WEED MANAGEMENT IN GINGER (*Zingiber officinale* Rosc.)

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Weed management in ginger (*Zingiber officinale* Rosc.)"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that thesis entitled **"Weed management in ginger (*Zingiber officinale* Rosc.)"** is a bonafide record of research work done independently by **Ms. Asha V. Pillai (2012-21-105)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Asha V. Pillai

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ABBREVIATIONS AND EXPANSION

ABBREVIATIONS	EXPANSION
@	at the rate of
B:C ratio	Benefit cost ratio
CD	Critical difference
cm	Centimetre
D	Density
DAP	Days after planting
DMP	Dry matter production
et al.	Co workers
F	Frequency
Fig.	Figure
g	Gram
g/m^2	Gram per meter square
/ha	Per hectare
HW	Hand weeding
i.e.,	That is
K	Potassium
Kg	Kilogram
Kg/ ha	kilogram per hectare
m	Metre

/m^2	Per square meter
Max	Maximum
mg	Milligram
mg/g	Milligram per gram
Min	Minimum
mm	Millimeter
N	Nitrogen
no./m^2	Number per square meter
P	Phosphorus
pH	Negative logarithm of hydrogen ion concentration
POP	Package of practices
RD	Relative density
RF	Relative frequency
Rs.	Rupees
SDR	Summed dominance ratio
sp., spp.	Species
t ha^{-1}	Tonnes per hectare
Temp.	Temperature
Var.	Variety
Viz.,	Namely

Introduction

1. INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) (Family: Zingiberaceae) is a herbaceous plant, the rhizomes of which are used as a spice. India is a leading producer of ginger in the world and during 2012-13 the country produced 7.45 lakh tonnes of the spice from an area of 157839 hectares. Ginger is cultivated in most of the states in India. However, states namely Karnataka, Orissa, Assam, Meghalaya, Arunachal Pradesh and Gujarat together contribute 65 per cent to the country's total production. The area under ginger cultivation in Kerala has declined from 10706 ha in 2001- 2002 to 4538 ha in 2013-14. The major constraint in the production of ginger in the state is labour shortage, infestation by large number of weeds and high incidence of pests and diseases.

Ginger crop is highly susceptible to weed competition especially in the initial stages of crop growth. In most cases weed management accounts for the major share of the total cost of cultivation. As the crop receives a high amount of external nutrition coupled with initial slow growth, conditions favour weed emergence which later compete with the crop for moisture, nutrients, space and sun light. Studies by the All India Co-ordinated Research Project on Weed Control indicated that 30-45 per cent yield reduction in ginger may occur due to uncontrolled weed growth (KAU, 2006).

Certain measures recommended to suppress weed growth in ginger are mulching, hand weeding, solarization etc. When mulching is practiced, weed growth is suppressed to some extent (Mishra and Mishra, 1982) which increases crop emergence, growth and yield. Mulching the beds with green leaves or organic wastes is essential to prevent soil splashing and erosion of soil during to heavy rain. It also adds organic matter to the soil, checks weed emergence and conserves moisture during the latter part of the cropping season. The first mulching is done at the time of planting with green leaves @ 10-12 tonnes/ha. Application of dried coconut leaves after removing the petiole or paddy straw (2-3 kg/bed) as mulch in ginger is also recommended for effective weed control (IISR, 2014).

Soil solarization results in effective weed control lasting for a whole year or even longer (Horowitz, 1980; Bell and Laemmlen, 1991). A number of commonly occurring weeds, particularly annual weeds, can be effectively controlled by soil solarization. These include, *Cynodon dactylon, Cyperus rotundus,* and *Digitaria ciliaris* among monocots, and *Crotalaria mucunata, Indigofera hirsuita* and *Knoxia* sp among dicots. Increased growth response is observed in plants cultivated in solarized soil. This is mainly evident as increase in plant height, number of leaves, better root formation and yield (KAU, 2011). Several soil borne pathogens can be controlled by solarization. This includes fungi like *Pythium, Phytophthora, Fusarium, Rhizoctonia* etc. The possible mechanisms of weed control through solarization suggested by Katan (1981) are thermal killing of weeds, thermal killing of seeds induced to germinate, breaking of seed dormancy and consequent killing of the germinating seed and biological control through weakening or other mechanisms.

Generally, two or three hand weedings are done depending up on weed growth (Mohanty *et al.,* 1990). The first weeding is done just before second mulching and the second weeding around 120 days after planting (Kannan and Nair, 1965; Vevai, 1971). Manual weeding consists of either pulling the weeds, chipping with a hoe or cutting the roots with a knife (Purseglove *et al.*, 1981).

Though hand weeding two to three times gives good control of weeds, shortage of labour and high labour charges are serious problems in the state. Many technological options are available at present for weed control in crops. However, choice of the method depends on many factors like location, crop, cost, season, labour availability etc. Use of herbicides is an important practice for most crops as it is easier, time and labour saving and economical as compared to other weed control measures (Rekha *et al.*, 2003).

The herbicide diuron 4.5 kg/ha has been used for controlling weeds in ginger in Queensland but its action may vary depending on soil type (Whiley, 1974). Diuron has a broad spectrum control and is applied as pre emergent herbicide before the shoot emergence. Pre emergence application of mixtures of alachlor + flumeturon at 0.75 + 0.75 kg/ ha provided effective control of some weed species and resulted in higher yields (Melifonwu and Orkwor, 1990). No systematic research work has been done in Kerala on the weed flora and the use of herbicides to control weeds in ginger. Therefore, no recommendation is available on herbicidal control of weeds in ginger in the state. Research work is also scanty on the efficient, economic and eco-friendly weed management practices in ginger. Hence the present investigation was undertaken with the following objectives:

1. To survey and document the weed flora of ginger in the major ginger growing districts of Kerala

2. To find out the efficient, economic and eco-friendly weed management practices for ginger, and

3. To study the persistence of herbicides found effective for weed management in ginger.

Review of Literature

2. REVIEW OF LITERATURE

Various options are available for weed control in ginger. However, choice of method or combination of methods depends on many factors. Use of herbicides is an important practice for most crops as it is easier, time and labour saving and economical as compared to other weed control measures. Several weed control measures are adopted in ginger *viz,* hand weeding, mulching, soil solarization and chemical control.

A review on weed flora in ginger and different methods used to control weeds in ginger is given in this chapter.

2.1. Weed flora of ginger crop

Almost all types of weeds can be found in ginger fields. However, the weed flora varies with location and season. According to Elmore (1983), the major weed flora in ginger field of California included *Amaranthus* sp., *Digitaria sanguinalis* and *Solanum nigrum*. Horowitz *et al.* (1983) and Satour *et al.* (1991) observed that *Amaranthus* sp. and *Portulaca oleracea* are the predominating weeds in ginger. Rubin and Benjamin (1984) reported that *Cynodon dactylon* was the worst weed in ginger because of its fast spreading and competitive nature. Similarly *Cyperus rotundus* was the worst weed observed in ginger crop in Israel by Katan *et al.*, 1976.

According to Chandran (1989), the predominating weed species in ginger fields were *Ageratum conyzoides, Alternanthera sessilis, Brachiaria ramosa, Curculigo orchioides, Desmodium triflorum, Hemidesmus indicus, Isachne miliacea, Lindernia crustacea, Merrimea tridentata* and *Oldenlandia corymbosa*. Milevoj (1989) found that *Vernonia cineria* was the most dominant weed species in ginger.

A field experiment was conducted at Kerala Agricultural University, Thrissur by Sainamol (1992) to study the dominant weed spectrum in ginger. She reported that the dominant weed species found in ginger field were *Amaranthus viridis, Cassia* sp., *Centrosema* sp., *Curculigo orchioides, Euphorbia hirta, Knoxia* sp., *Phyllanthus niruri, Scoparia dulcis, Sida rhombifolia, Stachytarpheta indica* and *Vernonia cineria*.

Rashid *et al*. (1992) reported that a survey of turmeric field in Banu district, Pakistan, indicated the presence of 83 weed species which belong to 73 genera. Of the 34 families, five were monocotyledonous and 29 were dicotyledonous. The most dominant mono and dicotyledonous families were Poaceae with 21 species and Asteraceae with 8 species. Gill *et al*. (2000) from Punjab observed that *Digitaria ischaemum, Cynodon dactylon, Cyperus rotundus, Dactyloctenium aegypticum, Euphorbia hirta, Commelina benghalensis* and *Eragrostis pilosa* as dominant species. In Japan, weed species that infest turmeric fields are *Acalypha australis* L., *Amaranthus spinosus, Amaranthus viridis, Bidens pilosa, Chenopodium album, Cyperus rotundus,Digitaria ciliaris, Oxalis corymbosa, Panicum repens, Paspalum distichum, Mimosa indica, Eleusine indica, Solanum nigrum* and *Sonchus oleraceus* (Hossain *et al*., 2005; Ishimine *et al*., 2004).

2.2. Methods of Weed Control

2.2.1. Soil solarization

Solarization is a method of hydrothermal disinfection. This is done by covering moist soil with transparent polythene sheet and exposing it to direct sunlight during the hottest period of the year. The presence of dormant weed seeds in agricultural soils provides a source for persistent weed problems that often require repeated control measures. Control of a wide spectrum of weeds is one of the visible results of solarization. Annual weeds are usually more sensitive than perennials.

Katan (1981) suggested the possible mechanisms of weed control are,

1. Thermal killing of weed seeds

2. Thermal killing of seeds induced to germinate

3. Breaking of seed dormancy and consequent killing of the germinating seeds

4. Biological control through weakening or other mechanisms

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

A field trial was conducted by Sainamol (1992) at College of Horticulture, Kerala Agricultural University to study the effect of soil solarization on weeds. In the experimental field, 30 different types of weeds were observed, out of which 6 were monocots and the remaining were dicots. Initially total weed population was almost same in the different treatment plots. At the time of removal of mulch, there were no weeds in the solarized beds, while the control and non-solarized beds were covered with different weed species.

Large number of researches conducted to evaluate the effect of solarization on different weeds and different agro climatic conditions of ginger which are summarized below

Response of representative weeds to soil solarization

Weeds controlled	**References**
Ageratum conyzoides	Chandran (1989)
Alysicarpus sp.	Sainamol (1992)
Alternanthera bettzickiana	Chandran (1989)
Amaranthus sp.	Katan (1981), Elmore (1983), Horowitz *et al.* (1983), Rubin and Benjamin (1984), Stapleton and De Vay (1985), Villapudua

	and Munnecke (1987), Abdel-Rahim *et al.* (1988), Satour *et al.* (1991)
A. viridis	Sainamol (1992)
Brachiaria ramosa	Chandran (1989)
Cassia sp.	Sainamol (1992)
Centrosema sp.	Sainamol (1992)
Curculigo orchioides	Chandran (1989), Sainamol (1992)
Desmodium tridentata	Chandran (1989)
Digitaria sanguinalis	Elmore (1983), Porter and Merriman (1983), Daelemans (1989)
Euphorbia hirta	Sainamol (1992)
Hemidesmus indicus	Chandran (1989)
Hyptis suaveolens	Sainamol (1992)
Isachne miliacea	Chandran (1989)
Knoxia sp.	Sainamol (1992)
Lantana camera	Vilasini (1996)
Lindernia crustacea	Chandran (1989)
Merrimea tridentata	Chandran (1989)
Mimosa pudica	Sainamol (1992)
Oldenlandia corymbosa	Chandran (1989)
Phyllanthus niruri	Sainamol (1992)

Phyllanthus sp.	Sainamol (1992)
Portulaca oleracea	Horowitz *et al.* (1983), Abdel-Rahim *et al.* (1988), Satour *et al.* (1991), Sainamol (1992)
Scoparia dulcis	Sainamol (1992)
Sida rhombifolia	Sainamol (1992)
Solanum nigrum	Elmore (1983), Porter and Merriman (1983)
Stachytarpheta indica	Sainamol (1992)
Vernononia sp.	Milevoj (1989)
Vernonia ceneria	Sainamol (1992)
Weeds partly or not controlled	
Cynodon dactylon	Rubin and Benjamin (1984), Fahim *et al.* (1987), Prakash and Mani (1991)
Cyperus esculentum	Elmore (1983)
Cyperus rotundus	Rubin and Benjamin (1983), Fahim *et al.* (1987), Satour *et al.* (1991), Prakash and Mani (1991)
Malva niceaensis	Katan *et al.* (1983), Horowitz *et al.* (1983), Rubin and Benjamin (1983), Satour *et al.* (1991)
Orobanche sp.	Horowitz *et al.* (1983), Prakash and Mani (1991)

A field experiment conducted at Kerala Agricultural University by Vilasini (1996) to study the effect of soil solarization to control weeds in ginger.

She observed 48 different species of weeds growing in ginger, out of which seven were monocots and the remaining, were dicots. At the time of land preparation, the field was completely covered with *Cynodon dactylon, Mimosa pudica, Scoparia dulcis, Lantana camera, Stachytarpheta indica* and *Cletoria ternatea*. When the weed population was counted one month after removing the mulch, a total of 1008 weeds were observed in non solarized plots, of which 363 were monocots and the remaining were dicots. *Cynodon dactylon* and *Knoxia* sp. were the major monocot and dicot weeds respectively during this period. Among the solarized plots, better control of both dicots and monocots was noticed in 45 days solarized plots. There were only 111 weeds at the time of harvesting. *Cynodon dactylon* was the major monocot while *Knoxia* sp. and *Amaranthus viridis* were the major dicots respectively in solarized plots.

Reports from KAU (2011) shows that a number of commonly occurring weeds, particularly annuals, can be effectively controlled by solarization. These include, *Cynodon dactylon, Cyperus rotundus, Digitaria ciliaris* among monocots and *Crotolaria muconata, Indigifera hersuita* and *Knoxia* sp. among dicots.

The effectiveness of soil solarization is influenced by several factors such as soil moisture, soil type, season, duration of solar heating, type of mulching materials and organic and inorganic matter content of soil (Vilasini, 1996).

2.2.1.1. Type of polythene mulching material

The effectiveness of soil solarization is influenced by the type of polyethylene material used. Katan *et al*. (1976) reported that transparent and white polyethylene should be used for solarization, because it transmits most of the solar radiation that heat the soil. According to Pullman *et al*. (1981), polyethylene sheets of 25 µm thick were more effective in heating soils and in killing soil borne fungi than 100 µm thick sheets.

2.2.1.2. Increased plant growth response

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

Increased plant growth and yield in cowpea (Chandran, 1989; Nair *et al.*, 1990), carrot (Cartia *et al.*, 1987), onion (Satour *et al.*, 1989; Hartz *et al.*, 1989), cotton (Katan *et al.*, 1983), potato (Davis, 1991), sugar beet (Stapleton and DeVay, 1984), tomato (Katan *et al.*, 1976), chillies (Cartia *et al.*, 1987; Sainamol 1992), egg plant (Katan *et al.*, 1976), peach (Stapleton and DeVay, 1982) have been reported in plants grown in solarized soil. In solarized soils yield and yield attributing characters like plant height, number of leaves, better root formation and root nodulation in legumes are increased (KAU, 2011).

2.2.1.3. Effect on soil microbes

Fungi

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

According to Triolo *et al.* (1989), the number of different colonizing species was reduced in solarized soil but prevalence of *Aspergillus, Fusarium, Penicillium* and *Trichoderma* was increased. Chandran (1989) and Sainamol (1992) suggested that the fungal population was reduced by solarization.

Bacteria

Stapleton and DeVay (1982, 1984) reported that some species of soil borne bacteria are sensitive to soil solarization; their thermal sensitivity depends up on the nature of the individual taxa. Population density of *Agrobacterium* spp., fluorescent pseudomonas, pectolytic pseudomonas and certain gram positive bacteria were reduced by 69-98 per cent immediately after solarization. Fluorescent pseudomonas got rapidly recolonised in the treated soils and no significant difference among treatments three to six months later ().

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

Katan (1987) observed that saprophytic bacteria survive much better than fungi in heated soil. According to Kaewruang *et al.* (1989) and Gamliel *et al.* (1989), solarization significantly increased the population of bacteria antagonistic to *F. oxysporum, F. solani* and *R. solani* at 0-10 cm depth, while Chandran (1989) and Sainamol (1992) failed to get the increased population of bacteria in solarized soil. Prakash and Mani (1991) found that bacterial populations increased during the first 30 days in both covered and uncovered soil but got decreased to 71 per cent in covered soil after 45 days.

Actinomycetes

Many of the actinomycetes are thermo tolerant, were sometimes reduced to a much lesser extent (45-58 %) or were even increased (26-158 %) following solarization (Stapleton and DeVay, 1984). Kaewruang *et al.* (1989) noticed that solarization significantly increased the population of actinomycetes (1.2 fold) antagonistic to *F. oxysporum*, *F. solani* and *R. solani* at 0-10 cm depth. Chandran (1989) and Sainamol (1992) found that a slight increase in the actinomycetes population in solarized plots. Whereas, Gamliel and Katan (1991) reported that actinomycetes were less affected by solarization.

2.2.2. Chemical weed control

The herbicide diuron @ 4.5 kg ai/ha has been used for controlling weeds in Queensland but its action may vary depending on soil type (Whiley, 1974). Diuron has a broad spectrum control and is applied as pre emergent herbicide before the shoots emerge. Paraquat is used as a post emergence, in the early stages of plant growth when applied between rows and in later stages limited to spot spraying between beds. Pre emergence application of 2, 4-D at 1 kg/ha (Mishra and Mishra, 1982) or atrazine at 1.5 kg/ha (Rethinam *et al.*, 1994) was also effective to control weeds in ginger.

Initial growth of turmeric plant is slow, if weeds are not controlled properly at this stage; it will result in considerable yield reduction. Ratnam *et al.* (2012) reported that application of the herbicide alachlor at the rate of 2.0 kg/ha led to effective weed control, as compared to manual weeding, leading to good benefit cost ratio. Pre emergence application of alachlor at the rate of 2.0 kg/ha in a turmeric field intercropped with pigeon pea or maize was more effective as compared to manual weeding (Mishra and Mishra, 1982). Balashanmugam *et al.* (1985) reported that pre emergence application of fluchloralin at the rate of 1 and 1.5 kg/ha, oxydiazon at 1.0 kg/ha, oxyfluorfen at 0.15 and 0.2 kg/ha and pendimethalin at 1.0 kg/ha gave effective control of broad leaved weeds and grasses but not of sedges. Oxyfluorfen at 0.15 kg/ha led to maximum rhizome yield followed by oxydiazon at 1.0 kg/ha, fluchloralin at 1.5 kg/ha and pendimethalin at 1.0 kg/ha.

Fabro and Robles (1982) reported that the response of mung bean and soyabean to oxyfluorfen at different rates and times of application. They found that the herbicide was best applied at four days before or after planting. Shoot growth recovered faster at 0.25 and 0.50 kg a.i./ha at four days after planting. According to Henderson (1996), the oxyfluorfen sprayed before transplanting was the best herbicide option in cabbage, due to the least cost, higher yields, most effective weed control. Oxyfluorfen at 0.3 kg/ha resulted in the higher crop yields (Singh *et al.* 1993). Bellinder *et al.* (1993) reported that numerous narrow leaved and broad leaved weeds were effectively suppressed by 0.42 kg/ha of oxyfluorfen in summer squash.

Singh *et al.* (1992) observed that higher yield was observed with pendimethalin (1.0 kg/ha) plus oxyfluorfen (0.15 kg/ha) applied as pre-emergence, it decreased 77.6 and 41.4 per cent fruit yield over the weedy check and hand weeding twice, respectively in bell pepper. Kumar and Thakral (1993) reported that pre-emergence application of pendimethalin @ 1.25 kg/ha resulted in minimum weed dry weight which was significantly lower than oxyfluorfen @ 0.25 kg/ha with or without hoeing or hand weeding twice, in chilli. The herbicide fluchloralin at 1.25 kg/ha, oxadaizon at 1.25 kg/ha and pendimethalin at 3.00 kg/ha were effective in improving crop yield through control of weeds in brinjal (Nandal, 1986). According to Nandal *et al.* (2007), oxadiazon at 1.0 kg/ha and oxadiazon at 0.75 + pendimethalin 0.75 kg/ha were the most effective in terms of weed control and yield in cabbage.

A field experiment was conducted to develop an effective weed management practice in French bean under subtropical agro-ecosystems of western Uttar Pradesh. Pre-planting and pre-emergence application of fluchloralin and pendimethalin 1.0 kg/ha resulted in significant increase in growth and yield attributes, viz. plant height, no. of branches, dry matter accumulation, no. of pods/plant and seeds/pod as well as seed and straw yield of french bean (Panotra *et al.*, 2012). Sharma *et al.* (2014) opined that pendimethalin was effective against *Dactyloctenium aegyptium* and *Digitaria sanguinalis*.

A field experiment was conducted by Soltani *et al.* (2004) to study the effect of flufenacet plus metribuzin on selected weed species in soybeans (*Glycine max*) in Ontario. They were reported that the pre application of metribuzin plus flufenacet at the lowest dose (0.67 kg/ha) provided full season control of *Chenopodium album* L. (common lambsquarter), *Amaranthus retroflexus* L. (redroot pigweed), and *Ambrosia artemesiifolia* L. (common ragweed). Higher dose (1 kg/ha) were needed to effectively control *Sinapis arvensis* L. (wild mustard) and *Setaria viridis* (L.) Beauv. (green foxtail) while the highest dose (1.68 kg/ha) was required for the control of *Abutilon theophrasti* Medic. (velvetleaf).

Field and laboratory experiments were conducted in the early and late rainy seasons in Thailand to evaluate the effect of pre-emergence application of herbicides on vegetable soybean production. The application of metribuzin at 525 g a.i./ha was sufficient to provide satisfactory full-season control of several weed species and gave the highest crop yield. In addition, pendimethalin at 1031.25 g a.i./ha, and tank mixed metribuzin at 350 g a.i./ha + pendimethalin at 928 g a.i./ha could provide a similar level of weed control as an alternative to reduce herbicide dosage thereby increasing food and environmental safety in vegetable soybean production (Pornprom *et al.*, 2010).

In USA, sponge wiper application of glyphosate was effective, economical and less time consuming in vegetable fields (Harisson, 1982). Andino *et al.* (1989) reported that tomatoes sown immediately after glyphosate application suffered no injury but transplanted tomatoes showed various symptoms, even when 15 days have elapsed between the herbicide applications and transplanting.

Sandhu and Bhatia (1992) suggested that application of glyphosate twice @ 1 kg/ha of commercial product were effective on nut sedge. Similar result with initial spraying of 2-3.5 kg /ha of glyphosate was documented by Hawton *et al.* (1992). Manickam and Gnanamurthy (1994) also reported that reduction of nut sedge biomass through spraying 1.0 per cent glyphosate with 0.5 per cent 2, 4-D sodium salt or 1 per cent ammonium sulphate. Satisfactory control of nut sedge and bermuda grass with glyphosate have been observed by Ahuja and Yaduraj (1995) under non cropped situation in India. Kandasamy *et al.* (1998) opined that very good control of *Cynodon dactylon* with sequential application of glyphosate at monthly interval.

A trial conducted by Sainudheen (2000) at Kerala Agricultural University, found that the glyphosate 1.2 kg/ha (twice at 45 days interval) during summer season followed by pre emergence application of metolachlor 1.0 kg/ha in okra gave good control of weeds. In summer season, solarization and glyphosate 1.2 kg/ha were very effective in reducing the weed problems and resulted in reduction of the underground vegetative propagules of perennial weeds. According to Rajkhowa and Barua (2006), the lowest weed dry matter accumulation and density was recorded in the treatment that received carfentrazone 10 g + glyphosate 600 g/ha at Jorhat, Assam.

Gopalakrisnan (2007), reported that spraying of post emergence herbicide glyphosate @ 1.2 kg/ha 45 days before sowing followed by a second application one month later on surviving weeds ensured complete control. Land preparation and sowing of the crop can be done 15 days after second application of herbicide.

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2.2.2.1. Combination herbicides

Pre emergence application of mixtures of alachlor and chloramben or fluometuron at 0.75 + 0.75 kg/ha provided effective control of some weed species and resulted in higher yields (Melifonwu and Orkwor, 1990). In China, combination of pendimethalin and acetochlor at 150-200 ml/mu (15 mu = 1 ha) is recommended to check weeds in the ginger field (Yang *et al.,* 2004). Works conducted the AICRP on weed control KAU centre has shown that combined application of oxyfluorfen and glyphosate in ginger resulted in the least count of weeds, less weed dry matter production, higher number of tillers, highest rhizome yield (KAU, 2014).

Malunjkar *et al.* (2012) reported that, among the different herbicides, pre-emergence application of pendimethalin 1.0 kg/ha + post-emergence application of imazethapyr 0.20 kg/ha recorded maximum weed control efficiency, minimum weed population and weed dry matter in ground nut at Jalgaon, Maharashtra. The same treatment combination recorded significantly higher dry pod yield. Younesabadi *et al.* (2013) found that tank mix pre-emergence application of pendimethalin 0.5 kg/ha + imazethapyr 0.075 kg/ha was next to weed free check and superior to all other treatments for the reduction of weed density but, with respect to reduction in weed dry weight, it was comparable with pendimethalin 0.5 kg/ha + hand weeding, which resulted in the lowest weed dry weight after weed free check in soyabean.

2.2.2.2. Integrated methods

Application of herbicide and one hand weeding was more economic than the common practice of farmers, which is two manual weedings. Mohanty *et al.* (1991) reported that mulching reduced weed growth in turmeric fields. Herbicide treatment alone did not provide season long weed control, but integrated treatments achieved similar levels of weed control by applying 0.7 kg/ha metribuzin followed by the application of 1.0 kg/ha of diuron (Gill *et al.*, 2000). Herbicide applications are effective in controlling weed growth significantly and enhancing rhizome yield as compared to fields with no control of weeds (Anil Kumar and Reddy, 2000).

Ajai *et al.* (2002) observed that pendimethalin and oxyfluorfen followed by manual weeding, resulted in 45 per cent and 35 per cent more rhizome yield compared to unweeded control treatments. Early weed establishment was found in shallow planted turmeric (at 4 cm depth), causing nutrient deficiency and reduced rhizome yield (Ishimine *et al.*, 2004). They also observed significantly reduced weed infestation at the second and third weeding with turmeric planted at depths of 8, 12 and 16 cm, because of better canopy structure compared to shallow planted crops.

The same herbicides used in ginger are also reported very promising weed control in vegetables.

An experiment conducted by Nandan *et al.* (2011), at Pulses Research Sub-Station Samba, Jammu to study the efficacy of pre and post emergence herbicides in controlling weeds of black gram under rainfed subtropical conditions of Jammu. They opined that the pendimethalin 1.0 kg/ha + hand weeding at 30 days after sowing was superior in controlling the weed flora and increasing the seed yield. The herbicide pendimethalin-based integrated weed management systems were beneficial in both okra and Indian spinach (Smith *et al.* 2009).

According to Leela (1993), pendimethalin for short duration crops like bean, peas and amaranthus because she observed good weed control up to 30 days only. She suggested pendimethalin followed by hand weeding for long duration vegetable crops. In field trials conducted in sandy loam soil of Jodhpur during 1991-92, the effects of pre-plant incorporated fluchloralin at 1.0 kg/ha, pendimethalin at 1.0 kg/ha, oxyfluorfen at 0.1- 0.3 kg/ha and metolachlor at 0.5-1.0 kg/ha for weed control in *Capsicum annuum* were evaluated. All weed control treatments decreased weed dry weight and increased fruit yield. Saimbhi *et al.* (1994) found that pendimethalin @ 0.5 kg/ha resulted in maximum weed control efficiency in okra in field trials at Jabalpur and Jalandhar. They also reported that pendimethalin 0.75 kg/ha followed by hand weeding at 35 days after sowing was the best method for weed control in okra. Frost and Hingston (2004) suggested that pendimethalin, clomazone and oxydiargyl were most effective herbicides, which gave best result when applied pre - crop transplanting. Gopalakrisnan (2007) opined that pre-emergence application of oxyfluorfen @ 0.25 kg/ha or pendimethalin @ 1.0 kg/ha or fluchloralin @ 1.5 kg/ha or alachlor @ 2.0 kg/ha followed by hand weeding at 30 to 45 days after planting was economical in crops like chilli, brinjal, tomato, okra etc.

Ameena *et al.* (2013) were conducted a field experiments at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India to study the effect of integrated weed management practices on growth, regeneration and tuber viability of purple nut sedge in okra for two years during summer seasons. Among the treatments, stale seedbed combined with pre-plant application of glyphosate 1.5 kg/ha followed either by polythene mulching or directed application of glyphosate 1.5 kg/ha between rows of okra was the most effective treatment in controlling nut sedge tuber production.

Integration of two or more methods of weed control is a viable option in weed management. Experiments conducted for three years at All India Co-ordinated Vegetable Improvement Programme, Vellanikkara indicated superiority of hand weeding over herbicides on the productivity of chilli (KAU, 1992). A trial conducted by Sainudheen (2000) at Kerala Agricultural University, suggested that soil solarization during summer season followed by pre emergence application of pendimethalin 1.0 kg/ha also gave good control of weeds in okra.

Pandey *et al.* (2001) found that reduced density of broad leaved and grass weeds with repeated weeding or herbicidal management with atrazine and pendimethalin in maize-wheat rotation. Mishra and Singh (2009) observed that the number of weed seeds decreased considerably in plots receiving herbicide spray + one hand weeding. Chakraborthy (2000) opined that the yield loss of brinjal was minimum under black polythene mulching followed by fluchloralin + one hand weeding.

According to Sharma *et al.* (2005), the higher weed control efficiency with either trifluralin or pendimethalin @0.75 kg/ha followed by hand weeding. Nagar (2005) also reported that pendimethalin followed by hand weeding remained the most effective treatment among herbicides in improving coriander yield and other attributes with the minimum weed competition index (0.62 per cent). Shaikh (2005) suggested that more than 80 per cent weed control efficiency was recorded in hand weeding, oxyfluorfen (0.10 kg/ha) and pendimethalin (0.75 kg/ha) supplemented with hand weeding. Mean chilli yield was higher in pendimethalin followed by hand weeding.

Tetteh *et al.* (2011) were conducted field experiments in Ghana to assess the effect of integrated weed management on the growth and yield of tomato. Treatments comprised of hand weeding, mulching, different herbicides at two rates of application and a combination of the different herbicides with hand weeding and mulching. The integrated weed management treatments performed much better than the single herbicide application. The most cost effective method of weed control was the use of mulch followed by the post emergence application of glyphosate (2.0 1/ha) combined with mulching.

Pre emergence application of pendimethalin 1.0 kg/ha followed by one hand weeding at 15 days after sowing resulted in 10.8 pods/plant as against 4.97 pods/plant in unweeded control in soyabean. Bhale *et al.* (2011) reported that pre-emergence spray of pendimethalin @ 1.0 kg a.i./ha followed by post emergence imazethapyr @ 75 g a.i./ha at 15 days after sowing increased pod yield of ground nut (1255 kg/ha) as compared to unweeded control.

Madukwe *et al.* (2012) reported that chemical weeding at 2-3 leaf stage of weed followed by hand weeding at 50days after planting was the effective weed control method in cowpea fields at Nigeria. Yadav *et al.* (2011) found that the highest grain yield was obtained with weed free check (1840 kg/ha) followed by two hand weeding and imazethapyr 100 g/ha + hand weeding in cluster bean at Rajasthan.

2.2.3. Hand weeding

Mohanty *et al.* (1990) reported that generally two or three hand weedings are required in ginger depending up on weed growth. The first weeding is done just before second mulching (45^{th} day) and the second weeding during 120 to 135^{th} day (Kannan and Nair, 1965; Vevai, 1971). Manual weeding consists of either pulling the weeds, chipping with a hoe or cutting the roots with a knife (Purseglove *et al.*, 1981).

2.2.4. Mulching and earthing up

The beneficial effect of mulching was reported by several workers. Mulching enhances germination, prevents washing of soil due to heavy rain and surface run off, increases infiltration, conserves moisture, regulates temperature, decreases evaporation, suppresses weed growth, enhances microbial activity, and improves soil fertility by adding organic matter. Joachim and Pieris (1934) reported that straw mulching increased yield in ginger by 12.2 per cent over unmulched. Application of forest leaves at 20 t/ ha in two equal splits, one at planting and second at 45th day after planting increased yield by 200 per cent (Kannan and Nair, 1965). According to Aiyadurai (1966), application of 14 tonnes of FYM as mulch per acre enhanced yield by 65 per cent and 12.5, 5.0 and 5.0 t/ha of mulch for the first, second and third mulching, respectively, are considered optimum (Randhawa and Nandpuri, 1970).

Mulching could change the physical and chemical environment of the soil resulting in increased availability of phosphorus and potassium (Muralidharan, 1973).

Several mulching materials were found effective to control weeds *viz*, coconut leaves (Aclan and Quisumbing, 1976), banana leaves (Mohanty, 1977), dry sal leaves (AICSCIP, 1985), shisam (Jha *et al*., 1986) and green forest leaves (Roy and Wamanan, 1988). Kingra and Gupta (1977) used dry grass and forest leaves as mulch at 15 t/ha, whereas Mohanty and Sarma (1978) used 15 t/ha green leaves at planting and 7.5 t/ha each at 45 and 90 days after planting to control weeds in ginger.

Owadally *et al*. (1981) stated that mulching with sugarcane trash and rice straw was beneficial to control weeds. Mishra and Mishra (1982) reported that mulching with dry leaves markedly suppressed the early weed growth and increased the crop emergence, growth and yield. Mulching was one of the methods to enhance germination rate and to increase the rhizome yield in ginger. First mulching is done with green leaves at the rate of 12-15 t/ha and the operation is repeated after a month and a half at the time of top dressing of fertilizers. Early planting combined with mulching with *Dalbergia sissoo* leaves gave the highest yield of fresh rhizomes compared to mulching with mango leaves or rice straw (Jha *et al*., 1986).

Application of paddy husk and wheat straw increased the rhizome yield of turmeric (Mahey *et al*., 1986). Singh and Randhava (1988) reported that application of straw mulch was more beneficial than intercropping turmeric with pigeon pea, maize or green gram in terms of net returns, and no improvement in the soil or curcumin content was noticed by mulch application. The maximum yield and cost benefit ratio were obtained with dry forest leaf litter mulch and intercropping with French bean followed by dry forest leaf litter mulch alone (Mohanty *et al.*, 1991).

Reports from AICRPS (1990) shows that performance of different live mulches were similar but superior to unmulched plots. Korla *et al.* (1990) found that FYM mixed with grass, pine needles and pea straw was effective as mulch and increased the yield in ginger. Daincha can be grown in inter rows and applied as second mulch after cutting at 60 DAP to control weeds (Valsala and Devi, 1990). Mohanty *et al.* (1990) observed that polythene as mulch material gave 19.9 tonne of fresh rhizome per ha compared to 12 tonne in unmulched plots. Reports from AICRPS (1992) shows that mulching three times with leaves and growing intercrop of soybean as live mulch was equally effective to control weeds.

The quantity of mulch applied varies with availability of materials. In general, 10 to 30 t/ha is applied twice or thrice, one at planting, second at 45 days after planting and third at 90^{th} day after planting. Commonly used mulch materials are green and dry forest leaves, residues like sugarcane trash, paddy, wheat, finger millet, little millet and barley straw and also weeds and vegetations of the locality. Live mulch materials like sunhemp, black gram, green gram, horse gram, niger, common sesbania, cluster bean, French bean, soybean, cowpea, daincha and red gram can be grown as intercrop and used for in situ mulching between 45 to 60 days after planting (Kandiannan *et al.*, 1996).

Kurian *et al.* (1997) reported that green manure crops of *Sesbania rostrata, S. aculeata, S. speciosa, Crotolaria juncea* or fodder cowpea, when grown amongst a ginger crop and used as the second mulch, or sown a second time two months after the ginger was planted and used as the third mulch, reduced weed problems in the ginger crop. The ginger rhizome yield was the highest with

S. aculeata used as the second mulch. Awasthi (1997) observed that in the kharif season, ginger variety Suprabha, grown with mulches of palas leaves, sal leaves, rice straw, dry grass, leaf mould or soil to control weeds the best treatment was palas leaf mulch, which produced average fresh yield of 21.90 t/ha compared with 16.75 t/ha in the unmulched control. Application of wheat straw as mulch improved both growth and yield in ginger (Gill *et al.*, 1999)

Mishra *et al.* (2000) reported that 12.5 t/ha green mulch material is to be applied thrice in a cropping season (at planting time, 45 DAP and 90 DAP) to obtain maximum yield. According to Monks and Bass (2000), straw residue of rye can inhibit the germination of some weeds like *Chenopodium album, Portulaca oleracea* and *Amaranthus retroflexus*. Mulching reduced the population and dry weight of broad leaved weeds significantly as compared to grass weeds (Radwan and Hussain, 2001). Alam *et al.* (2003) noticed that sun grass mulch gave significantly higher yield compared to other mulches.

Kumar *et al.* (2003) reported that application of mulch at the rate of 10 t/ha conserved more moisture and increased the yield by 12 per cent and paddy straw mulch increased the yield by 18 per cent. Hussain *et al.* (2005) noted that mulching suppressed weed growth and improved the yield. Menze *et al.* (2005) reported that mulching doubled the rhizome productivity and had no effect on the essential oil content of the crop. Dinesh (2006) found that higher organic matter content (5.68 %) and nitrogen content (69.4 kg/ha) in the surface layer during rhizome formation were recorded with 10 t mulch /ha. The maximum organic matter content and maximum phosphorus content in the surface layer during rhizome formation were obtained with rice straw mulch.

Ramakrishna *et al.*, 2006 reported that straw mulches are most effective to control weeds which decreases weed emergence and growth. Annu and Sarnaik (2006) noted that mulching using paddy straw resulted in obtaining the tallest plants, with maximum number of leaves, both of which were very positively reflected in enhanced rhizome yield. Application of paddy straw mulch at the rate of 22.5 t/ha increased rhizome yield by 62.2 per cent as compared to no mulching (Swain *et al.*, 2007).

Reports from IISR (2014) showed that mulching the beds with green leaves or organic wastes is essential to prevent soil splashing and erosion of soil due to heavy rain. It also adds organic matter to the soil, checks weed emergence and conserves moisture during the latter part of the cropping season. The first mulching is done at the time of planting with green leaves @ 10-12 t/ha. Application of dried coconut leaves after removing the petiole or paddy straw (2-3 kg/bed) as mulch in ginger is also recommended for effective weed control.

Vevai (1971) observed that soil stirring and earthing up are essential to control weed growth in some extent and also it helps in enlargement of daughter rhizomes. Earthing up provides adequate aeration for roots and protects the rhizome from scale insects apart from controlling weeds (Panigrahi and Patro, 1985).

2.2.5. Effect of herbicides on soil microbes

The half life of various herbicides ranges from 9 to 116 years. It means that in soil without micro organisms herbicide application would threaten all living things with unforeseeable consequences. Michaelidou *et al.* (2000) opined that herbicides are specific regarding their toxic level. However, the application of several chemicals may lead to synergy and development of toxic effects hazardous for humans and the ecosystem. Rate of herbicide decomposition in soil depends on the properties of the preparation applied, herbicide dose (Schuster and Schroder, 1990; Milosevia *et al.*, 2000), physical and chemical soil properties (Willems *et al.*, 1996;), humidity, temperature, plant cover, soil cultivation technique and the types of the soil microorganisms present (Barriuso and Houot, 1996; Govedarica *et al.*, 2000; Willems *et al.*, 1996; Milosevia *et al.*, 2000).

In general, herbicides affect microbes indirectly, causing physiological changes, increased enzymatic production or, when applied in high doses, death of susceptible groups of micro organisms (Cervelli *et al.*, 1978). According to Lynch (1983), microbes degrade herbicides in the course of metabolic and co metabolic processes. Soil microbiological population uses herbicides and their metabolites as sources of biogenous elements (Cook and Hutter, 1981; Radosevich *et al.*, 1995). It has been noticed that certain groups of microorganisms (primary population) start to decompose herbicides a few days after their arrival. On the other hand, which produces induced enzymes, decomposes herbicides while these are passing through a period of adaptation. They also reported that microorganisms are efficient decomposers of aliphatic and hydroxyl compounds, but they decompose aromatic substances at a slower rate. The compounds that contain oxygen, sulfur or nitrogen in the ring are slowest to decompose.

Long-term application (19 years) of glyphosate reduces C biomass in soil, but ammonification and nitrification are increased compared with untreated soil (Hart and Brookes, 1996). Studies of numerous authors (Lynch, 1983; Radosevich *et al.*, 1995; Milosevia *et al.*, 2000) show that herbicide decomposing microorganisms belong to bacteria and fungi: *Arthrobacter, Pseudomonas, Bacillus, Actinomycetes, Mycoplana, Agrobacterium, Corynebacterium, Arthrobacter, Flavobacterium, Nocardia* and *Trichoderma*. Effect of herbicides on the composition and morphology of soil microbial population depends on the composition and dose of herbicides applied but also on the kind of microorganisms present (Miskovia *et al.*, 1983; Milosevia *et al.*, 2000).

In general, herbicides affect soil microbes indirectly. Herbicides may be a source of nutrition for microbes (Cook and Hutter, 1981), in which case they significantly affect microbial growth and multiplication. However, herbicides also affect the microbes physiologically: a) by changing their biosynthetic mechanism (a change in the level of protein biosynthesis is reflected on the ratio of extracellular and intracellular enzymes); b) by affecting protein biosynthesis (induction or repression of synthesis of certain enzymes); c) by affecting the cellular membranes (changes in transport and excretion processes); d) by affecting plant growth regulators (transport of indolacetic acid, gibberellin synthesis and ethylene level); e) applied in high doses, they may kill microorganisms.

Under laboratory conditions, normal dose of glyphosate inhibited de hydrogenise activity (DHA) by 5-10 per cent (3 weeks after herbicide application). A tenfold dose of glyphosate affected negatively the activity of this oxide-reducing enzyme by 5 per cent (11 weeks after herbicide application) (Schuster and Schroder, 1990).

Application of pesticides and other chemicals used in agriculture affects the vital functions and population dynamics of soil microorganisms. Microorganisms are a heterogeneous group of organisms whose enzymatic systems comprise 60-90 per cent of the total metabolic activity of the soil (Lee, 1994). Population size, enzymatic activity and biodiversity of certain systematic and physiological groups of microorganisms may serve as bio indicators of changes taking place in the soil following herbicide application (Milosevia *et al.*, 1995, 2000; Govedarica *et al.*, 2000). According to Milosevia *et al.* (2000), herbicides tended to reduce the total number of soil microorganisms 7 to 30 days after application.

At normal field recommended rates, herbicides are considered to have no major or long term effect on microbial populations. Sebiomo *et al.* (2011) reported that some micro organisms were able to degrade the herbicide, while some others were adversely affected depending on the application rates and the type of herbicide used. Therefore, effects of herbicides on microbial growth, either stimulating or depressive, depend on the chemicals (type and concentration), microbial species and environmental conditions (Zain *et al.*, 2013).

A field experiment conducted in the Department of Agronomy at West Bengal by Adhikary *et al.* (2014) to study the impact of three commonly used herbicides (pendimethalin, oxyfluorfen and propaquizafop) on soil microbial populations in chilli. They reported that the herbicide treatments significantly inhibited the development of microbial populations in the soil, and the degree of inhibition varied with the types of herbicide. Increasing trend of inhibition on growth of microbial populations was observed from the initial effect until 15 days after application. No inhibition was observed at 15 DAA to harvest. The study suggests that the herbicide application to soil cause transient impacts on microbial population growth, when applied at recommended field application rate.

2.2.6. Residual effect of herbicides on soil and crops

Regarding their degradation period, pesticides may be divided in two groups: a) residual, with long toxic action and b) contact, with short toxic action. A study of Barriuso and Houot (1996) showed that simazine mineralizes faster than atrazine. A hormone herbicide 2, 4-D decomposes in soil very fast. It is decomposed by several microorganisms: *Mycoplana, Corynebacterium, Achromobacter, Rhizobium, Arthrobacter, Flavobacter* and some actinomycetes (Lynch, 1983).

Pesticide adsorption or desorption depends on the physical and chemical soil properties. The process of adsorption depends on the concentration and solubility of herbicides in soil solution, ion exchange capacity, organic matter content, pH, moisture and temperature of soil, etc. Soils with heavy mechanical composition have a higher pesticide adsorbing capacity than light (sandy) soil (Willems *et al.*, 1996).

Glyphosate [N-(phosphonomethyl) glycine] is a broad-spectrum, non-selective, post emergence herbicide that is widely used in agriculture. The commercial success of glyphosate as a highly effective herbicide has stimulated several studies on its behaviour and persistence in soil (Krzysko-Lupicka and Orlik, 1997; Forlani *et al.*, 1999; Jonge and Jonge, 1999). Wiren-Lehr *et al.* (1997) observed that mineralization of glyphosate is related to the both the activity and biomass of soil microorganisms. Microbial degradation of glyphosate produces the major metabolite aminomethyl phosphonic acid (AMPA), and ultimately leads to the production of water, carbon dioxide and phosphate (Forlani *et al.*, 1999).

The presence of glyphosate in soil may cause changes to the microbial population and activity of the soil. Wardle and Parkinson (1990) observed that the presence of glyphosate in soil was related to temporary increase in both the number of bacteria in the soil and the overall microbial activity of the soil, although the number of fungi and actinomycetes was not affected. Stratton and Stewart (1992) conducted an experiment to study the effect of glyphosate on the number of microorganisms in a soil, microbial biomass and soil respiration. They observed only a small increase in microbial biomass but no negative or positive effects in respect to the number of microorganism or soil respiration. Haney *et al.* (2000) and Busse *et al.* (2001) evaluated the effect of glyphosate on the microbial community of soils and observed that microbial activity was stimulated in the presence of this herbicide.

An experiment was conducted at the farm of Zonal Adaptive Research Station, Uttar Banga Krishi Viswavidhyalaya, West Bengal by Subhendu (2009) to evaluate the effect of pendimethalin on the yield, weed density and phytotoxicity in different varieties of rai (*Brassica juncea*) and yellow sarson (*B. campestris* var. yellow sarson) under higher soil moisture regime in *Terai* region of West Bengal. Pre emergence application of pendimethalin at higher dose i.e. 1.0 kg/ha recorded higher plant mortality (30.92 %) due to the presence of higher concentration of pendimethalin residue (0.292 µg/g) till the tenth day of crop age and consequently had the reduced yield (12.59 q/ha) than the dose of 0.7 kg/ha (13.33 q/ha) where plant mortality was only 12.62 per cent due to comparatively lower level of pendimethalin residue (0.192 µg/g). Although the application of pendimethalin at the rate of 1.0 kg/ha was able to control weed more efficiently (18.96/m^2) than the dose of 0.7 kg/ha (30.4 l/m^2) and subsequent lower doses. The herbicide leached down to the root zone resulting in phytotoxicity towards crop. Yellow sarson group (*Brassica campestris*) showed more susceptibility than rai (*Brassica juncea*) group against pendimethalin application at higher doses.

Pendimethalin is a low volatile and low mobile herbicide having low water solubility (Savage and Jordan 1980; Schleicher *et al.*, 1995). It is moderately persistent with a field half life of approximately 30 days and lateral and downward movement is restricted (Lee *et al.*, 2000). It does not go rapid microbial degradation. Slight loss can occur from photodecomposition and volatilization. It is strongly absorbed by moist soil, practically insoluble in water and thus does not leach appreciably in moist soil (Aktar *et al.*, 2008). Signori and Deuber (1979) revealed that the leaching of pendimethalin was higher in loamy soil than in clay soils.

2.2.7. Nutrient removal of weeds under different control methods

Chungi and Ramteke (1998) suggested that weeds accumulate higher concentration of plant nutrients in their tissues than crops. Growth habits and efficient photosynthetic pathway (C_4) resulted in higher nutrient content and high removal of nutrients by most of the weeds than crops (Singh and Sharma, 1984). Loomis (1958) reported that weeds are severe competitors for nutrients than for water and have high nutrient use efficiency than rice.

Setty and Hosmani (1977) reported negative correlation coefficient between weeds and crops regarding the nutrient uptake. Maximum concentration of NPK in plant part of okra at harvest was observed with the application fluchloralin @ 0.48 l/ha 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 in weed control treatments (Suresh, 1984).

According to Vethamani and Balakrishnan (1990), the highest uptake of N, P and K occurred in okra treated with fluchloralin at 2 kg/ha and receiving N at 50 kg/ha as well as polythene mulching. Kundra *et al.* (1993) observed 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.

The combination of manual weeding and chemical weeding reduced the nutrient removal by weeds and the maximum N, P and K removal by weeds were recorded in unweeded check (Choubey *et al.,* 1999). Nagar (2005) showed that two hand weeding at 30 and 45 days after sowing brought about the maximum reduction in weed density and dry matter production at 60, 75, 90 days after sowing and at harvest. It also resulted in lowest depletion of nutrients (N, P, K and S) at harvest in coriander.

Yadav *et al.* (2011) opined that the uninterrupted weed growth depleted 108.5 kg N, 15.8 kg P and 151.6 kg K/ha, while such losses were lowest with two hand weeding at Rajasthan. Maximum uptake of N (133.8 kg/ha), P (32.5 kg/ha) and K (135.1 kg/ha) by cluster bean was recorded in two hand weeding (20 and 40 DAS), while in weedy check plots N, P and K uptake by crop was 40.6, 9.8 and 41.1 kg/ha, respectively.

2.2.8. Economics of weed control

A field experiment conducted at Kerala Agricultural University by Sainudheen (2000) to study the economic returns of different weed control methods in okra. He reported that the higher total return was obtained from glyphosate 1.2 kg/ha in the summer season followed by solarization. However, the higher return per rupee invested on weed control was obtained from combinations of metolachlore 1.0 kg/ha with glyphosate 1.2 kg/ha in summer season, solarization and that of glyphosate 0.8 kg/ha.

Yadav (2001) observed that higher net returns were obtained in oxyfluorfen at 0.3 kg/ha + two hoeing, closely followed by lower dose of oxyfluorfen (0.2 kg/ha) with two hoeing in transplanted chilli. Patel *et al.* (2004) opined that pre plant application of pendimethalin supplemented with hand weeding in transplanted chilli gave highest net profit and B: C ratio. Shaikh (2005) recorded higher net monetary returns in pendimethalin followed by hand weeding over weedy check and fluchloralin.

Subrao (2010) reported that, higher B:C ratio was observed with the application of pendimethalin @ 1.0 kg/ha followed by pendimethalin @ 1.0 kg/ha and weed free check as compared to other treatments in brinjal. According to Malunjkar *et al.* (2012), pre-emergence application of pendimethalin 1.0 kg/ha + post-emergence application of imazethapyr recorded significantly higher gross returns, net returns and B: C ratio of 2.44. Panotra *et al.* (2012) observed that application of pendimethalin 1.0 kg/ha increased the net return of French bean significantly over weedy check, besides at B: C. ratio of 1.12 during two cropping seasons in Uttar Pradesh.

Upadhyay *et al.* (2012) opined that the maximum net profit (Rs.43233/ha) and B: C ratio (3.67) were recorded under Odyssey (mixture of imazethapyr + imazamox + adjuvant) in soyabean at Jabalpur. According to the report of KAU (2014), the combined application of herbicides oxyfluorfen and glyphosate in ginger resulted better weed control. The highest rhizome yield and B:C ratio was recorded in this treatment followed by pendimethalin + hand weeding and oxyfluorfen + hand weeding.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Weed management in ginger (*Zingiber officinale* Rosc.) was carried out at the Agronomy Farm, College of Horticulture, Vellanikkara during March 2013 to January 2015. The main objectives of the investigation were to study the weed flora of ginger in the major ginger growing districts of Kerala and to find out efficient, economic and eco-friendly weed management practices for ginger. The investigation was carried out in two parts.

Part I : Survey of weed flora of ginger in the major ginger growing districts of Kerala

Part II : Field experiment on management of weeds in ginger.

3.1. General details

Location

The farm is located at latitude of 10° 31' and longitude of 76° 13' in central Kerala at an altitude of 40.3 m above mean sea level.

Climate and weather conditions

The weather parameters during cropping period are given in Fig. 1.

Soil characters

The physico-chemical characteristics of the soil of the experimental field are presented in Table 1.

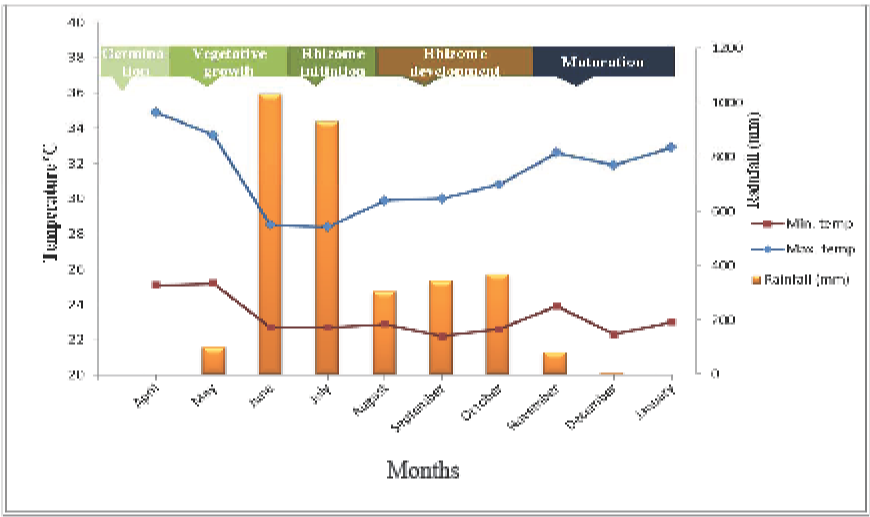


Fig. 1 Weather data during the crop growth period (1st year)

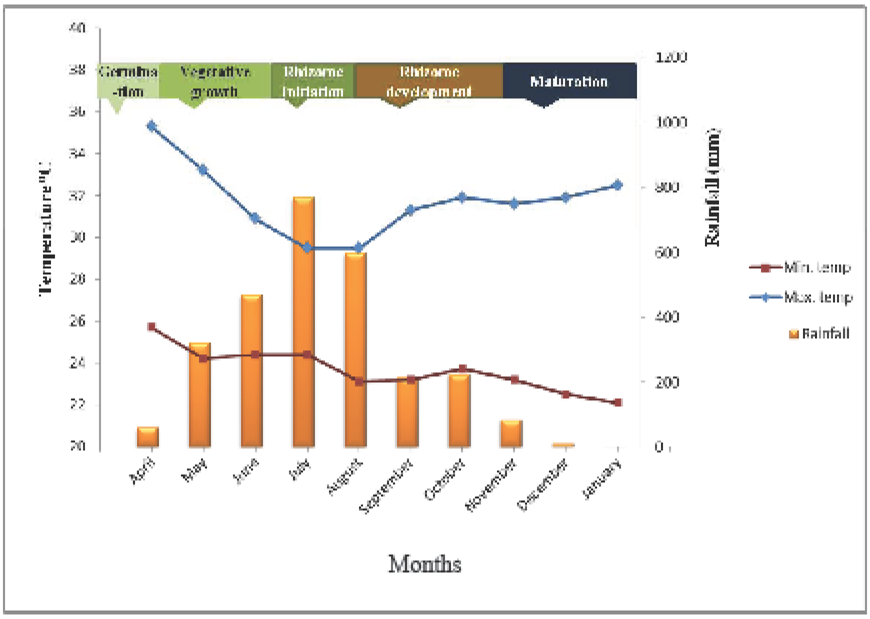


Fig. 1. Weather data during the crop growth period (2nd year)

Table 1. Physico-chemical characteristics of the soil

Particular	Value	Soil texture	Method used
A) Particle size analysis			
Coarse sand (%)	30.90	Sandy clay loam	International Pipette Method (Piper, 1966)
Fine sand (%)	26.30		
Silt (%)	19.64		
Clay (%)	23.16		
pH	4.82	Strongly acidic	pH meter with glass electrode (Jackson, 1958)
B) Available nutrients			
Organic Carbon (%)	1.21	Chromic acid wet digestion method (Walkley and Black, 1934)	
Available N (kg/ha)	452	Alkaline potassium permanganate method (Subbiah and Asija, 1956)	
Available P_2O_5 (kg/ha)	22	Bray colorimeter method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)	
Available K_2O (kg/ha)	236.14	Neutral normal ammonium acetate method (Jackson, 1958)	

Season and variety

The crop period was from March 2013 to January 2015 (two crops). The ginger variety used was Athira released from the Department of Plantation crops and spices, College of Horticulture, Kerala agricultural University. The variety can be used as vegetable and dry ginger. The average productivity of the variety is 22 t/ha and duration is eight months.

Cropping history of experimental plot

The experimental site was under various tuber crops during the past two years and before that it was under rubber crop.

3.2. Experiments

3.2.1. Part I

Survey of weed flora of ginger

Stratified random survey was done in major ginger growing districts of Kerala namely Waynad, Palakkad, Idikki and Thrissur districts during 2013 and 2014. In each district, five panchayaths were selected and five representative ginger fields were surveyed in each panchayath to study the extent of weed infestation in different agro ecological conditions of Kerala.

Survey was undertaken in Wayanad and Palakkad regions during October and November 2013 (Plate 1- 7). In Thrissur and Idikki districts, survey was conducted during October and November 2014. At least 25 ginger growing fields were selected in each district. The observations on the intensity of weed infestation in ginger fields were recorded from quadrats of one square meter from five random spots and the average was worked out. Based on the average weed count, relative frequency, relative density and summed dominance ratio of important weed species were calculated in different districts.

3.2.2. Part II

Field Experiment

Field experiments were conducted during 01-04-2013 to 01-01-2014 and 01-04-2014 to 01-01-2015 to find out efficient, economic and eco-friendly weed management practices for ginger.

Plate 1. Lay out of the experimental plot (first year)

Plate 2. Lay out of the experimental plot (second year)

Plate 3. Survey in Palakkad

Fimbristylis miliacea

Scoparia dulcis

Ageratum conyzoides

Mollugo pentaphylla

Ludwigia parviflora

Eclipta alba

Plate 4. Important weeds in Palakkad based on SDR

Plate 5 Survey in Thrissur

Cyperus difformis

Alternanthera bettzickiana

Physalis minima

Vernonia cineria

Spilanthes paniculata

Mollugo disticha

Plate 6. Important weeds in Thrissur based on SDR

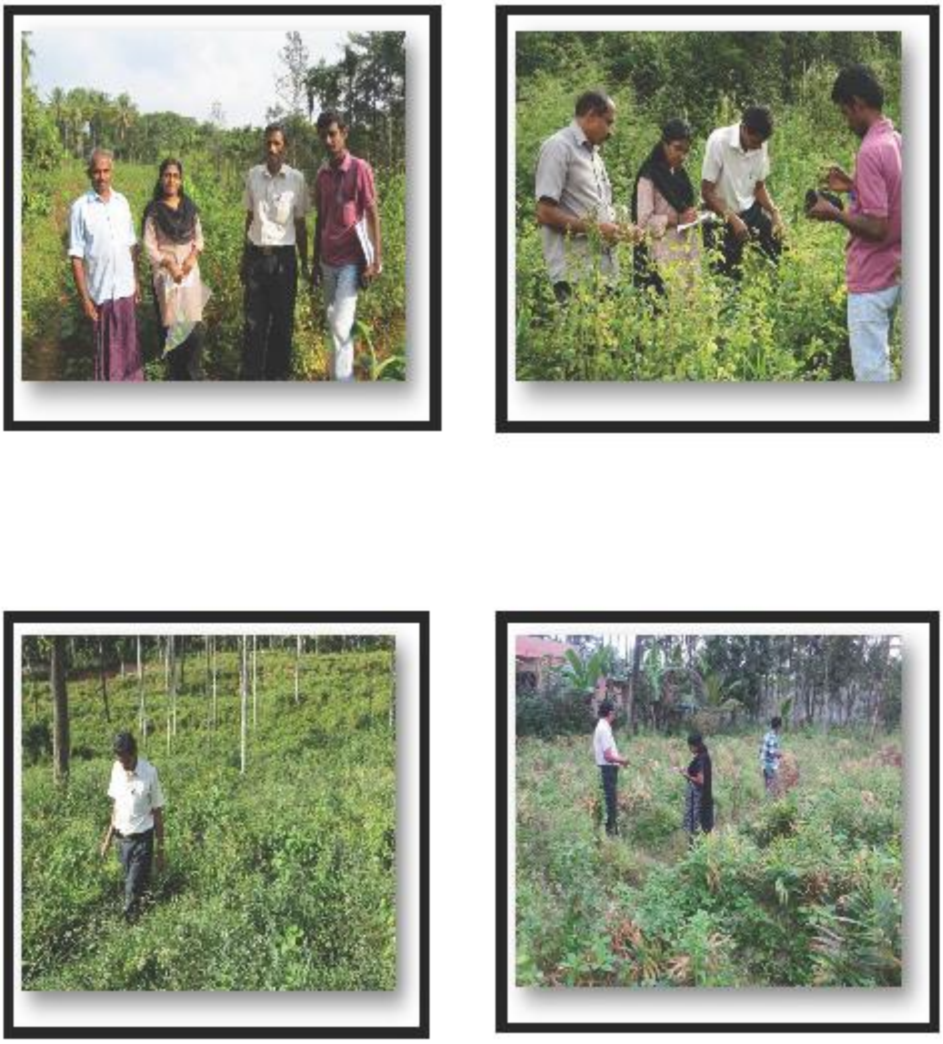


Plate 7. Survey in Wayanad

Spilanthes radicans

Ageratum conyzoides

Crassocephalum crepidioides

Scoparia dulcis

Erigeron canadensis

Mimosa pudica

Plate 8. Important weeds in Wayanad based on SDR

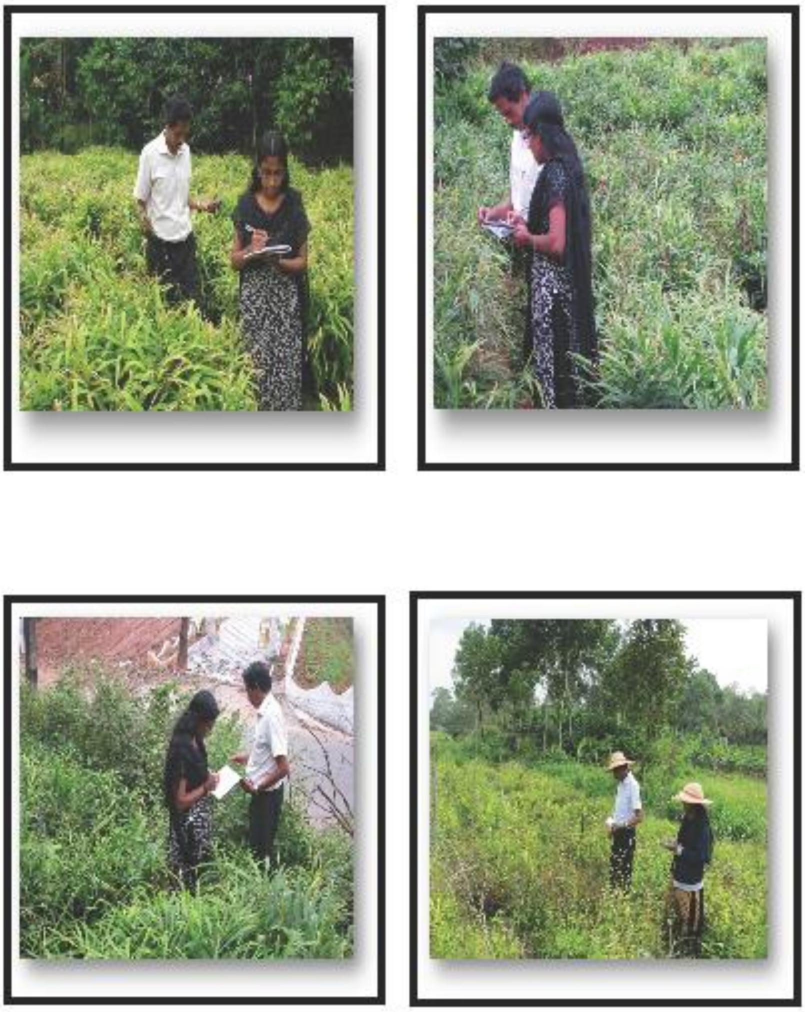


Plate 9. Survey in Idukki

Ageratum conyzoides

Spilanthes radicans

Blumea sp.

Bidens pilosa var. *minor*

Scoparia dulcis

Mitracarpus hirtus

Plate 10. Important weeds in Idukki based on SDR

Treatments

T_1: Pendimethalin @ 1.5kg /ha after planting but before mulching

T_2: Oxyfluorfen @ 0.20 kg /ha after planting but before mulching

T_3: Metribuzin @ 0.525 kg /ha after planting but before mulching

T_4: Glyphosate @ 0.80 kg /ha just before the emergence of sprouts of ginger

T_5: Glufosinate ammonium @ 0.45kg /ha just before the emergence of sprouts of ginger

T_6: Pendimethalin @ 1.5kg/ha + one hand weeding at first mulching

T_7: Oxyfluorfen @ 0.20 kg/ha + one hand weeding at first mulching

T_8: Metribuzin @0.525 kg/ha + one hand weeding at first mulching

T_9: Soil solarization for 45 days before planting ginger

T_{10} : PoP recommendations, KAU (two hand weedings at 45 and 90 days after planting)

T_{11} : Unweeded control

Design : RBD

Replication : 3

Net plot size : $8m^2$ (4 beds of 2m × 1m size)

Gross plot size: 10.8 m^2

Spacing : 25 cm × 25cm

Pre emergence herbicides were applied after planting, but before mulching. Post emergence herbicides (glyphosate and glufosinate ammonium) were applied twenty five days after planting, just before the emergence of sprouts of ginger. Pre emergence herbicides followed by hand weeding was adopted in

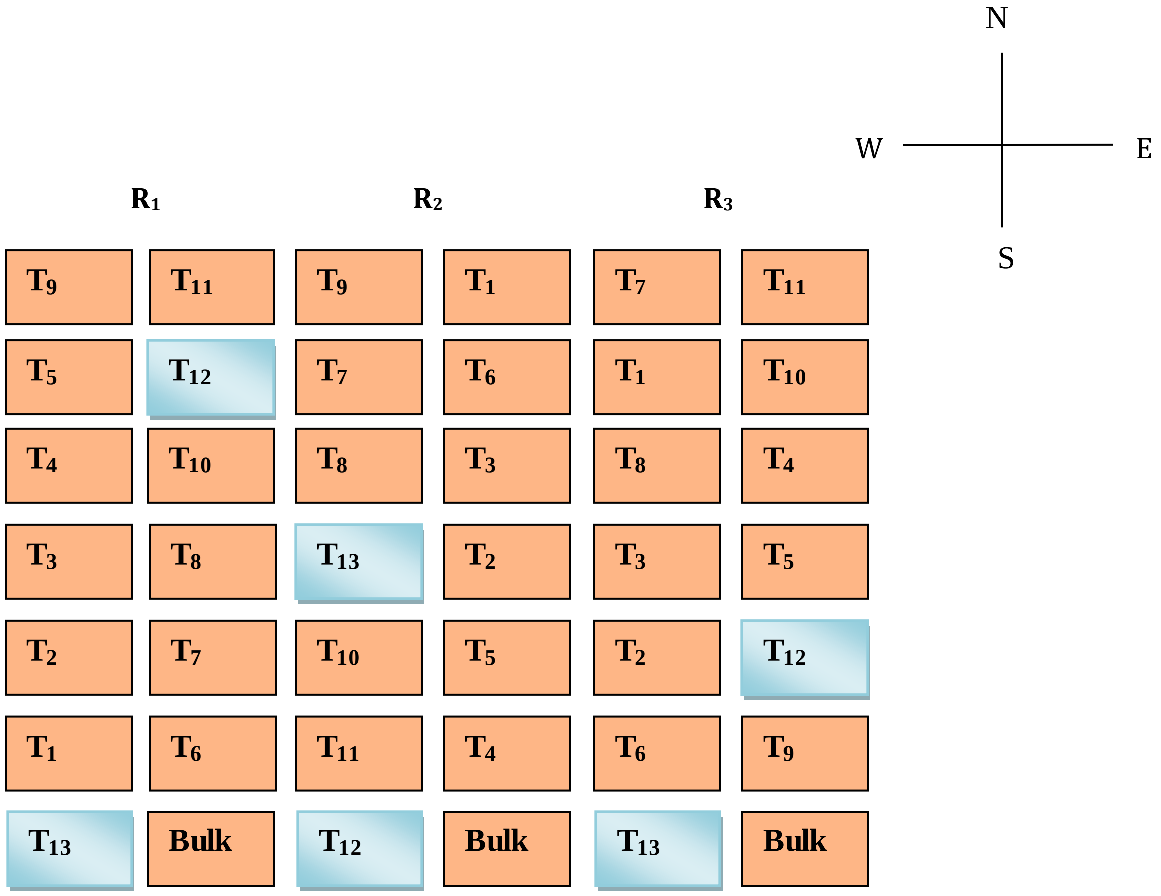
Plate 11. Application of pre emergence herbicides

the treatments T_6, T_7, T_8. Manual weeding and mulching were done at 45 days after planting (DAP) in T_6, T_7, T_8. Weeding was undertaken in T_{10} at 45 and 90 DAP before each mulching.

Soil solarization was done for 45 days before planting of ginger (T_9). Solarization is a method of hydrothermal disinfection. The bed for raising crop was leveled and pebbles present on the surface removed before solarization. Required quantity of organic manure was incorporated in the beds and sufficiently irrigated. Thereafter, the moist beds were covered with transparent thin polythene sheet of 150 gauge. The edges of the sheet were covered with soil to keep it in position in order to maintain the temperature and moisture inside the polythene mulch. Soil temperatures at depths of 10 and 15 cm from solarized bed at periodical interval were recorded. For this, soil thermometers were installed in the centre of the bed at depths of 10 and 15 cm in the hole made for inserting the thermometer. Soil temperatures were recorded at 8.30 am and 2.30 pm. Soil temperature in solarized bed was recorded 24 h after mulching when it got stabilized under the mulch.

In the second crop season (March 2014 to January 2015) two additional treatments, namely, combinations of glyphosate (0.8 kg/ha) and pendimethalin (1.5 kg/ha) (T_{12}) and glyphosate (0.8 kg/ha) and oxyfluorfen (0.2 kg/ha) (T_{13}) were additionally included. The combinations of these herbicides were applied at twenty five days after planting, just before the emergence of sprouts of ginger.

All the treatments received mulching and earthing up both at 60 and 120 DAP.



T_{12} and T_{13} were additional treatments given in second year only

Fig. 2. Layout plan of the experimental field

Land preparation, planting and fertilizer application

The area was ploughed with tractor and then pulverised by using a rotavator and then leveled. The plot size was 8 m^2 (4 beds of 2 m×1 m size). FYM @ 30 t/ha was applied as basal dose along with full dose of P_2O_5 (50 kg/ha) and 50 per cent K_2O (25 kg/ha). Half dose of N (38 kg/ha) was applied at 60 DAP. The remaining quantity of N (38 kg/ha) and K_2O (25 kg/ha) were applied at 120 DAP.

Plant protection

Rhizoctonia leaf blight disease and shoot borer incidence were observed in ginger and was managed by spraying SAAF (Mancozeb + Bavistin) @ 0.30 per cent concentration and dimethoate at 0.05 per cent concentration respectively.

Harvesting

Harvesting was done after the plants fully dried. After harvest, the fibrous roots as well as the soil particles attached to the rhizomes were removed and stored in the field laboratory.

3.3. Observations

3.3.1. Part I - Observations during survey of weed flora

Density

Density was calculated by using the formula

$$\text{Density (D)} = \frac{\text{Total number of individuals of a species in all the qauadrats}}{\text{Total number of samples surveyed}}$$

Frequency

Frequency was calculated by using the formula

$$\text{Frequency (F)} = \frac{\text{Number of location in which a species occur}}{\text{Total number of locations sampled}}$$

Relative density

Relative density was calculated by using the formula

$$\text{Relative density (RD)} = \frac{\text{Density of a species}}{\text{Sum density of all species}} \times 100$$

Relative frequency

Relative frequency was calculated by using the formula

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of a species}}{\text{Sum frequency of all species}} \times 100$$

Summed dominance ratio

Summed dominance ratio was calculated by using the formula

$$\text{SDR} = \frac{\text{IVI of the given species}}{\text{No. of parameters used to work out IVI}}$$

IVI – importance value index = RF+ RD

3.3.2. Part II – Observations of field experiment

3.3.2.1. Observations on weeds

Weed count

Species wise weed count was taken using a 50 cm × 50 cm (0.25 m^2) quadrat. The quadrat was placed at random and samples were taken from each plot at 45, 90 and 180 DAP and were reported as number/ m^2.

Dry matter production of weeds

The weeds uprooted from the quadrat were cleaned, air dried and then oven dried at 80 ± 5^o C and dry weight was recorded in g/m^2 at 45, 90 and 180 DAP and recorded as kg/ha.

Nutrient removal by weeds

The N, P, K content of weeds at 45, 90 and 180 DAP were analyzed by standard procedures (Jackson, 1958). Total N content of the weed samples was determined by Microkjeldal digestion and distillation method. Plant samples were digested in diacid mixture and the P content was determined by Vanado molybdo phosphoric yellow colour method. Intensity of colour was read using Spectronic 20 spectrophotometer at 420 nm. Potassium content in the diacid digest was estimated using flame photometer. The nutrient uptake of weeds at 45, 90 and 180 DAP was calculated as the product of nutrient content and the plant dry weight and expressed in kg/ha (Plates 8-11).

3.3.2.2. Biometric observations on crop

Germination per cent of ginger at 45 DAP

The number of rhizomes germinated in each plot was counted at 45th day of planting to work out the germination per cent.

Phytotoxic symptoms on the crop at 45 DAP

Phytotoxic symptoms on the crop was recorded up to 45 days after spraying of herbicides

No. of tillers/plant at 180 DAP

The number of tillers per plant was determined from five observational plants by counting the number of aerial shoots and average computed.

No. of leaves/tiller at 180 DAP

The number of leaves per tiller was determined by counting number of leaves of all the aerial shoots from five observational plants and the averages calculated.

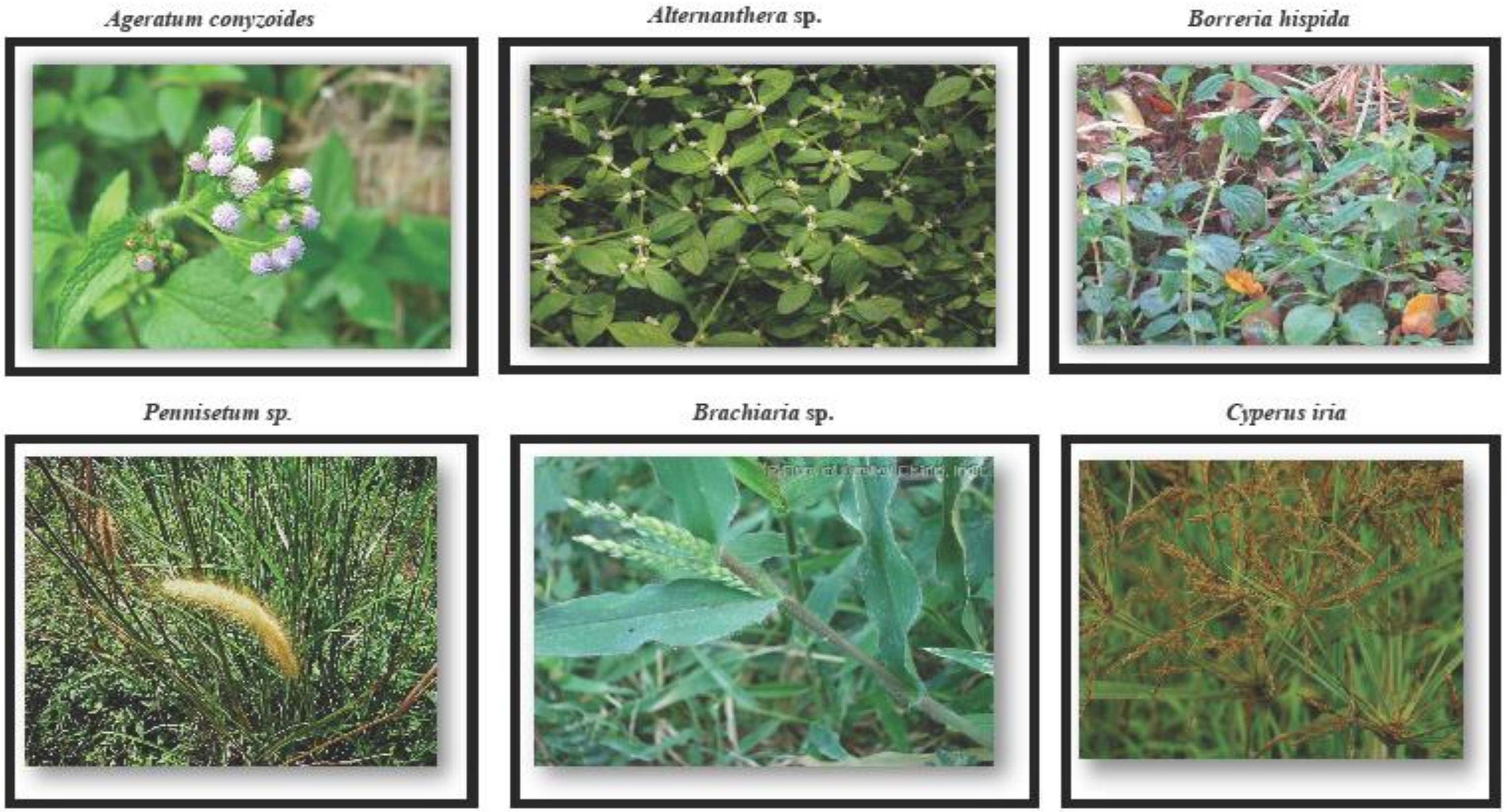


Plate 12. Major weeds in the experimental plot

Pendimethalin

Oxyfluorfen

Soil solarization

Unweeded control

Plate 13. Field view of different weed management practices at 3 MAP

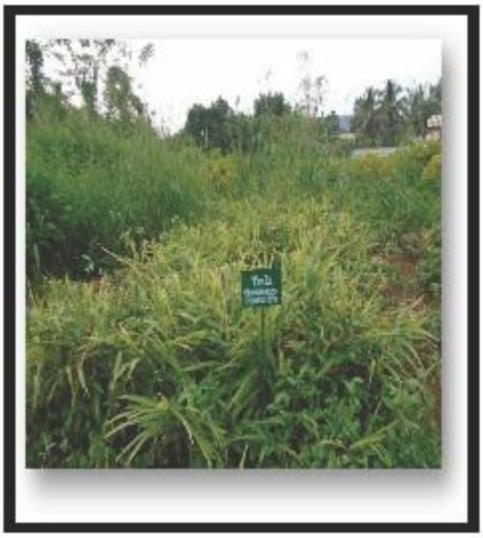
Glyphosate

Glufosinate ammonium

POP

Plate 14. Field view of different weed management practices at 3 MAP

Oxyflourfen + Glyphosate



POP

Unweeded control

Oxyfluorfen + 1 HW

Plate 15. Field view of different weed management practices at 6 MAP

Height of plant at180 DAP

Height of the plant was measured from base to the growing tip of observational plants at 180 DAP and the mean values computed and expressed in cm.

Incidence of major pests and diseases

The incidence of pest like shoot borer and disease like leaf blight were observed and timely control measures were adopted.

Fresh weight of rhizomes at harvest

The plot yield was recorded by taking the weight of the entire rhizomes harvested from from the four plots of size 2 × 1 m^2 in each treatments and the total yield was calculated and expressed in t/ ha (Plate 12 and 13).

Dry weight of rhizomes

The harvested ginger from the observational plants were cleaned, recorded fresh weight, air dried and then oven dried at 80 ± 5^{o} C and the averages were worked out and dry weight was recorded in kg/ha.

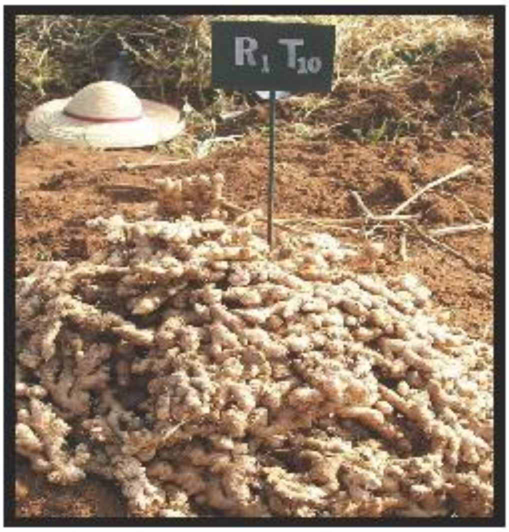
3.3.2.3. Soil analysis

Initial status of major nutrients in soil was estimated. Soil samples were collected before land preparation and soil analysis was done for pH, texture, organic carbon, available N, P and K using the standard procedures as shown in Table 1.

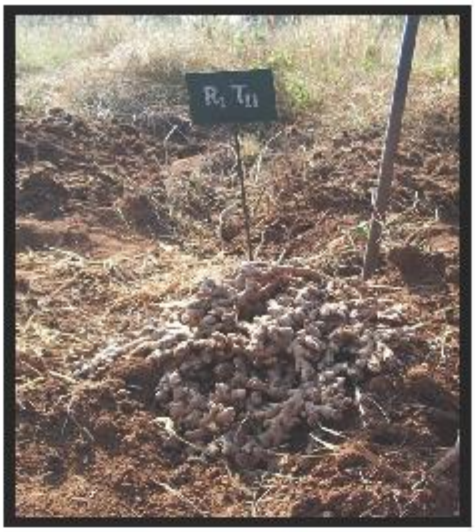
3.3.2.4. Microbial count in soil

Microbial count (total bacteria and fungi) in soil was analyzed two months after spraying of herbicides by serial dilution and plate technique using appropriate medium. For the isolation of fungi, Rose Bengal agar medium was used at 10 $^{-3}$ dilution and for bacteria soil extract agar medium was used at 10 $^{-5}$ dilution.

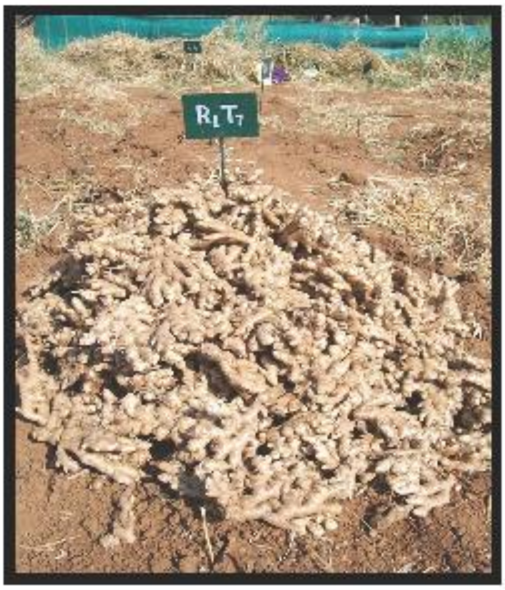
POP



Unweeded control



Oxyfluorfen + 1 HW



Oxyfluorfen + Glyphosate

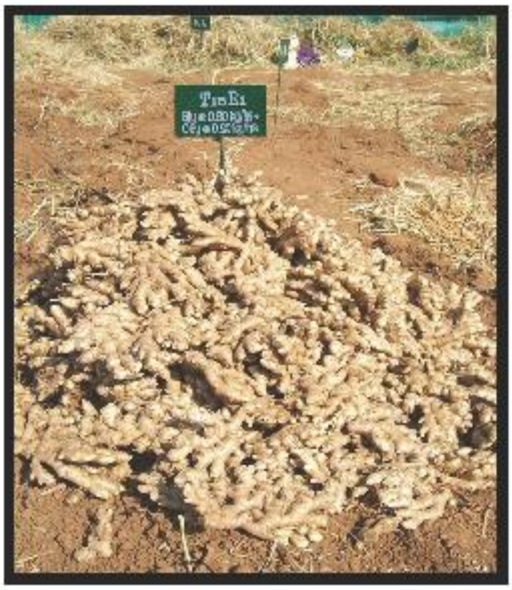


Plate 16. Comparison of yield (t/ha) in different weed management practices

3.3.2.5. Herbicide residue analysis in ginger

The residue of the most successful herbicides *viz,* pendimethalin and oxyfluorfen were analyzed at the time of harvest by using gas chromatographic method. The maximum residue limits of pendimethalin, oxyfluorfen, metribuzin, glyphosate and glufosinate ammonium in the food commodity range from 0.01-0.1 mg/kg.

Gas chromatographic technique outlined by Sankaran *et al.* (1993) was employed for the determination of oxyfluorfen and pendimethalin residues in ginger. Slight modifications were made in the clean up step so as to remove colour from the extract.

Procedure employed to clean up of the extract

a. Pendimethalin

Clean up – The contents in the evaporating flask are dissolved in 10 ml of hexane and transferred to a glass column with 2.5 cm sodium sulphate at both the ends and 2 cm activated charcoal column in between the sodium sulphate layers and washed with 50 ml hexane. The beaker was placed below the column and the residue eluted with 50 ml of 60 per cent benzene in hexane. The eluate collected was evaporated to dryness in a rotary evaporator and the residue was dissolved in 2.5 ml benzene.

b. Oxyfluorfen

Clean up – the concentrated extract was transferred to a glass column filled with 5 cm sodium sulphate at both the ends and 2 cm activated charcoal column in between the sodium sulphate layers. The residue was eluted with 100 ml of acetone and the acetone was evaporated to dryness in a rotary evaporator. The residue was dissolved in 1 ml of acetone for GC determination.

3.3.2.6. Economics of weed control

Economics of cultivation of ginger was worked out by considering the total expenditure and total income of the crops. The benefit cost ratio was calculated as follows

B:C ratio = Gross income/ Cost of cultivation

Profit = Gross income – Cost of cultivation

3.4. Data analysis

The data were subjected to analysis of variance using the statistical package 'MSTAT-C' (Freed, 1986). Data on weed biomass, which showed wide variation, were subjected to square root transformation $\sqrt{(x+0.5)}$ to make the analysis of variance valid (Gomez and Gomez, 1984). Multiple comparisons among treatment means, where the F test was significant (at 5% level), were done with Duncan's Multiple Range Test (DMRT) (Duncan, 1955).

Results

RESULTS

The field experiment on "Weed management in ginger (*Zingiber officinale* Rosc.)" was conducted during March 2013 to January 2015 at Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur. The investigation was carried out in two parts. Part I : Survey of weed flora of ginger in the major ginger growing districts of Kerala and Part II : Field experiment on management of weeds in ginger. The data generated from the experiment were statistically analyzed and presented here.

Part I

4.1. Survey of weed flora of ginger in the major ginger growing districts of Kerala

Survey was undertaken in Wayanad and Palakkad districts during October and November 2013. In Thrissur and Idikki districts, survey was conducted during October and November 2014. The results of the study indicated wide variation in weed species in the four districts surveyed.

Palakkad

Sixty eight weed species observed in the ginger growing fields of Palakkad district are presented in Table 2. Among this, the distribution of broad leaved weeds, grasses and sedges is in the order of 69.1 per cent (47 nos.), 22.0 per cent (15 nos.) and 8.8 per cent (6 nos.) respectively. Based on the SDR values, the most dominant broad leaved weed species observed in the Palakkad district were *Scoparia dulcis*, *Ageratum conyzoides*, *Mollugo pentaphylla* and *Ludwigia parviflora* (SDR: 18.101, 17.012, 16.05 and 15.859 respectively). In terms of frequency, *Scoparia dulcis* was the most widely distributed weed species (88 per cent). The other important broad leaved weeds were *Eclipta alba*, *Emilia sonchifolia*, *Lindernia crustacea* etc. *Leptochloa chinensis* (SDR: 10.156) was observed as the most dominant grass weed followed by *Echinochloa colona* (SDR: 7.562). The occurance of the grass weed, *Ischaemum indicum* was comparatively less in this location (SDR: 5.749). Among the sedges, *Fimbristylis miliacea* and *Cyperus iria* (SDR: 19.703 and 10.156 respectively) were the dominant species. In terms of density *Fimbristylis miliacea* recorded maximum spread (2.810).

Thrissur

Data on fifty three weed species found growing along with ginger in Thrissur district is furnished in Table 3. Among these, the distribution of broad leaved weeds was 74 per cent (39 nos.) grasses 19.2 per cent (10 nos.) and sedges 6.8 per cent (4 nos.) respectively. *Cyperus difformis* (SDR: 8.304) was the most dominant sedge followed by *Cyperus haspan* (SDR: 5.392). Among broad leaved weeds, *Alternanthera bettzickiana* had the highest SDR value (8.054). Among other broad leaved weeds, *Physalis minima* (SDR: 6.879), *Vernonia cineria* (SDR: 5.887), *Spilanthes paniculata* (SDR: 5.639), *Mollugo disticha* (SDR: 5.516), *Ageratum conyzoides* (SDR: 5.021), *Oldenlandia umbellata* (SDR: 4.525) etc. were dominated in the crop. Among the grasses, *Brachiaria mutica* (SDR: 5.205), *Eragrostis japonica* (SDR: 4.525) and *Setaria sphacelata* (SDR: 4.399) dominated in Thrissur district. *Alternanthera bettzickiana* was the widely spread weed species among the broad leaved weeds, as indicated by the high relative density (6.679) and *Cyperus difformis* was the most frequently occurred weed species in terms of frequency (88 per cent)

Wayanad

Weed population in ginger fields of Wayanad district, (Table 4) accounted for a total number of sixty one weed species. Among these the distribution of broad leaved weeds, grasses and sedges are in the order of 77 per cent (49 nos.) 16.4 per cent (10 nos.) and 6.6 per cent (4 nos.) respectively. Based on SDR, *Spilanthes radicans* and *Ageratum conyzoides* emerged as the most dominant broad leaved weed species (SDR: 27.134 and 23.964 respectively). The other important broad leaved weed species observed in this district were *Crassocephalum crepidioides, Scoparia dulcis* and *Erigeron Canadensis*. (SDR:

18.646, 16.372 and 13.746 respectively). The most dominant grass weed was *Digitaria ciliaris* with an SDR value 8.395. The other most important grass weed was *Eleusine indica* (SDR: 5.906). Among the sedges, *Cyperus iria* was the dominant species (SDR: 6.210) followed by *Cyperus rotundus* (SDR: 5.384). *Cyperus iria* recorded lower relative frequency value in Wayanad District (3.080) than *Cyperus rotundus* (3.850). *Spilanthes radicans* recorded maximum spread in terms of relative density (47.852).

Idukki

Weed species recorded in ginger grown fields during the survey in Idukki district are depicted in Table 5. A total of fifty weed species were observed in the ginger fields of Idukki district. Among these, the distribution of broad leaved weeds was 80 per cent (40 nos.), grasses 16 per cent (8 nos.) and sedges 4 per cent (2 nos.), respectively. *Ageratum conyzoides* and *Spilanthes radicans* were the most dominating broad leaved weed species (SDR: 10.841 and 10.160 respectively). The other important broad leaved weeds observed were *Crassocephalum crepidioides, Blumea sp.,* and *Bidens pilosa var. minor* with SDR values 8.737, 8.056 and 7.560, respectively. Among grasses, *Eragrostis* sp. recorded the maximum POPulation with SDR value of 5.391 followed by *Ischaemum indicum* (5.021). At the same time these species recorded higher relative frequencies of 6.947 and 7.444 respectively.

The average yield obtained in Palakkad, Thrissur, Wayanad and Idukki districts were in the order of 2538 t/ha, 181 t/ha, 0.2 lakh tonnes and 4306 t/ha respectively.

Table 2. Weed spectrum of ginger in Palakkad district

Name of weeds	Frequency	Average density	Relative frequency	Relative density	SDR
Fimbristylis miliacea	84.000	2.810	5.390	34.016	19.703
Scoparia dulcis	88.000	2.409	5.647	30.556	18.101
Ageratum conyzoides	72.000	2.833	4.620	29.403	17.012
Mollugo pentaphylla	60.000	3.267	3.850	28.250	16.050
Ludwigia parviflora	72.000	2.611	4.620	27.097	15.859
Eclipta alba	64.000	2.188	4.107	20.179	12.143
Cyperus iria	56.000	2.071	3.593	16.720	10.156
Leptochloa chinensis	56.000	2.071	3.593	16.720	10.156
Emilia sonchifolia	64.000	1.688	4.107	15.566	9.837
Lindernia crustacean	40.000	2.900	2.567	16.720	9.643
Mimosa pudica	56.000	1.714	3.593	13.837	8.715
Echinochloa colona	56.000	1.429	3.593	11.531	7.562
Phyllanthus niruri	64.000	1.031	4.107	9.513	6.810
Vernonia ceneria	40.000	1.660	2.567	9.570	6.069
Ischaemum indicum	48.000	1.217	3.080	8.417	5.749
Eragrostis sp.	44.000	1.364	2.823	8.648	5.736
Cyperus difformis	40.000	1.400	2.567	8.071	5.319
Sphaeranthus indicus	28.000	2.143	1.797	8.648	5.222
Oldenlandia umbellata	36.000	1.556	2.310	8.071	5.191
Eleusine indica	44.000	1.182	2.823	7.495	5.159
Eragrostis japonica	36.000	1.467	2.310	7.610	4.960
Isachne miliacea	28.000	2.000	1.797	8.071	4.934
Sacciolepis interrupta	24.000	2.333	1.540	8.071	4.806

Name of weeds	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Digitaria ciliaris	32.000	1.400	2.053	6.457	4.255
Cleome burmanni	40.000	1.000	2.567	5.765	4.166
Spilanthes calva	20.000	2.400	1.283	6.918	4.101
Dactyloctenium aegyptium	36.000	1.111	2.310	5.765	4.038
Cynedrella nodiflora	32.000	1.250	2.053	5.765	3.909
Blumea sp.	36.000	1.000	2.310	5.189	3.749
Euphorbia hirta	24.000	1.667	1.540	5.765	3.653
Commelina benghalensis	28.000	1.343	1.797	5.419	3.608
Chromolaena odorata	36.000	0.756	2.310	3.920	3.115
Mollugo disticha	16.000	1.500	1.027	3.459	2.243
Cyperus haspan	16.000	1.400	1.027	3.229	2.128
Brachiaria mutica	16.000	1.400	1.027	3.229	2.128
Spilanthes radicans	16.000	1.250	1.027	2.883	1.955
Alternanthera sessilis	12.000	1.667	0.770	2.883	1.826
Coldenia procumbens	16.000	1.000	1.027	2.306	1.666
Corchorus olitorius	16.000	1.000	1.027	2.306	1.666
Panicum repens	16.000	0.850	1.027	1.960	1.493
Heliotropium indicum	8.000	2.000	0.513	2.306	1.410
Spilanthes paniculata	8.000	2.000	0.513	2.306	1.410
Acanthospermum hispidum	16.000	0.775	1.027	1.787	1.407
Echinochloa crusgalli	12.000	1.133	0.770	1.960	1.365
Solanum nigrum	16.000	0.725	1.027	1.672	1.349
Cyperus killing	12.000	1.067	0.770	1.845	1.307
Ammaia baccifera	12.000	1.000	0.770	1.730	1.250

Name of weeds	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Sida acuta	12.000	1.000	0.770	1.730	1.250
Tridax procumbens	12.000	1.000	0.770	1.730	1.250
Hydrolia zeylanica	8.000	1.500	0.513	1.730	1.121
Stachytarpheta indica	8.000	1.500	0.513	1.730	1.121
Physalis minima	12.000	0.533	0.770	0.922	0.846
Amaranthus viridis	8.000	1.000	0.513	1.153	0.833
Bidens pilosa var. minor	8.000	1.000	0.513	1.153	0.833
Crassocephalum crepidioides	8.000	1.000	0.513	1.153	0.833
Cyperus rotundus	8.000	1.000	0.513	1.153	0.833
Desmodium triflorum	8.000	1.000	0.513	1.153	0.833
Leucas aspera	8.000	1.000	0.513	1.153	0.833
Spermacoce ocymoides	8.000	1.000	0.513	1.153	0.833
Xanthium indicum	8.000	1.000	0.513	1.153	0.833
Aerva lanata	8.000	0.750	0.513	0.865	0.689
Trianthema portulacastrum	8.000	0.700	0.513	0.807	0.660
Mikania micrantha	8.000	0.700	0.513	0.807	0.660
Centella asiatica	4.000	1.000	0.257	0.577	0.417
Oxalis corniculata	4.000	1.000	0.257	0.577	0.417
Chloris barbata	4.000	1.000	0.257	0.577	0.417
Setaria glauca	4.000	0.300	0.257	0.173	0.215

Table 3. Weed spectrum of ginger in Thrissur district

Name of weeds	Frequency	Average density	Relative frequency	Relative density	SDR
Cyperus difformis	88.00	2.090	10.918	5.689	8.304
Alternanthera betzickiana	76.00	2.842	9.429	6.679	8.054
Physalis minima	76.00	1.842	9.429	4.329	6.879
Vernonia cenera	64.00	1.937	7.940	3.834	5.887
Spilanthes paniculata	60.00	2.066	7.444	3.834	5.639
Mollugo disticha	60.00	1.933	7.444	3.586	5.516
Cyperus haspan	60.00	1.80	7.444	3.339	5.392
Brachiaria sp.	52.00	2.461	6.451	3.957	5.205
Ageratum conyzoides	60.00	1.432	7.444	2.597	5.021
Eragrostis japonica	52.00	1.615	6.451	2.597	4.525
Oldenlandia umbellate	52.00	1.615	6.451	2.597	4.525
Setaria glauca	44.00	2.454	5.459	3.339	4.399
Biophytum sensitivum	52.00	1.153	6.451	1.855	4.153
Mimosa pudica	52.00	1.153	6.451	1.855	4.153
Fimbristylis miliacea	48.00	1.50	5.955	2.226	4.091
Ischaemum indicum	48.00	1.25	5.955	1.855	3.905
Coldenia procumbens	40.00	2.20	4.962	2.721	3.842
Desmodium triflorum	44.00	1.181	5.459	1.607	3.533
Isachne miliacea	40.00	1.70	4.962	2.102	3.533
Phyllanthus niruri	40.00	1.50	4.962	1.855	3.409
Amaranthus viridis	36.00	1.777	4.466	1.978	3.223
Clerodendron infortunatum	36.00	1.111	4.466	1.236	2.852
Crassocephalum crepidioides	32.00	1.75	3.970	1.731	2.851
Lindernia crustacean	32.00	1.75	3.970	1.731	2.851
Eleusine indica	32.00	1.50	3.970	1.484	2.727
Mikania micrantha	32.00	1.00	3.970	0.989	2.480

Name of weeds	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Borreria hispida	28.00	1.00	3.473	0.865	2.170
Cardiospermum helicacabum	24.00	1.833	2.977	1.360	2.169
Cleome burmanni	24.00	1.666	2.977	1.236	2.107
Eclipta alba	24.00	1.666	2.977	1.236	2.107
Ludwigia parviflora	20.00	2.20	2.481	1.360	1.921
Digitaria ciliaris	20.00	2.00	2.481	1.236	1.859
Scoparia dulcis	20.00	2.00	2.481	1.236	1.859
Aerva lanata	24.00	0.833	2.977	0.618	1.798
Pennisetum sp.	20.00	1.60	2.481	0.989	1.735
Sphaeranthus indicus	16.00	1.75	1.985	0.865	1.425
Spermacoce ocymoides	16.00	1.25	1.985	0.618	1.302
Tridax procumbens	16.00	1.25	1.985	0.618	1.302
Leptochloa chinensis	12.00	2.00	1.488	0.742	1.115
Centrosema pubescens	12.00	1.666	1.488	0.618	1.054
Synedrella nodiflora	12.00	1.666	1.488	0.618	1.054
Dactyloctenium aegyptium	12.00	1.666	1.488	0.618	1.054
Chromolaena odorata	12.00	1.00	1.488	0.371	0.930
Stachytarpheta indica	12.00	1.00	1.488	0.371	0.930
Mollugo pentaphylla	8.00	2.50	0.992	0.618	0.805
Centella asiatica	8.00	2.00	0.992	0.494	0.744
Echinochloa colona	8.00	1.50	0.992	0.371	0.682
Leucas aspera	8.00	1.50	0.992	0.371	0.682
Sacciolepis interrupta	4.00	7.00	0.496	0.865	0.681
Commelina benghalensis	4.00	2.00	0.496	0.247	0.372
Cyperus rotundus	4.00	2.00	0.496	0.247	0.372
Emilia sonchifolia	4.00	2.00	0.496	0.247	0.372
Sida acuta	4.00	1.00	0.496	0.123	0.310

Table 4. Weed spectrum of ginger in Wayanad district

Name of the weed	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Spilanthes radicans	100.000	3.320	6.417	47.852	27.134
Ageratum conyzoides	100.000	2.880	6.417	41.511	23.964
Crassocephalum crepidioides	96.000	2.250	6.160	31.133	18.646
Scoparia dulcis	88.000	2.136	5.647	27.097	16.372
Erigeron Canadensis	96.000	1.542	6.160	21.332	13.746
Mimosa pudica	96.000	1.471	6.160	20.352	13.256
Blumea sp.	88.000	1.373	5.647	17.411	11.529
Ludwigia parviflora	92.000	1.139	5.903	15.105	10.504
Spermacoce ocymoides	84.000	1.162	5.390	14.067	9.729
Digitaria ciliaris	64.000	1.375	4.107	12.684	8.395
Cyperus iria	48.000	1.350	3.080	9.340	6.210
Mitracarpus hirtus	52.000	1.146	3.337	8.590	5.963
Eleusine indica	52.000	1.131	3.337	8.475	5.906
Synedrella nodiflora	52.000	1.038	3.337	7.783	5.560
Cyperus rotundus	60.000	0.800	3.850	6.918	5.384
Spermacoce latifolia	44.000	1.245	2.823	7.899	5.361
Axonopus compressus	84.000	0.438	5.390	5.304	5.347
Chromolaena odorata	84.000	0.314	5.390	3.805	4.598
Spilanthes calva	24.000	2.000	1.540	6.918	4.229
Oxalis corniculata	24.000	1.500	1.540	5.189	3.364
Scirtococcum trigonum	24.000	1.367	1.540	4.728	3.134
Phyllanthus niruri	28.000	0.800	1.797	3.229	2.513
Centella asiatica	28.000	0.786	1.797	3.171	2.484

Name of weeds	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Bidens pilosa var. *minor*	20.000	1.200	1.283	3.459	2.371
Vernonia ceneria	16.000	1.500	1.027	3.459	2.243
Spilanthes paniculata	20.000	0.980	1.283	2.825	2.054
Fimbristylis miliacea	16.000	1.250	1.027	2.883	1.955
Drymaria cordata	12.000	1.667	0.770	2.883	1.826
Desmodium triflorum	20.000	0.720	1.283	2.076	1.679
Oldenlandia umbellata	12.000	1.333	0.770	2.306	1.538
Eragrostis sp.	12.000	1.167	0.770	2.018	1.394
Commelina benghalensis	16.000	0.600	1.027	1.384	1.205
Cleome monophylla	8.000	1.500	0.513	1.730	1.121
Ischaemum indicum	16.000	0.425	1.027	0.980	1.003
Cleome burmanni	8.000	1.250	0.513	1.441	0.977
Alloteropsis cimicina	12.000	0.633	0.770	1.095	0.933
Heliotropium indicum	8.000	1.000	0.513	1.153	0.833
Sphagneticola trilobata	8.000	1.000	0.513	1.153	0.833
Portulaca oleracea	12.000	0.500	0.770	0.865	0.817
Ehinochloa crusgalli	12.000	0.400	0.770	0.692	0.731
Leucas aspera	16.000	0.175	1.027	0.404	0.715
Eclipta alba	8.000	0.750	0.513	0.865	0.689
Cynodon dactylon	8.000	0.700	0.513	0.807	0.660
Stachytarpheta indica	8.000	0.700	0.513	0.807	0.660
Setaria glauca	8.000	0.650	0.513	0.749	0.631
Ehinochloa colona	8.000	0.600	0.513	0.692	0.603
Oplismenus burmanni	8.000	0.600	0.513	0.692	0.603

Name of weeds	Frequency	Average density	Relative frequency	Relative density	SDR
Sida rhombifolia	8.000	0.600	0.513	0.692	0.603
Emilia sonchifolia	8.000	0.450	0.513	0.519	0.516
Lantana camara	8.000	0.350	0.513	0.404	0.458
Amaranthus viridis	4.000	1.000	0.257	0.577	0.417
Lindernia crustacean	4.000	1.000	0.257	0.577	0.417
Pennisetum pedicellatum	4.000	1.000	0.257	0.577	0.417
Sida acuta	4.000	1.000	0.257	0.577	0.417
Commelina diffusa	8.000	0.250	0.513	0.288	0.401
Solanum nigrum	8.000	0.150	0.513	0.173	0.343
Justicia sp.	4.000	0.600	0.257	0.346	0.301
Alternanthera sessilis	4.000	0.400	0.257	0.231	0.244
Urena lobata var. *lobata*	4.000	0.300	0.257	0.173	0.215
Clerodendron infortunatum	4.000	0.200	0.257	0.115	0.186
Paspalum conjugatum	4.000	0.100	0.257	0.058	0.157

Table 5. Weed spectrum of ginger in Idukki district

Name of weeds	Frequency	Average density	Relative frequency	Relative density	SDR
Ageratum conyzoides	96.00	3.291	11.910	9.771	10.841
Spilanthes radicans	92.00	3.130	11.414	8.905	10.160
Crassocephalum crepidioides	88.00	2.409	10.918	6.555	8.737
Blumea sp.	84.00	2.190	10.421	5.689	8.056
Bidens pilosa var. *Minor*	80.00	2.10	9.925	5.194	7.560
Scoparia dulcis	76.00	2.421	9.429	5.689	7.559
Vernonia ceneria	76.00	2.368	9.429	5.565	7.498
Metracarpus sp.	76.00	2.210	9.429	5.194	7.312
Synedrella nodiflora	68.00	2.470	8.436	5.194	6.816
Spermacoce ocymoides	68.00	2.176	8.436	4.576	6.507
Erigeron Canadensis	68.00	2.058	8.436	4.329	6.383
Mimosa pudica	64.00	2.437	7.940	4.823	6.382
Eragrostis sp.	56.00	2.214	6.947	3.834	5.391
Phyllanthus niruri	52.00	2.615	6.451	4.205	5.328
Borreria hispida	56.00	2.071	6.947	3.586	5.267
Fimbristylis miliacea	56.00	1.857	6.947	3.215	5.082
Ischaemum indicum	60.00	1.40	7.444	2.597	5.021
Alternanthera sessilis	48.00	2.50	5.955	3.71	4.833
Sphaeranthus indicus	48.00	2.166	5.955	3.215	4.586
Lindernia crustacean	52.00	1.538	6.451	2.473	4.463
Mikania micrantha	56.00	1.00	6.947	1.731	4.340
Commelina benghalensis	48.00	1.666	5.955	2.473	4.215
Eleusine indica	48.00	1.583	5.955	2.350	4.153
Pennisetum pedicellatum	44.00	1.636	5.459	2.226	3.843
Biophytum sensitivum	40.00	1.50	4.962	1.855	3.409
Ludwigia parviflora	36.00	2.00	4.466	2.226	3.346

Name of weeds	**Frequency**	**Average density**	**Relative frequency**	**Relative density**	**SDR**
Axonopus compressus	40.00	1.20	4.962	1.484	3.224
Cyperus rotundus	32.00	2.00	3.970	1.978	2.975
Stachytarpheta indica	28.00	2.285	3.473	1.978	2.726
Digitaria ciliaris	32.00	1.25	3.970	1.236	2.604
Oxalis corniculata	28.00	1.857	3.473	1.607	2.541
Amaranthus viridis	24.00	1.166	2.977	0.865	1.922
Chromolaena odorata	24.00	1.166	2.977	0.865	1.922
Mimosa invisa	20.00	2.00	2.481	1.236	1.859
Spermacoce latifolia	16.00	1.75	1.985	0.865	1.425
Emilia sonchifolia	16.00	1.50	1.985	0.742	1.364
Paspalum conjugatum	16.00	1.25	1.985	0.618	1.302
Eclipta alba	12.00	2.00	1.488	0.742	1.115
Oldenlantia umbellate	12.00	2.00	1.488	0.742	1.115
Centella asiatica	8.00	2.00	0.992	0.494	0.744
Sida rhombifolia	8.00	2.00	0.992	0.494	0.744
Spilanthes calva	8.00	1.50	0.992	0.371	0.682
Alloteropsis cimicina	8.00	1.00	0.992	0.247	0.620
Sida acuta	8.00	1.00	0.992	0.247	0.620
Desmodium triflorum	4.00	2.00	0.496	0.247	0.372
Ehinochloa colona	4.00	2.00	0.496	0.247	0.372
Oplismenus burmanni	4.00	2.00	0.496	0.247	0.372
Clerodendron infortunatum	4.00	1.00	0.496	0.123	0.310
Leucas aspera	4.00	1.00	0.496	0.123	0.310
Solanum nigrum	4.00	1.00	0.496	0.123	0.310

Part II

4.2. Field experiment on management of weeds in ginger

4.2.1. Studies on weeds

4.2.1.1. Weed spectrum

During the cropping periods of 2013-2014 (first year) and 2014-2015 (second year), total weed species appeared in the ginger plots were 23 and 31 nos. respectively. Major weeds found in experimental field in both the years were broad leaved, which comprised of *Ageratum conyzoides, Alternanthera bettzikiana, Borreria hispida,* etc. *Pennisetum pedicellatum* and *Brachiaria* sp. were the dominant grass species observed in the experimental plots. *Cyperus iria* was the only sedge observed in the experimental field and its population was very low compared to other groups. The total number of weeds found in the experimental plots during the two cropping seasons is categorized in to broad leaved, grasses and sedges and is presented in Tables 6.

4.2.1.2. Weed density

In both the years, species wise weed count was taken at 45, 90 and 180 days after planting of the crop and the major weeds based on the dominance is presented in Table 7-12. During the first year (2013-2014), at 45 DAP (Table 7), the population of total broad leaved weeds was 16.66/m^2 in unweeded control whereas it was only 4.00/ m^2 in POP. Compared to unweeded control, the dicot weed population was less in the treatments receiving pre emergence herbicides (T_1, T_2 and T_3). The total number of broad leaved weeds in plots which received pre-emergence herbicide followed by hand weeding (T_6, T_7) was on par with POP (hand weeding) and solarized plots (T_9). In the two treatments (T_4, T_5) where post emergence herbicides were sprayed, total broad leaved weed population was higher than other treatments but lower than unweeded control (T_{11}).

During the second year (2014-2015) (Table 8) also maximum broad leaved weed POPulation was observed in unweeded control (23.00/m^2) followed by pre emergence herbicides pendimethalin and metribuzin (T_1 and T_3) and the post emergence herbicide glufosinate ammonium (T_5). Pre emergence herbicides followed by hand weeding (T_6 and T_8) also recorded lower weed count than pre emergence herbicides alone. The lower total broad leaved weeds count was recorded in hand weeding (POP) (T_{10}), which was on par with treatments which received the pre emergence herbicide oxyfluorfen followed by hand weeding (T_7) and soil solarization (T_9). The additional treatments consisting of combined application of pre emergence herbicides and glyphosate (T_{12} and T_{13}) recorded lower count and which was statistically on par with POP, oxyfluorfen + hand weeding (T_7) and soil solarization (T_9).

Pooled analysis (Table 9) of the count of total broad leaved weeds for both the seasons also showed similar trend observed during the two cropping seasons. The higher broad leaved weed population was recorded in unweeded control (19.83/m^2) followed by pre emergence herbicides treated plots (T_1 and T_3) and the plot which received post emergence application of glufosinate ammonium (T_5). Pre emergence herbicide followed by hand weeding (T_6 and T_7), POP (T_{10}), and soil solarization (T_9) could significantly reduce the dicot weed population.

During 2013-14, total monocot population was lesser compared to broad leaved weeds. Population of monocots (grasses) was also higher in unweeded control (4.33/m^2). Count of grass weeds in pre emergence herbicides applied plots (T_1, T_2, T_3) was on par with pre emergence herbicides followed by hand weeding (T_6, T_7, T_8), post emergence herbicides (T_4 and T_5), POP (T_{10}) and solarized plots (T_9). All the treatments except unweeded control could significantly reduce the monocot population. *Cyperus iria* was the only sedge present and its population ranged from 1.00 to 3.66 /m^2. All the treatments, except T_4, T_5 and T_{11} could reduce the sedge population significantly.

During 2014-15 also, highest count of monocots was registered in the treatment unweeded control (T_{11}) (5.66/m^2). Significant reduction in monocots was observed in hand weeding (T_{10}), and pre emergence herbicides followed by hand weeding (T_6 and T_7), which were on par with metribuzin followed by hand weeding (T_8), soil solarization (T_9) and glyphosate (T_4). All treatments except T_3, T_4, T_5 and T_{11} could significantly reduce the population. The additional treatments, consisting of combined application of pre emergence and post emergence herbicide (T_{12} and T_{13}) recorded significant reduction in monocot population which was on par with hand weeding (T_{10}), pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8), soil solarization (T_9) and glyphosate (T_4).

Pooled analysis of the data on total monocots showed that maximum count (5/m^2) was recorded in unweeded control (T_{11}) followed by pre emergence herbicide (T_3) and post emergence herbicide treated plots (T_4 and T_5). Best control of monocots was observed in plots receiving pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding (T_{10}). Treatments metribuzin followed by hand weeding (T_8), soil solarization (T_9) and glyphosate (T_4) also could reduce monocot population significantly. Pre emergence herbicides (T_1, T_2), pre emergence herbicides followed by hand weeding (T_6, T_7, T_8), soil solarization (T_9), POP (T_{10}) could significantly reduce the sedges by 45 DAP.

During the first year (2013-2014) significantly higher total weed count was registered in unweeded control (24.66/m^2) followed by pre emergence herbicides (T_1, T_3) and post emergence herbicide (T_5) at 45 DAP, whereas the lowest count was recorded in hand weeding (T_{10}) which was on par with T_6, T_7, T_8 and T_9 .

During 2014-2015 (second year) also, the highest total weeds count was recorded in T_{11} (32.66/m^2) followed by pre emergence herbicide metribuzin (T_3) and post emergence herbicide glufosinate ammonium (T_5) and the minimum population was registered in pre emergence herbicide followed by hand weeding (T_7), POP (T_{10}) and which was on par with pre emergence herbicide followed by hand weeding (T_6 and T_8) and soil solarization (T_9). The additional treatments, which received combination of pre emergence and post emergence herbicides (T_{12}

and T_{13}) could significantly reduce the total weed population and was on par with T_7, T_{10}, T_6, T_8 and T_9.

Pooled analysis of total weeds count at 45 DAP (Table 12) also shows similar trend. The maximum total weeds count was recorded in T_{11} (28.66/m^2) followed by plots which received pre emergence herbicide metribuzin (T_3) and post emergence herbicide glufosinate ammonium (T_5). The lowest population was observed in pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding alone (T_{10}) and these were on par with soil solarization (T_9). The pre emergence herbicide oxyflorfen (T_2) alone recorded lower total weed count than other pre emergence herbicide alone.

By 90 DAP, an increase in weed count could be observed. The highest value of total weed count of 34.33/m^2 during first year (Table 10) was registered in unweeded control followed by post emergence herbicide glufosinate ammonium (T_5) and they were on par with pre emergence herbicide alone (T_1 and T_3). Pre emergence herbicides followed by hand weeding resulted in significantly lower weed count than pre emergence herbicide alone. Hand weeding (POP), solarized plots and pre emergence herbicides followed by hand weeding (T_6 and T_7), recorded statistically lower value of total weed count and were significantly superior to all other treatments.

During second year (2014-2015) also, the maximum total weed population (41.33/ m^2) was recorded in treatment T_{11} (Table 11) and it was 14 per cent more compared to 2013-2014 and was on par with post emergence herbicide glufosinate ammonium (T_5). Pre emergence herbicides followed by hand weeding recorded significantly lower weeds count compared to pre emergence herbicide alone. Post emergence herbicide glyphosate (T_4) also registered higher total weed population compared to all other treatments but was lower than unweeded control. Hand weeding (T_{10}) and oxyfluorfen followed by hand weeding (T_7) had given

Table 6. List of weeds found in the experimental field

	Weed species	Common name		Family
		English	**Malayalam**	
Broad leaved weeds (dicots)	*Ageratum conyzoides* Linn.	Goat weed	Appa	Asteraceae
	Alternanthera bettzickiana (Regel)	Calico plant	-	Amaranthaceae
	Biophytum sensitivum (Linn.)	Life plant	Mukkutty	Oxalidaceae
	Borreria hispida (Linn.)	Button weed	Tharthaval	Rubiaceae
	Calopagonium muconoides (Benth.)	Calapo	-	Fabaceae
	Cassia torra Linn.	Sickle pod	Ponnum thakara	Fabaceae
	Catharanthus pusillus (L.)	Pusilla	Milagu pundu	Apocynaceae
	Cleome burmanni Linn.	Yellow spider flower	Kattukadyan	Capparaceae
	Commelina benghalensis Linn.	Day flower	Kanavazhi	Commelinaceae
	Curculigo orchioides Gaertn.	Black musale	Nilappana	Hypoxidaceae
	Emilia sonchifolia (L.) DC	Red tassel flower	Muyal cheviyan	Asteraceae
	Gloriosa superba L.	Flame lily	Menthonni	Colchicaceae
	Hemidesmus indicus (L.)	Indian sarsaparilla	Narunneendi	Asclepidaceae
	Ichnocarpus frutescens (L.)	Black creeper	Parvalli	Apocynaceae
	Ludvigia parviflora Linn.	Water primrose	Neer grampoo	Onagraceae
	Melochia corchorifolia Linn.	Chocolate weed	-	Malvaceae
	Mitracarpus polycladus Linn.	Girdle pod	-	Rubiaceae
	Mikania micrantha (Kunth.)	Mile a minute	American valli	Asteraceae
	Mimosa pudica Linn.	Touch-me-not	Thottavadi	Fabaceae
	Oldenlandia umbellata D.C.	Chay root	Onathumba	Rubiaceae
	Peperomia pellucida Linn.	-	Mashithandu	Piperaceae
	Phyllanthus niruri Linn.	-	Keezharnelli	Phyllanthaceae

	Weed species	Common name		Family
		English	Malayalam	
	Scoparia dulcis Linn.	Lico rice weed	Kallurukki	Scrophulariaceae
	Sida rhombifolia Linn.	-	Kurumthotti	Malvaceae
	Synedrella nodiflora Gaertn	Node weed	Venappacha	Asteraceae
	Vernonia ceneria (L.) Less		Poovamkurunnu	Asteraceae
Grasses (monocots)	*Brachiaria mutica* (Trin.) Stapf.	Para grass	Seema pullu	Poaceae
	Echinocloa colona (L.)	Junkle rice	Kavada	Poaceae
	Pennisetum polystachion (L.) Schult.	Mission grass	-	Poaceae
Sedges	*Cyperus iria* Linn.	Umbrella sedge	Muthanga	Cyperaceae

Table 7. Species wise weed count at 45 DAP (No./m^2) as influenced by management practices (first year)

Treatments	Weed count at 45 DAP (No./m^2)									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T$_1$ – Pendimethalin 1.5 kg/ha	1.77 ^{cd} (2.66)	1.95 ^{b} (3.33)	1.85 ^{b} (3.00)	2.11 ^{ab} (4.00)	3.67 ^{b} (13.00)	1.34 ^{b} (1.33)	1.34 ^{ab} (1.33)	1.76 ^{b} (2.66)	1.22 ^{c} (1.00)	4.13 ^{b} (16.66)
T$_2$ – Oxyfluorfen 0.2 kg/ha	1.46 ^{e} (1.66)	1.67 ^{c} (2.33)	1.77 ^{b} (2.66)	1.58 ^{d} (2.00)	3.02 ^{d} (8.66)	1.34 ^{b} (1.33)	1.34 ^{ab} (1.33)	1.77 ^{b} (2.66)	1.22 ^{c} (1.00)	3.58 ^{c} (12.33)
T$_3$ – Metribuzin 0.525 kg/ha	1.95 ^{b} (3.33)	1.77 ^{bc} (2.66)	2.11 ^{a} (4.00)	1.77 ^{cd} (2.66)	3.62 ^{b} (12.66)	1.46 ^{b} (1.66)	1.34 ^{ab} (1.33)	1.85 ^{b} (3.00)	1.34 ^{bc} (1.33)	4.17 ^{b} (17.00)
T$_4$ – Glyphosate 0.8 kg/ha	1.67 ^{d} (2.33)	1.67 ^{c} (2.33)	1.77 ^{b} (2.66)	1.77 ^{cd} (2.66)	3.23 ^{c} (10.00)	1.22 ^{b} (1.00)	1.22 ^{b} (1.00)	1.58 ^{b} (2.00)	1.46 ^{b} (1.66)	3.76 ^{c} (13.66)
T$_5$ – Glufosinate ammonium 0.45 kg/ha	1.87 ^{bc} (3.00)	1.95 ^{b} (3.33)	1.85 ^{ab} (3.00)	2.19 ^{a} (4.33)	3.76 ^{b} (13.66)	1.34 ^{b} (1.33)	1.34 ^{ab} (1.33)	1.76 ^{b} (2.66)	1.46 ^{b} (1.66)	4.30 ^{b} (18.00)
T$_6$ - Pendimethalin 1.5 kg/ha + 1 HW	1.22 ^{f} (1.00)	1.22 ^{d} (1.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	2.12 ^{f} (4.00)	1.22 ^{b} (1.00)	1.22 ^{b} (1.00)	1.58 ^{b} (2.00)	1.22 ^{c} (1.00)	2.73 ^{d} (7.00)
T$_7$ - Oxyfluorfen 0.2 kg/ha + 1 HW	1.22 ^{f} (1.00)	1.22 ^{d} (1.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	2.12 ^{f} (4.00)	1.22 ^{b} (1.00)	1.22 ^{b} (1.00)	1.58 ^{b} (2.00)	1.22 ^{c} (1.00)	2.73 ^{d} (7.00)
T$_8$ - Metribuzin 0.525 kg/ha + 1 HW	1.46 ^{e} (1.66)	1.34 ^{d} (1.33)	1.34 ^{c} (1.33)	1.22 ^{e} (1.00)	2.41 ^{e} (5.33)	1.22 ^{b} (1.00)	1.22 ^{ab} (1.00)	1.58 ^{b} (2.00)	1.22 ^{c} (1.00)	2.97 ^{d} (8.33)
T$_9$ - Soil solarisation	1.22 ^{f} (1.00)	1.34 ^{d} (1.33)	1.34 ^{c} (1.33)	1.22 ^{e} (1.00)	2.27 ^{ef} (4.66)	1.22 ^{b} (1.00)	1.22 ^{ab} (1.00)	1.58 ^{b} (2.00)	1.22 ^{c} (1.00)	2.85 ^{d} (7.66)
T$_{10}$ – POP (2 hand weedings)	1.22 ^{f} (1.00)	1.22 ^{d} (1.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	2.12 ^{f} (4.00)	1.22 ^{b} (1.00)	1.22 ^{ab} (1.00)	1.58 ^{b} (2.00)	1.22 ^{c} (1.00)	2.73 ^{d} (7.00)
T$_{11}$ - Unweeded control	2.27 ^{a} (4.66)	2.27 ^{a} (4.66)	2.12 ^{a} (4.00)	1.95 ^{bc} (3.33)	4.14 ^{a} (16.66)	1.77 ^{a} (2.66)	1.46 ^{a} (1.66)	2.19 ^{a} (4.33)	2.03 ^{a} (3.66)	5.01 ^{a} (24.66)
CD values (5 %)	0.16	0.21	0.25	0.21	0.21	0.21	0.20	0.26	0.17	0.21

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 8. Species wise weed count at 45 DAP (No./m²) as influenced by management practices (second year)

Treatments	Weed count at 45 DAP ($No.m^{-2}$)									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T_1 – Pendimethalin 1.5 kg/ha	2.27 ^{b} (4.66)	2.41 ^{a} (5.33)	1.95 ^{c} (3.33)	2.19 ^{ab} (4.33)	4.26 ^{bc} (17.66)	1.55 ^{bc} (2.00)	1.46 ^{b} (1.66)	2.02 ^{b} (3.66)	1.34 ^{de} (1.33)	4.81 ^{cd} (22.66)
T_2 – Oxyfluorfen 0.2 kg/ha	1.87 ^{c} (3.00)	2.11 ^{a} (4.00)	2.02 ^{c} (3.66)	1.87 ^{c} (3.00)	3.75 ^{d} (13.66)	1.46 ^{bcd} (1.66)	1.34 ^{b} (1.33)	1.87 ^{bcd} (3.00)	1.22 ^{e} (1.00)	4.25 ^{e} (17.66)
T_3 – Metribuzin 0.525 kg/ha	2.41 ^{ab} (5.33)	2.33 ^{a} (5.00)	2.33 ^{b} (5.00)	2.03 ^{bc} (3.66)	4.41 ^{bc} (19.00)	1.67 ^{ab} (2.33)	1.46 ^{b} (1.66)	2.11 ^{b} (4.00)	1.46 ^{cd} (1.66)	5.00 ^{bc} (24.66)
T_4 – Glyphosate 0.8 kg/ha	2.27 ^{b} (4.66)	2.19 ^{a} (4.33)	2.19 ^{bc} (4.33)	2.03 ^{bc} (3.66)	4.18 ^{c} (17.00)	1.34 ^{cd} (1.33)	1.34 ^{b} (1.33)	1.77 ^{cde} (2.66)	1.58 ^{bc} (2.00)	4.70 ^{d} (21.66)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.41 ^{ab} (5.33)	2.41 ^{a} (5.33)	2.12 ^{bc} (4.00)	2.41 ^{a} (5.33)	4.52 ^{b} (20.00)	1.46 ^{bcd} (1.66)	1.46 ^{b} (1.66)	1.95 ^{bc} (3.33)	1.67 ^{b} (2.33)	5.11 ^{b} (25.66)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	1.34 ^{e} (1.33)	1.34 ^{b} (1.33)	1.34 ^{d} (1.33)	1.55 ^{d} (2.00)	2.53 ^{ef} (6.00)	1.22 ^{d} (1.00)	1.22 ^{b} (1.00)	1.58 ^{e} (2.00)	1.22 ^{e} (1.00)	3.07 ^{g} (9.00)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	1.22 ^{e} (1.00)	1.22 ^{b} (1.00)	1.22 ^{d} (1.00)	1.34 ^{d} (1.33)	2.19 ^{g} (4.33)	1.22 ^{d} (1.00)	1.22 ^{b} (1.00)	1.58 ^{e} (2.00)	1.22 ^{e} (1.00)	2.79 ^{f} (7.33)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	1.58 ^{d} (2.00)	1.46 ^{b} (1.66)	1.46 ^{d} (1.66)	1.46 ^{d} (1.66)	2.73 ^{e} (7.00)	1.34 ^{cd} (1.33)	1.22 ^{b} (1.00)	1.67 ^{de} (2.33)	1.34 ^{de} (1.33)	3.33 ^{g} (10.66)
T_9 - Soil solarisation	1.22 ^{e} (1.00)	1.34 ^{b} (1.33)	1.34 ^{d} (1.33)	1.34 ^{d} (1.33)	2.33 ^{fg} (5.00)	1.34 ^{cd} (1.33)	1.22 ^{b} (1.00)	1.67 ^{de} (2.33)	1.34 ^{de} (1.33)	3.02 ^{g} (8.66)
T_{10} – POP (2 hand weedings)	1.22 ^{e} (1.00)	1.22 ^{b} (1.00)	1.22 ^{d} (1.00)	1.34 ^{d} (1.33)	2.19 ^{g} (4.33)	1.22 ^{d} (1.00)	1.22 ^{b} (1.00)	1.58 ^{e} (2.00)	1.22 ^{e} (1.00)	2.79 ^{g} (7.33)
T_{11} - Unweeded control	2.53 ^{a} (6.00)	2.40 ^{a} (5.33)	2.67 ^{a} (6.66)	2.34 ^{a} (5.00)	4.84 ^{a} (23.00)	1.87 ^{a} (3.00)	1.76 ^{a} (2.66)	2.47 ^{a} (5.66)	2.12 ^{a} (4.00)	5.75 ^{a} (32.66)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	1.22 ^{e} (1.00)	1.22 ^{b} (1.00)	1.22 ^{d} (1.00)	1.34 ^{d} (1.33)	2.19 ^{g} (4.33)	1.22 ^{d} (1.00)	1.22 ^{b} (1.00)	1.58 ^{e} (2.00)	1.22 ^{e} (1.00)	2.79 ^{g} (7.33)
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	1.22 ^{e} (1.00)	1.22 ^{b} (1.00)	1.22 ^{d} (1.00)	1.34 ^{d} (1.33)	2.19 ^{g} (4.33)	1.22 ^{d} (1.00)	1.22 ^{b} (1.00)	1.58 ^{e} (2.00)	1.22 ^{e} (1.00)	2.79 ^{g} (7.33)
CD values (5 %)	0.20	0.28	0.23	0.27	0.27	0.22	0.23	0.23	0.17	0.25

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 9. Total weed count at 45 DAP (No./m^{2}) as influenced by management practices (pooled analysis)

Treatments	Weed count at 45 DAP (No.m^{-2})											
	Total dicots			Total monocots			Total sedges			Total weeds		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	3.67 ^{b} (13.00)	4.26 ^{bc} (17.66)	3.97 ^{b} (15.33)	1.76 ^{b} (2.66)	2.02 ^{b} (3.66)	1.90 ^{bc} (3.17)	1.22 ^{c} (1.00)	1.34 ^{de} (1.33)	1.28 (1.17) ^{de}	4.13 ^{b} (16.66)	4.81 ^{cd} (22.66)	4.47 ^{c} (19.66)
T_2 – Oxyfluorfen 0.2 kg/ha	3.02 ^{d} (8.66)	3.75 ^{d} (13.66)	3.39 ^{d} (11.17)	1.77 ^{b} (2.66)	1.87 ^{bcd} (3.00)	1.82 ^{bcd} (2.83)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	1.22 ^{e} (1.00)	3.58 ^{c} (12.33)	4.25 ^{e} (17.66)	3.92 ^{e} (14.99)
T_3 – Metribuzin 0.525 kg/ha	3.62 ^{b} (12.66)	4.41 ^{bc} (19.00)	4.02 ^{b} (15.83)	1.85 ^{b} (3.00)	2.11 ^{b} (4.00)	1.99 ^{b} (3.50)	1.34 ^{bc} (1.33)	1.46 ^{cd} (1.66)	1.40 ^{cd} (1.50)	4.17 ^{b} (17.00)	5.00 ^{bc} (24.66)	4.59 ^{bc} (20.83)
T_4 – Glyphosate 0.8 kg/ha	3.23 ^{c} (10.00)	4.18 ^{c} (17.00)	3.71 ^{c} (13.50)	1.58 ^{b} (2.00)	1.77 ^{cde} (2.66)	1.68 ^{cde} (2.33)	1.46 ^{b} (1.66)	1.58 ^{bc} (2.00)	1.52 ^{bc} (1.83)	3.76 ^{c} (13.66)	4.70 ^{d} (21.66)	4.23 ^{d} (17.66)
T_5 – Glufosinate ammonium 0.45 kg/ha	3.76 ^{b} (13.66)	4.52 ^{b} (20.00)	4.14 ^{b} (16.83)	1.76 ^{b} (2.66)	1.95 ^{bc} (3.33)	1.86 ^{bcd} (3.00)	1.46 ^{b} (1.66)	1.67 ^{b} (2.33)	1.57 ^{b} (2.00)	4.30 ^{b} (18.00)	5.11 ^{b} (25.66)	4.71 ^{b} (21.83)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	2.12 ^{f} (4.00)	2.53 ^{ef} (6.00)	2.33 ^{f} (5.00)	1.58 ^{b} (2.00)	1.58 ^{e} (2.00)	1.58 ^{e} (2.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	1.22 ^{e} (1.00)	2.73 ^{d} (7.00)	3.07 ^{g} (9.00)	2.91 ^{g} (8.00)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	2.12 ^{f} (4.00)	2.19 ^{g} (4.33)	2.16 ^{f} (4.17)	1.58 ^{b} (2.00)	1.58 ^{e} (2.00)	1.58 ^{e} (2.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	1.22 ^{e} (1.00)	2.73 ^{d} (7.00)	2.79 ^{f} (7.33)	2.77 ^{g} (7.16)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	2.41 ^{e} (5.33)	2.73 ^{e} (7.00)	2.57 ^{e} (6.17)	1.58 ^{b} (2.00)	1.67 ^{de} (2.33)	1.63 ^{de} (2.17)	1.22 ^{c} (1.00)	1.34 ^{de} (1.33)	1.28 ^{de} (1.17)	2.97 ^{d} (8.33)	3.33 ^{g} (10.66)	3.15 ^{f} (9.49)
T_9 - Soil solarisation	2.27 ^{ef} (4.66)	2.33 ^{fg} (5.00)	2.30 ^{f} (4.83)	1.58 ^{b} (2.00)	1.67 ^{de} (2.33)	1.63 ^{de} (2.17)	1.22 ^{c} (1.00)	1.34 ^{de} (1.33)	1.28 ^{de} (1.17)	2.85 ^{d} (7.66)	3.02 ^{g} (8.66)	2.94 ^{fg} (8.16)
T_{10} – POP (2 hand weedings)	2.12 ^{f} (4.00)	2.19 ^{g} (4.33)	2.16 ^{f} (4.17)	1.58 ^{b} (2.00)	1.58 ^{e} (2.00)	1.58 ^{e} (2.00)	1.22 ^{c} (1.00)	1.22 ^{e} (1.00)	1.22 ^{e} (1.00)	2.73 ^{d} (7.00)	2.79 ^{g} (7.33)	2.77 ^{g} (7.16)
T_{11} - Unweeded control	4.14 ^{a} (16.66)	4.84 ^{a} (23.00)	4.49 ^{a} (19.83)	2.19 ^{a} (4.33)	2.47 ^{a} (5.66)	2.34 ^{a} (5.00)	2.03 ^{a} (3.66)	2.12 ^{a} (4.00)	2.08 ^{a} (3.83)	5.01 ^{a} (24.66)	5.75 ^{a} (32.66)	5.39 ^{a} (28.66)
CD values (5%)	0.21	0.27	0.24	0.26	0.23	0.25	0.17	0.17	0.17	0.21	0.25	0.23

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMR

Table 10. Species wise weed count at 90 DAP (No./m^2) as influenced by management practices (first year)

Treatments	Weed count at 90 DAP (No.m^{-2})									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T_1 – Pendimethalin 1.5 kg/ha	2.11^{bc} (4.00)	2.34^{b} (5.00)	2.33^{ab} (5.00)	2.26^{ab} (4.66)	4.37^{b} (18.66)	1.67^{bc} (2.33)	1.46^{b} (1.66)	2.11^{bc} (4.00)	1.34^{b} (1.33)	4.94^{bc} (24.00)
T_2 – Oxyfluorfen 0.2 kg/ha	1.85^{cde} (3.00)	2.03^{cde} (3.66)	2.18^{abc} (4.33)	1.77^{bcd} (2.66)	3.76^{de} (13.66)	1.58^{c} (2.00)	1.46^{b} (1.66)	2.03^{bc} (3.66)	1.34^{b} (1.33)	4.37^{de} (18.66)
T_3 – Metribuzin 0.525 kg/ha	2.33^{b} (5.00)	2.18^{bcd} (4.33)	2.41^{a} (5.33)	1.95^{c} (3.33)	4.30^{b} (18.00)	1.77^{bc} (2.66)	1.46^{b} (1.66)	2.19^{bc} (4.33)	1.46^{b} (1.66)	4.94^{bc} (24.00)
T_4 – Glyphosate 0.8 kg/ha	2.11^{bc} (4.00)	2.09^{bcd} (4.00)	2.25^{abc} (4.66)	1.95^{c} (3.33)	4.06^{c} (16.00)	1.58^{c} (2.00)	1.34^{b} (1.33)	1.95^{bc} (3.33)	1.46^{b} (1.66)	4.63^{cd} (21.00)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.34^{b} (5.00)	2.27^{bc} (4.66)	2.40^{a} (5.33)	2.34^{a} (5.00)	4.52^{b} (20.00)	1.87^{ab} (3.00)	1.46^{b} (1.66)	2.27^{ab} (4.66)	1.58^{b} (2.00)	5.21^{b} (26.66)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	1.77^{de} (2.66)	1.87^{de} (3.00)	1.67^{def} (2.33)	1.58^{de} (2.00)	3.23^{f} (10.00)	1.58^{c} (2.00)	1.34^{b} (1.33)	1.95^{bc} (3.33)	1.34^{b} (1.33)	3.89^{f} (14.66)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	1.67^{e} (2.33)	1.77^{ef} (2.66)	1.58^{f} (2.00)	1.46^{ef} (1.66)	3.02^{fg} (8.66)	1.46^{d} (1.66)	1.34^{b} (1.33)	1.85^{c} (3.00)	1.34^{b} (1.33)	3.66^{f} (13.00)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	1.95^{cd} (3.33)	2.03^{cde} (3.66)	1.95^{cde} (3.33)	1.58^{de} (2.00)	3.58^{e} (12.33)	1.77^{abc} (2.66)	1.34^{b} (1.33)	2.11^{bc} (4.00)	1.46^{b} (1.66)	4.29^{e} (18.00)
T_9 - Soil solarisation	1.67^{e} (2.33)	1.58^{f} (2.00)	1.67^{ef} (2.33)	1.46^{ef} (1.66)	2.97^{g} (8.33)	1.58^{c} (2.00)	1.46^{b} (1.66)	2.03^{bc} (3.66)	1.46^{b} (1.66)	3.76^{f} (13.66)
T_{10} – POP (2 hand weedings)	1.22^{f} (1.00)	1.22^{g} (1.00)	1.22^{g} (1.00)	1.22^{f} (1.00)	2.12^{h} (4.00)	1.22^{d} (1.00)	1.22^{b} (1.00)	1.58^{d} (2.00)	1.22^{c} (1.00)	2.73^{g} (7.00)
T_{11} - Unweeded control	2.67^{a} (6.66)	2.67^{a} (6.66)	2.48^{a} (5.66)	2.41^{a} (5.33)	4.98^{a} (24.33)	2.03^{a} (3.66)	1.67^{a} (2.33)	2.54^{a} (6.00)	2.12^{a} (4.00)	5.90^{a} (34.33)
CD values (5 %)	0.29	0.26	0.32	0.25	0.22	0.24	0.30	0.31	0.22	0.30

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 11. Species wise weed count at 90 DAP (No./m^2) as influenced by management practices (second year)

Treatments	Weed count at 90 DAP (No.m^{-2})									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T_1 – Pendimethalin 1.5 kg/ha	2.67^{a} (6.66)	2.79^{a} (7.33)	2.54^{b} (6.00)	2.55^{ab} (6.00)	5.14^{b} (26.00)	1.85^{bcd} (3.00)	1.77^{b} (2.66)	2.47^{bcd} (5.66)	1.34^{de} (1.33)	5.78^{b} (33.00)
T_2 – Oxyfluorfen 0.2 kg/ha	2.34^{b} (5.00)	2.54^{a} (6.00)	2.47^{b} (5.66)	2.19^{cd} (4.33)	4.63^{c} (21.00)	1.77^{cde} (2.66)	1.67^{bc} (2.33)	2.34^{cde} (5.00)	1.22^{e} (1.00)	5.24^{c} (27.00)
T_3 – Metribuzin 0.525 kg/ha	2.67^{a} (6.66)	2.61^{a} (6.33)	2.73^{b} (7.00)	2.41^{abc} (5.33)	5.07^{b} (25.33)	2.03^{abc} (3.66)	1.77^{ab} (2.66)	2.60^{abc} (6.33)	1.46^{cd} (1.66)	5.80^{b} (33.33)
T_4 – Glyphosate 0.8 kg/ha	2.67^{a} (6.66)	2.67^{a} (6.66)	2.61^{b} (6.33)	2.34^{bc} (5.00)	5.01^{b} (24.66)	1.87^{bcd} (3.00)	1.77^{ab} (2.66)	2.48^{bcd} (5.66)	1.58^{bc} (2.00)	5.72^{b} (32.33)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.79^{a} (7.33)	2.79^{a} (7.33)	2.67^{b} (6.66)	2.67^{a} (6.66)	5.33^{ab} (28.00)	2.12^{ab} (4.00)	2.03^{a} (3.66)	2.85^{a} (7.66)	1.67^{b} (2.33)	6.20^{a} (38.00)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	1.95^{cd} (3.33)	2.02^{bc} (3.66)	1.85^{c} (3.00)	1.95^{de} (3.33)	3.71^{de} (13.33)	1.67^{de} (2.33)	1.58^{bcd} (2.00)	2.19^{defg} (4.33)	1.22^{e} (1.00)	4.37^{de} (18.66)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	1.77^{de} (2.66)	1.77^{c} (2.66)	1.77^{c} (2.66)	1.85^{e} (3.00)	3.38^{ef} (11.00)	1.46^{e} (1.66)	1.46^{cd} (1.66)	1.94^{fg} (3.33)	1.22^{e} (1.00)	3.97^{fg} (15.33)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	2.12^{bc} (4.00)	2.18^{b} (4.33)	2.03^{c} (3.66)	1.95^{de} (3.33)	3.97^{d} (15.33)	1.55^{de} (2.00)	1.58^{bcd} (2.00)	2.11^{efg} (4.00)	1.34^{de} (1.33)	4.59^{d} (20.66)
T_9 - Soil solarisation	1.58^{e} (2.00)	1.85^{bc} (3.00)	1.85^{c} (3.00)	1.87^{e} (3.00)	3.38^{ef} (11.00)	1.67^{de} (2.33)	1.58^{bcd} (2.00)	2.19^{defg} (4.33)	1.34^{de} (1.33)	4.13^{ef} (16.66)
T_{10} – POP (2 hand weedings)	1.22^{f} (1.00)	1.22^{d} (1.00)	1.22^{d} (1.00)	1.34^{f} (1.33)	2.19^{g} (4.33)	1.22^{e} (1.00)	1.22^{e} (1.00)	1.58^{h} (2.00)	1.22^{e} (1.00)	2.79^{h} (7.33)
T_{11} - Unweeded control	2.90^{a} (8.00)	2.73^{a} (7.00)	3.02^{a} (8.66)	2.67^{a} (6.66)	5.55^{a} (30.33)	2.19^{a} (4.33)	1.76^{ab} (2.66)	2.72^{ab} (7.00)	2.12^{a} (4.00)	6.46^{a} (41.33)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	2.03^{c} (3.66)	1.95^{bc} (3.33)	2.03^{c} (3.66)	2.03^{de} (3.66)	3.85^{d} (14.33)	1.77^{cd} (2.66)	1.58^{bcd} (2.00)	2.27^{cdef} (4.66)	1.22^{e} (1.00)	4.52^{d} (20.00)
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	1.58^{e} (2.00)	1.67^{c} (2.33)	1.77^{c} (2.66)	1.77^{e} (2.66)	3.18^{f} (9.66)	1.46^{e} (1.66)	1.34^{d} (1.33)	1.85^{gh} (3.00)	1.22^{e} (1.00)	3.76^{g} (13.66)
CD values (5 %)	0.23	0.31	0.26	0.24	0.32	0.28	0.25	0.31	0.17	0.31

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ

Table 12. Total weed count at 90 DAP (No./m^2) as influenced by management practices (pooled analysis)

Treatments	Total dicots			Total monocots			Total sedges			Total weeds		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	4.37^{b} (18.66)	5.14^{b} (26.00)	4.76^{bc} (22.33)	2.11^{bc} (4.00)	2.47^{bcd} (5.66)	2.29^{bc} (4.83)	1.34^{b} (1.33)	1.34^{de} (1.33)	1.34^{def} (1.33)	4.94^{bc} (24.00)	5.78^{b} (33.00)	5.38^{bc} (28.50)
T_2 – Oxyfluorfen 0.2 kg/ha	3.76^{de} (13.66)	4.63^{c} (21.00)	4.20^{d} (17.33)	2.03^{bc} (3.66)	2.34^{cde} (5.00)	2.19^{cde} (4.33)	1.34^{b} (1.33)	1.22^{e} (1.00)	1.28^{ef} (1.17)	4.37^{de} (18.66)	5.24^{c} (27.00)	4.83^{de} (22.83)
T_3 – Metribuzin 0.525 kg/ha	4.30^{b} (18.00)	5.07^{b} (25.33)	4.69^{bc} (24.67)	2.19^{bc} (4.33)	2.60^{abc} (6.33)	2.40^{abc} (5.33)	1.46^{b} (1.66)	1.46^{cd} (1.66)	1.46^{cd} (1.66)	4.94^{bc} (24.00)	5.80^{b} (33.33)	5.40^{bc} (28.66)
T_4 – Glyphosate 0.8 kg/ha	4.06^{c} (16.00)	5.01^{b} (24.66)	4.54^{c} (20.33)	1.95^{bc} (3.33)	2.48^{bcd} (5.66)	2.22^{cde} (4.50)	1.46^{b} (1.66)	1.58^{bc} (2.00)	1.52^{bc} (1.83)	4.63^{cd} (21.00)	5.72^{b} (32.33)	5.21^{cd} (26.66)
T_5 – Glufosinate ammonium 0.45 kg/ha	4.52^{b} (20.00)	5.33^{ab} (28.00)	4.93^{ab} (24.00)	2.27^{ab} (4.66)	2.85^{a} (7.66)	2.56^{ab} (6.17)	1.58^{b} (2.00)	1.67^{b} (2.33)	1.63^{b} (2.17)	5.21^{b} (26.66)	6.20^{a} (38.00)	5.73^{ab} (32.33)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	3.23^{f} (10.00)	3.71^{de} (13.33)	3.47^{f} (11.67)	1.95^{bc} (3.33)	2.19^{def} (4.33)	2.08^{cde} (3.38)	1.34^{b} (1.33)	1.22^{e} (1.00)	1.28^{ef} (1.17)	3.89^{f} (14.66)	4.37^{de} (18.66)	4.14^{f} (16.66)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	3.02^{fg} (8.66)	3.38^{ef} (11.00)	3.21^{fg} (9.83)	1.85^{cd} (3.00)	1.94^{f} (3.33)	1.90^{e} (1.17)	1.34^{b} (1.33)	1.22^{e} (1.00)	1.28^{ef} (1.17)	3.66^{fg} (13.00)	3.97^{f} (15.33)	3.82^{g} (14.16)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	3.58^{e} (12.33)	3.97^{d} (15.33)	3.78^{e} (13.83)	2.11^{bc} (4.00)	2.11^{ef} (4.00)	2.11^{cde} (4.00)	1.46^{b} (1.66)	1.34^{de} (1.33)	1.40^{cde} (1.20)	4.29^{e} (18.00)	4.59^{d} (20.66)	4.45^{e} (19.33)
T_9 - Soil solarisation	2.97^{g} (8.33)	3.38^{ef} (11.00)	3.18^{g} (9.67)	2.03^{bc} (3.66)	2.19^{def} (4.33)	2.12^{cde} (4.00)	1.46^{b} (1.66)	1.34^{de} (1.33)	1.40^{cde} (1.50)	3.76^{f} (13.66)	4.13^{ef} (16.66)	3.95^{f} (15.16)
T_{10} – POP (2 hand weedings)	2.12^{h} (4.00)	2.19^{g} (4.33)	2.16^{h} (4.17)	1.58^{d} (2.00)	1.58^{g} (2.00)	1.58^{f} (2.00)	1.22^{c} (1.00)	1.22^{e} (1.00)	1.22^{f} (1.00)	2.73^{g} (7.00)	2.79^{g} (7.33)	2.77^{h} (7.16)
T_{11} - Unweeded control	4.98^{a} (24.33)	5.55^{a} (30.33)	5.20^{a} (27.33)	2.54^{a} (6.00)	2.72^{ab} (7.00)	2.64^{a} (6.50)	2.12^{a} (4.00)	2.12^{a} (4.00)	2.12^{a} (4.00)	5.90^{a} (34.33)	6.46^{a} (41.33)	6.19^{a} (37.83)
CD values (5%)	0.22	0.32	0.27	0.31	0.31	0.31	0.22	0.17	0.19	0.30	0.31	0.30

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

significantly lower total weed counts of 7.33 and 15.33/m^2 respectively than all others. Soil solarization also resulted in lower weed count (T_9). Among the additional treatments, the combination of oxyfluorfen and glyphosate (T_{13}) had given the lowest total weed count after hand weeding (T_{10}) and was on par with oxyfluorfen followed by hand weeding (T_7).

Pooled analysis of two years also showed similar trend (Table 12). The highest total weed count (37.83/m^2) was registered in unweeded control (T_{11}) (Table 13) followed by post emergence herbicide glufosinate ammonium (T_5). Pre emergence herbicides followed by hand weeding resulted in significantly lower weed count than pre emergence herbicide alone. Post emergence herbicide glyphosate (T_4) also recorded comparatively lower total weed population than unweeded control. The plots which received hand weeding (T_{10}) soil solarization (T_9) oxyfluorfen + hand weeding (T_7) and pendimethalin + hand weeding (T_6) had given the lower total weed count and were statistically superior and were effective in reducing the weed problem.

Statistical analysis of data at 180 DAP (2013-2014) revealed that the treatments were significantly influenced the total count of weeds (Table 13). In general, an increase in weed count was noticed in all the treatments during different periods. In the case of total weed population, unweeded control recorded highest weed count (43.00/m^2) followed by post emergence herbicide glufosinate ammonium (T_5) and pre emergence herbicide metribuzin (T_3). Post emergence herbicide glyphosate (T_4) resulted in comparatively lower population than glufosinate ammonium (T_5). The treatments of pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding (T_{10}) and soil solarization (T_9) could significantly reduce the total weeds count compared to other treatments.

Similar trend was followed in the second year also (2014-2015) (Table 14). The treatment unweeded control (T_{11}) registered higher weed count (47.66/m^2) and was on par with post emergence herbicide glufosinate ammonium (T_5). The pre emergence herbicides pendimethalin (T_1) and metribuzin (T_3) and the post emergence herbicide glyphosate were the next treatments recording higher total weed population. Post emergence herbicide glyphosate (T_4) registered comparatively lower population than glufosinate ammonium (T_5). The plots which received pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding alone (T_{10}) and soil solarization (T_9) recorded lower total weeds count at 180 DAP. These treatments were significantly superior to all other treatments. Among the additional treatments, combination of oxyfluorfen and glyphosate (T_{13}) significantly lowered the total weed count (16.33/m^2) and was superior to all other treatments.

Pooled analysis of total weed count at 180 DAP (Table 15) was carried out. In the case of total weed population, unweeded control recorded significantly higher weed count (45.33/m^2) followed by post emergence herbicide glufosinate ammonium (T_5). Post emergence herbicide glyphosate (T_4) resulted in lower weed count compared to unweeded control (T_{11}) and was on par with pre emergence herbicides pendimethalin (T_1) and metribuzin (T_3). The treatments of pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding (T_{10}) and soil solarization (T_9) could significantly reduce the total weed count compared to all other treatments.

4.2.1.3. Weed dry weight

Dry matter production of weeds at various stages of crop growth was affected by different weed control methods and the results are presented in Table 16. Data showed a progressive increase in weed dry weight from 45 DAP to harvest in all the treatments. The weed dry weight in unweeded control (T_{11}) was higher than all other treatments at various stages of observation. The lowest weed dry weight was recorded in hand weeding (T_{10}) and was observed as statically the best treatment at 45 to 180 DAP. In both the years' dry matter accumulation of weeds by various treatments showed similar trend.

Total weed count at 180 DAP (No./m^2) as influenced by management practices (first year)

Treatments	Weed count at 180 DAP (No.m^{-2})									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T_1 – Pendimethalin 1.5 kg/ha	2.54 ^{bc} (6.00)	2.67 ^{ab} (6.66)	2.55 ^{abc} (6.00)	2.48 ^{b} (5.66)	4.98 ^{c} (24.33)	1.95 ^{b} (3.33)	1.77 ^{ab} (2.66)	2.54 ^{b} (6.00)	1.46 ^{cd} (1.66)	5.69 ^{c} (32.00)
T_2 – Oxyfluorfen 0.2 kg/ha	2.33 ^{cde} (5.00)	2.48 ^{bc} (5.66)	2.47 ^{abcd} (5.66)	2.19 ^{cd} (4.33)	4.59 ^{de} (20.66)	1.87 ^{b} (3.00)	1.77 ^{ab} (2.66)	2.48 ^{b} (5.66)	1.34 ^{d} (1.33)	5.30 ^{e} (27.66)
T_3 – Metribuzin 0.525 kg/ha	2.73 ^{b} (7.00)	2.47 ^{bc} (5.66)	2.67 ^{ab} (6.66)	2.33 ^{bc} (5.00)	4.98 ^{c} (24.33)	2.03 ^{ab} (3.66)	1.77 ^{ab} (2.66)	2.61 ^{b} (6.33)	1.58 ^{bcd} (2.00)	5.75 ^{bc} (32.66)
T_4 – Glyphosate 0.8 kg/ha	2.11 ^{ef} (4.00)	2.47 ^{bc} (5.66)	2.60 ^{ab} (6.33)	2.33 ^{bc} (5.00)	4.63 ^{de} (21.00)	1.77 ^{b} (2.66)	1.67 ^{b} (2.33)	2.33 ^{b} (5.00)	1.67 ^{bc} (2.33)	5.36 ^{de} (28.33)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.67 ^{b} (6.66)	2.67 ^{ab} (6.66)	2.79 ^{a} (7.33)	2.67 ^{a} (6.66)	5.27 ^{b} (27.33)	1.87 ^{b} (3.00)	1.77 ^{ab} (2.66)	2.48 ^{b} (5.66)	1.77 ^{b} (2.66)	6.01 ^{b} (35.66)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	2.27 ^{cde} (4.66)	2.27 ^{cde} (4.66)	2.27 ^{cd} (4.66)	2.03 ^{d} (3.66)	4.26 ^{f} (17.66)	1.77 ^{b} (2.66)	1.67 ^{b} (2.33)	2.33 ^{b} (5.00)	1.46 ^{cd} (1.66)	4.98 ^{f} (24.33)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	2.11 ^{ef} (4.00)	2.11 ^{de} (4.00)	2.19 ^{d} (4.33)	2.12 ^{d} (4.00)	4.10 ^{f} (16.33)	1.77 ^{b} (2.66)	1.67 ^{b} (2.33)	2.33 ^{b} (5.00)	1.58 ^{bcd} (2.00)	4.87 ^{f} (23.33)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	2.33 ^{cde} (5.00)	2.41 ^{bcd} (5.33)	2.41 ^{bcd} (5.33)	2.12 ^{d} (4.00)	4.48 ^{e} (19.66)	1.95 ^{b} (3.33)	1.67 ^{b} (2.33)	2.47 ^{b} (5.66)	1.58 ^{bcd} (2.00)	5.27 ^{e} (27.33)
T_9 - Soil solarisation	2.19 ^{de} (4.33)	2.03 ^{e} (3.66)	2.19 ^{d} (4.33)	2.03 ^{d} (3.66)	4.06 ^{f} (16.00)	1.77 ^{b} (2.66)	1.77 ^{ab} (2.66)	2.41 ^{b} (5.33)	1.58 ^{bcd} (2.00)	4.87 ^{f} (23.33)
T_{10} – POP (2 hand weedings)	2.03 ^{e} (3.66)	2.18 ^{cde} (4.33)	2.19 ^{d} (4.33)	2.03 ^{d} (3.66)	4.05 ^{f} (16.00)	1.77 ^{b} (2.66)	1.67 ^{b} (2.33)	2.33 ^{b} (5.00)	1.34 ^{d} (1.33)	4.77 ^{f} (22.33)
T_{11} - Unweeded control	3.07 ^{a} (9.00)	2.85 ^{a} (7.66)	2.67 ^{ab} (6.66)	2.73 ^{a} (7.00)	5.55 ^{a} (30.33)	2.27 ^{a} (4.66)	2.03 ^{a} (3.66)	2.96 ^{a} (8.33)	2.19 ^{a} (4.33)	6.59 ^{a} (43.00)
CD values (5 %)	0.27	0.31	0.29	0.18	0.22	0.26	0.29	0.31	0.23	0.25

Table 14. Species wise weed count at 180 DAP (No./m^2) as influenced by management practices (second year)

Treatments	Weed count at 180 DAP (No.m^{-2})									
	Ageratum	*Alternanthera*	*Borreria*	Other dicots	Total dicots	*Brachiaria*	*Pennisetum*	Total monocots	Total sedges	Total weed count
T_1 – Pendimethalin 1.5 kg/ha	2.91 ^{ab} (8.00)	3.02 ^{a} (8.66)	2.73 ^{bc} (7.00)	2.67 ^{ab} (6.66)	5.55 ^{b} (30.33)	1.95 ^{abc} (3.33)	1.87 ^{bcd} (3.00)	2.61 ^{cde} (6.33)	1.46 ^{bc} (1.66)	6.23 ^{b} (38.33)
T_2 – Oxyfluorfen 0.2 kg/ha	2.61 ^{bc} (6.33)	2.79 ^{abc} (7.33)	2.73 ^{bc} (7.00)	2.33 ^{cde} (5.00)	5.10 ^{cd} (25.66)	1.87 ^{bcd} (3.00)	1.77 ^{bcde} (2.66)	2.48 ^{def} (5.66)	1.34 ^{c} (1.33)	5.75 ^{c} (32.66)
T_3 – Metribuzin 0.525 kg/ha	2.90 ^{ab} (8.00)	2.85 ^{abc} (7.66)	2.96 ^{ab} (8.33)	2.54 ^{bc} (6.00)	5.50 ^{b} (30.00)	2.19 ^{ab} (4.33)	1.95 ^{abc} (3.33)	2.85 ^{abc} (7.66)	1.58 ^{bc} (2.00)	6.33 ^{b} (39.66)
T_4 – Glyphosate 0.8 kg/ha	2.91 ^{ab} (8.00)	2.96 ^{ab} (8.33)	2.79 ^{bc} (7.33)	2.48 ^{bc} (5.66)	5.46 ^{bc} (29.33)	1.95 ^{abc} (3.33)	2.03 ^{ab} (3.66)	2.73 ^{bcd} (7.00)	1.67 ^{bc} (2.33)	6.25 ^{b} (38.66)
T_5 – Glufosinate ammonium 0.45 kg/ha	3.02 ^{a} (8.66)	3.02 ^{a} (8.66)	2.91 ^{ab} (8.00)	2.79 ^{a} (7.33)	5.75 ^{ab} (32.66)	2.26 ^{a} (4.66)	2.27 ^{a} (4.66)	3.13 ^{a} (9.33)	1.77 ^{b} (2.66)	6.71 ^{a} (44.66)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	2.26 ^{cde} (4.66)	2.40 ^{de} (5.33)	2.18 ^{de} (4.33)	2.18 ^{def} (4.33)	4.36 ^{fg} (18.66)	1.77 ^{cd} (2.66)	1.77 ^{bcde} (2.66)	2.40 ^{def} (5.33)	1.34 ^{c} (1.33)	5.07 ^{d} (25.33)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	2.11 ^{def} (4.00)	2.27 ^{de} (4.66)	2.11 ^{e} (4.00)	2.11 ^{ef} (4.00)	4.13 ^{gh} (16.66)	1.67 ^{cd} (2.33)	1.55 ^{de} (2.00)	2.19 ^{fg} (4.33)	1.34 ^{c} (1.33)	4.76 ^{de} (22.33)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	2.41 ^{cd} (5.33)	2.60 ^{bcd} (6.33)	2.48 ^{cd} (5.66)	2.19 ^{def} (4.33)	4.70 ^{ef} (21.66)	1.87 ^{bcd} (3.00)	1.77 ^{bcde} (2.66)	2.48 ^{def} (5.66)	1.46 ^{bc} (1.66)	5.43 ^{c} (29.00)
T_9 - Soil solarisation	2.02 ^{ef} (3.66)	2.33 ^{de} (5.00)	2.18 ^{de} (4.33)	2.19 ^{def} (4.33)	4.21 ^{gh} (17.33)	1.77 ^{cd} (2.66)	1.67 ^{bcde} (2.33)	2.33 ^{efg} (5.00)	1.46 ^{bc} (1.66)	4.94 ^{de} (24.00)
T_{10} – POP (2 hand weedings)	1.85 ^{f} (3.00)	2.03 ^{ef} (3.66)	2.18 ^{de} (4.33)	2.11 ^{ef} (4.00)	3.93 ^{h} (15.00)	1.76 ^{cd} (2.66)	1.67 ^{cde} (2.33)	2.33 ^{efg} (5.00)	1.34 ^{c} (1.33)	4.66 ^{e} (21.33)
T_{11} - Unweeded control	3.12 ^{a} (9.33)	3.07 ^{a} (9.00)	3.18 ^{a} (9.66)	2.79 ^{a} (7.33)	5.98 ^{a} (35.33)	2.27 ^{a} (4.66)	2.03 ^{ab} (3.66)	2.97 ^{ab} (8.33)	2.12 ^{a} (4.00)	6.94 ^{a} (47.66)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	2.48 ^{cd} (5.66)	2.54 ^{cd} (6.00)	2.48 ^{cd} (5.66)	2.41 ^{cd} (5.33)	4.81 ^{de} (22.66)	1.93 ^{abcd} (3.33)	1.85 ^{bcd} (3.00)	2.59 ^{cde} (6.33)	1.44 ^{bc} (1.66)	5.58 ^{c} (30.66)
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	1.85 ^{f} (3.00)	1.77 ^{f} (2.66)	1.67 ^{f} (2.33)	1.95 ^{f} (3.33)	3.43 ^{i} (11.33)	1.58 ^{d} (2.00)	1.46 ^{e} (1.66)	2.03 ^{g} (3.66)	1.34 ^{c} (1.33)	4.10 ^{f} (16.33)

CD values (5 %)	0.34	0.33	0.28	0.23	0.37	0.31	0.31	0.32	0.30	0.31

Table 15 . Total weed count at 180 DAP (No./m^2) as influenced by management practices (pooled analysis)

Weed count at 180 DAP (No.m^{-2})												
Treatments	Total dicots			Total monocots			Total sedges			Total weeds		
	13-14	14-15	13-15	13-14	14-15	13-15	13-14	14-15	13-15	13-14	14-15	13-15
T_1 – Pendimethalin 1.5 kg/ha	4.98^{c} (24.33)	5.55^{b} (30.33)	5.37^{c} (27.33)	2.54^{b} (6.00)	2.61^{cde} (6.33)	2.58^{bcd} (6.17)	1.46^{cd} (1.66)	1.46^{bc} (1.66)	1.46^{cd} (1.66)	5.69^{c} (32.00)	6.23^{b} (38.33)	5.96^{c} (35.16)
T_2 – Oxyfluorfen 0.2 kg/ha	4.59^{de} (20.66)	5.10^{cd} (25.66)	4.81^{d} (23.17)	2.48^{b} (5.66)	2.48^{def} (5.66)	2.48^{cd} (5.67)	1.34^{d} (1.33)	1.34^{c} (1.33)	1.34^{d} (1.33)	5.30^{e} (27.66)	5.75^{c} (32.66)	5.53^{de} (30.16)
T_3 – Metribuzin 0.525 kg/ha	4.98^{c} (24.33)	5.50^{b} (30.00)	5.38^{c} (27.17)	2.61^{b} (6.33)	2.85^{abc} (7.66)	2.73^{abc} (7.00)	1.58^{bcd} (2.00)	1.58^{bc} (2.00)	1.58^{bcd} (2.00)	5.75^{bc} (32.66)	6.33^{b} (39.66)	6.04^{c} (36.16)
T_4 – Glyphosate 0.8 kg/ha	4.63^{de} (21.00)	5.46^{bc} (29.33)	5.18^{c} (25.17)	2.33^{b} (5.00)	2.73^{bcd} (7.00)	2.54^{bcd} (6.00)	1.67^{bc} (2.33)	1.67^{bc} (2.33)	1.68^{bc} (2.33)	5.36^{de} (28.33)	6.25^{b} (38.66)	5.81^{cd} (33.49)
T_5 – Glufosinate ammonium 0.45 kg/ha	5.27^{b} (27.33)	5.75^{ab} (32.66)	5.71^{b} (30.00)	2.48^{b} (5.66)	3.13^{a} (9.33)	2.81^{ab} (7.50)	1.77^{b} (2.66)	1.77^{b} (2.66)	1.77^{b} (2.67)	6.01^{b} (35.66)	6.71^{a} (44.66)	6.37^{b} (40.17)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	4.26^{f} (17.66)	4.36^{efg} (18.66)	4.13^{f} (18.17)	2.33^{b} (5.00)	2.40^{def} (5.33)	2.37^{d} (5.17)	1.46^{cd} (1.66)	1.34^{c} (1.33)	1.40^{cd} (1.50)	4.98^{f} (24.33)	5.07^{d} (25.33)	5.03^{f} (24.83)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	4.05^{f} (16.00)	4.13^{fgh} (16.66)	3.82^{g} (16.33)	2.33^{b} (5.00)	2.19^{fg} (4.33)	2.27^{d} (4.67)	1.34^{d} (1.33)	1.34^{c} (1.33)	1.34^{d} (1.33)	4.77^{f} (22.33)	4.76^{de} (22.33)	4.77^{f} (22.33)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	4.48^{e} (19.66)	4.70^{de} (21.66)	4.45^{e} (20.67)	2.47^{b} (5.66)	2.48^{def} (5.66)	2.48^{cd} (5.67)	1.58^{bcd} (2.00)	1.46^{bc} (1.66)	1.52^{bcd} (1.83)	5.27^{e} (27.33)	5.43^{c} (29.00)	5.35^{e} (28.17)
T_9 - Soil solarisation	4.06^{f} (16.00)	4.21^{gh} (17.33)	3.95^{fg} (16.67)	2.41^{b} (5.33)	2.33^{efg} (5.00)	2.38^{d} (5.17)	1.58^{bcd} (2.00)	1.46^{bc} (1.66)	1.51^{bcd} (1.83)	4.87^{f} (23.33)	4.94^{de} (24.00)	4.91^{f} (23.67)
T_{10} – POP (2 hand weedings)	4.10^{f} (16.33)	3.93^{h} (15.00)	3.78^{g} (15.67)	2.33^{b} (5.00)	2.33^{efg} (5.00)	2.33^{d} (4.18)	1.58^{bcd} (2.00)	1.34^{c} (1.33)	1.45^{cd} (1.67)	4.87^{f} (23.33)	4.66^{e} (21.33)	4.77^{f} (22.33)
T_{11} - Unweeded control	5.55^{a} (30.33)	5.98^{a} (35.33)	6.18^{a} (32.83)	2.96^{a} (8.33)	2.97^{ab} (8.33)	2.97^{a} (8.33)	2.19^{a} (4.33)	2.12^{a} (4.00)	2.16^{a} (4.10)	6.59^{a} (43.00)	6.94^{a} (47.66)	6.77^{a} (45.33)
CD values (5%)	0.22	0.37	0.30	0.31	0.32	0.32	0.23	0.30	0.27	0.25	0.31	0.28

During first year (2013-14), at 45 DAP, significantly the lower weed dry matter production was recorded in POP (T_{10}). It was on par with pre emergence herbicides + hand weeding (T_6, T_7 and T_8) and soil solarization which was significantly superior to all other treatments. The highest dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5).

During second year (2014-15), also significantly the lower dry matter production was registerd in POP (T_{10}). It was on par with pre emergence herbicides + hand weeding (T_6, T_7 and T_8) and soil solarization which was significantly superior to all other treatments. The higher dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5). Among the additional treatments, oxyfluorfen+glyphosate (T_{13}) registered the lowest dry matter production of weeds (118.76 kg/ha) and was on par with POP, soil solarization and pre emergence herbicides + hand weeding (T_6, T_7 and T_8).

Pooled analysis of the weed dry matter production also showed similar trend. Significantly lower weed dry matter was observed in POP (T_{10}) and was on par with pre emergence herbicides + hand weeding (T_6, T_7 and T_8) and soil solarization. Pre emergence herbicides alone registered comparatively less weed dry matter than post emergence herbicides glyphosate and glufosinate ammonium (T_4 and T_5).

At 90 DAP, the lower dry weight of weeds was recorded in POP (T_{10}) and it was significantly superior to all other treatments during 2013-14. It was followed by pre emergence herbicides + hand weeding (T_6 and T_7) and were significantly superior to all other treatments except T_{10}. Soil solarization (T_9) also could reduce the weed dry matter significantly. The higher weed dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5). These treatments were statically inferior to all others.

During 2014-15 (second year), the trend was similar. Significantly the lower dry matter production of weeds was recorded in POP (T_{10}). It was on par with pre emergence herbicides + hand weeding (T_6, T_7 and T_8) and soil solarization which were significantly superior to all other treatments. The highest dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5). Among the additional treatments, oxyfluorfen+glyphosate (T_{13}) registered the lowest dry matter production of weeds (129.10 kg/ha) and was statistically on par with POP.

The pooled data of weed dry weight at 90 DAP, showed the lowest value in POP (103.20 kg/ha) (T_{10}) which was significantly superior to all other treatments. The next best treatments were pre emergence herbicide followed by hand weeding (T_6, T_7 and T_8) and soil solarization which also recorded statistically lower dry weight than the pre emergence and post emergence herbicides.

During 2013-14 (first year) at 180 DAP also, significantly the lower weed dry matter production was recorded in POP (T_{10}). It was followed by pre emergence herbicides + hand weeding (T_6 and T_7) and were significantly superior to all other treatments except T_{10}. Soil solarization also could reduce the weed dry matter significantly compared to other treatments. The pre emergence herbicides oxyfluorfen and pendimethalin also could reduce the weeds dry matter compared to metribuzin and other post emergence herbicides. The highest dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5).

During 2014-15 (second year) also, the significant reduction in weed dry matter production was observed in POP (T_{10}). It was followed by pre emergence herbicides + hand weeding (T_6, T_7 and T_8) and soil solarization. The highest weed dry matter was recorded in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5). Among the additional treatments, oxyfluorfen+glyphosate (T_{13}) registered the lowest dry matter production of weeds (148.50 kg/ha) at 180 DAP and was on par with POP.

At 180 DAP, the pooled data of total weed dry weight showed that the treatments receiving hand weeding (T_{10}) recorded significantly the lower dry matter production (127.40 kg/ha) followed by pre emergence herbicides + hand weeding and soil solarization which were significantly superior to all other treatments except T_{10}. Pre emergence herbicides oxyfluorfen and pendimethalin also reduced the weed dry matter than other pre emergence herbicide metribuzin. Post emergent herbicide glufosinate ammonium (T_5) recorded maximum dry matter production compared to all other treatments but lower than unweeded control (T_{11}).

4.2.1.4. Nutrient removal by weeds

N, P, K removal by weeds was the higher in unweeded control (T_{11}) and was the lowest in POP (T_{10}) at all stages of crop growth. The uptake of nutrients increased from 45 DAP to 180 DAP (Table 17).

During first year (2013-14), at 45 DAP, the lowest N removal by weeds (1.62 kg/ha) was observed in POP (T_{10}) which was significantly lower than other treatments and was on par with pre emergence herbicides pendimethalin and oxyfluorfen + hand weeding (T_6 and T_7) and soil solarization. N uptake by weeds in post emergence herbicide applied plots (T_4 and T_5) was statistically higher compared to pre emergence herbicides pendimethalin and oxyfluorfen alone.

During 2014-15 (second year), also the trend was same. Significantly the lower N uptake by weeds was noticed in the same treatment ie, POP (T_{10}) (2.43 kg/ha) followed by pre emergence herbicides pendimethalin and oxyfluorfen + hand weeding (T_6 and T_7) which was significantly superior to all other treatments. While the N removal by weeds in unweeded control (T_{11}) was 52.29 kg/ha, the reduction in N removal by T_{10}, T_6 and T_7 was very much substantial. Post emergence herbicides recorded comparatively higher N uptake by weeds than pre emergence herbicides alone. The highest N removal by weeds was registered in unweeded control (T_{11}). Among the additional treatments, oxyfluorfen+glyphosate (T_{13}) registered the lowest N uptake of weeds (2.37 kg/ha) at 45 DAP and it was statistically on par with POP (T_{10}).

At 45 DAP, the pooled data showed that, N removal by weeds ranged from 2.02 kg/ha (T_{10}) to 52.60 kg/ha (T_{11}) (Table 16). The lowest N uptake by weeds was observed in POP (T_{10}) (2.02 kg/ha) which was significantly superior to other treatments. Pre emergence herbicides followed by hand weeding (T_6 and T_7) also recorded significantly lower N uptake by weeds than other treatments. N uptake by weeds in post emergence herbicide applied plots (T_4 and T_5) was statistically higher compared to pre emergence herbicide application. Among the pre emergence herbicides, pendimethalin and oxyfluorfen could reduce the N uptake by weeds substantially. The highest N removal by weeds was observed in unweeded control (T_{11}) and it accounted to 52.60 kg/ha.

By 90 DAP, the N removal by weeds was increased in all the treatments. During 2013-14 (first year), the lowest N uptake by weeds (1.64 kg/ha) noticed in POP (T_{10}) was significantly lower. It was followed by pendimethalin + HW, oxyfluorfen + HW and metribuzin + HW and soil solarization and were significantly superior to all other treatments except T_{10}. The next best treatment was pre emergence herbicide pendimethalin (T_1) which was on par with oxyfluorfen (T_2). The highest N removal by weeds (57.36 kg/ha) was registered in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5).

During 2014-15 (second year) also significantly the lower N removal by weeds was observed in POP (T_{10}) (2.48 kg/ha) followed by pendimethalin + HW oxyfluorfen + HW, metribuzin + HW (T_6, T_7 and T_8) and soil solarization which were significantly superior to all other treatments except T_{10}. The next best treatment was pre emergence herbicide pendimethalin (T_1) which was on par with oxyfluorfen (T_2). The maximum N removal by weeds (57.93 kg/ha) was observed in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5). Among the additional treatments, oxyfluorfen + glyphosate (T_{13}) registered the lowest N uptake by weeds (2.58 kg/ha) which was on par with POP (T_{10}).

By 90 DAP, the pooled data also showed significantly the lower N removal by weeds in POP (T_{10}). Next best treatment oxyfluorfen + hand weeding (T_7), also registered lower N uptake which was on par with pendimethalin + hand weeding (T_6). Soil solarization also could significantly reduce the N uptake by weeds compared to pre emergence and post emergence herbicides alone. The highest N removal by weeds was registered in unweeded control (T_{11}) accounting for 57.64 kg/ha and was followed by post emergence herbicide glufosinate ammonium (T_5).

At 180 DAP (2013-14), also the N uptake by weeds followed similar trend as that of 45 and 90 DAP. Here also, significantly the lower N uptake (2.20 kg/ha) was observed in POP (T_{10}) followed by pre emergence herbicides + hand weeding (T_6 and T_7). These treatments were significantly superior to all others except T_{10}. The next best treatment was soil solarization (T_9) (3.95 kg/ha) and it could reduce the N removal by weeds significantly. Post emergence herbicides (T_4 and T_5) and pre emergent herbicide metribuzin (T_3) was statistically inferior to other treatments but superior to unweeded control (T_{11}). Unweeded control removed 63.07 kg/ha of N through the weeds.

During second year also, the lowest N uptake by weeds (2.89 kg/ha) was observed in the POP (T_{10}) followed by pre emergence herbicides + hand weeding (T_6 and T_7) and was significantly superior to all other treatments. Treatments T_6 and T_7 were on par. The next best treatment, soil solarization (T_9) also could significantly reduce the N removal by weeds (4.39 kg/ha). The maximum N uptake by weeds (63.72 kg/ha) was observed in unweeded control (T_{11}) and post emergence herbicide glufosinate ammonium (T_5) and were statistically inferior compared to other treatments. Among the additional treatments, oxyfluorfen +

glyphosate (T_{13}) recorded the lowest N uptake by weeds (2.97 kg/ha) and it was statistically on par with POP (T_{10}).

At 180 DAP, the pooled data also showed the lowest N uptake by weeds (2.54 kg/ha) in POP (T_{10}) which was significantly superior to all other treatments. This was followed by pre emergence herbicides + hand weeding (T_6 and T_7) which were on par and significantly superior to all other treatments except T_{10}. The next best treatment was soil solarization (T_9) (4.17 kg/ha) which also could reduce the N uptake by weeds significantly. Metribuzin (T_3) recorded higher N uptake than the other pre emergence herbicides, pendimethalin and oxyfluorfen (T_1 and T_2). The maximum N uptake by weeds (63.39 kg/ha) was noticed in unweeded control (T_{11}) followed by post emergence herbicide glufosinate ammonium (T_5).

In the case of P uptake by weeds (Table 18), the trend was almost similar to that of N uptake. P uptake also showed a progressive increase from 45 DAP to 180 DAP. The removal was 14.44 kg/ha and 14.58 kg/ha during first year and second year in unweeded control at 180 DAP, whereas only 0.50 kg/ha and 0.66 kg/ha respectively were removed in POP (T_{10}). The treatment (T_{10}) was significantly superior to other treatments during 45, 90 and 180 DAP during both the years. The next better treatments which minimized P uptake by weeds were pendimethalin + HW and oxyfluorfen + HW and their effects were statistically on par and significantly superior to all other treatments except T_{10} at 45, 90 and 180 DAP during both the seasons. Soil solarization resulted in P removal of 0.9 kg/ha and 1.00 kg/ha respectively during first year and second year at 180 DAP. Effect of soil solarization was superior to all other treatments except T_{10}, T_6, T_7 and T_8. Among the herbicide treatments, glufosinate ammonium was the least effective treatment in both the years at 45, 90 and 180 DAP and was significantly inferior to other treatments but superior to unweeded control. The maximum P uptake by weeds was noticed in unweeded control (T_{11}) at all stages in both the years. The pooled data also showed similar trend.

Among the additional treatments tried during second year (2014 – 2015), oxyfluorfen + glyphosate recorded the lowest (0.68 kg/ha) P removal by weeds at 180 DAP and was on par with POP (T_{10}). These treatments were significantly superior to all others except T_{10} in 2014 -2015.

K removal by weeds also followed the similar pattern. There was no much nutrient removal in POP (T_{10}) due to negligible weed growth, whereas, in unweeded control, K removal was 94.61 kg/ha and 95.58 kg/ha during first year and second year at 180 DAP, respectively (Table 19). The treatment POP (T_{10}) was significantly superior to all other treatments at 45, 90 and 180 DAP during both the years.

Table 16. Effect of weed management practices on weed dry weight (kg/ha)

Treatments	45 DAP			90 DAP			180 DAP		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	20.95^{e} (438.86)	22.10^{e} (488.40)	21.52^{e} (463.63)	27.81^{e} (776.83)	28.68^{e} (825.46)	28.24^{e} (801.15)	33.66^{d} (1136.23)	34.41^{d} (1186.90)	34.03^{e} (1161.57)
T_2 – Oxyfluorfen 0.2 kg/ha	20.86^{e} (434.93)	22.01^{e} (484.36)	21.43^{e} (459.65)	28.00^{e} (786.70)	28.72^{e} (827.43)	28.36^{e} (807.07)	33.47^{d} (1120.80)	34.19^{d} (1169.93)	33.83^{e} (1145.37)
T_3 – Metribuzin 0.525 kg/ha	34.70^{c} (1209.00)	35.46^{c} (1262.26)	35.08^{c} (1235.63)	40.49^{c} (1641.20)	41.03^{c} (1685.23)	40.76^{c} (1663.22)	43.69^{c} (1910.03)	44.26^{c} (1959.93)	43.98^{c} (1934.98)
T_4 – Glyphosate 0.8 kg/ha	30.64^{d} (942.00)	31.34^{d} (985.50)	30.99^{d} (963.75)	34.79^{d} (1210.50)	35.46^{d} (1257.36)	35.13^{d} (1233.93)	42.89^{c} (1841.06)	43.46^{c} (1889.90)	43.18^{d} (1865.48)
T_5 – Glufosinate ammonium 0.45 kg/ha	40.56^{b} (1646.86)	41.12^{b} (1692.76)	40.84^{b} (1669.82)	43.61^{b} (1901.70)	44.13^{b} (1947.36)	43.87^{b} (1924.53)	49.03^{b} (2405.96)	49.50^{b} (2452.46)	49.27^{b} (2429.22)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	9.15^{f} (83.40)	10.90^{g} (118.50)	10.07^{f} (100.95)	11.51^{g} (132.20)	12.99^{g} (168.30)	12.27^{f} (150.25)	12.79^{f} (163.2)	14.10^{e} (198.50)	13.46^{f} (180.85)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	9.11^{f} (82.50)	11.01^{g} (120.80)	10.10^{f} (101.65)	11.43^{g} (130.20)	12.87^{g} (165.34)	12.17^{f} (147.77)	12.72^{f} (161.30)	13.99^{e} (195.40)	13.37^{f} (178.35)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	9.27^{f} (85.60)	10.88^{g} (117.90)	10.11^{f} (101.75)	13.14^{f} (172.20)	14.44^{g} (208.20)	13.80^{f} (190.20)	14.26^{e} (203.10)	15.02^{e} (225.40)	14.65^{f} (214.25)
T_9 - Soil solarisation	9.31^{f} (86.30)	10.90^{g} (118.50)	10.14^{f} (102.40)	13.01^{f} (168.90)	13.99^{g} (195.40)	13.51^{f} (182.15)	14.07^{e} (197.50)	14.84^{e} (219.80)	14.46^{f} (208.65)
T_{10} – POP (2 hand weedings)	9.04^{f} (81.40)	11.04^{g} (121.50)	10.05^{f} (101.45)	9.09^{h} (82.30)	11.16^{h} (124.10)	10.18^{g} (103.20)	10.52^{g} (110.30)	12.04^{f} (144.50)	11.30^{g} (127.40)
T_{11} - Unweeded control	51.10^{a} (2614.83)	51.39^{a} (2645.33)	51.25^{a} (2630.13)	53.56^{a} (2868.36)	53.82^{a} (2896.60)	53.69^{a} (2882.48)	56.16^{a} (3153.66)	56.45^{a} (3186.03)	56.30^{a} (3169.85)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	17.06^{f} (290.60)	-	-	21.53^{f} (463.10)	-	-	32.82^{d} (1076.86)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	10.92^{g} (118.76)	-	-	11.38^{h} (129.10)	-	-	12.20^{f} (148.50)	-
CD value (5%)	1.93	2.16	1.89	1.65	1.83	1.74	1.32	1.62	1.47

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 17. Effect of weed management practices on N removal by weeds (kg/ha)

Treatments	45 DAP			90 DAP			180 DAP		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	3.04 [e] (8.77)	3.20 [e] (9.76)	3.12 [e] (9.27)	4.00 [e] (15.53)	4.11 [e] (16.50)	4.06 [e] (16.02)	4.81 [d] (22.72)	4.92 [d] (23.73)	4.87 [d] (23.23)
T_2 – Oxyfluorfen 0.2 kg/ha	3.03 [e] (8.69)	3.19 [e] (9.68)	3.11 [e] (9.19)	4.02 [e] (15.73)	4.12 [e] (16.54)	4.07 [e] (16.14)	4.78 [d] (22.41)	4.88 [d] (23.39)	4.83 [d] (22.90)
T_3 – Metribuzin 0.525 kg/ha	4.96 [c] (24.18)	5.07 [c] (25.24)	5.02 [c] (24.71)	5.77 [c] (32.82)	5.84 [c] (33.70)	5.81 [c] (33.26)	6.22 [c] (38.20)	6.30 [c] (39.19)	6.26 [c] (38.69)
T_4 – Glyphosate 0.8 kg/ha	4.39 [d] (18.84)	4.49 [d] (19.71)	4.44 [d] (19.27)	4.97 [d] (24.21)	5.06 [d] (25.14)	5.01 [d] (24.67)	6.10 [c] (36.82	6.18 [c] (37.79)	6.14 [c] (37.30)
T_5 – Glufosinate ammonium 0.45 kg/ha	5.78 [b] (32.93)	5.86 [b] (33.85)	5.82 [b] (33.39)	6.20 [b] (38.03)	6.28 [b] (38.94)	6.24 [b] (38.49)	6.97 [b] (48.11)	7.03 [b] (49.04)	7.00 [b] (48.58)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	1.47 [f] (1.66)	1.69 [f] (2.37)	1.58 [f] (2.01)	1.77 [f] (2.64)	1.96 [g] (3.36)	1.87 [f] (3.00)	1.94 [f] (3.26)	2.11 [ef] (3.97)	2.02 [e] (3.61)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	1.46 [f] (1.65)	1.70 [f] (2.41)	1.59 [f] (2.03)	1.76 [f] (2.60)	1.95 [g] (3.30)	1.85 [f] (2.95)	1.93 [f] (3.22)	2.09 [f] (3.90)	2.01 [e] (3.56)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	1.48 [f] (1.71)	1.69 [f] (2.35)	1.59 [f] (2.03)	1.98 [f] (3.44)	2.15 [g] (4.16)	2.07 [f] (3.80)	2.13 [e] (4.06)	2.23 [e] (4.50)	2.18 [e] (4.28)
T_9 - Soil solarisation	1.49 [f] (1.72)	1.70 [f] (2.37)	1.59 [f] (2.04)	1.96 [f] (3.37)	2.09 [g] (3.90)	2.03 [f] (3.64)	2.10 [ef] (3.95)	2.21 [ef] (4.39)	2.16 [e] (4.17)
T_{10} – POP (2 hand weedings)	1.45 [f] (1.62)	1.71 [f] (2.43)	1.59 [f] (2.02)	1.46 [g] (1.64)	1.72 [h] (2.48)	1.60 [g] (2.06)	1.64 [g] (2.20)	1.84 [g] (2.89)	1.74 [f] (2.54)
T_{11} - Unweeded control	7.26 [a] (52.29)	7.30 [a] (52.90)	7.28 [a] (52.60)	7.60 [a] (57.36)	7.64 [a] (57.93)	7.62 [a] (57.64)	7.97 [a] (63.07)	8.01 [a] (63.72)	7.99 [a] (63.39)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	2.51 [e] (5.81)	-	-	3.12 [f] (9.26)	-	-	4.69 [d] (21.53)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	1.69 [f] (2.37)	-	-	1.75 [h] (2.58)	-	-	1.86 [g] (2.97)	-
CD values (5%)	0.27	0.30	0.28	0.22	0.25	0.23	0.18	0.22	0.20

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 18. Effect of weed management practices on P removal by weeds (kg/ha)

Treatments	45 DAP			90 DAP			180 DAP		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	1.58 e (2.01)	1.65 e (2.23)	1.61 e (2.12)	2.01 e (3.55)	2.06 e (3.78)	2.04 e (3.66)	2.38 d (5.20)	2.43 d (5.43)	2.41 d (5.31)
T_2 – Oxyfluorfen 0.2 kg/ha	1.57 e (1.99)	1.64 e (2.21)	1.61 e (2.10)	2.02 e (3.60)	2.06 e (3.78)	2.05 e (3.69)	2.37 d (5.13)	2.41 d (5.35)	2.39 d (5.24)
T_3 – Metribuzin 0.525 kg/ha	2.45 c (5.53)	2.50 c (5.78)	2.48 c (5.65)	2.83 c (7.51)	2.86 c (7.71)	2.84 c (7.61)	3.04 c (8.74)	3.07 c (8.97)	3.05 c (8.86)
T_4 – Glyphosate 0.8 kg/ha	2.19 d (4.31)	2.23 d (4.51)	2.21 d (4.41)	2.45 d (5.54)	2.50 d (5.75)	2.48 d (5.65)	2.98 c (8.43)	3.02 c (8.65)	3.00 c (8.54)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.83 b (7.54)	2.87 b (7.75)	2.85 b (7.64)	3.03 b (8.70)	3.06 b (8.91)	3.05 b (8.81)	3.39 b (11.01)	3.42 b (11.20)	3.40 b (11.12)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	0.93 f (0.38)	1.02 g (0.54)	0.98 f (0.46)	1.05 g (0.60)	1.12 g (0.77)	1.09 g (0.68)	1.11 e (0.74)	1.18 e (0.90)	1.15 e (0.82)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	0.93 f (0.37)	1.02 g (0.55)	0.98 f (0.46)	1.04 g (0.59)	1.12 g (0.75)	1.08 g (0.67)	1.11 e (0.73)	1.18 e (0.89)	1.14 ef (0.81)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	0.94 f (0.39)	1.01 g (0.53)	0.98 f (0.46)	1.13 f (0.78)	2.20 e (0.95)	1.17 f (0.87)	1.19 e (0.93)	1.23 e (1.03)	1.21 e (0.98)
T_9 - Soil solarisation	0.94 f (0.39)	1.02 g (0.54)	0.98 f (0.46)	1.12 f (0.77)	1.18 g (0.89)	1.15 f (0.83)	1.18 e (0.90)	1.22 e (1.00)	1.20 e (0.95)
T_{10} – POP (2 hand weedings)	0.93 f (0.37)	1.02 g (0.55)	0.98 f (0.46)	0.93 h (0.37)	1.03 h (0.56)	0.98 g (0.47)	1.00 f (0.50)	1.07 f (0.66)	1.04 f (0.58)
T_{11} - Unweeded control	3.52 a (11.97)	3.54 a (12.11)	3.54 a (12.04)	3.69 a (13.13)	3.71 a (13.20)	3.70 a (13.20)	3.86 a (14.44)	3.88 a (14.58)	3.87 a (14.51)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	1.35 f (2.24)	-	-	1.61 f (2.12)	-	-	2.33 d (4.93)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	1.02 g (0.54)	-	-	1.04 h (0.59)	-	-	1.08 f (0.68)	-
CD values (5%)	0.13	0.14	0.14	0.10	0.11	0.10	0.09	0.10	0.10

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 19. Effect of weed management practices on K removal by weeds (kg/ha)

Treatments	45 DAP			90 DAP			180 DAP		
	First year	Second year	Pooled	First year	Second year	Pooled	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	3.69^{e} (13.16)	3.89^{e} (14.65)	3.79^{e} (13.90)	4.86^{e} (23.30)	5.01^{e} (24.76)	4.95^{e} (24.03)	5.87^{d} (34.08)	6.00^{d} (35.60)	5.94^{d} (34.84)
T_2 – Oxyfluorfen 0.2 kg/ha	3.67^{e} (13.04)	3.87^{e} (14.53)	3.78^{e} (13.78)	4.89^{e} (23.60)	5.02^{e} (24.82)	4.97^{e} (24.21)	5.83^{d} (33.62)	5.96^{d} (35.09)	5.90^{d} (34.36)
T_3 – Metribuzin 0.525 kg/ha	6.05^{c} (36.27)	6.18^{c} (37.86)	6.12^{c} (37.06)	7.04^{c} (49.23)	7.14^{c} (50.55)	7.09^{c} (49.89)	7.60^{c} (57.30)	7.69^{c} (58.79)	7.65^{c} (58.04)
T_4 – Glyphosate 0.8 kg/ha	5.35^{d} (28.26)	5.47^{d} (29.56)	5.42^{d} (28.91)	6.06^{d} (36.31)	6.18^{d} (37.72)	6.12^{d} (37.01)	7.46^{c} (55.23)	7.56^{c} (56.69)	7.51^{c} (55.96)
T_5 – Glufosinate ammonium 0.45 kg/ha	7.05^{b} (49.40)	7.15^{b} (50.78)	7.11^{b} (50.09)	7.58^{b} (57.05)	7.67^{b} (58.42)	7.63^{b} (57.73)	8.52^{b} (72.17)	8.60^{b} (73.57)	8.56^{b} (72.87)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	1.73^{f} (2.502)	2.01^{g} (3.55)	1.87^{f} (3.02)	2.11^{fg} (3.96)	2.35^{g} (5.04)	2.23^{f} (4.50)	2.32^{f} (4.89)	2.54^{e} (5.95)	2.43^{e} (5.42)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	1.72^{f} (2.475)	2.03^{g} (3.62)	1.88^{f} (3.04)	2.09^{g} (3.90)	2.33^{g} (4.96)	2.22^{f} (4.43)	2.31^{f} (4.83)	2.52^{e} (5.86)	2.41^{e} (5.35)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	1.75^{f} (2.568)	2.00^{g} (3.53)	1.88^{f} (3.05)	2.38^{f} (5.16)	2.59^{g} (6.24)	2.49^{f} (5.70)	2.56^{e} (6.09)	2.69^{e} (6.76)	2.63^{e} (6.42)
T_9 - Soil solarisation	1.75^{f} (2.589)	2.01^{g} (3.55)	1.88^{f} (3.07)	2.35^{f} (5.06)	2.52^{g} (5.86)	2.44^{f} (5.46)	2.53^{ef} (5.92)	2.66^{e} (6.59)	2.59^{e} (6.25)
T_{10} – POP (2 hand weedings)	1.75^{f} (2.44)	2.03^{g} (3.64)	1.88^{f} (3.04)	1.72^{h} (2.46)	2.05^{h} (3.72)	1.89^{g} (3.09)	1.95^{g} (3.30)	2.19^{f} (4.33)	2.07^{f} (3.82)
T_{11} - Unweeded control	8.87^{a} (78.44)	8.92^{a} (79.36)	8.91^{a} (78.90)	9.30^{a} (86.05)	9.34^{a} (86.89)	9.32^{a} (86.47)	9.75^{a} (94.61)	9.80^{a} (95.58)	9.77^{a} (95.09)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	3.03^{f} (8.71)	-	-	3.79^{f} (13.89)	-	-	5.72^{d} (32.30)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	2.01^{g} (3.56)	-	-	2.09^{h} (3.87)	-	-	2.22^{f} (4.45)	-
CD values (5%)	0.33	0.37	0.35	0.28	0.31	0.29	0.22	0.28	0.25

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

The next better treatments which could minimize the K removal by weeds are pendimethalin + hand weeding, oxyfluorfen + hand weeding, metribuzin + hand weeding and soil solarization and their effects were statistically on par and superior to all other treatments except T_{10} at 45, 90 and 180 DAP during both the years. Among the herbicide treatments post emergence herbicide glufosinate ammonium was the least effective at 45, 90 and 180 DAP during both the years and was significantly inferior to all others and superior to unweeded control (T_{11}). The higher K uptake by weeds was noticed in unweeded control (T_{11}) at all the stages during both the years. The pooled data also followed the similar trend.

Among the additional treatments tried during 2014 - 2015, combination of oxyfluorfen and glyphosate (T_{13}) recorded the lowest K removal by weeds and it was on par with POP (T_{10}).

4.2.2. Observations on ginger

4.2.2.1. Germination per cent

All the treatments recorded more than 90 per cent germination. The herbicides did not affect germination seriously. The effect of treatments was not consistent between two seasons (Table 20).

4.2.2.2. Phytotoxic symptoms on crop

No phytotoxicity symptom was noticed on ginger plants in any of the treatments.

Table 20. Effect of weed management practices on germination per cent of ginger

Treatments	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	9.70 ^{abc} (93.60)	9.63 ^{b} (92.27)	9.66 ^{b} (92.94)
T_2 – Oxyfluorfen 0.2 kg/ha	9.75 ^{ab} (94.49)	9.67 ^{ab} (93.08)	9.71 ^{ab} (93.79)
T_3 – Metribuzin 0.525 kg/ha	9.72 ^{ab} (94.01)	9.62 ^{bc} (92.16)	9.67 ^{ab} (93.09)
T_4 – Glyphosate 0.8 kg/ha	9.64 ^{c} (91.60)	9.55 ^{d} (90.85)	9.57 ^{c} (91.23)
T_5 – Glufosinate ammonium 0.45 kg/ha	9.65 ^{bc} (92.65)	9.57 ^{cd} (91.18)	9.61 ^{bc} (91.92)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	9.64 ^{bc} (92.67)	9.66 ^{b} (92.82)	9.65 ^{b} (92.75)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	9.71 ^{bc} (92.51)	9.64 ^{b} (92.43)	9.64 ^{b} (92.47)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	9.72 ^{ab} (93.71)	9.63 ^{b} (92.37)	9.67 ^{ab} (93.04)
T_9 - Soil solarisation	9.73 ^{ab} (93.99)	9.65 ^{b} (92.67)	9.68 ^{ab} (93.33)
T_{10} – POP (2 hand weedings)	9.78 ^{a} (95.15)	9.63 ^{b} (92.39)	9.70 ^{ab} (93.77)
T_{11} - Unweeded control	9.60 ^{ab} (94.25)	9.72 ^{a} (94.08)	9.72 ^{a} (94.17)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	9.63 ^{b} (92.42)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	9.64 ^{b} (92.43)	-
CD values (5%)	0.09	0.05	0.07

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 21. Effect of weed management practices on number of tillers per plant

Treatments	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	4.31[c] (18.06)	3.44 [fg] (11.36)	3.88 [e] (14.72)
T_2 – Oxyfluorfen 0.2 kg/ha	4.45 [bc] (19.33)	3.90 [e] (14.73)	4.18 [d] (17.03)
T_3 – Metribuzin 0.525 kg/ha	3.42 [ef] (11.20)	2.94 [h] (8.20)	3.18 [fg] (9.70)
T_4 – Glyphosate 0.8 kg/ha	3.55 [de] (12.13)	3.24 [g] (10.06)	3.40 [f] (11.10)
T_5 – Glufosinate ammonium 0.45 kg/ha	3.24 [f] (10.06)	2.85 [hi] (7.66)	3.05 [g] (8.87)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	4.57 [ab] (20.46)	4.64 [bc] (21.06)	4.61 [bc] (20.77)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	4.64 [ab] (21.06)	4.57 [c] (20.46)	4.61 [bc] (20.77)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	4.32 [d] (18.13)	4.45 [cd] (19.33)	4.38 [cd] (18.73)
T_9 - Soil solarisation	4.49 [abc] (19.73)	4.30 [d] (18.06)	4.40 [cd] (18.90)
T_{10} – POP (2 hand weedings)	4.68 [a] (21.46)	4.85 [ab] (23.10)	4.77 [ab] (22.28)
T_{11} - Unweeded control	2.85 [g] (7.66)	2.67 [I] (6.66)	2.77 [h] (7.17)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	3.66 [f] (12.93)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	4.89 [a] (23.53)	-
CD values (5%)	0.20	0.23	0.22

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

4.2.2.3. No. of tillers per plant

Significantly the higher tiller count per plant was observed in hand weeding (T_{10}) (21.46 nos.) during 2013-2014 which was on par with pendimethalin or oxyflorfen followed by hand weeding (T_6 and T_7) and solarization (T_9) (Table 21). The lower tiller count (7.66 nos.) was observed in unweeded control (T_{11}) and it was significantly inferior to all other treatments. Pre emergence herbicide metribuzin (T_3) and post emergence herbicides glyphosate and glufosinate ammonium (T_4 and T_5) also had lesser tillering.

During the second cropping season (2014-2015) also the highest number of tillers per plant was observed in POP (T_{10}) (23.10 nos.) followed by pendimethalin + hand weeding and these treatments were statistically superior to all other treatments. Next better treatments were pendimethalin, Oxyfluorfen and metribuzin followed by hand weeding (T_6, T_7 and T_8). Soil solarization (T_9) also resulted in significantly higher tiller count. Unweeded control (T_{11}), post emergence herbicides glyphosate and glufosinate ammonium (T_4 and T_5) and pre emergence herbicide metribuzin (T_3) negatively influenced tiller production. Among the additional treatments, Glyphosate + Oxyfluorfen (T_{13}) produced more number of tiller count. The treatment T_{13} was at par with T_{10} and significantly superior to all other treatments.

Pooled analysis of the two years of data also showed similar trend. Here also the higher number of tillers per plant was produced in POP (T_{10}) (22.28 nos.) followed by pendimethalin + hand weeding and Oxyfluorfen + hand weeding which were significantly superior to all other treatments. Next better treatments were metribuzin followed by hand weeding (T_8) and soil solarization (T_9). Post emergence herbicides negatively influenced tiller production. The lower number of tillers was produced in unweeded control (7.17 nos.).

4.2.2.4. No. of leaves per tiller

During 2013-2014, the number of leaves per tiller showed wide variation with respect to various treatments (Table 22). Highest leaf count (21.66 nos.) was recorded in POP (T_{10}) and it was statistically on par with pre emergence herbicides pendimethalin (19.80 nos.) and oxyfluorfen (19.53 nos.) followed by hand weeding (T_6 and T_7). Soil solarization (T_9) also registered higher number of leaves per tiller compared to pre emergence and post emergence herbicides alone. However, unweeded control registered lowest value (7.60 nos.) which was significantly inferior to all other treatments.

During second year, the count of leaves per tiller did not show much variation with respect to various treatments. Here the higher leaf count was recorded in POP (T_{10}) and oxyfluorfen (T_2) and oxyfluorfen followed by hand weeding (T_7) (16.50, 16.06 and 15.96 nos. respectively) which were on par with all other treatments except metribuzin (T_3), glufosinate ammonium (T_5) and unweeded control (T_{11}). The lowest leaves count was observed in post emergence herbicide glufosinate ammonium (T_5) (9.76 nos.), which was significantly inferior to all other treatments. Among the additional treatments, oxyfluorfen + glyphosate (T_{13}) recorded the highest number of leaves per tiller (19.12 nos.) and was on par with all other treatments except metribuzin (T_3), glufosinate ammonium (T_5) and unweeded control (T_{11}).

Pooled analysis of number of leaves per tiller for two cropping periods (2013-2014 and 2014-2015) also showed that POP was the best treatment to produce maximum number of leaves per tiller. It was at par with pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8) and soil solarization (T_9). The worst treatments were unweeded control (T_{11}) and post emergence herbicide glufosinate ammonium (T_5), which were statistically on par.

Table 22. Effect of weed management practices on number of leaves per tiller

Number of leaves/ tiller			
Treatments	**First year**	**Second year**	**Pooled**
T_1 – Pendimethalin 1.5 kg/ha	3.72 [e] (13.40)	3.76 [ab] (13.73)	3.75 [cd] (13.57)
T_2 – Oxyfluorfen 0.2 kg/ha	3.87 [de] (14.53)	4.06 [a] (16.06)	3.97 [bc] (15.30)
T_3 – Metribuzin 0.525 kg/ha	3.37 [fg] (10.93)	3.47 [bc] (11.66)	3.43 [de] (11.30)
T_4 – Glyphosate 0.8 kg/ha	3.58 [ef] (12.33)	3.80 [ab] (14.03)	3.69 [cd] (13.18)
T_5 – Glufosinate ammonium 0.45 kg/ha	3.20 [g] (9.80)	3.20 [c] (9.76)	3.20 [e] (9.78)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	4.50 [ab] (19.80)	3.97 [ab] (15.33)	4.24 [ab] (17.57)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	4.47 [ab] (19.53)	4.05 [a] (15.96)	4.26 [ab] (17.75)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	4.05 [cd] (15.93)	4.02 [ab] (15.73)	4.04 [abc] (15.83)
T_9 - Soil solarisation	4.30 [bc] (18.06)	3.86 [ab] (14.50)	4.09 [abc] (16.28)
T_{10} – POP (2 hand weedings)	4.70 [a] (21.66)	4.11 [a] (16.50)	4.41 [a] (19.08)
T_{11} - Unweeded control	2.84 [h] (7.60)	3.55 [bc] (12.13)	3.20 [e] (9.87)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	3.77 [ab] (13.76)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	4.42 [a] (19.12)	-
CD values (5%)	0.27	0.49	0.38

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 23. Effect of weed management practices on height of plant (cm)

Height of plant			
Treatments	**First year**	**Second year**	**Pooled**
T_1 – Pendimethalin 1.5 kg/ha	7.96 ^{d} (62.86)	7.51 ^{cd} (56.00)	7.74 ^{de} (59.43)
T_2 – Oxyfluorfen 0.2 kg/ha	8.16 ^{cd} (66.13)	7.81 ^{bc} (60.66)	7.99 ^{cd} (63.40)
T_3 – Metribuzin 0.525 kg/ha	7.46 ^{e} (55.20)	7.00 ^{de} (48.66)	7.23 ^{fg} (54.93)
T_4 – Glyphosate 0.8 kg/ha	7.88 ^{d} (61.66)	7.02 ^{de} (49.00)	7.46 ^{efg} (55.33)
T_5 – Glufosinate ammonium 0.45 kg/ha	7.51 ^{e} (55.93)	6.80 ^{e} (46.00)	7.16 ^{fg} (50.97)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	8.33 ^{bc} (69.00)	8.23 ^{ab} (67.33)	8.29 ^{abc} (68.17)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	8.68 ^{ab} (75.00)	8.29 ^{ab} (68.33)	8.49 ^{ab} (71.67)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	7.89 ^{d} (61.86)	8.23 ^{ab} (67.33)	8.06 ^{bcd} (64.60)
T_9 - Soil solarisation	8.16 ^{cd} (66.20)	8.21 ^{ab} (67.00)	8.19 ^{abc} (66.60)
T_{10} – POP (2 hand weedings)	8.72 ^{a} (75.66)	8.41 ^{a} (70.33)	8.57 ^{a} (73.00)
T_{11} - Unweeded control	7.34 ^{e} (53.53)	6.74 ^{e} (45.00)	7.05 ^{g} (49.27)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	7.51 ^{cd} (56.00)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	8.57 ^{a} (73.00)	-
CD values (5%)	0.33	0.51	0.42

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

4.2.2.5. Height of plant

The highest plant height (75.66 cm) was registered in POP (T_{10}) during 2013-14 (Table 23) which was at par with oxyfluorfen followed by hand weeding (T_7). The lowest values were recorded in unweeded control, pre emergence herbicide metribuzin (T_3) and the post emergence herbicide glufosinate ammonium (T_5) (53.53, 55.20 and 55.93 cms. respectively), which were statistically inferior to all other treatments.

During 2014-15 also, the maximum height (70.33 cm) was recorded by POP (T_{10}) from among the regular treatments, and it was on par with pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8) and soil solarization (T_9). Among the additional treatments (T_{12} and T_{13}), the combination of oxyfluorfen and glyphosate (T_{13}) recorded plant height (73.00 cm) on par with POP (T_{10}).

Pooled analysis also showed similar trend of both the years. Here also the maximum height was recorded by POP (73.00 cm) and was on par with T_6, T_7 and T_9. Lowest plant height was recorded by the treatments T_{11}, T_3, T_4 and T_5.

4.2.2.6. Incidence of major pests and diseases

Incidence of Rhizoctonia leaf blight and shoot borer was observed in ginger and timely control measures were adopted. No variation between treatments could be observed in the experimental plot during both the years.

4.2.2.7. Fresh yield of ginger

The higher yield of 20.64 and 19.76 t/ha respectively were produced by POP (T_{10}) and oxyfluorfen followed by hand weeding (T_7) during 2013-14 which were statistically on par and significantly superior to all other treatments (Table 24). The next best practices were pendimethalin followed by hand weeding (T_6) as well as soil solarization (T_9) where yields of 18.08 and 16.74 t/ha respectively could be realized. However, the treatment T_6 was significantly superior to T_9. Post emergence herbicide glufosinate ammonium (T_5) and unweeded control (T_{11})

recorded significantly the lower yields of 7.22 and 6.74 t/ha respectively compared to all other treatments. The pre emergence herbicide, metribuzin (T_3) and post emergence herbicides, glyphosate and glufosinate ammonium were not very effective in producing a good yield.

During 2014-2015, from among the regular treatments POP (T_{10}) recorded the higher yield of 13.35 t/ha and was at par with pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8). Soil solarization (T_9) and oxyfluorfen (T_2) were also promising in giving good yield, though they were statistically inferior to T_{10}. The yield from T_1, T_3 and T_4, T_5 was inferior. The newly added treatment glyphosate + oxyfluorfen (T_{13}) also gave a good yield (13.53t/ha) on par with POP.

Pooled analysis of data for two years of the experiment also showed similar trend as that of two cropping seasons. The best two treatments based on pooled analysis are POP (T_{10}) and oxyflorfen + hand weeding (T_7), the yield of both of which are on par. The third best treatment was pendimethalin + hand weeding (T_6) followed by soil solarisation (T_9). Lowest yields were recorded by unweeded control (T_{11}) followed by glufosinate ammonium (T_5). From the pre emergence herbicides alone, oxyfluorfen (T_2) was superior to others (T_1 and T_3). Post emergence herbicides, glyphosate and glufosinate ammonium were not effective in giving a reasonable yield. However, glyphosate was better than glufosinate ammonium.

Correlation between fresh yield of ginger and dry matter production of weeds at 45, 90 and 180 DAP during both the years is presented in Table 25. It showed high negative correlation betweed weed dry matter and yield. Weed growth at 45, 90 and 180 DAP affected fresh yield of ginger indicating that weed growth up to 180 DAP in ginger is harmful to ginger production.

4.2.2.8. Dry yield of ginger

The maximum dry weight (6.53 t/ha) recorded in hand POP (T_{10}) and was on par with oxyflorfen followed by hand weeding (T_7) (6.25 t/ha) during 2013-14

(Table 26). These treatments were significantly superior to all other treatments. Next best treatment was pendimethalin + HW (5.72 t/ha). It was significantly superior to all other treatments except T_{10} and T_7. Soil solarization (T_9) also recorded higher dry weight of ginger though inferior to T_{10}, T_7 and T_6. The post emergence herbicide glufosinate ammonium (T_5) and unweeded control (T_{11}) recorded the low dry yield of 2.28 and 2.013 t/ha respectively, and were statistically inferior to best treatments.

During second cropping season (2014-15), among the regular treatments, the highest dry yields of 4.53 t/ha was recorded by POP (T_{10}). The next best treatments were pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8). T_{10}, T_6, T_7 and T_8 were on par. Effects of soil solarization (T_9) and oxyflorfen (T_2) were at par with T_6, T_7 and T_8 but inferior to T_{10}. Pendimethalin (T_1), Metribuzin (T_3), Glyphosate (T_4), Glufosinate ammonium (T_5) and unweeded control (T_{11}) were inferior treatments. Among the additional treatments, combination of oxyflorfen and glyphosate (T_{13}) recorded the highest dry yield (4.59 t/ha) and was on par with POP.

The best two treatments based on pooled analysis are POP (T_{10}) and oxyflorfen + hand weeding (T_7). Nevertheless, T_{10} was significantly superior to T_7. The third best treatment was pendimethalin + hand weeding (T_6), followed by soil solarisation (T_9). Lowest yields were recorded by unweeded control (T_{11}) followed by glufosinate ammonium (T_5).

4.2.2.9. Economics of ginger

During 2013 -2014, oxyflorfen + hand weeding (T_7) recorded the highest net return followed by POP (T_{10}) and pendimethalin + hand weeding (T_6). Soil solarization was the fourth best treatment. During 2014 -2015, among the regular treatments, first, second, third and fourth best treatments were in the order of POP (T_{10}), pendimethalin + hand weeding (T_6), oxyflorfen + hand weeding (T_7) and solarization (T_9) respectively. Among the additional treatments, glyphosate + oxyfluorfen (T_{13}) gave the highest net return during 2014 – 2015. By taking the average of the two years of the regular treatments, POP (T_{10}) gave the highest net return of Rs. 763225, followed by T_7 (Rs. 744075) and T_6 (Rs. 700558). The data presented in Table 25 revealed that the highest B:C ratio (5.9) was recorded in oxyflorfen + hand weeding (T_7) followed by pendimethalin + hand weeding (5.3) (T_6) during 2013-2014. Post emergence herbicide glufosinate ammonium (T_5) and unweeded control (T_{11}) recorded the lowest B:C ratio (Table 27).

During 2014-15, analysis of the B:C ratio showed that among the regular treatments, oxyflorfen + hand weeding (3.5) (T_7) and pendimethalin + hand weeding (3.5) (T_6) recorded the highest B:C ratio compared to all other treatments (Table 28). The next best treatments were metribuzin + hand weeding (T_8) and pre emergence herbicide oxyfluorfen (T_2). The lowest B:C ratio of 1.8 was recorded by unweeded control (T_{11}) (Table 27).

The additional treatment glyphosate + oxyfluorfen (T_{13}) resulted in the highest B: C ratio of 4.4 during 2014 -2015. By taking the average of B: C ratio of the two years of the regular treatments, oxyflorfen + hand weeding (T_7) gave the highest value of 4.7 followed by pendimethalin + hand weeding (4.4) and the third best value was recorded by POP (T_{10}) accounting to 3.95.

4.2.3. Effect of herbicides on soil microflora

The microbial count in soil two months after spraying of herbicides is depicted in Table 29. The data shows significant variation in microbial count between treatments during 2013-14. The maximum fungus count was recorded in POP ($59.33*10^3$ nos.) (T_{10}) which was on par with unweeded control ($58.66*10^3$ nos.) (T_{11}) and both of these were significantly superior to all others. Among the herbicides, post emergence herbicides (T_4 and T_5) resulted in higher fungus count than plots which received pre emergence herbicides (T_1, T_2 and T_3). The lowest count was recorded in pre emergence herbicide oxyfluorfen ($25*10^3$ nos.) (T_2) which was statistically inferior to all other treatments.

During 2014-15 also, the maximum fungus count ($47.33*10^3$ nos.) was recorded in POP (T_{10}) which was on par with unweeded control ($47.00 *10^3$ nos.)

(T_{11}). Soil solarization (T_9) also recorded higher fungal population which was at par with all other treatments except pre emergence herbicides pendimethalin (T_1) and oxyfluorfen (T_2). T_9 was inferior to T_{10} and T_{11}. Statistically inferior count was recorded in oxyfluorfen alone (T_2). Among the additional treatments, oxyflorfen+ glyphosate (T_{13}) recorded significantly inferior count and it was on par with oxyfluorfen alone (T_2).

Pooled analysis of total fungal count showed that the maximum count ($53.33*10^3$ nos.) was recorded in the treatments POP (T_{10}) which was on par with unweeded control (52.83 $*10^3$ nos.) (T_{11}). The next best treatment was soil solarization (42.00 $*10^3$ nos.) (T_9), which was on par with all other treatments except pre emergence herbicides pendimethalin (T_1) and oxyfluorfen (T_2). Statistically inferior fungal count was recorded in oxyfluorfen alone (T_2). In general, herbicides and solarization reduced the fungus count significantly compared to T_{11} and T_{10}. Among the herbicides oxyfluorfen was more harmful to fungal growth in soil than other herbicides.

Among different treatments, the highest bacterial count was recorded in POP (27.66 $*10^3$ nos.) (T_{10}) and was on par with unweeded control ($25.66*10^3$ nos.) (T_{11}) during 2013-14. These treatments were significantly superior to all other treatments. Soil solarization (T_9) also resulted in high bacterial count ($19.33*10^3$ nos.) and was on par with post emergence herbicide glyphosate (T_4). The lowest count was in pre emergence herbicide oxyfluorfen alone and this was statistically inferior to all others.

During 2014-15 also the maximum count was recorded in the treatments POP and unweeded control (T_{10} and T_{11}) which were significantly superior to all other treatments. The next best treatment was soil solarization which was at par with post emergence herbicides glyphosate (T_4) and glufosinate ammonium (T_5). The additional treatments, pendimethalin + glyphosate (T_{12}) and oxyflorfen+ glyphosate (T_{13}) also recorded significantly inferior bacterial count and was on par with oxyfluorfen (T_2), and pendimethalin (T_1).

Pooled analysis also shows the similar trend. The maximum count was recorded in the treatments, POP and unweeded control (T_{10} and T_{11}) which were significantly superior to all other treatments. The next best treatment was soil solarization (T_9) which was at par with post emergence herbicides. The pre emergence herbicide metribuzin (T_3) recorded significantly higher count than other pre emergence herbicides oxyfluorfen (T_2) and pendimethalin (T_1). The lowest bacterial counts were observed in pre emergence herbicides oxyfluorfen (T_2) and pendimethalin (T_1) and this was statistically inferior to all others. Pendimethalin and Oxyfluorfen were highly harmful to the survival of bacteria in soil.

4.2.4. Herbicide residue in ginger

The residues of the most promising herbicides found very effective to control weeds in ginger were analyzed after harvest of the crop and results are presented in Table 30. During 2013-14, the pre emergence herbicides pendimethalin (T_1), oxyfluorfen (T_2), pendimethalin + hand weeding (T_6) and oxyfluorfen + hand weeding (T_7) recorded below detectable level of herbicide residue in ginger.

Table 24. Effect of weed management practices on fresh yield of ginger (t/ha)

Treatments	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	3.39 [e] (11.02)	2.48 [d] (5.66)	2.94 [ef] (8.34)
T_2 – Oxyfluorfen 0.2 kg/ha	3.49 [e] (11.69)	3.25 [bc] (10.10)	3.37 [d] (10.90)
T_3 – Metribuzin 0.525 kg/ha	3.18 [f] (9.61)	2.40 [d] (5.26)	2.79 [fg] (7.44)
T_4 – Glyphosate 0.8 kg/ha	3.24 [f] (10.02)	2.47 [d] (5.62)	2.86 [f] (7.82)
T_5 – Glufosinate ammonium 0.45 kg/ha	2.77 [g] (7.22)	2.37 [d] (5.17)	2.58 [gh] (6.20)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	4.31 [b] (18.08)	3.52 [ab] (11.97)	3.92 [bc] (15.03)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	4.50 [a] (19.76)	3.48 [ab] (11.72)	4.00 [ab] (15.74)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	4.01 [d] (15.60)	3.45 [abc] (11.45)	3.73 [c] (13.53)
T_9 - Soil solarisation	4.15 [c] (16.74)	3.32 [bc] (10.61)	3.74 [c] (13.68)
T_{10} – POP (2 hand weedings)	4.59 [a] (20.64)	3.71 [a] (13.35)	4.16 [a] (17.00)
T_{11} - Unweeded control	2.69 [g] (6.74)	2.17 [d] (4.23)	2.43 [h] (5.49)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	3.12 [c] (9.26)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	3.74 [a] (13.53)	-
CD values (5%)	0.13	0.30	0.22

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 25. Effect of weed management practices on dry yield of ginger (t/ha)

Treatments	First year	Second year	Pooled
T_1 – Pendimethalin 1.5 kg/ha	1.86 [e] (3.48)	1.38 [d] (1.92)	1.64 [g] (2.70)
T_2 – Oxyfluorfen 0.2 kg/ha	1.92 [e] (3.69)	1.85 [bc] (3.42)	1.88 [f] (3.56)
T_3 – Metribuzin 0.525 kg/ha	1.74 [f] (3.04)	1.33 [de] (1.79)	1.55 [h] (2.41)
T_4 – Glyphosate 0.8 kg/ha	1.77 [f] (3.16)	1.37 [de] (1.91)	1.59 [g] (2.53)
T_5 – Glufosinate ammonium 0.45 kg/ha	1.51 [g] (2.28)	1.32 [de] (1.75)	1.42 [I] (2.02)
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	2.39 [b] (5.72)	2.01 [ab] (4.08)	2.21 [c] (4.90)
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	2.49 [a] (6.25)	1.99 [ab] (3.97)	2.26 [b] (5.11)
T_8 - Metribuzin 0.525 kg/ha + 1 HW	2.22 [d] (4.93)	1.97 [ab] (3.90)	2.10 [e] (4.41)
T_9 - Soil solarisation	2.30 [c] (5.30)	1.89 [bc] (3.59)	2.11 [d] (4.45)
T_{10} – POP (2 hand weedings)	2.55 [a] (6.53)	2.12 [a] (4.53)	2.35 [a] (5.53)
T_{11} - Unweeded control	1.45 [g] (2.13)	1.19 [e] (1.43)	1.33 [j] (1.78)
T_{12} - Pendimethalin 1.5 + Glyphosate 0.8 kg/ha	-	1.77 [c] (3.14)	-
T_{13} - Oxyfluorfen 0.2 + Glyphosate 0.8 kg/ha	-	2.14 [a] (4.59)	-
CD values (5%)	0.12	0.21	0.17

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 26. Correlation between dry matter of weeds and yield of ginger

Yield / Dry matter of weeds	First year	Second year
45 DAP	-0.844	-0.825
90 DAP	-0.898	-0.876
180 DAP	-0.936	-0.917

Table 27. Economics of ginger cultivation under various weed management practices during first year (ha)

Treatments	Cost of cultivation other than weed control (Rs.)	Cost for weed control (Rs.)	Total cost of cultivation (Rs.)	Yield (t/ha)	Return (Rs.)	Net Returns (Rs.)	B:C ratio
T_1 – Pendimethalin 1.5 kg/ha	180475	1693	182168	11.02	661200	479032	3.6
T_2 – Oxyfluorfen 0.2 kg/ha	180475	1407	182352	11.69	701400	519048	3.8
T_3 – Metribuzin 0.525 kg/ha	180475	1307	182152	9.61	576600	394448	3.1
T_4 – Glyphosate 0.8 kg/ha	180475	1217	181972	10.02	601200	419228	3.3
T_5 – Glufosinate ammonium 0.45 kg/ha	180475	3347	186232	7.22	433200	246968	2.3
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	180475	10693	200942	18.08	1084800	883858	5.3
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	180475	10407	200352	19.76	1185600	985248	5.9
T_8 - Metribuzin 0.525 kg/ha + 1 HW	180475	12347	204232	15.6	936000	731768	4.6
T_9 - Soil solarisation	180475	50,000	230475	16.74	1000400	769925	4.3
T_{10} – POP (2 hand weedings)	180475	40000	256475	20.64	1238400	981925	4.8
T_{11} - Unweeded control	180475	0	180475	6.74	404400	223925	2.2

Table 28. Economics of ginger cultivation under various weed management practices during second year (ha)

Treatments	Cost of cultivation other than weed control (Rs.)	Cost for weed control (Rs.)	Total cost of cultivation (Rs.)	Yield (t/ha)	Return (Rs.)	Net Return (Rs.)	B:C ratio
T_1 – Pendimethalin 1.5 kg/ha	180475	1693	182924	5.67	340200	157376	1.8
T_2 – Oxyfluorfen 0.2 kg/ha	180475	1407	182352	10.10	606000	423648	3.3
T_3 – Metribuzin 0.525 kg/ha	180475	1307	182152	5.26	315600	133448	1.7
T_4 – Glyphosate 0.8 kg/ha	180475	1217	181972	5.63	337800	155828	1.8
T_5 – Glufosinate ammonium 0.45 kg/ha	180475	3347	186232	5.17	310200	123968	1.6
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	180475	10693	200942	11.97	718200	517258	3.5
T_7 - Oxyfluorfen 0.2 kg/ha + 1 HW	180475	10407	200352	11.72	703200	502848	3.5
T_8 - Metribuzin 0.525 kg/ha + 1 HW	180475	12347	204232	11.45	687000	482768	3.3
T_9 - Soil solarisation	180475	50,000	230475	10.62	637200	406725	2.7
T_{10} – POP (2 hand weedings)	180475	40000	256475	13.35	801000	544525	3.1
T_{11} - Unweeded control	180475	0	180475	4.23	253800	73325	1.4
T_{12} - Pendimethalin + Glyphosate	180475	1973	182448	9.27	556200	373752	3.0
T_{13} - Oxyfluorfen + Glyphosate	180475	1687	182162	13.53	811800	629638	4.4

Table 29. Effect of weed management practices on microbial count in soil (cfu)

Treatments	**Fungus (* 10^3)**			**Bacteria (* 10^5)**		
	First year	**Second year**	**Pooled**	**First year**	**Second year**	**Pooled**
T_1 – Pendimethalin	6.25 ^{c} (38.66)	5.20 ^{cd} (26.66)	5.75 ^{c} (32.67)	3.33 ^{d} (10.66)	2.88 ^{d} (8.00)	3.13 ^{d} (9.33)
T_2 – Oxyfluorfen	5.04 ^{d} (25.00)	3.75 ^{e} (13.66)	4.45 ^{d} (19.33)	2.64 ^{e} (6.66)	2.78 ^{d} (7.33)	2.73 ^{d} (7.00)
T_3 – Metribuzin	6.46 ^{bc} (41.33)	5.46 ^{bcd} (29.33)	5.98 ^{bc} (35.33)	3.62 ^{d} (12.66)	3.48 ^{c} (11.66)	3.55 ^{c} (12.17)
T_4 – Glyphosate	6.91 ^{b} (47.33)	6.01 ^{b} (35.66)	6.48 ^{b} (41.5)	4.70 ^{bc} (21.66)	4.26 ^{b} (17.66)	4.49 ^{b} (19.67)
T_5 - Glufosinate ammonium	6.67 ^{bc} (44.00)	5.60 ^{bc} (31.00)	6.16 ^{bc} (37.5)	4.55 ^{c} (20.33)	4.22 ^{b} (17.33)	4.39 ^{b} (18.81)
T_9 - Soil solarisation	6.95 ^{b} (48.00)	6.03 ^{b} (36.00)	6.51 ^{b} (42.00)	4.67 ^{bc} (19.33)	4.56 ^{b} (20.33)	4.50 ^{b} (19.83)
T_{10} – POP	7.72 ^{a} (59.33)	6.90 ^{a} (47.33)	7.33 ^{a} (53.33)	5.27 ^{a} (27.33)	5.11 ^{a} (25.66)	5.19 ^{a} (26.50)
T_{11} - Unweeded control	7.69 ^{a} (58.66)	6.88 ^{a} (47.00)	7.30 ^{a} (52.83)	5.11 ^{ab} (25.66)	4.66 ^{ab} (21.33)	4.89 ^{ab} (23.50)
T_{12} - Pendimethalin + Glyphosate	-	4.86 ^{d} (23.33)	-	-	2.66 ^{d} (6.66)	-
T_{13} - Oxyfluorfen + Glyphosate	-	4.05 ^{e} (16.00)	-	-	2.73 ^{d} (7.00)	-
CD values (5%)	0.53	0.61	0.58	0.48	0.47	0.48

$\sqrt{X+1}$ transformed values. Original values are given in the paranthesis. In a column, values followed by same alphabets do not differ significantly in DMRT

Table 30. Residue analysis of herbicides in ginger during first year (µg/g)

Treatments	Herbicide residue
T_1 – Pendimethalin- 1.5 kg/ha	BDL
T_2 – Oxyfluorfen- 0.2 kg/ha	BDL
T_6 - Pendimethalin 1.5 kg/ha + 1 HW	BDL
T_7 – Oxyfluorfen 0.2 kg/ha + 1 HW	BDL
T_{10} – POP (2 hand weedings)	BDL

Discussion

5. DISCUSSION

The results of the experiment on ‘‘Weed management in ginger (*Zingiber officinale* Rosc.)” are discussed below.

Part I

5.1. Survey of weed flora of ginger in the major ginger growing districts of Kerala

It was revealed from the survey that infestation of broad leaved weeds is more than grasses and sedges in all the four districts. The results of the study indicated wide variation in weed species in the four districts surveyed. The total number of dicots, monocots and sedges observed in the four districts surveyed were in the order of 69.1 per cent (47 nos.), 22.0 per cent (15 nos.) and 8.8 per cent (6 nos.) respectively in Palakkad district, 74 per cent (39 nos.) grasses 19.2 per cent (10 nos.) and sedges 6.8 per cent (4 nos.) respectively in Thrissur district, 77 per cent (49 nos.) 16.4 per cent (10 nos.) and 6.6 per cent (4 nos.) respectively in Wayanad district, and 80 per cent (40 nos.), grasses 16 per cent (8 nos.) and sedges were 4 per cent (2 nos.) respectively in Idukki district .

The distribution and dominance of weed species observed in Thrissur and Palakkad districts (plains) were entirely different due to the variation in soil and climatic conditions. In Palakkad area, most of the soils are alluvial in nature and area is receiving an annual rainfall of 207.59 cm. In this district ginger is mostly cultivated in traditional rice fields, because of the higher profit from ginger than rice. The crop is being cultivated on a commercial scale after providing deep trenches for drainage. Thus, weed flora in these fields are those typically associated with rice. Based on the SDR values, following are the ten most dominant weed species observed in the Palakkad district. *Fimbristylis miliacea, Scoparia dulcis, Ageratum conyzoides, Mollugo pentaphylla, Ludwigia parviflora, Eclipta alba, Cyperus iria, Leptochloa chinensis, Emilia sonchifolia* and

Lindernia crustacea. Of these, 7 species were dicots, one species monocots and 2 species sedges.

On the contrary, in Thrissur district, ginger is mostly cultivated in laterite soils in the uplands and area is receiving an annual rainfall of 312.9 cm. So weeds commonly seen in Thrissur district are upland weeds. Based on the SDR values, *Cyperus difformis, Alternanthera betzickiana, Physalis minima, Vernonia ceneria, Spilanthes paniculata, mollugo disticha, Cyperus haspan, Brachiaria* sp., *Ageratum conyzoides* and *Eragrostis japonica* are the prominent weed species observed in Thrissur district. Out of these, 6 species were dicots, 2 species monocots and 2 species sedges. Among broad leaved weeds, *Alternanthera bettzickiana* had the highest SDR value (8.054). *Alternanthera bettzickiana* is a newly introduced weed species in Kerala which is spreading fast in cultivated and non cultivated areas (Bijoy *et al.*, 2009).

Coming to the weeds in ginger in the high range areas of Kerala, based on SDR values, *Spilanthes radicans* and *Ageratum conyzoides* emerged as the most dominant broad leaved weed species in Wayanad areas (SDR: 27.134 and 23.964 respectively). The other important weed species observed in the Wayanad district were *Crassocephalum crepidioides, Scoparia dulcis Erigeron Canadensis, Mimosa pudica, Blumea* sp., *Ludwigia parviflora, Spermacoce ocymoides* and *Digitaria ciliaris* etc. Among these, 9 species were dicots and 1 species monocots. These weeds are typical to high range areas because of the favorable climatic condition of that particular area. Similar weeds were observed in the tea plantations of high ranges of Kerala by Abraham and Rathish (2009).

In Idukki district which also come under high ranges, *Ageratum conyzoides* and *Spilanthes radicans* were the most dominated broad leaved weed species (SDR: 10.841 and 10.160 respectively). The other important weed species observed based on SDR values were, *Crassocephalum crepidioides, Blumea* sp. *Bidens pilosa* var. *minor, Scoparia dulcis, Vernonia cineria, Mitracarpus* sp., *Synedrella nodiflora* and *Spermacoce ocymoides* etc. The most dominant weed species observed in Idukki district based on the SDR values are dicots.

The weed species observed in Idukki and Wayanad districts were almost the same, may be due to the similar soil and climatic conditions in the high range areas of Kerala. At the same time, variation in weed species was observed between the plains and the high range ecosystems of Kerala due to the variability in climatic conditions, mainly temperature and soil type. The results indicated that the growth and distribution of weed flora largely depend on the climatic conditions of the region and soil type.

Comparison of the weed flora over the four districts shows that the weed species *Ageratum conyzoides, Scoparia dulcis, Ludwigia parviflora, Cyperus iria, Mimosa pudica* and *Eragrostis japonica* are seen both in plains and high ranges. These weeds are usually seen in the annual crops like vegetables, tubers, spices etc. The distribution of these weeds is not affected by variation in climate or soil type, they mainly grow in association with the micro climate under crops.

Part II

5.2. Field experiment on management of weeds in ginger.

5.2.1. Studies on weeds

5.2.1.1. Weed spectrum, density, and dry weight

The results of the weed growth, count and dry matter production are presented in Table 6 to 11. It was found that broad leaved weeds accounted for the major portion of the weed flora of the ginger field. During 2013-14, of the total weed flora present in the ginger field, 68 per cent were broad leaved during initial stage of crop growth (45 DAP) (Fig. 3) which increased to 70 per cent at 180 DAP in unweeded control. Grasses constituted 18 per cent during the initial phase of crop growth (45 DAP) and then increased to 19 per cent by180 DAP (Fig. 4-5). During second cropping period (2014-15), the total broad leaved population was 70 per cent during the initial stage of crop growth (45 DAP) and then increased to

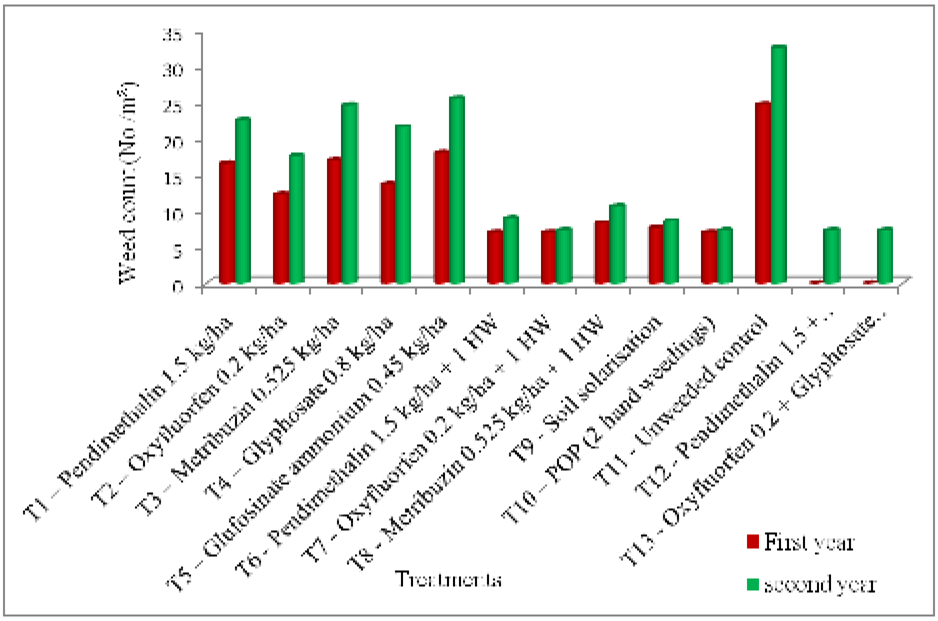


Fig.3. Weed count at 45 DAP (No./m^2)

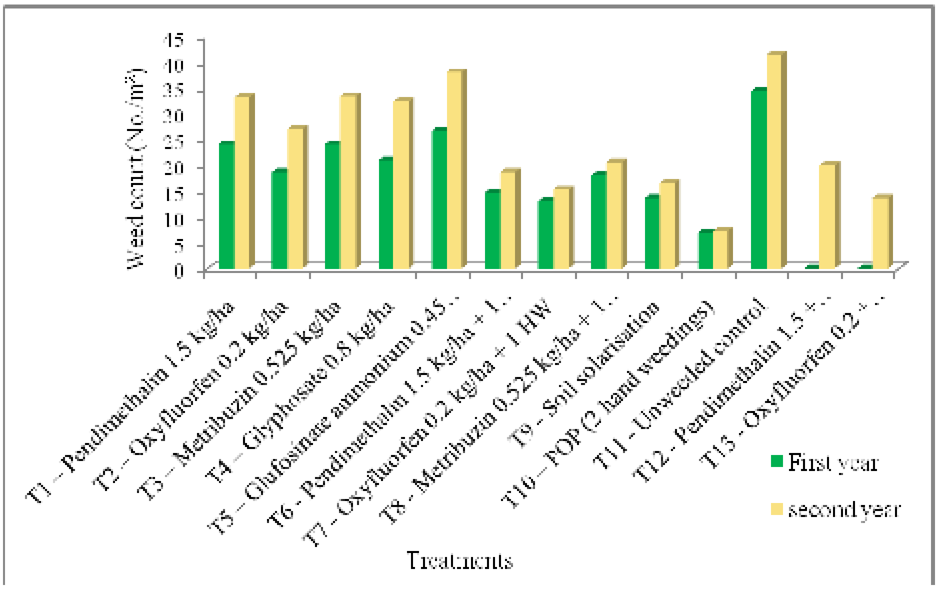


Fig.4. Weed count at 90 DAP (No./m^2)

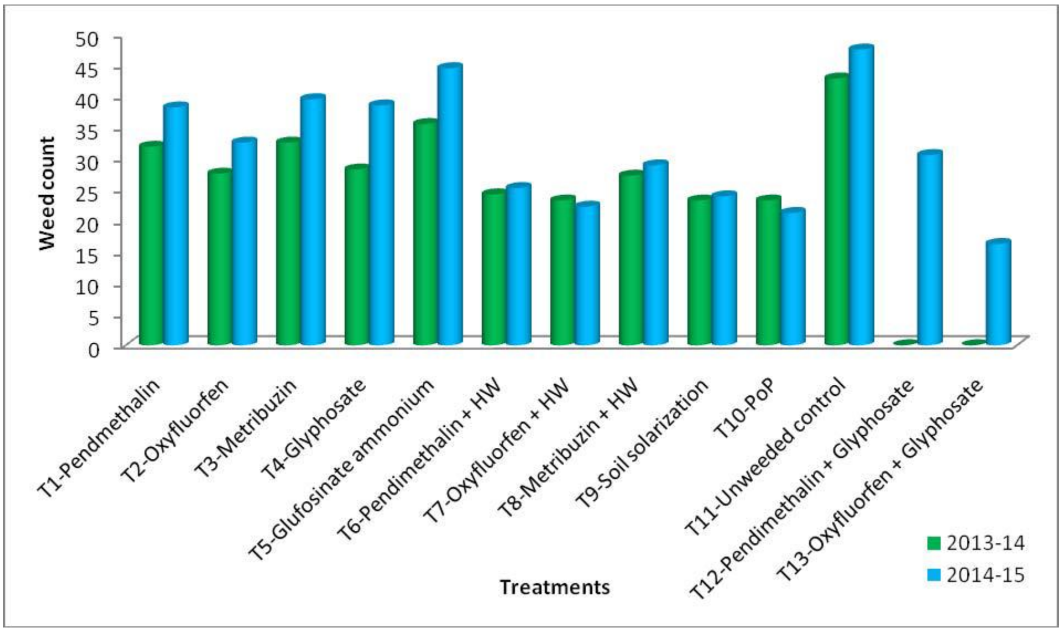


Fig. 5. Weed count at 180 DAP

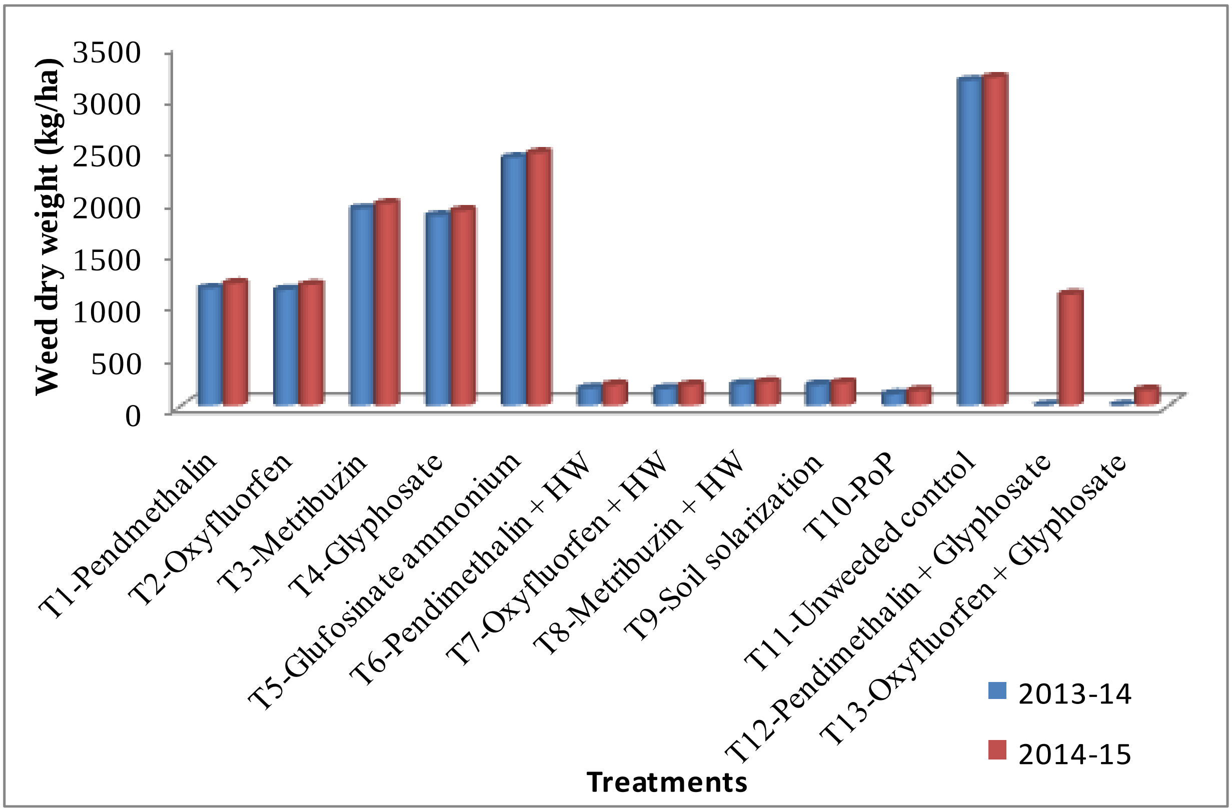


Fig. 6. Weed dry weight (kg/ha) at 180 DAP

74 per cent by 180 DAP. Of the total weed population, grasses occupied 17 per cent at 45 DAP and there was no change at 180 DAP in unweeded control. During 2013-14, in the initial stage of observation, 15 per cent of total weed count was sedges and it reduced to 10 per cent by 180 DAP. The total sedge population was decreased from 12 at 45 DAP to 8 per cent at 180 DAP.this is due to luxurious growth of broad leaved weeds and grasses like *Ageratum, Alternenthera, Borreria, Pennisetum* which suppressed the growth of sedges. Compared to the first year, the weed population was more in 2014-15. This may be due to the variability in climatic conditions, especially the distribution of rainfall. The distribution of rainfall during 2013 April, May, June were in the order of 0, 99.10 and 1031.8 mm respectively while during 2014 it was in the order of 61.0, 323.6 and 469.8 mm respectively. The distribution of rainfall was more uniform during 2014-15, which was more favourable for better growth of crops and weeds.

The pooled data clearly shows that hand weeding is the best treatment to control weed growth in ginger. Two hand weedings at 45 and 90 DAP, gave good weed control during the entire period of crop growth. Compared to the pre emergence herbicide oxyfluorfen, weed population was lesser in POP by 52, 40 and 26 per cent respectively at 45, 90 and 180 DAP of ginger growth. When pendimethalin or oxyfluorfen alone were applied as pre emergence (immediately after planting T_1 and T_2) they could control the weeds only during the initial stage. When these treatments were combined with hand weeding at 45 DAP (T_6 and T_7) reasonable control of the weeds over the entire period of crop growth could be obtained. The population of broad leaved weeds present in pre emergence herbicide pendimethalin or oxyfluorfen was more compared to grasses. Kumar *et al.* (2013) also observed that efficacy of oxyfluorfen and pendimethalin was more on grasses than broad leaved weeds. Between oxyfluorfen and pendimethalin, oxyfluorfen resulted in more prolonged weed suppression. This is because oxyfluorfen is strongly adsorbed on the soil surface and leaching to the lower layers is lesser than pendimethalin. Earlier studies have also shown the superiority of oxyfluorfen for prolonged weed control in rice (Nimmy, 2015). Among the pre emergence herbicides, Metribuzin (T_3) was least effective in reducing the weed population. Among the post emergence herbicides tried, glyphosate (T_4) and glufosinate ammonium (T_5) were also not very effective in reducing the weed population in the ginger crop compared to other herbicides. This may be due to the fact that, glyphosate controlled only the already germinated weeds when it was sprayed 25 DAP. The weeds which got germinated thereafter from the weed seed bank present in the soil could not be controlled by glyphosate. In the case of glufosinate ammonium, being contact in action it permitted re growth of the weeds after the initial drying. It could be seen that compared to unweeded control, there was conspicuous reduction in population of the weeds.

Soil solarization also resulted in good control of weeds. Sainudheen (2000) has also reported the effect of solarization on weed control in another study conducted in vegetables in KAU. Solarization has two complimentary effects; (1) inducing the emergence of dormant propagules and foliar scorching of emerged plants under plastic cover and (2) decreased weed emergence after removal of the polythene sheets (Horowitz *et al.*, 1983). Reduction in weed germination in solarized beds due to the induction of secondary dormancy by relatively high temperature has been reported by Koller (1972). Exposure of seeds to temperature above optimum for germination results in a reduction of the germination rate, possibly due to denaturation of functional protein. Similar findings have been reported by Lewitt (1980) and Taylorson and Hendricks (1977).

Among the additional treatments tried during 2014-15, oxyfluorfen + glyphosate was the best combination for reducing the weed population and it was on par with hand weeding (POP). When pre emergence herbicide alone or post emergence herbicide glyphosate alone were applied, the weed suppression was not satisfactory. But glyphosate combined with oxyfluorfen resulted in good reduction in weed population. This is because, glyphosate could take care of the already germinated weeds (the weeds which emerged up to the germination of ginger ie. about 30 days after planting) and oxyfluorfen could prevent the germination of weed seeds for another two to three months.

The pooled data of weed dry matter production depicted in Table 15 (Fig. 6) shows that at 45 DAP, significant reduction in weed dry weight accounting to 96 per cent reduction compared to unweeded control (T_{11}) was observed in hand weeding (T_{10}). This was because of the reduction in weed count due to the hand weeding done at 45 DAP in this treatment (T_{10}). Pendimethalin and oxyfluorfen followed by hand weeding (T_6 and T_7) also resulted in 87.0 and 87.7 per cent lower weed dry matter compared to T_{11}. This was due to the effect of Pendimethalin and oxyfluorfen on weed control in the initial stages of weed growth followed by the effect of hand weeding at 45 DAP.

The effects of pre emergence herbicides, oxyfluorfen and Pendimethalin on weed dry matter production was lesser than that of combination of these herbicides with hand weeding. Nevertheless, both of these could reduce the weed dry weight by 82 per cent compared to unweeded control. The effectiveness of pre emergence herbicides on weed control during the initial stages of crop growth has been reported by Leela (1993) in vegetables, where Pendimethalin and oxyfluorfen were found good for early weed control. Decrease in weed dry weight by pre emergence application of Pendimethalin and oxyfluorfen was also reported by Singh *et al.* (1993) in capsicum.

Soil solarization also could significantly reduce the weed dry matter production by 80.4 per cent at 45 DAP due to the reduced emergence of weeds. Hendricks and Taylorson (1976) reported that heating weed seeds from 30.0 - 35.0 ^{o} C modified the membrane permeability which resulted in the leakage of endogenous amino acids which in turn reduced the germination rate. They also reported that the reduction in weed population may be due to a combination of factors like thermal killing of weeds, inducing seed dormancy, breaking of seed dormancy through production of carbon dioxide and other gases in soil, altering seed metabolism or action of soil micro flora on the weakened seeds, may all be responsible for the destruction of weeds under mulch.

Weed dry weight in post emergence herbicides applied plots (T_4 and T_5) was higher compared to other treatments though they were significantly superior to unweeded control. Between glufosinate ammonium and glyphosate, the latter was more efeective on suppression of weed growth. This is because of the fact that glufosinate ammonium, being a contact herbicide, induces re growth of the weeds after the initial drying while glyphosate results in complete killing of the weeds sprayed, as it is a systemic in nature. Sainudheen (2000) and Ameena *et al.* (2013) also reported advantage of directed application of glyphosate for weed control in vegetables.

Among the additional treatments tried during 2014-15, oxyfluorfen + glyphosate, recorded significant reduction in weed dry weight (95 per cent compared to T_{11}) at 45 DAP and was on par with hand weeding (POP). This was because of reduction in weed count due to the combined effect of pre emergence and post emergence herbicide on germinating and already germinated weeds.

Weed dry weight increased in all the treatments by 90 and 180 DAP. Here also the highest reduction in weed dry weight was observed in T_{10} which received hand weeding (POP). At 90 and 180 DAP, T_{10} was reduced weed dry weight by 90 and 91 per cent respectively over T_{11}. This was followed by T_6 and T_7. Soil solarization was better than pre emergence herbicides alone (T_1 and T_2). It was found that even a single spray of combination of pre emergence and post emergence herbicide is more effective than pre emergent herbicide alone, pre emergence herbicide + hand weeding, soil solarization or post emergent herbicides in suppressing weeds. But the results pertain to only a single season and needs to repeat for conformation. The effective weed control by using combination of pre emergence and post emergence herbicide has been reported by Sajeera (2014) in Ash gourd.

5.2.1.2. Nutrient removal by weeds

Nutrient removal by weeds presented in Table 16, 17 and 18 (Fig. 7-9) followed a trend similar to dry matter production. At 45 DAP, negligible removal of nutrients in hand weeded plots is due to very low weed growth. Nagar (2005) in coriander also reported the lowest depletion of nutrients by two hand weedings. The reduction in nutrient removal by weeds registered in oxyfluorfen and pendimethalin and metribuzin followed by hand weeding (T_6, T_7 and T_8) was due to weeding at 45 DAP and resultant lower weed dry matter production recorded at this stage. Choubey *et al.* (1999) in rice reported reduced nutrient removal by weeds in the combination of manual weeding and chemical weeding. Third lowest removal of N, P and K by weeds was recorded by pendimethalin and oxyfluorfen (T_1 and T_2) due to their weed suppression ability up to 45 DAP. Next to T_1 and T_2, soil solarization could record significant reduction in nutrient removal by weeds. This may be due to the reduction in weed count in solarized plots leading to reduced weed dry matter production in the early stages of ginger growth. Similar result was observed by Vilasini (1996) in ginger.

The newly added treatment, oxyfluorfen + glyphosate also recorded negligible removal of nutrients by weeds at 45 DAP and was on par with PoP. It is due to very low weed growth and their dry matter production at 45 DAP of ginger. Since the data pertains to a single year, the treatment needs further study.

The uptake of nutrients by weeds increased with progressive increase in crop growth stages (90 and 180 DAP), as the weed dry matter production also increased with time. By 90 and 180 DAP also, significant reduction in nutrient removal was observed in hand weeded plots (PoP). The second best treatments which substantially reduced nutrient uptake by weeds at 90 and 180 DAP as at 45 DAP were pre emergence herbicides + HW (T_6 and T_7) due to reduced weed dry matter production. At 45 DAP, pre emergence herbicides pendimethalin and oxyfluorfen alone (T_1 and T_2) were the third best treatments which reduced nutrient removal by weeds. But at 90 and 180 DAP, soil solarization (T_9) emerged

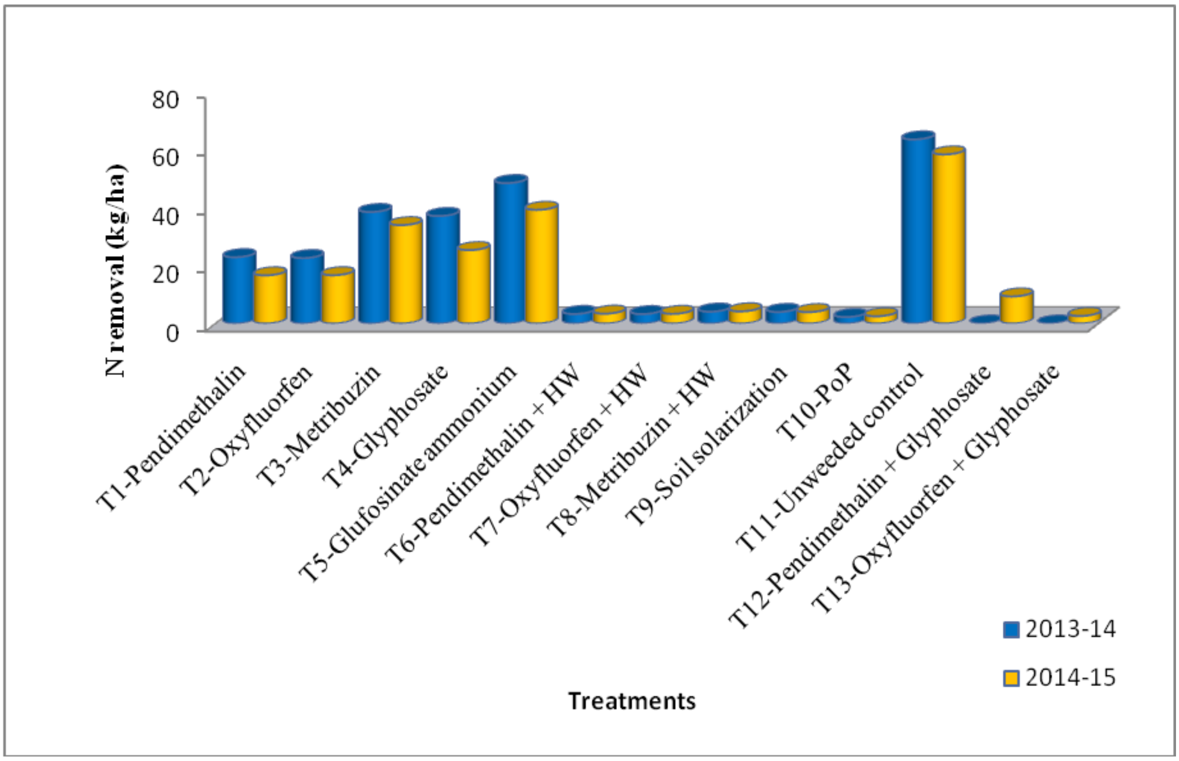


Fig. 7. N removal by weeds (kg/ha) at 180 DAP

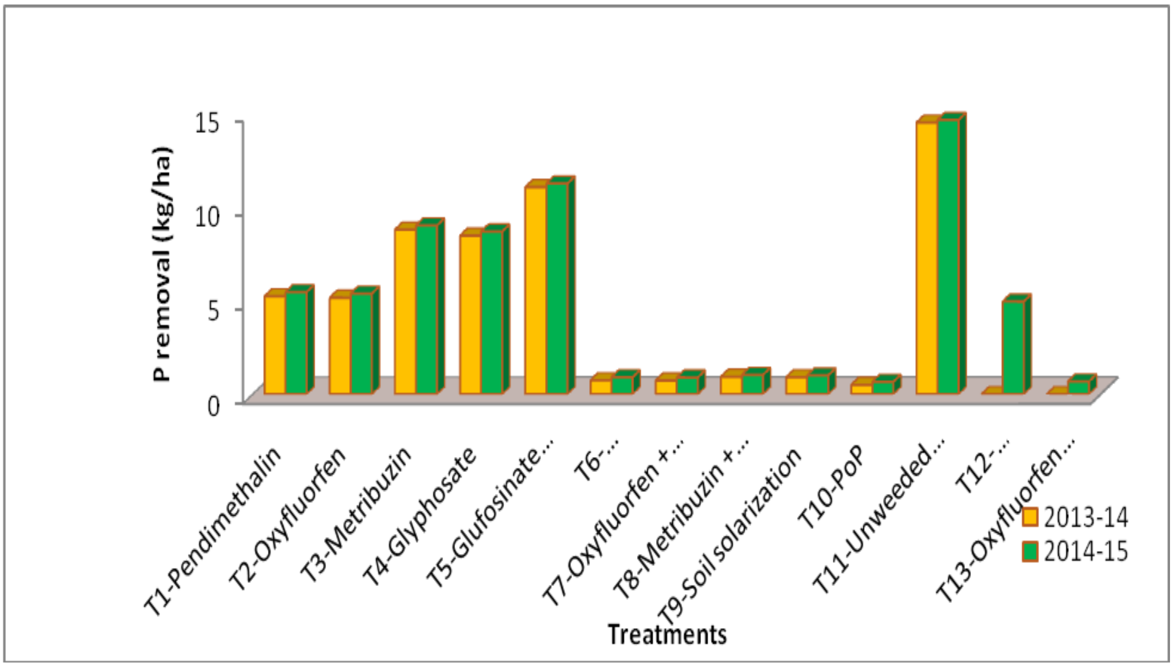


Fig. 8. P removal by weeds (kg/ha) at 180 DAP

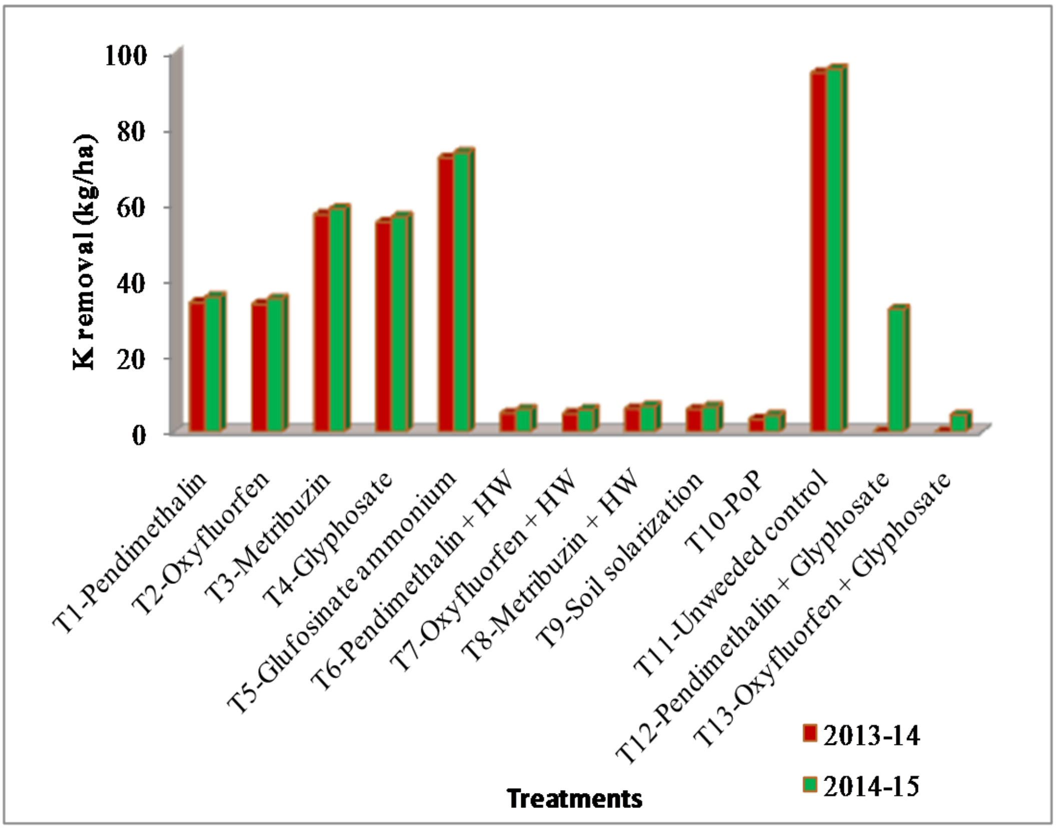


Fig. 9. K removal by weeds (kg/ha) at 180 DAP

as the third best treatment. This is because the weed suppression ability of soil solarization continued up to 180 DAP, while that of T_1 and T_2 declined after 45 DAP. At 90 and 180 DAP also a single spray of the combination of pre emergence and post emergence herbicides oxyfluorfen + glyphosate was very effective in reducing N, P and K removal by weeds.

5.2.2. Studies on crop

5.2.2.1. Germination of ginger

Germination of ginger (Fig. 3) showed that the per cent germination was almost similar in all the treatments. All the treatments recorded more than 90 per cent germination. The herbicides did not affect germination seriously. The effect of treatments was not consistent between two seasons.

5.2.2.2. Plant growth parameters

The pooled data of plant growth parameters like number of leaves/tiller, height of plant and number of tillers per plant (Fig. 4, 5 and 6) shows that the highest values were recorded in hand weeding (T_{10}). This may be due to less weed population and weed dry matter recorded at various stages of crop growth which favored better plant nutrition and growth. Nutrient removal by weeds also recorded lower values in these treatments compared to all other treatments. Plants could get the available nutrients in the soil for their better growth and development. As the height of the plant was more, more number of leaves was formed. The leaves number in this treatment was 19.08 compared to 9.87 in unweeded check, where the crop suffered severe weed competition.

Pre emergence herbicides followed by hand weeding (T_6, T_7 and T_8) also resulted in the second best values of number of tillers, number of leaves/tiller and height of plant next to T_{10} because of lower weeds count, weed dry matter production and nutrient removal by weeds at different stages of crop growth, due to the effect of pre emergence herbicides on germinating weeds and hand weeding adopted at 60 DAP which favored better nutrition for crop growth.

Soil solarization also could record significantly higher values of number of tillers, number of leaves/tiller and height of plant. Increase in the plant growth parameters as a result of solarization was reported in ginger (Vilasini, 1996), chillies (Sainamol, 1992), wheat (Cook *et al.*, 1987) and peach seedlings (Stapleton and DeVay, 1982). Apart from weed competition, other favourable effects like good soil moisture regime, soil temperature etc. were found to promote the plant growth in solarized fields (Gutal *et al.*, 1992; Chinnathurai *et al.*, 2012). The higher nutrient uptake by crop and dry matter production in this treatment indicates favourable effect of soil solarization on crop growth. Similar result was also reported by Sainudheen (2000) in bhindi.

All the growth parameters like tiller number, number of leaves per tiller and height of the plant were significantly lower in post emergence herbicide sprayed plots (T_4 and T_5) and in metribuzin (T_5) sprayed plot (pre emergence herbicide) due to comparatively higher weed dry weight and nutrient removal by weeds. Pendimethalin and oxyfluorfen alone sprayed plots (T_1 and T_2) recorded better growth parameters than T_3, T_4 and T_5 due to better control of weeds and lower removal of nutrient by weeds.

The negative effect of weed competition on various plant growth parameters are evident from the low values observed in unweeded check. Similar results were also noticed by Manjunath *et al.* (1989) and Singh and Singh (1994) in onion.

The variation in tiller number, number of leaves per tiller and height of plants between post emergence herbicides glyphosate (T_4) and glufosinate ammonium (T_5) and unweeded control (T_{11}) was not very wide, probably because crop experienced almost similar weed competition in these treatments.

The additional treatment combination of oxyfluorfen and glyphosate (T_{13}) tried in 2014-15, also recorded higher values of plant growth parameters like number of tillers, number of leaves/tiller, height of plant etc. which were on par with POP. This is due to less weed population and weed dry matter production recorded at various stages of crop growth which favoured better plant nutrition and growth. Nutrient removal by weeds also recorded lower values in these treatments compared to all other treatments. The effect of combined application oxyfluorfen and glyphosate to control weeds in ash gourd was reported by Sajeera (2014) in Ash gourd.

5.2.2.3. Yield

The pooled data of fresh weight of rhizome (Fig. 7) shows that, the highest fresh rhizome yield was recorded in hand weeding (17.0 t/ha) (T_{10}) which is 67 per cent more than the unweeded control. Least weed growth and nutrient removal by weeds were also observed in this treatment compared to others and this helped the crop to make use of the nutrients applied which favorably influenced the crop growth and fresh rhizome yield. Pre emergence herbicides followed by hand weeding (T_7 and T_6) were the next best treatments after POP which resulted in the yields of 15.74 and 15.03 t/ha respectively. These treatments produced 65 and 63 per cent more yield than unweeded control. Here also the higher yields were due to less competition from weeds which favoured better vegetative growth.

Soil solarization was the third best treatment which also could significantly increase the yield of ginger (13.68 t/ha) compared to all other treatments. The yield was about 60 per cent higher in solarization compared to unweeded control. Abdul-Baki *et al.* (1992) reported 95 per cent increase in yield of tomato by solarization. Less competition from weeds for space and low nutrient removal by weeds in soil solarized plots contributed to better growth of ginger plants. Yield increase by solarization has been reported by several workers in a variety of crops like chilly (Sainamol, 1992); cowpea (Chandran, 1989; Nair *et al.*, 1990) and gypsophylla (Gamliel *et al.*, 1993).

It was found that the fresh rhizome yield was lowest in unweeded control (T_{11}) followed by post emergent herbicide glufosinate ammonium (T_5). This was due to high weed competition, as indicated by high weed dry matter production at all stages of crop growth. Due to this, nutrient removal by weeds was also high. Ultimately it affected the vegetative growth of the plant. Post emergence herbicides glyphosate (T_4) and glufosinate ammonium (T_5) were not very effective in increasing ginger yield due to their ineffectiveness in checking weed growth in crop. Among the pre emergence herbicide, metribuzin also was not effective due to same reason. Between the pre emergence herbicides pendimethalin (T_1) and oxyfluorfen (T_2) the yield of rhizome was more in T_2 because oxyfluorfen resulted in more prolonged weed suppression. This is because oxyfluorfen is strongly adsorbed on the soil surface and leaching to the lower layers is lesser than pendimethalin. Earlier studies have also shown the superiority of oxyfluorfen for prolonged weed control in rice (Nimmy, 2015).

The newly added treatment oxyfluorfen + glyphosate (T_{13}) tried in 2014-15, also recorded the higher fresh rhizome yield and was on par with hand weeding (T_{10}). In this treatment 69 per cent yield increase was observed compared to unweeded control. Here also the weed competition was less compared to other treatments and this helped the crop to make use of the nutrients applied which favorably influenced crop yield. A single spray of pre emergence herbicides pendimethalin and oxyfluorfen alone was not very effective in controlling weed growth effectively so reduction in number of tillers per plant and yield was recorded in these treatments compared to the combination treatment (T_{13}). This may be due to the fact that effectiveness of pre emergence herbicides lasted only for a period of short span of about two to three months after that uncontrolled weed growth occurred and adversely affected crop performance. Similar results have been reported by Sajeera (2014) in Ash gourd.

Correlation between fresh yield of ginger and dry matter production of weeds at 45, 90 and 180 DAP during both the shows that the negative correlation. The yield of rhizome is decreased with increase in weed dry matter production. The crop is more sensitive to weed competition during the entire stages of crop growth.

The yield of dry ginger also followed similar trend as that of fresh weight of ginger rhizome. Pooled data of dry weight of ginger presented in Table 24 (Fig. 7) shows that the highest value was registered in the treatment hand weeding (T_{10}) (5.53 t/ha). The low values of crop growth parameters and low yield (fresh and dry) were noticed in the treatments where weed competition was severe. Similar results were also reported by Subrao (2010) in brinjal.

Among the additional treatments, oxyfluorfen + glyphosate (T_{13}) registered the highest dry weight of ginger (4.59 t/ha) and it was on par with POP (T_{10}). It can be inferred that better growth parameters, yield attributes and yield recorded in this treatment is due to effective weed management which contributed to the better performance of the crop.

5.2.3. Economics of weed control

During 2013-14, analysis of the returns from the production of ginger under various weed control methods indicated that the highest net return of Rs. 985248/ha could be achieved through the herbicide oxyfluorfen followed by hand weeding (T_7). Here B:C ratio was 5.9. The next best practice in terms of net returns was pendimethalin followed by hand weeding (Rs. 883858/ ha) (T_6) which registered the B:C ratio of 5.3. Reduced cost on weed management and rhizome yield very close to T_{10} made these treatments first and second in terms of net return and B:C ratio. Subrao (2010) reported that the highest B:C ratio of 5.06 with application of pendimethalin at 1.5 kg/ha followed by hand weeding in brinjal.

Though hand weeding gave the highest rhizome yield, because of high cost involved in two hand weedings it was the third best treatment in terms of net return and B: C ratio. Hand weeding gave a net return of Rs. 981925/ ha and a B:C ratio of 4.8. Metribuzin followed by hand weeding was the other better treatment with a high B: C ratio of 4.6 and net return of Rs. 731768/ha. Soil solarization also could record high B:C ratio of 4.3 and recorded a net return of Rs 769925/ha . Cost for weed control was maximum in soil solarization due to the high cost of polythene sheet used in this treatment; however, increased yield resulted in high returns and B:C ratio.

Pre emergence herbicides application alone (T_1, T_2 and T_3) is not promising as it resulted in lower yields due to high weed competition and B:C ratio of only 3.6, 3.8 and 3.1 could be realized. Among the pre emergence herbicides, maximum net return was given by oxyfluorfen (T_2). Panotra *et al.* (2012) found that application of pendimethalin at 1.0 kg/ha increased the net return of French bean significantly over weedy check. Post emergence herbicides Glyphosate and glufosinate ammonium were not promising to give a high net return.

During 2014-15, analysis of the net return and B:C ratio shows that among the regular treatments, hand weeding (T_{10}) gave the highest net return of Rs. 544525 with B: C ratio of 3.1 followed by (T_6) pendimethalin + hand weeding Rs. 517258 and B: C ratio of 3.5 and (T_7) oxyfluorfen + hand weeding (Rs. 502848 and 3.5). Metribuzin followed by hand weeding was the other best treatment which also resulted in high B: C ratio of 3.3 and net returns of Rs. 482768/ha.

The effect of soil solarization (T_9) was less than that of the above treatments and it recorded the net return of Rs. 406725/ha and the B: C ratio of 2.7 during 2014-15. Cost for weed control was maximum in soil solarization due to the high cost of polythene sheet used in this treatment. Among the pre emergence herbicides alone, Oxyfluorfen (T_2) gave a net return of Rs. 423648 and a B: C ratio of 3.3. This is because of the higher yield in T_2 than in T_1 and T_3. The post emergence herbicides Glyphosate and glufosinate ammonium gave very low returns and B: C ratio due to very poor yield of rhizomes in those plots. During 2014-15, the additional treatment T_{13} gave more return of Rs. 629638 and B : C ratio of 4.4 than PoP (T_{10}). Even though hand weeding resulted in high yield on par with Glyphosate + Oxyfluorfen (T_{13}), the net return and B:C ratio of hand weeding treatment were low in this treatment because of the high cost of cultivation due to large number of laborers engaged for hand weeding operation.

If averages of net returns and B: C ratios of two years of the study are taken, highest net returns and B: C ratios are in the order of T_{10}, Rs. 763225 (3.95), T_7, Rs. 744048 (4.7), T_6, Rs. 700558 (4.4), T_8, Rs. 607268 (3.95), T_9, Rs. 588325 (3.5) and T_2, Rs. 471348 (3.55). Though T_{13} gave good yield, net return and B: C ratio during 2014-15, it needs further confirmation by more trials. The study clearly shows that the hand weeding (POP - T_{10}) pre emergence application of pendimethalin or oxyfluorfen followed by hand weeding at 60 DAP in ginger can lead to high profit to the farmer.

5.2.4. Microbial count in soil

Pooled data on the effect of the herbicides on microbial count in soil is presented in Table 27 (Fig. 10). It shows that the maximum microbial population (both fungi and bacteria) was observed in unweeded control (T_{11}) and hand weeding (T_{10}). The microbial population was reduced in the herbicides applied plots. Highest reduction was observed in oxyfluorfen (T_2) and its combination with glyphosate (T_{13}) followed by pendimethalin (T_1) and its combination with glyphosate (T_{12}). The herbicides adversely affect soil microorganisms which are responsible for numerous biological processes essential for crop production.

Bera *et al.* (2013) have reported that microorganisms are able to degrade herbicides and utilize them as a source of biogenic elements for their own physiological processes. However, before degradation, herbicides have toxic effects on microorganisms, reducing their abundance, activity and consequently, the diversity of their communities.

Soil solarisation also recorded comparatively lower microbial population than hand weeding and unweeded control. This may be due to the higher temperature developed inside the polythene sheet. Sharma (2002) also reported that the population of antagonistic microorganisms increased after solarization, however, total microbial population including fungi, bacteria and actinomycetes decreased. Similar result has been reported by Vilasini (1996).

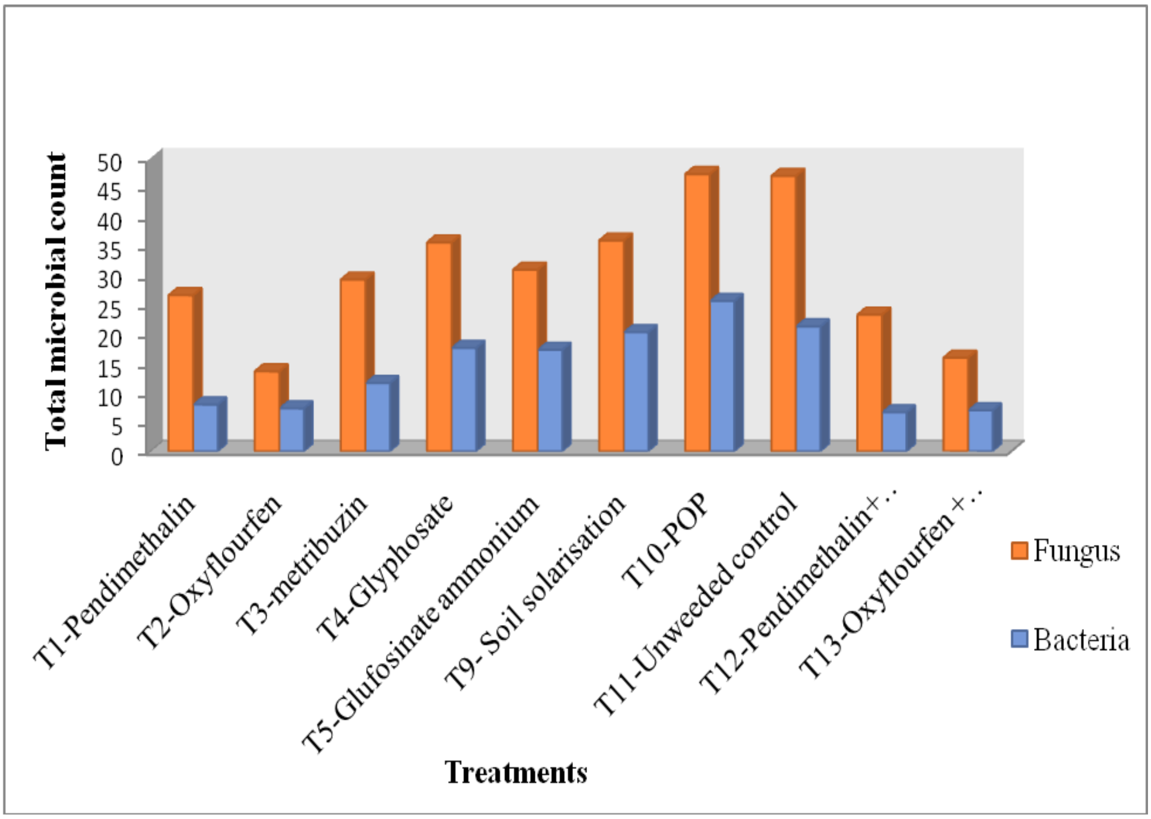


Fig. 10 .Total microbial count in soil – second year (cfu)

5.2.5. Herbicide residue in ginger

The herbicide residue in the harvested fresh rhizomes of ginger is presented in Table 28. It shows that, the herbicide residues were below detectable level in pendimathalin (T_1), oxyfluorfen (T_2), pendimathalin + hand weeding (T_6) and oxyfluorfen + hand weeding (T_7). This may be due to the degradation of herbicides over time and also by luxurious growth of weeds after 45 days of planting. The degradation of herbicides also depends on environmental conditions and microbial population in soil. Similar results were reported by Adhikary *et al.* (2014).

Summary

6. SUMMARY

The present investigation entitled "Weed management in ginger (*Zingiber officinale* Rosc.) was carried out at the Agronomy Farm, College of Horticulture, Vellanikkara during March 2013 to January 2015 using the variety Karthika. The main objective of the investigation was to study the weed flora of ginger in the major ginger growing districts of Kerala and to develop efficient, economic and eco-friendly weed management practices in ginger. The investigation was carried out in two parts.

Part I : Survey of weed flora of ginger in the major ginger growing districts of Kerala

Part II : Field experiment on management of weeds in ginger.

Part I : Survey of weed flora of ginger in the major ginger growing districts of Kerala

Stratified survey was conducted in major ginger growing districts of Kerala namely Waynad, Palakkad, Idikki and Thrissur districts during 2013 and 2014. In each district, five panchayaths were selected and five representative ginger fields were surveyed in each panchayath to study the extent of weed infestation in different agro ecological conditions of Kerala. The survey sites were selected in each district, covering at least 25 ginger growing fields. The observations on the intensity of weed infestation in ginger were recorded from quadrats of one square meter from five random spots and the average was worked out. Based on the average weed count, relative frequency, relative density and summed dominance ratio of important weed species were calculated for each district.

Sixty eight weed species were observed in the ginger growing fields of Palakkad district. Of these the distribution of dicots, monocots and sedges were in the order of 69.1, 22.0 and 8.8 per cent respectively. Based on the SDR values, the most dominant broad leaved weed species observed in the Palakkad district were *Scoparia dulcis, Ageratum conyzoides, Mollugo pentaphylla* and *Ludwigia parviflora* (SDR: 18.101, 17.012, 16.05 and 15.859 respectively). *Leptochloa chinensis* (10.156) was the most dominant grass weed followed by *Echinochloa colona* (7.562). Among the sedges, *Fimbristylis miliacea* and *Cyperus iria* (19.703 10.156) were the dominant species.

In the Thrissur district fifty three weed species were observed. Dicots, monocots and sedges were in the order of 74.0, 19.2 and 6.8 per cent respectively. *Cyperus difformis* (SDR: 8.304) was the most dominant sedge followed by *Cyperus haspan* (SDR: 5.392). Among broad leaved weeds, *Alternanthera betzickiana* had the highest SDR value (8.054). Among the other broad leaved weeds, *Physalis minima* (6.879), *Vernonia cenera* (5.887), *Spilanthes paniculata* (5.639), *Mollugo disticha* (5.516), *Ageratum conyzoides* (5.021), *Oldenlandia umbellata* (4.525) dominated in the crop. Among the grasses, *Brachiaria mutica* (5.205), *Eragrostis japonica* (4.525) and *Setaria sphacelata* (4.399) dominated in Thrissur district.

A total number of sixty one weed species were observed in Wayanad district. Among these the distribution of broad leaved weeds, grasses and sedges was in the order of 77 per cent (49 nos.) 16.4 per cent (10 nos.) and 6.6 per cent (4 nos.) respectively. Based on SDR, *Spilanthes radicans* and *Ageratum conyzoides* emerged as the most dominant broad leaved weed species (SDR: 27.134 and 23.964 respectively). The other important broad leaved weed species observed in this district were *Crassocephalum crepidioides, Scoparia dulcis* and *Erigeron Canadensis*. (SDR: 18.646, 16.372 and 13.746 respectively). The most dominant grass weed was *Digitaria ciliaris* with an SDR value 8.395. Among the sedges, *Cyperus iria* was the dominant species (SDR: 6.210) followed by *Cyperus rotundus* (SDR: 5.384)

A total of fifty weed species were observed in the ginger fields of Idukki district. Dicots, monocots and sedges were in the order of 80.0, 16.0 and 4.0 per cent respectively *Ageratum conyzoides* and *Spilanthes radicans* were the most dominant broad leaved weed species (SDR: 10.841 and 10.160 respectively). The other important broad leaved weeds observed were *Crassocephalum crepidioides, Blumea* sp. and *Bidens pilosa* var. *minor* with SDR values 8.737, 8.056 and 7.560 respectively. Among grasses, *Eragrostis* sp. recorded the maximum population with SDR value of 5.391 followed by *Ischaemum indicum* (5.021).

The weed species observed in Idukki and Wayanad districts were almost the same, may be due to the similar soil and climatic conditions observed in the high range areas of Kerala. At the same time, variation in weed species was observed between the plains and the high range ecosystems of Kerala due to the variability in climatic conditions mainly temperature and soil type. The results indicated that the growth and distribution of weed flora largely depended on the climatic conditions of the region and soil type.

The efficient, economic and eco friendly weed management practice for ginger in different district is hand weeding, mulching and earthing up if labourers are plenty. Soil solarisation is another eco friendly method can adopt for small scale farmers.

Part II : Field experiment on management of weeds in ginger.

The field experiment was laid out in RBD with three replications. The treatments included were pendimethalin @ 1.5 kg/ha after planting but before mulching, oxyfluorfen @ 0.20 kg/ha after planting but before mulching, metribuzin @ 0.525 kg/ha after planting but before mulching, glyphosate @ 0.80 kg /ha just before the emergence of sprouts of ginger, glufosinate ammonium @ 0.45kg/ha just before the emergence of sprouts of ginger, pendimethalin @ 1.5kg/ha + one hand weeding at first mulching, oxyfluorfen @ 0.20 kg/ha + one hand weeding at first mulching, metribuzin @0.525 kg/ha + one hand weeding at first mulching, soil solarization for 45 days before planting ginger, POP recommendations (KAU) and unweeded control

In the second crop season (March 2014 to January 2015) two additional treatments namely, combinations of glyphosate and pendimethalin (T_{12}) and glyphosate and oxyfluorfen (T_{13}) were included. The combinations of these herbicides were applied at twenty five days after planting, just before the emergence of sprouts of ginger.

Weed spectrum

Major weeds found in experimental field in both the years were broad leaved which comprised of *Ageratum conyzoides*, *Alternanthera bettzickiana*, *Borreria hispida* etc. *Pennisetum pedicellatum* and *Brachiaria sp*. were the dominant grass species in the experimental plots. *Cyperus iria* was the only sedge observed in the experimental field and its population was very low compared to other groups.

Weed density

Weed count at 45, 90 and 180 DAP showed that the maximum total weeds count was recorded in T_{11} (28.66/m^2, 41.33/m^2 and 45.33/m^2 respectively) followed by post emergence herbicide glufosinate ammonium (T_5). The lowest weed population was observed in pre emergence herbicides followed by hand weeding (T_6 and T_7), hand weeding alone (T_{10}) and soil solarization (T_9).

Among the additional treatments in 2014-15, combination of oxyfluorfen and glyphosate (T_{13}) significantly lowered the total weed count (16.33/m^2) followed by pre emergence herbicides + hand weeding (T_6 and T_7), hand weeding alone (T_{10}) and soil solarization (T_9) during 2014-15.

Weed dry weight

Weed dry matter at 45, 90 and 180 DAP showed similar trend of weed count. The lowest and significantly reduced weed dry matter was observed in PoP (T_{10}) followed by pre emergence herbicides + hand weeding (T_6 and T_7) at all the stages of observation. Among the additional treatments tried in 2014-2015, oxyfluorfen+glyphosate (T_{13}) registered the lower dry matter production of weeds at all stages and was on par with POP.

Nutrient removal by weeds

Pooled analysis of nutrient removal by weeds at 45, 90 and 180 DAP also shows similar trend of weed dry matter production. At 45, 90 and 180 DAP, significantly the lower N uptake was observed in POP (T_{10}) (2.54 kg/ha) followed by pre emergence herbicides + hand weeding (T_6 and T_7). Both T_6 and T_7 were significantly superior to all other treatments except T_{10}. The next best treatment was soil solarization (T_9) which also could reduce the N uptake by weeds significantly at all stages of observation.

The P removal by weeds was 14.44 kg/ha and 14.58 kg/ha during 2013 to 2014 and 2014 to 2015 in unweeded control, at 180 DAP, whereas only 0.50 kg/ha and 0.66 kg/ha removal was registered in POP (T_{10}). The treatment (T_{10}) was significantly superior to other treatments. This was followed by T_6 and T_7 and was significantly superior to other treatments. Soil solarization resulted in P removal of 0.9 kg/ha and 1.00 kg/ha respectively during 2013 to 2014 and 2014 to 2015 at 180 DAP.

K removal by weeds also followed the similar pattern. There was not much nutrient removal in POP (T_{10}) due to negligible weed growth whereas, in unweeded control K removal was 94.61 kg/ha and 95.58 kg/ha during 2013 to 2014 and 2014 to 2015 at 180 DAP.

Among the additional treatments tried during 2014-15, oxyfluorfen + glyphosate (T_{13}) recorded the lowest N, P and K removal by weeds and which was on par with POP (T_{10}).

Plant growth parameters

Pooled analysis of the experiment showed that the highest number of tillers per plant, number of leaves per tiller and height of plant produced in POP (T_{10}) followed by pendimethalin + hand weeding and Oxyfluorfen + hand weeding which were significantly superior to all other treatments. Next best treatments were metribuzin followed by hand weeding (T_8) and soil solarization (T_9).

Among the additional treatments tried in 2014-15, glyphosate + oxyfluorfen (T_{13}) also produced higher number of tillers, leaves per tiller and taller plants. The treatment T_{13} was at par with T_{10} and significantly superior to all other treatments.

Fresh weight and dry weight of ginger

Pooled analysis of two years of experiment revealed that the best two treatments were POP (T_{10}) and oxyflorfen + hand weeding (T_7), which were on par. The third best treatment was pendimethalin + hand weeding (T_6) followed by soil solarisation (T_9). The newly added treatment glyphosate + oxyfluorfen (T_{13}) also gave higher fresh (13.53 t/ha) and dry yield (4.59 t/ha) which was on par with POP. This is because, the plant growth parameters were maximum in these treatments. In these treatments there was low weed competition compared to others and this helped the crop to make use of the nutrients applied which favorably influenced the fresh rhizome yield.

Economics of ginger

Based on the averages of the net returns and B: C ratios of the two years of the study, highest net returns and B: C ratios are in the order of T_{10}, Rs. 763225 (3.95), T_7, Rs. 744048 (4.7), T_6, Rs. 700558 (4.4), T_8, Rs. 607268 (3.95), T_9, Rs. 588325 (3.5) and T_2, Rs. 471348 (3.55) respectively.

Microbial count in soil

Pooled analysis of total fungal and bacterial count shows that the maximum counts were recorded in the treatments POP (T_{10}) which was on par with unweeded control (T_{11}). The next best treatment was soil solarization (T_9). The microbial population was reduced in the herbicides applied plots. Highest reduction was observed in oxyfluorfen (T_2) and its combination with glyphosate (T_{13}) followed by pendimethalin (T_1) and its combination with glyphosate (T_{12}).

The herbicides adversely affect soil microorganisms which are responsible for numerous biological processes essential for crop production.

Herbicide residue in ginger

The herbicide residue in the harvested fresh rhizomes of ginger showed that, the herbicide residues were below detectable level in pendimathalin (T_1), oxyfluorfen (T_2), pendimathalin + hand weeding (T_6) and oxyfluorfen + hand weeding (T_7) and these treatments were compatible with POP (T_{10}) where no herbicides were used.

Conclusion

Weed management is an important operation in ginger cultivation and weed control is possible by hand weeding or by chemical method. Study revealed that highest yield of rhizome and net returns (Rs. 763225) were obtained by following the POP practice of weed control (weed removal by hands at 45 and 90 DAP). When pre emergence herbicide pendimethalin or oxyfluorfen alone or post emergence herbicides glyphosate or glufosinate ammonium alone were applied, the weed suppression was not satisfactory. But glyphosate combined with oxyfluorfen resulted in good reduction in weed population. This is because, glyphosate could take care of the already germinated weeds (the weeds which germinated up to the emergence of ginger shoots ie. about 30 days after planting) and oxyfluorfen could prevent the germination of weed seeds for another two to three months. When pendimethalin or oxyfluorfen alone were applied as pre emergence (T_1 and T_2) they could control the weeds only during the initial stage and after that, uncontrolled weed growth occurred which adversely affected crop performance. When these treatments were combined with hand weeding at 45 DAP (T_6 and T_7) reasonable control of the weeds over the entire period of crop growth could be obtained. Second best net return of Rs. 744048 was recorded by oxyfluorfen + hand weeding (T_7) followed by pendimethalin + HW (T_6). Highest B: C ratio of 4.7 was recorded by oxyfluorfen + HW, followed by pendimethalin + HW (4.4) and POP (3.95). The study clearly shows that when sufficient laborers available, the POP recommendation of two hand weedings at 45 and 90 DAP may be followed as this is an environmentally safe method. When labour shortage is experienced, most economical method of weed control in ginger is pre emergence application of oxyfluorfen or pendimethalin followed by a hand weeding at first mulching. A single application of oxyfluorfen + glyphosate is also a very effective weed control measure in ginger. But the study needs further confirmation by conducting more field experiments.

In case of extreme labour shortage, the use of safe herbicides becomes a must for weed control in ginger. Though there is a common feeling that use of glyphosate may cause environmental problems, studies indicate that recommended dose does not cause any health problem to human beings and animals because the action of this herbicide on the bio synthesis of essential amino acids *viz,* leucine and tryptophan which are only present in plants. The chemical is inactivated when come in contact with soil and is not subjected to leaching losses. Under organic farming, if area is limited, soil solarization is an alternative. For the commercial cultivation of ginger, the only alternative is hand weeding, mulching and earthing up.

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Appendices

APPENDIX I

Weather parameters during the experimental period

(January 2013- January 2015)

Year	Month	Max. Temperature (°C)	Min. Temperature (°C)	Relative humidity (%)	Rainfall (mm)
2013	**January**	34.1	22.3	52	0
	February	34.7	23.3	57	84.4
	March	35.4	24.4	64	14.6
	April	34.9	25.1	71	0
	May	33.6	25.2	77	99.1
	June	28.5	22.7	90	1031.8
	July	28.4	22.7	91	932.3
	August	29.9	22.9	84	305.9
	September	30	22.2	85	344.1
	October	30.8	22.6	83	369.8
	November	32.6	23.9	73	82
	December	31.9	22.3	61	0.5
2014	**January**	32.9	23	51	0
	February	34.7	22.9	56	0
	March	36.7	24.2	55	0
	April	35.3	25.7	73	61
	May	33.2	24.2	77	323.6
	June	30.9	24.4	85	469.8
	July	29.5	24.4	87	768

	August	29.5	23.1	87	599.8
	September	31.3	23.2	82	215.1
	October	31.9	23.7	81	224.6
	November	31.6	23.2	72	85.3
	December	31.9	22.5	65	9.6
2015	**January**	32.5	22.1	58	0

APPENDIX II

COST OF INPUTS, PRICE OF PRODUCES AND LABOUR COST

Sl.No	Item	Unit	Rs.
A.	**Inputs**		
1	Tractor charge	Hour	400.00
2	Ginger rhizomes (var. Athira)	Kg	60.00
3	FYM	T	1000.00
4	Urea	Kg	10.00
5	SSP	Kg	6.00
6	Muriate of Potash	Kg	20.00
7	Phosphobacteria	Kg	40.00
B	**Herbicides**		
1	Pendimethalin	1 lit	500.00
2	Oxyfluorfen	100 ml	250.00
3	Metribuzin	1Kg	350.00
4	Glyphosate	1 lit	350.00
5	Glufosinate ammonium	1 lit	5000.00
C	**Produces**		
1	Rhizome	Kg	60.00
D	**Labour wages**		
1	Men	Day	450.00
2	Women	Day	300.00

WEED MANAGEMENT IN GINGER (*Zingiber officinale* Rosc.)

By

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(2012-21-105)

ABSTRACT OF THE THESIS

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ABSTRACT

The present investigation entitled "Weed management in ginger (*Zingiber officinale* Rosc.) was carried out at the Agronomy Farm, College of Horticulture, Vellanikkara during March 2013 to January 2015 using the variety Karthika. The main objective of the investigation was to study the weed flora of ginger in the major ginger growing districts of Kerala and to find out efficient, economic and eco-friendly weed management practices in ginger. The investigation was carried out in two parts. 1) Survey of weed flora of ginger in the major ginger growing districts of Kerala 2) field experiment on management of weeds in ginger.

Stratified survey was done in major ginger growing districts of Kerala namely Waynad, Palakkad, Idikki and Thrissur districts during 2013 and 2014. The average number of dicots, monocots and sedges found growing in ginger plots in these districts were in the order of 69.1, 22.0 and 8.8 per cent respectively. Based on the SDR values, the most dominant broad leaved weed species observed in the Palakkad district were *Scoparia dulcis, Ageratum conyzoides, Mollugo pentaphylla* and *Ludwigia parviflora. Leptochloa chinensis* was the most dominant grass weed. *Fimbristylis miliacea* and *Cyperus iria* were the dominant sedge species. In the Thrissur district *Cyperus difformis* was the most dominant sedge. Among broad leaved weeds, *Alternanthera bettzickiana* had the highest SDR value. Among the grasses, *Brachiaria mutica*, *Eragrostis japonica* and *Setaria sphacelata* dominated in Thrissur district. In the Wayanad district *Spilanthes radicans* and *Ageratum conyzoides* emerged as the most dominant broad leaved weed species. The most dominant grass weed was *Digitaria ciliaris.* Among the sedges, *Cyperus iria* was the dominant species. In Idukki district *Ageratum conyzoides* and *Spilanthes radicans* were the most dominating broad leaved weed species. Among grasses, *Eragrostis* sp. recorded the maximum population followed by *Ischaemum indicum*.

The field experiments were laid out in RBD with three replications during 2013-2015. The treatments included were pendimethalin @ 1.5 kg /ha after

planting but before mulching, oxyfluorfen @ 0.20 kg /ha after planting but before mulching, metribuzin @ 0.525 kg /ha after planting but before mulching, glyphosate @ 0.80 kg /ha just before the emergence of sprouts of ginger, glufosinate ammonium @ 0.45 kg /ha just before the emergence of sprouts of ginger, pendimethalin @ 1.5 kg/ha + one hand weeding at first mulching, oxyfluorfen @ 0.20 kg/ha + one hand weeding at first mulching, metribuzin @0.525 kg/ha + one hand weeding at first mulching, soil solarization for 45 days before planting ginger, POP recommendations (KAU) and unweeded control

In the second crop season (March 2014 to January 2015) two additional treatments namely, combinations of glyphosate with pendimethalin (T_{12}) or oxyfluorfen (T_{13}) were additionally included. The combinations of these herbicides were applied at twenty five days after planting, just before the emergence of sprouts of ginger.

Major weeds found in experimental field in both the years were broad leaved weeds comprising of *Ageratum conyzoides*, *Alternanthera bettzickiana*, *Borreria hispida,* etc. *Pennisetum pedicellatum* and *Brachiaria* sp. were the dominant grass species. *Cyperus iria* was the only sedge. Significantly the lower weed population, weed dry weight and nutrient removal by weeds were observed in PoP (T_{10}) followed by pre emergence herbicides + hand weeding (T_6, T_7 and T_8), at 45, 90 and 180 DAP. Among the additional treatments, oxyflourfen+glyphosate (T_{13}) registered the lowest dry matter production, weed population and nutrient removal by weeds at 45, 90 and 180 DAP and was on par with POP.

The plant growth parameters like number of tillers per plant, number of leaves per tiller and plant height were maximum in POP (T_{10}) followed by pendimethalin + hand weeding and Oxyfluorfen + hand weeding which were significantly superior to all other treatments. The additional treatment tried in 2014-2015, glyphosate + oxyfluorfen (T_{13}) also produced higher tiller count, number of leaves per tiller and height of plant. The treatment T_{13} was at par with T_{10} and significantly superior to all other treatments.

The highest fresh yield and dry yield were recorded in POP (T_{10}) followed by oxyflorfen + hand weeding (T_7). The third best treatment was pendimethalin + hand weeding (T_6) followed by soil solarisation (T_9). The newly added treatment glyphosate + oxyfluorfen (T_{13}) also gave the highest fresh (13.53t/ha) and dry yield (4.59 t/ha) which was on par with POP. Pendimethalin, metribuzin, glyphosate and glufosinate ammonium were far inferior to produce a reasonable yield of rhizomes. The highest net return was recorded by POP recommendation (T_{10}) followed by oxyflorfen + hand weeding (T_7). The highest B:C ratio was recorded by oxyfluorfen + hand weeding (4.7) followed by pendimethalin + hand weeding (4.4) and PoP (3.95). When laborers are available in plenty, PoP practice of weed removal by hand at 45 and 90 DAP is the best as this is environment friendly. If labour shortage is experienced oxyflorfen + hand weeding or pendimethalin + hand weeding can be adopted. The additional treatment glyphosate + oxyfluorfen (T_{13}) tried during 2014-2015 only was also effective in controlling weeds and giving a good yield. But the treatment needs further verification by field trials.

The total fungal and bacterial count two months after spraying of herbicides also showed the maximum count in the treatment PoP (T_{10}) which was on par with unweeded control (T_{11}). Herbicide residue analysis in ginger showed that all the promising herbicides to control weeds in ginger recorded below detectable level of residue in rhizomes.