagiriyappa *et al.* (1999) in groundnut in terms of plant height, number of leaves and crop DMP. Other treatments also resulted in better vegetative growth compared to control. The highest plant height, number of leaves and okra DMP were observed in polyethylene mulching (among the subplots) irrespective of the summer season treatments. Increase in plant height and prolonged crop growth by polyethylene mulching was earlier reported by Saikia *et al.* (1997) in okra, Zengerle (1981) in tomato and Aranjo *et al.* (1992) in cucumber, due to the higher temperature, better weed control and lack of competition from weeds.

Increase in soil temperature and higher CO_2 around the plant, better moisture conservation (Gutal, 1992) along with reduced weed competition may be the reasons for the superiority of this treatment. The favourable effect of these factors on crop growth need no emphasis. The reduced total weed count and weed DMP observed in the hand weeding treatment was reflected in the okra crop also. Among the pre-emergence herbicides, plant height, number of leaves and crop DMP were the highest in metolachlor 1.0 kg ha^{-1} + HW during 1998 and pendimethalin 1.0 kg ha^{-1} + HW during 1999. This can be attributed to the reduced competition from all types of weeds. Better vegetative growth of okra by reduced weed competition is in accordance with the finding of Adejonwo *et al.* (1990) and Saimbhi *et al.* (1994). However, metolachlor caused phytotoxicity to okra during 1999 characterised by stunted growth and under developed root system. Water stagnation in the field due to continuous rains for a few days after sowing and pre-emergence herbicide application, may be the reason.

5.4 Yield attributes and yield

Higher number of fruits (Table 18) and total yield obtained in solarization and glyphosate 1.2 kg ha^{-1} treatments, can be ascribed to the reduced competition from weeds especially *Cynodon dactylon* and *Cyperus rotundus*, which were severely reduced by these treatments in the summer season. Yield increment up to 64 per cent by solarization alone in okra was reported by Bawazir *et al.* (1995). Ismaileh (1991) reported enhanced tomato yield after solarization.

Irrespective of the summer season treatments polyethylene mulching resulted in higher number of fruits per plant and total okra yields in 1998 (4.54 t ha^{-1}) and also in 1999 (4.24 t ha^{-1}). Polyethylene mulching for higher yields were earlier reported by Saikia *et al.* (1997) in okra, Silvestri *et al.* (1985), Liu *et al.* (1987) and Gutal *et al.* (1992) in tomato and Kwon *et al.* (1988) in red pepper, while higher number of fruit production per plant was observed by Mashingaidze (1996) in tomato. The superiority of mulching may be due to higher number of leaves, plant height and prolonged fruiting period for the okra plants in the mulched plots as discussed earlier.

For total yield, hand weeding (2.57 t ha^{-1}) and metolachlor 1.0 kg ha^{-1} + HW (2.40 t ha^{-1}) were the other better treatments in 1998 (Fig.8a) Superiority of metolachlor as a pre-emergence herbicide for obtaining higher yields in okra has been noticed (AICVIP, 1998). During 1999, application of metolachlor resulted in crop phytotoxicity and poor yield. Pendimethalin 1.0 kg ha^{-1} + HW was the best pre-emergence herbicide in this year. This was in line with the observations of Leela (1993) and Saimbhi *et al.* (1994) in okra. Polyethylene mulching in combination with glyphosate 1.2 kg ha^{-1} (5.28 t ha^{-1}) was the superior treatment during 1998 and was on par with that of solarization, which was the best during 1999 (4.75 t ha^{-1}). Combination of solarisation and mulching for higher yield was suggested by Ismaileh (1991) in tomato. After the mulching combinations, glyphosate 1.2 kg ha^{-1} followed by metolachlor 1.0 kg ha^{-1} + HW was the next best in 1998 (3.31 t ha^{-1}), which was on par with that of hand weeding. Solarization or glyphosate 1.2 kg ha^{-1} followed by pendimethalin were the better treatments in 1999. Lowest yield obtained in the absolute control in 1998 (0.66 t ha^{-1}) and in 1999 (0.52 t ha^{-1}) is attributed to the competition from perennial and annual weeds. Lowest weed index values (Table 20) indicated the superiority of polyethylene mulching in 1998 (14.17%) and 1999 (10.74%). Its combination with glyphosate 1.2 kg ha^{-1} and solarization resulted in nil weed index values.

Fig. 8a. Effect of treatments on yield in okra (1998)

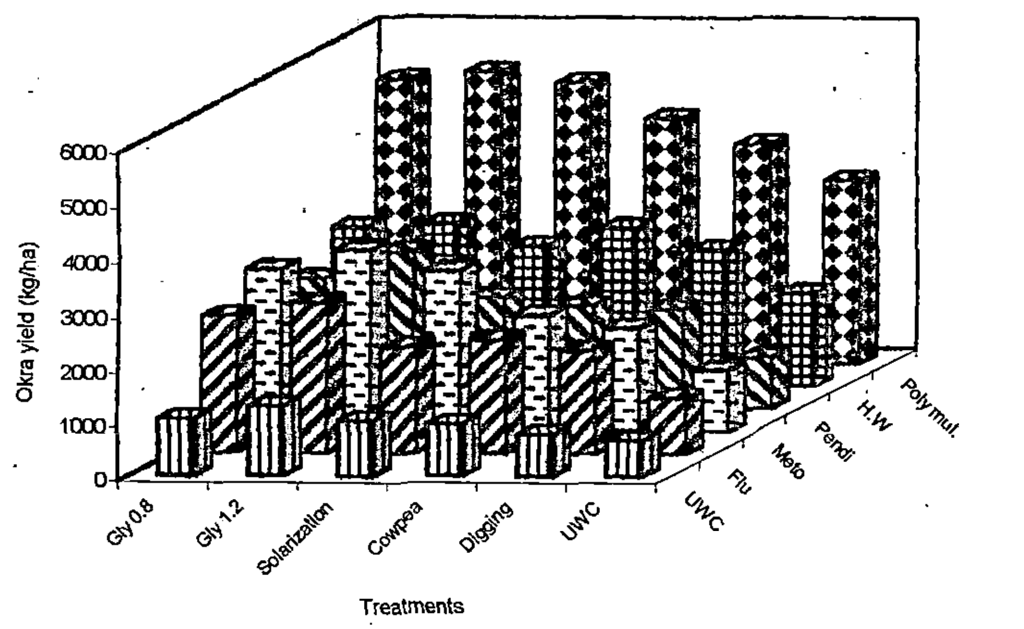
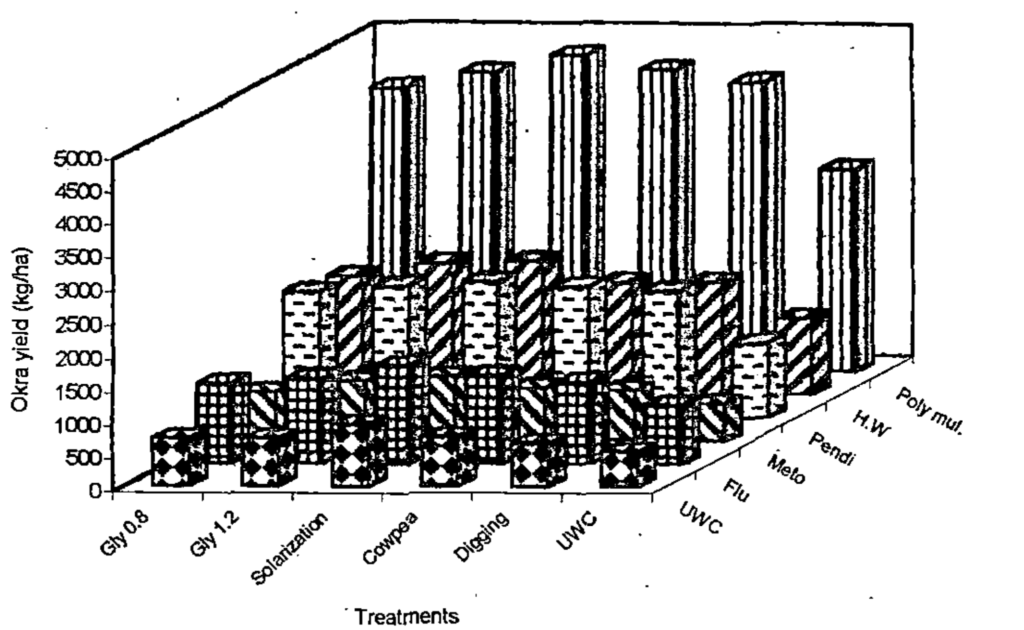


Fig. 8b. Effect of treatments on yield in okra (1999)

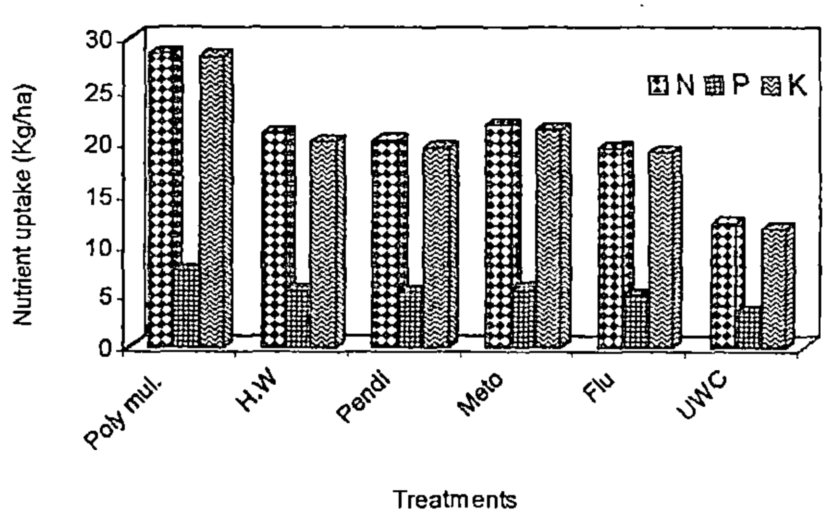


Eventhough there was no weed in the black polyethelene mulched plots coming under different main plots, the weed index values were different. This difference cannot be attributed to the effect of weeds, which is actually due to the residual effect of summer season treatments.

5.5 Nutrient uptake

The results on the nutrient uptake by the crop showed that wherever the competition from weeds was less, the nutrient uptake by the crop was higher. As there was not much variation in the content of nutrients in okra due to different treatments, the uptake of nutrients followed almost the same trend of dry matter production of crop (Table 21). Similarly the nutrient removal by weeds was in line with the dry matter production of weeds (Table 22).

Fig. 9. Effect of treatments on nutrient uptake by okra at 60 DAS (1998)



Glyphosate treatments and solarization resulted in higher uptake of N, P and K by crop and lower uptake by weeds at all the stages. Setty and Hosmani (1977) observed negative correlation coefficient between crops and weeds regarding nutrient uptake. Among the subplot treatments, plastic mulching resulted in maximum uptake of N, P and K at all the stages (Fig. 9). This can be attributed to the lowest weed competition in these treatments. Increased nutrient uptake by okra with weed free conditions has been reported by Soundararajan *et al.* (1981). Hand weeding and pre-emergence herbicides, especially metolachlor and pendimethalin, enhanced nutrient uptake by crop. This is in line with the reports of Vethamani and Balakrishnan (1990) and Kundra *et al.* (1993). Minimum nutrient uptake by the crop was observed in the control plots, due to the increased competition between crop and weeds. This was earlier reported by Kumar and Singh (1986). However, total uptake of nutrients by weeds and crop was much higher in the control. This is in line with the observations of Suresh (1984) and Satao *et al.* (1995).

5.6 Economics

The economic analysis of different treatments given to okra in 1998 revealed that, return per rupee invested was the highest from metolachlor 1.0 kg ha^{-1} + HW at 45 DAS which was given after glyphosate application (1.2 kg ha^{-1}) i.e., Rs.2.41 followed by metolachlor-solarization combination (Rs.2.28). However, maximum additional return due to weed control was obtained from the mulching combinations. The higher expenditure on weed control brought down the cost benefit ratio.

SUMMARY

6. SUMMARY

Field experiments were conducted during 1998 and 1999 at the vegetable research farm of the Department of Olericulture, College of Horticulture, Kerala Agricultural University, Thrissur, during 1998 and 1999, to develop an integrated method for managing weeds including problem perennial weeds like *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L. etc. in okra. The experiment was laid out in a split plot design, with three replications. Systemic herbicide glyphosate, solarization, smother cropping (cowpea) and monthly digging were compared mainly for the control of *Cynodon* and *Cyperus*, in the summer seasons of 1998 and 1999 (Main plot treatments). In the subsequent okra crop, in the kharif season, pre-emergence herbicides like pendimethalin, metolachlor and Fluchloralin followed by one hand weeding at 45 DAS were compared with polyethylene mulching, hand weeding and unweeded control (sub plot treatments) in each main plot. The salient findings of the trial are summarised below.

Major part of the weed flora of the experimental field was constituted by grasses and sedges. In the control plot, *Cynodon dactylon* and *Cyperus rotundus* together constituted 78 per cent of the total weed flora in kharif season. *Digitaria ciliaris, Dactyloctenium aegyptium, Eleusine indica* and *Ischaemum rugosum* were the major grasses. *Cyperus rotundus* and *Cyperus iria* were the main sedges. *Ludwigia parviflora, Synedrella nodiflora, Cleome viscosa* and *Ageratum conyzoides* were the major broad leaved weeds.

No weed growth was observed in the solarized plots as any weed germinated was killed due to the hot condition under the polyethylene sheets. Solarization also considerably reduced underground vegetative propagules of *Cynodon dactylon* and *Cyperus rotundus* and it was the best treatment in reducing count of propagules of *Cynodon*, but was on par with glyphosate 1.2 kg ha^{-1} for reduction of *Cyperus rotundus* propagules.

In the subsequent okra crop also, there was 85 per cent and 97 per cent reduction in count of *Cynodon* in 1998 and 1999 respectively, at 30 DAS, while *Cyperus rotundus* reduction was not appreciable in 1998 and was 50 per cent only in 1999. By solarization alone, count of grasses, broad leaved weeds and sedges were reduced by 76, 36 and 57 per cent in okra at 30 DAS. Weed dry matter production also followed the same trend as observed in case of total weed count.

By solarisation maximum temperature in soil was raised by 8.5°C and 6.7°C at 5 and 10 cm depths in April respectively. Corresponding temperature increment in May was by 8.2 and 7°C. The mean monthly temperature was higher in April than in May. Hence the effect of solarization will be more if practiced in April.

During 1998, glyphosate 1.2 kg ha^{-1} applied twice at 45 days gap, was the best at 30 DAS though it was on par with solarization for broad spectrum control of weeds including bermuda grass and nutgrass and total weed dry matter production in okra. During 1999, solarization was the best treatment. The reduction of bermuda grass and nut grass population was 88 and 74 per cent in 1998 and 93 and 79 per cent in 1999 respectively in okra at 30 DAS. Glyphosate 1.2 kg ha^{-1} was superior to glyphosate 0.8 kg ha^{-1} in reducing total weed count and weed dry matter production.

Smother cropping significantly reduced total weed count and weed dry matter production especially count of *Cynodon dactylon* in the okra crop in both years of study.

Monthly digging, though effective to some extent for the control of *Cynodon* and *Cyperus*, control of annual weeds was poor in the summer and kharif seasons.

The highest weed control efficiency (78.11%) was observed in glyphosate 1.2 kg ha^{-1} in 1998 and in solarization (67.46%) in 1999. In the kharif seasons hand weeding (78.78%) and pendimethalin (60.13%) were the best ones in 1998 and 1999, respectively. This was also reflected in the various crop growth characters studied. Number of leaves, plant height, crop dry matter production. Number of fruits per plant and total yield of okra were higher in mulching treatments, especially after solarization or application of glyphosate 1.2 kg ha^{-1}. This was followed by metolachlor 1.0 kg ha^{-1} with the above combinations.

Pre-emergence spray of metolachlor 1.0 kg ha^{-1} or pendimethalin 1.0 kg ha^{-1} + HW after solarization or glyphosate 1.2 kg ha^{-1} were effective for higher yields. Lower weed index values were recorded for glyphosate 1.2 kg ha^{-1} and solarization in 1998 and 1999. Mulching had the lowest weed index among the kharif season treatments.

Among the summer season weed control treatments glyphosate 1.2 kg ha^{-1} resulted in minimum uptake of all the major nutrients (N, P and K) by weed in the okra crop in 1998. Among the kharif season treatments in okra, mulching with black polyethylene sheets resulted in lowest uptake of nutrients by weeds followed by hand weeding and metolachlor 1.0 kg ha^{-1}. The highest uptake was in the control among the summer and kharif season treatments.

The highest nutrient uptake by okra was in the glyphosate 1.2 kg ha^{-1} (summer) and in mulching (kharif season). The nutrient uptake in the weedy checks were the lowest in 1998. Among the pre-emergence herbicides studied, metolachlor 1.0 kg ha^{-1} was the best in 1998 as far as the nutrient uptake was concerned.

The additional returns due to weed control was highest in polyethylene mulching. However, the return per rupee invested on weed control was the highest for combinations of glyphosate 1.2 kg ha^{-1} or solarization (summer) with metolachlor + HW (kharif).

Conclusion

The study indicated that solarization of the soil for two months during summer season or spraying glyphosate 1.2 kg ha^{-1} twice at monthly intervals were very effective for controlling the weeds including the perennial ones like *Cyperus rotundus, Cynodon dactylon* etc. In addition to the control of the weeds present in the field, these treatments resulted in significant reduction in the underground propagules of the weeds also. In the okra crop, mulching the soil with black polythene sheets was the best treatment for weed control. However it was costlier than other pre-emergence herbicide treatments. In addition, this treatment resulted in better crop growth also. Among the pre-emergence herbicides tested metolachlor 1.0 kg ha^{-1} gave the best results. Its effect was temporary and hence required a fallow up hand weeding at 45 DAS. Considering the economics (return/rupee invested) application of glyphosate 1.2 kg ha^{-1} twice in the summer season can be recommended for areas having severe infestation of *Cynodon dactylon* and *Cyperus rotundus*. For controlling problems of annual weeds in okra crop, pre-emergence spray of metolachlor 1.0 kg ha^{-1} followed by a hand weeding at 45 DAS is the best.

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*Originals not seen

APPENDICES

Appendix I. Weekly distribution of weather parameters (20-3-1998 to 15-9-1998).

Meteor-ological week	Rainfall (mm)	Evaporation (mm)	Surface temperatures °C		Sunshine (h day^{-1})	Relative humidity	
			Max.	Min		Morning	Afternoon
12	0	6.5	37.5	23.7	10.5	84	44
13	11.0	6.5	36.2	22.9	9.0	88	50
14	0.0	5.5	37.5	25.1	9.6	83	40
15	0.0	5.4	36.4	26.1	9.1	86	52
16	4.2	5.4	36.6	26.8	8.5	85	30
17	57.2	6.0	35.9	24.6	8.7	89	53
18	4.8	4.7	35.2	25.5	8.5	89	54
19	79.0	4.2	35.5	25.3	6.5	88	61
20	107.4	8.4	32.4	24.1	4.6	93	59
21	11.0	2.9	33.6	25.9	8.3	91	72
22	24.4	9.3	34.4	25.2	8.8	86	62
23	65.7	3.8	32.0	23.9	6.4	92	53
24	118.0	3.1	30.0	23.1	2.2	94	71
25	257.3	2.3	29.0	22.4	3.0	96	81
26	368.7	2.1	27.8	23.2	0.3	95	79
27	250.6	2.4	29.0	23.8	2.5	96	89
28	140.1	2.6	29.2	24.0	2.4	95	81
29	116.2	2.9	29.8	24.1	4.9	96	77
30	151.6	2.4	29.2	23.4	3.0	96	84
31	80.0	8.2	30.3	23.4	4.6	97	76
32	80.9	2.8	29.2	23.8	2.1	95	80
33	12.7	3.1	30.5	24.5	4.6	94	73
34	274.7	2.1	28.5	23.5	2.5	95	84
35	129.9	3.4	30.2	23.6	5.4	94	72
36	184.4	2.7	30.7	23.7	3.8	96	82
37	169.4	2.9	28.4	22.9	3.2	95	80

Appendix – I contd.

(18-3-1999 to 25-8-1999)

Meteorological week	Rainfall (mm)	Evaporation (mm)	Surface temperatures °C		Sunshine (h day^{-1})	Relative humidity	
			Max.	Min.		Morning	Afternoon
11	0.0	4.9	35.2	25.0	8.4	89	54
12	0.0	4.5	34.8	25.0	8.4	91	55
13	0.0	4.9	34.9	25.1	7.5	89	54
14	26.2	5.7	34.9	24.5	7.8	90	55
15	0.0	5.6	33.2	25.8	7.4	86	59
16	7.6	3.9	33.1	26.2	4.6	89	62
17	5.2	3.6	32.0	25.9	4.2	90	59
18	35.0	4.4	33.6	25.8	6.3	89	59
19	37.0	3.1	31.0	25.2	6.4	90	66
20	51.6	3.2	30.4	25.1	5.5	88	74
21	221.6	2.9	29.0	23.8	2.6	95	85
22	143.2	3.1	29.8	23.5	5.0	96	75
23	134.7	3.2	29.1	22.8	4.8	94	81
24	170.9	2.5	28.4	22.7	1.8	95	81
25	114.8	2.9	29.6	23.2	5.1	95	76
26	21.6	3.8	30.9	23.0	5.9	92	67
27	114.7	2.9	29.6	23.1	3.7	95	80
28	124.6	2.6	29.0	22.9	3.1	96	76
29	326.5	1.8	26.9	22.8	0.5	97	92
30	182.8	1.9	27.7	23.7	1.1	95	82
31	194.1	2.4	25.7	23.3	2.7	95	84
32	121.5	3.0	29.5	23.7	5.2	95	75
33	8.9	3.5	30.6	24.1	7.5	93	69
34	3.2	3.6	30.0	23.6	6.9	93	69

Appendix II. Nutrient content of weeds at different growth stages of okra in 1998

Treatments	Nutrient content (%)					
	N		P		K	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Glyphosate 0.8 + pl.mul	-	-	-	-	-	-
Glyphosate 0.8 + H.W.	2.1	1.8	0.23	0.21	2.3	2.0
Glyphosate 0.8 + Pendi	2.0	1.6	0.19	0.20	2.2	1.9
Glyphosate 0.8 + Meto	2.2	2.0	0.20	0.19	2.4	2.0
Glyphosate 0.8 + Flu	2.0	1.9	0.19	0.18	1.9	1.9
Glyphosate 0.8 + UWC	1.9	1.9	0.19	0.19	2.1	2.0
Glyphosate 1.2 + pl.mul	-	-	-	-	-	-
Glyphosate 1.2 + H.W.	2.1	1.9	0.30	0.30	2.2	2.0
Glyphosate 1.2 + Pendi	2.0	1.8	0.26	0.28	2.1	2.0
Glyphosate 1.2 + Meto	2.3	2.0	0.24	0.24	2.4	2.1
Glyphosate 1.2 + Flu	2.1	1.9	0.21	0.20	2.1	2.1
Glyphosate 1.2 + UWC	2.0	1.8	0.20	0.20	2.0	2.0
Solarization + pl.mul	-	-	-	-	-	-
Solarization + H.W.	2.0	2.0	0.28	0.26	2.1	2.0
Solarization + Pendi	2.1	2.0	0.27	0.26	2.1	1.9
Solarization + Meto	2.2	2.0	0.27	0.25	2.2	2.0
Solarization + Flu	2.0	1.9	0.25	0.26	2.0	1.9
Solarization +UWC	1.9	1.9	0.21	0.21	1.8	1.8
Cowpea + pl.mul	-	-	-	-	-	-
Cowpea + H.W.	1.9	1.9	0.27	0.27	1.9	2.0
Cowpea + Pendi	2.0	1.8	0.24	0.24	2.0	1.9
Cowpea + Meto	2.2	1.9	0.28	0.27	2.2	2.0
Cowpea + Flu	2.0	1.8	0.20	0.21	2.0	1.9
Cowpea + UWC	1.8	1.8	0.19	0.20	1.9	1.9
Digging + pl.mul	-	-	-	-	-	-
Digging + H.W.	1.8	1.7	0.22	0.21	2.0	1.8
Digging + Pendi	1.8	1.7	0.21	0.21	2.0	1.8
Digging + Meto	2.0	1.9	0.22	0.21	2.0	1.9
Digging + Flu	1.9	1.8	0.20	0.19	2.1	2.0
Digging + UWC	1.8	1.8	0.18	0.18	1.9	1.8
UWC + pl.mul	-	-	-	-	-	-
UWC + H.W.	1.9	1.6	0.20	0.20	2.0	1.8
UWC + Pendi	1.9	1.6	0.22	0.20	2.0	1.8
UWC + Meto	1.9	1.8	0.19	0.21	2.0	1.9
UWC + Flu	1.8	1.7	0.18	0.18	2.0	1.6
UWC + UWC	1.8	1.6	0.19	0.18	2.0	1.6

Appendix III. Nutrient content of okra at different growth stages in 1998

Treatments	Nutrient content (%)					
	N		P		K	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Glyphosate 0.8 + pl.mul	2.3	2.2	0.87	0.57	2.3	2.1
Glyphosate 0.8 + H.W.	2.4	2.2	0.83	0.53	2.2	2.0
Glyphosate 0.8 + Pendi	2.3	2.1	0.84	0.54	2.3	1.9
Glyphosate 0.8 + Meto	2.4	2.1	0.82	0.54	2.1	2.0
Glyphosate 0.8 + Flu	2.3	2.1	0.79	0.54	2.1	1.9
Glyphosate 0.8 + UWC	2.2	2.0	0.80	0.54	2.0	1.8
Glyphosate 1.2 + pl.mul	2.5	2.2	0.87	0.59	2.4	2.2
Glyphosate 1.2 + H.W.	2.3	2.2	0.81	0.57	2.2	2.1
Glyphosate 1.2 + Pendi	2.2	2.0	0.82	0.55	2.3	2.1
Glyphosate 1.2 + Meto	2.3	2.1	0.82	0.56	2.4	2.2
Glyphosate 1.2 + Flu	2.2	2.0	0.80	0.55	2.2	2.0
Glyphosate 1.2 + UWC	2.2	2.0	0.80	0.54	2.1	1.9
Solarization + pl.mul	2.4	2.3	0.88	0.59	2.4	2.2
Solarization + H.W.	2.4	2.1	0.85	0.57	2.4	2.2
Solarization + Pendi	2.3	2.1	0.85	0.55	2.4	2.1
Solarization + Meto	2.3	2.2	0.86	0.56	2.3	2.2
Solarization + Flu	2.2	2.1	0.82	0.54	2.3	2.1
Solarization +UWC	2.2	2.0	0.80	0.54	2.1	2.0
Cowpea + pl.mul	2.3	2.2	0.83	0.58	2.3	2.2
Cowpea + H.W.	2.2	2.2	0.82	0.57	2.3	2.1
Cowpea + Pendi	2.3	2.1	0.81	0.56	2.1	2.0
Cowpea + Meto	2.3	2.1	0.83	0.57	2.2	2.0
Cowpea + Flu	2.2	2.0	0.80	0.55	2.2	2.0
Cowpea + UWC	2.2	2.0	0.80	0.54	2.1	1.9
Digging + pl.mul	2.4	2.1	0.84	0.58	2.2	2:1
Digging + H.W.	2.3	2.1	0.82	0.57	2.0	2.0
Digging + Pendi	2.3	2.1	0.82	0.55	2.0	2.0
Digging + Meto	2.3	2.2	0.80	0.55	2.0	1.9
Digging + Flu	2.3	2.2	0.80	0.55	2.1	2.0
Digging + UWC	2.1	2.0	.0.79	0.54	2.1	1.9
UWC + pl.mul	2.2	2.0	0.82	0.58	2.0	2.1
UWC + H.W.	2.2	2.1	0.80	0.57	2.1	2.0
UWC + Pendi	2.1	2.1	0.80	0.55	2.0	2.0
UWC + Meto	2.2	2.0	0.80	0.55	2.0	2.0
UWC + Flu	2.1	1.9	.0.78	0.55	2.0	1.9
UWC + UWC	2.1	1.9	0.79	0.54	1.9	1.9

Appendix IVa. Cost of cultivation (excluding weed control operations) for various treatments (Rs. ha^{-1})

Details	Poly. mulching	H.W.	Pendi	Meto	Flu	UWC
Glyphosate 0.8	13490	12510	12230	12510	12300	11810
Glyphosate 1.2	13560	12510	12510	12720	12440	11950
Solarization	13420	12300	11950	12440	11950	11810
Cowpea	13070	12440	11950	12090	12090	11740
Digging	13000	12300	11880	11950	11950	11600
UWC	12750	11810	11390	11530	11460	1180

Wages : Rs.100/man, Rs.70/woman
Spraying : 6 men/ha
Fertilizer : Urea Rs.4.25/kg, FF Rs.6.25/kg, MOP Rs.3.90/kg
Herbicide cost : Pendimethalin (Stomp 30 EC) Rs.490/lit
Metolachlor (Dual 50 EC) Rs.590/lit
Fluchloralin (Basalin 45 EC) Rs.560/lit
Spraying : 6 men/ha
Handweeding (3 handweeding) 141 women/ha
Price of okra : Rs.6/kg
Harvesting : 110 kg/women

Appendix-IVb. Cost of mulching with black polyethylene

Details	Cost (Rs. ha^{-1})
1. Cost of sheet for 1 ha (Rs.72/kg, 13 m^2/kg)	53352.00
2. Effective cost per season considering life span of 2 years (4 seasons)	13338.00
3. Laying charge	600.00
Total cost for mulching in one season	13938.00

Appendix V. Abstract of analysis of variance of studies on weeds in the summer season

Character	Source	df	Mean sum of squares	
			1998	1999
<u>Weed Count</u>				
Cynodon dactylon	Treatment	4	395.40*	317.97*
	Error	8	1.04	3.26
Cyperus rotundus	Treatment	4	16.19*	109.99*
	Error	8	0.15	0.55
Panicum repens	Treatment	4	1.21*	-
	Error	8	0.10	-
Cyperus iria	Treatment	4	22.25*	6.62*
	Error	8	0.26	0.23
Other weeds	Treatment	4	80.37*	82.41*
	Error	8	1.05	0.81
Total weeds	Treatment	4	499.07	317.61*
	Error	8	0.77	1.81
Total pooled	Treatment	4	733.56*	-
	Error	16	1.28	-
<u>Propagules count</u>				
Cynodon dactylon	Treatment	5	34.12*	27.72*
	Error	10	0.13	0.15
Cyperus rotundus	Treatment	5	17.53*	25.30*
	Error	10	0.51	0.85
Total	Treatment	5	47.33*	51.60*
	Error	10	0.43	0.59
Total (pooled)	Treatment	5	94.53*	-
	Error	20	0.1	-
<u>Weed dry matter production</u>				
Cyperus dactylon	Treatment	4	2.75*	2.17*
	Error	8	0.07	0.03
Cyperus rotundus	Treatment	4	1.06*	0.64*
	Error	8	0.12	0.02
Panicum repens	Treatment	4	0.53*	-
	Error	8	0.12	-
Cyperus iria	Treatment	4	0.67*	0.32*
	Error	8	0.02	0.01
Other weeds	Treatment	4	1.38*	0.85*
	Error	8	0.01	0.02

Appendix V. continued.

Total weeds	Treatment	4	1.27*	0.67*
	Error	8	0.01	0.01
<u>Propagules dry matter production</u>				
Cynodon dactylon	Treatment	5	0.63*	0.91*
	Error	10	0.01	0.01
Cyperus rotundus	Treatment	5	0.32*	1.05*
	Error	10	0.01	0.18
Total	Treatment	5	0.41*	0.78*
	Error	10	0.01	0.02

*Significant at 5% level

Appendix VI. Abstract of analysis of variance of studies on weeds in okra at different stages

Source	Df	Mean sum of squares															
		Cynodon dactylon				*Cyperus rotundus*				*Cyperus iria*				Broad leaved weeds			
		1998		1999		1998		1999		1998		1999		1998		1999	
		30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Main plot	5	86.87*	88.39*	128.21*	66.00*	25.78*	4.83*	18.25*	7.69*	16.69*	1.66*	22.49*	6.61*	3.61*	2.09*	26.67*	7.14*
Error a	10	2.59	0.90	1.05	0.56	0.82	1.33	0.38	0.72	0.52	1.32	0.50	0.44	1.25	0.44	0.18	0.46
Subplot	4	1.27	6.88*	4.92*	9.07*	3.21*	3.98*	3.90*	6.35*	41.59*	56.56*	10.12*	4.79*	32.37*	22.64*	22.06*	18.34*
Interaction	20	1.60	1.37*	3.32*	2.89*	1.20*	0.83	1.43*	1.22*	1.27	2.12*	2.70*	1.39*	1.17	1.07*	3.45*	1.41*
Error b	48	0.91	0.63	0.95	1.21	0.37	0.60	0.28	0.44	0.77	0.84	0.33	0.38	1.14	1.14	0.49	0.15

Source	Df	Mean sum of squares													
		Other grass weed count				Total weed count				Total weed drymatter production				WCE	
		1998		1999		1998		1999		1998		1999		1998	1999
		30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS		
Main plot	5	6.70*	3.15*	16.87*	7.14*	69.21*	48.14*	88.07*	48.40*	0.29*	0.19*	0.24*	0.22*	1608.49*	3100.78*
Error a	10	0.96	0.90	0.31	0.46	1.59	0.38	0.33	0.36	0.01	0.01	0.01	0.01	25.62	23.24
Sub plot	4	29.13*	28.66*	16.73*	18.39*	27.62*	72.67*	25.27*	62.17*	0.71*	2.29*	0.19*	0.74*	5901.18*	3273.47*
Interaction	20	1.80*	1.88*	2.10*	1.41*	1.21	0.90*	1.37*	1.69*	0.04*	0.01*	0.01*	0.01*	165.25*	88.69*
Error b	48	0.94	0.86	0.44	0.15	0.84	0.45	0.33	0.37	0.01	0.01	0.01	0.01	17.17	13.05

Appendix VII. Abstract of analysis of variance of studies on okra at various growth stages

Source	Df	Mean sum of squares							
		Number of leaves		Plant height		Okra dry matter production			
		1998	1999	1998	1999	1998		1999	
						30 DAS	60 DAS	30 DAS	60 DAS
Main plot	5	9.91*	14.41*	767.05*	1919.44*	5195.20*	136671.87*	4.58*	77..92*
Error	10	0.53	0.22	8.83	21.48	990.59	4450.57	0.05	1.28
Subplot	5	22.67*	25.55*	843.27*	843.27*	85645.48*	970084.47*	98.37*	619.04*
Interaction	25	0.86*	0.48*	36.37*	36.37*	873.24*	7708.47*	0.59*	5.70*
Error	60	0.10	0.12	6.21	6.21	881.48	4492..21	0.14	1.29

Source	Df	Mean sum of squares					
		No. of fruits		Total yield		Weed index	
		1998	1999	1998	1999	1998	1999
Main plot	5	34.74*	7.69*	476.47*	137.92*	2075.57*	610.78*
Error	10	0.10	0.03	4.30	0.93	18.47	4.16
Subplot	5	88.98*	132.13*	2526.75*	3052.07*	8997.80*	13528.48*
Interaction	25	2.01*	1.02*	22.77*	11.44*	82.82*	50.72*
Error	60	0.05	0.03	2.44	1.31	8.07	5.75

*Significant at 5% level

Appendix VIII. Abstract of analysis of variance of the nutrient content of weeds in okra at various stages (1998)

Source	Df	Mean sum of squares					
		Nitrogen		Phosphorus		Potassium	
		30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Main plot	5	105.78*	121.25*	1.17*	1.85*	129.42*	114.19*
Error a	10	2.61	2.39	0.05	2.78	2.78	2.37
Sub plot	4	430.63*	3982.78*	3.79*	43.71*	472.25*	4092.90*
Interaction	20	12.91*	42.08*	0.19*	0.63*	13.94*	32.54*
Error b	48	1.62	2.13	0.02	0.02	2.03	2.52

Appendix IX. Abstract of analysis of variance of the nutrient content of okra at various stages (1998)

Source	Df	Mean sum of squares					
		Nitrogen		Phosphorus		Potassium	
		30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Main plot	5	7.70*	89.20*	0.71*	4.61*	11.34*	79.01*
Error a	10	0.09	0.54	0.01	0.02	0.08	0.96
Sub plot	5	64.32*	489.48*	8.82*	32.69*	63.05*	500.56*
Interaction	25	0.88*	3.70*	0.10*	0.22*	1.10*	3.98*
Error b	60	0.08	0.99	0.01	0.05	0.05	0.97

* Significant at 5% level

INTEGRATED WEED MANAGEMENT IN OKRA
(*Abelmoschus esculentus* [L.] Moench.)

By

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

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2000

ABSTRACT

Field experiments were conducted during summer and kharif seasons of 1998 and 1999 at College of Horticulture, Kerala Agricultural University, Thrissur, with the objective of developing an integrated method for management of weeds, especially perennial weeds like *Cynodon dactylon* (L.) and *Cyperus rotundus* L. in okra. Broadspectrum herbicide glyphosate, solarization, smother cropping with cowpea and monthly digging were compared with unweeded control in the summer season, for their effect on weeds. In the subsequent okra crop, during kharif season, different pre-emergence herbicides and farmer's practice of hand weeding were compared with black polyethylene mulching and unweeded control. The experiment was carried out in a split-plot design with three replications, taking summer season treatments as main plots and weed control methods in okra, as sub plots.

Cynodon dactylon and *Cyperus rotundus* were the predominant perennial weeds in the field. *Cyperus iria, Digitaria ciliaris, Dactyloctenium aegyptium, Eleusine indica* and *Ludwigia parviflora* were the major annual weeds.

In summer season treatments, solarization and glyphosate 1.2 kg ha^{-1} were very effective in reducing the weed problems. They also resulted in reduction in the underground vegetative propagules of perennial weeds. Solarization resulted in increasing the soil temperature by 8.5 and 6.7°C at 5 and 10 cm depths respectively, during April.

In the subsequent okra crop, black polyethylene mulching gave complete prevention of any weed problems. Among the other combinations, glyphosate 1.2 kg ha^{-1} (twice at 45 days interval) during summer season followed by metolachlor 1.0 kg ha^{-1} + HW at 45 DAS in okra crop (in 1998) as well as solarization followed by pendimethalin 1.0 kg ha^{-1} + HW at 45 DAS (in 1999).

The total returns was higher in plots which received polyethylene mulching in the okra crop, irrespective of main plot treatments given in the summer season. Among them, highest total return was obtained from glyphosate 1.2 kg ha^{-1} in the summer season followed by polyethylene mulching in okra crop (Rs.31,704 ha^{-1}), followed by solarization followed by black polyethylene mulching (Rs.30,594 ha^{-1}). However, the highest return per rupee invested on weed control was obtained from combinations of metolachlor 1.0 kg ha^{-1} (in okra) with glyphosate 1.2 kg ha^{-1} in summer season (Rs.2.41), solarization (Rs.2.28) and that of glyphosate 0.8 kg ha^{-1}. But all the combinations of weedy control in summer season, except that of polyethylene mulching resulted in loss as far as the cost of weed control and the total cost is concerned.