EVALUATION OF HERBICIDAL PROPERTIES OF HORTICULTURAL CROP PRODUCTS AND BY-PRODUCTS IN ORGANIC FARMING OF OKRA [*Abelmoschus esculentus* (L.) Moench]

by

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(2017- 12-019)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"EVALUATION OF HERBICIDAL PROPERTIES OF HORTICULTURAL CROP PRODUCTS AND BY-PRODUCTS IN ORGANIC FARMING OF OKRA [*Abelmoschus esculentus* (L.) Moench]"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Saranya Sasikumar

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LIST OF ABBREVIATIONS

B:C	Benefit : Cost
cm	Centimeter
et al.	And others
Fig.	Figure
FYM	Farm yard manure
^oC	Degree celcius
g^{-1}	Per gram
gm^{-2}	Gram per metre square
i.e.,	That is
KAU	Kerala Agricultural University
Kg	Kilo gram
NHB	National Horticulture Board
APEDA	Agricultural and Processed Food Products Export Development Authority
w/v	Weight by volume
mg	Milligram
no.	Number
NS	Non significant
$kgha^{-1}$	Kilogram per hectare
SE (m)	Standard error of mean
$t\ ha^{-1}$	Tonnes per hectare
a.i.	Active ingredient

LIST OF SYMBOLS

%	Per cent
@	at the rate of
/	Per

Introduction

1. INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench) is an economically important vegetable crop grown in both tropical and subtropical parts of the world. The immature fruits are used as vegetable which can be used in salads, soups and stews, as fresh or dried, fried or boiled vegetable. India is the largest producer of okra in the world. In Kerala, 3.01 thousand ha is the area and 29.27 thousand MT is the production of okra (NHB, 2018).

The side effects of the modern agricultural chemicals raise serious questions about the overall benefits of the protective foods like vegetables. Avoidance of synthetic substances for pest management play a role in organic farming (Nazir *et al*., 2016). Alternate technologies to substitute conventional practices are very necessary for adoption of organic farming in vegetables (KAU, 2012). India produces around 1.70 million MT of organic products. Okra is one of the major organically cultivated and exported vegetables (APEDA, 2018).

There are so many factors that determine the growth and yield of okra, such as the quality of seeds, climatic and nutritional factors and cultural practices (Kusvuran, 2012). Moreover, losses due to poor weed management is more as compared to pest and disease attack (Khalil and Jan, 2002). An annual average loss of 30-45 per cent was observed with inadequate weed management and weed control policy (Usoroh, 1981).

Organic farmers are facing more difficulties in weed management. The lack of weed control can result in yield loss due to weed competition and also weeds act as a reservoir for pathogens. Gogoi *et al*. (1996) found that the first to seven weeks after planting is the most critical period for weed growth in okra. A weed free period up to 7 weeks from sowing resulted in yield comparable with those obtained in a weed free situation. Regular weeding is necessary in okra and destruction of weeds like *Croton sparsiflora* and *Ageratum* sp. is very necessary to control yellow vein mosaic disease (KAU, 2017). Farmers have to opt for scarce and expensive manual labour to hand weed in an organic production system. In Kerala, the labour wages are higher in agricultural sector than in other states of India (GOI, 2017). In rural Kerala, for male general agricultural workers, the average daily wage rate is Rs. 658.93, whereas the national average is Rs. 265.36. For female labourers, it is Rs. 442.50 compared to the national average of Rs. 206.59.

Synthetic herbicides being completely ruled out in organic production systems, horticultural crop products and by-products that have contact herbicidal properties and are commonly available can be explored as alternatives to synthetic herbicides to integrate into organic weed control strategies. Horticultural crop products such as coconut vinegar, which can be cheaply manufactured from the waste coconut water, clove leaf oil and eucalyptus oil, which can be extracted from leaves of clove and eucalyptus, cashew nut shell liquid, which is an easily available by-product from cashew processing industry and lemon extract, which is also a commonly available product from market, can be utilised as alternatives for synthetic herbicides.

An often overlooked organic weed management practice is the stale seed bed technique in which weed seeds just below the soil surface are allowed to germinate and then killed prior to planting. Farmers encountered much difficulty to destroy flushed weeds by shallow cultivation in the seed bed when stale seed bed was practiced in upland conditions (KAU, 2012). Weed control levels achieved with "no-disturbance' techniques like herbicide are considered better than techniques that disturbed the soil. Organic mulches may also be used effectively for weed management in okra.

Considering these facts, this investigation aims

- to evaluate herbicidal properties of by-products like coconut vinegar, cashew nut shell liquid, lemon extract clove leaf oil and eucalyptus oil in order to standardise them as herbicides.

- to study their herbicidal efficacy when integrated with stale seed bed method in organically grown okra.
- to study the impact of bio herbicides on soil parameters.

Review of literature

2. REVIEW OF LITERATURE

The study entitled "Evaluation of herbicidal properties of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculentus* (L.) Moench]" was conducted in the Department of Vegetable Science, College of Agriculture, Vellayani during 2017-18. The study consisted of two parts, preliminary evaluation of horticultural crop products and by-products as herbicides and evaluation of herbicides in organic farming of okra. The literature related to this study is reviewed below.

2.1 ORGANIC VEGETABLE PRODUCTION

Organic farming is emerging as an alternative farm practice due to increasing consciousness about sustainable agriculture and chemical free production of food (Pandey and Pandey, 2009).

Worthington (2001) surveyed on the existing literature for nutrient comparison between organic and conventional crops with the help of statistical methods for identifying the significant differences and trends in data and reported that the nutrients such as vitamin C, magnesium, iron, and phosphorus content was significantly higher and nitrate content was significantly lower in organic crops than in conventional crops. He also reported that organic crops contain significantly less amount of heavy metals and higher mineral content which ensures the quality of organic crops as compared to conventional crops.

Organic weed management is the leading deterrent for conversion to organic production since it remains as the most difficult, frustrating, expensive, and time-consuming management aspect despite an increasing selection of cultivation equipment and an improved understanding of weed management techniques and weed ecology (Webber *et al*., 2012).

2.2 WEED INFESTATION IN VEGETABLES

In vegetable crops the yield loss due to weeds was reported to be 70 to 80 per cent and the extent to which damage occur due to weeds varies with the crop and nature of weeds (Rana *et al.*, 2011).

Syriac and Geetha (2007) reported that the major grass weeds infesting vegetable fields of Kerala were *Digitaria sanguinalis*, *Eleusine indica*, *Eragrostis* sp., and *Paspalum* sp., broad leaved weeds such as *Ageratum conyzoides*, *Commelina benghalensis*, *Cleome viscose*, *Leucas aspera*, *Ludwigia perennis*, *Phyllanthus niruri* and *Vernonia cinerea*, and sedges such as *Cyperus iria*, *Cyperus rotundus*, *Kyllinga monocephala*.

The major weed flora infesting vegetable fields of Yemen were *Convolvulus arvensis*, *Cynodon dactylon*, *Cyperus rotundus*, *Datura fastuosa*, *Echinochloa colonum*, *Schnonwia thebaica*, and *Tribulus terrestris* as reported by Al-Khathiri (1994).

Leela (2003) reported that common monocot weeds infesting vegetables were *Brachiaria* spp., *Cyperus* spp., *Cynodon dactylon*, *Chloris barbata*, *Commelina benghalensis*, *Digitaria marginata*, *Dactyloctenium aegyptium*, *Echinochloa* spp., *Eragrostis* spp., *Imperata cylindrica*, *Panicum repens* and dicot weeds were *Achyranthus aspera*, *Acanthospermum hispidum*, *Celosia argentea*, *Euphorbia* spp., *Lagasca mollis*, *Leucas aspera*, *Oldenlandia corymbosa*, *Oxalis* spp., *Parthenium hysterophorus*, *Phyllanthus niruri*, *Polycarpaea corymbosa*, *Mimosa pudica* and *Mollugo cerviana*.

The major monocotyledonous weeds seen in fields of Knol- Khol and radish were *Brachiaria erusiformis*, *Cynodon dactylon*, *Digitaria marginata*, *Setaria glauca*, sedges were *Cyperus rotundus* and broad leaved weeds such as *Commelina benghalensis* (Leela, 1987).

Saimbhi *et al.* (1994) described the major weeds infesting vegetable fields of Jalandhar in Punjab were *Cyperus rotundus*, *Elusine indica*, *Tiranthema portulacastrum*, *Celosia argentina*, *Portulaca* spp. and *Amaranthus* spp.

Bottenberg *et al.* (1997) reported that in the mid western United States, Redrood pigweed (*Amaranthus retroflexus*) and common purslane (*Portulaca oleraceae*) are present in the vegetable fields.

The adverse effects of *Amaranthus retroflexus*, *Agropyron repens*, *Chenopodium album*, *Cirsium arvense*, *Cynodon dactylon*, *Echinochloa crusgalli*, and *Sorghum halepense* in vegetables of Macedonian fields was reported by Kostov and Pacanoski (2007).

Bhowmik and Reddy (1988) reported that *Amaranthus retroflexus*, when left uncontrolled could cause 60 per cent yield loss in potatoes, onions, watermelon and cabbage. They also reported that yield reduction in tomato was 36 per cent due to the season long interference of *Chenopodium album*.

In okra, yield reduction due to weed competition ranges from 59 per cent to 90 per cent as reported by Singh *et al.* (1982). *Amaranthus viridis, Ageratum conyzoides, Commelina benghalensis, Cyperus rotundus, Physalis minima*, and *Setaria glauca* were the major weeds in okra as reported by Bhalla and Pramar (1982). While according to Adejonwo *et al.* (1990) *Acanthospermum hispidum, Ageratum conyzoides, Amaranthus spinosus, Commelina benghalensis, Cyperus rotundus, Cynodon dactylon, Digitaria horizontals, Dactyoctenium aegyptium, Eleusine indica* and *Solanum nigrum* are the dominating weeds of okra.

In Kerala, the major weed species infesting okra field were *Ageratum conyzoides, Brachiaria distachya, Cleome viscose, Cynodon dactylon, Cyperus rotundus, Digitaria ciliaris, Eleusine indica, and Ludwigia parviflora* (KAU, 1992).

Sainudheen (2000) stated the major perennial weeds in okra are *Cyperus rotundus* and *Cynodon dactylon* and annual weeds are *Cyperus iria*, *Dactyloctenium aegyptium*, *Digitaria ciliaris*, *Eleusine indica* and *Ludwigia parviflora*.

Cyperus rotundus, Talinum triangulare, Paspalum conjugatum, Digitaria horizontalis, Mollugo nudiculis, Euphorbia heterophylla, Dactyloctenium aegyptium, and *Cleome viscosa* are the major weeds in okra field as pointed out by Norman *et al*. (2011).

2.3 CRITICAL STAGE OF CROP-WEED COMPETITION

Various factors affect the extent to which crop weed competition occurs such as competition for moisture, nutrients and sunlight.

The weed management strategy that has to be adopted is determined by the period in which the crop life is susceptible to weed infestation. The presence of weed during the early stages of crop growth will not affect the yield and also if the field is kept weed free till a particular period of time, the weeds that emerge subsequently will not affect the yield of the crop. This intervening period was termed as critical period of weed competition (Hewson and Roberts, 1973).The critical period of weed competition in vegetables was observed to be the period from emergence to four weeks after emergence.

The duration of weed competition in transplanted onion was studied by Paller *et al*. (1973) and found a yield reduction of 42 per cent in plots having weeds for only two weeks and thereby concluded that weed free period of seven weeks after transplanting is required for maximum yield. The critical stage of crop weed competition in tomato was upto 30 days from transplanting (Rajagopal and Sankaran, 1979).

A weed free period for 20 to 40 days of transplanting of brinjal yields similar to weed free condition and also the cost of weeding was reduced as reported by Nandal and Pandita (1988).

According to Singh *et al.* (1982) weed free environment at critical stages will result in maximum yields in okra, tomato (Beste, 1979), radish (Gambhir *et al.*, 1983) and summer squash (Ponchio *et al.*, 1984). Rana *et al.* (2011) reported that the critical stage of crop weed competition in vegetables are cauliflower (30), cabbage (30-45), tomato (30-45), peppers (30-45), onion (30-75), brinjal (20-60), cumin (15-30), potato (25-30), turnip (15-20) and carrot (20-40) days after sowing.

Critical stage of crop weed competition in okra was observed to be 15-30 days after sowing (Singh *et al.*, 1982; Rana *et al.*, 2011). Zareen *et al.* (2017) reported that yield of okra was best in plots that receive weeding 30 days after sowing which was followed by 15 days after sowing.

2.3 NUTRIENT REMOVAL BY WEEDS

Qasem and Hill (1993) reported that the competitive ability of weeds such as *Chenopodium album* and *Senecio vulgaris* was higher than that of tomato for certain nutrients such as N, P, K, Ca and Mg.

Nutrient removal by weeds was higher (63 kg N, 11 kg P, and 88 kg K per hectare) when compared with potato in potato field as reported by Mani *et al.* (1973). Varghese and Nair (1986) investigated on the competition for nutrients by rice and weeds and he reported that the nutrient demand for crop and weed was highest for K, then for N and least for P. He also noted that competition for weeds with the crop for N and K was during 11-50 days and for P was during 21-40 days.

The root efficiency for uptake of K and Mg was higher for *Chenopodium album* than that of tomato, whereas N and P uptake was higher from 5 and 4 weeks (Qasem, 1993).

2.4 WEEDS AS ALTERNATE HOST

Weeds act as an alternate host for several pest and diseases in vegetables. The initial infection of okra mosaic virus was observed in nearby plot weeds as reported by Fajinmi and Fajinmi (2010).

Weeds such as *Achanthospermum hispidum*, *Parthenium hysterophorus*, *Ageratum conyzoides*, *Datura stramonium*, *Gynandropsis pentaphylla* and *Euphorbia genniculata* acts as host for the source of inoculums for tomato (Sastry, 1984). Ramappa *et al.* (1998) reported that *Bemissia tabaci* transmits Tomato Leaf Curl Virus (ToLCV) to weeds such as *Achanthospermum hispidum, Ageratum conyzoides, Euphorba geniculata, Oxalis corniculata, Parthenium hysterophorus, Synedrella nodiflora Nicotiana benthamiana.*

2.5 WEED MANAGEMENT METHODS IN VEGETABLES

2.5.1 Chemical methods of weed management in vegetables

Prakash *et al.* (1999) reported that pre-emergence application of alachlor at the rate of 2-3 kgha^{-1} along with hand weeding 45 DAT produces maximum fruit dry yield in chilli. Rajput *et al.* (2003) reported that maximum plant characters and yield was obtained in weed free plot, followed by treatment with fluchloralin 2kg along with hand-weeding at 45 days after transplanting of chilli. Syriac and Geetha (2007) reported highest yield in brinjal with pre emergence herbicides alachlor (2 and 2.5 kg a.i. ha^{-1}), pendimethalin (2kg a.i. ha^{-1}) and oxadiazon (0.5 and 0.75 kg a.i. ha^{-1}) and hand weeding twice. Maximum yield attributes in cluster bean was obtained by two hand weeding at 20 and 35 days after sowing and treatment with imazethapyr 100gha^{-1} at 20 days after sowing along with one hand weeding 35 days after sowing (Dhaker *et al.*, 2009). Highest grain yield in cluster bean was obtained with weed free check followed by two hand weeding and imazethapyr along with hand weeding 40 days after sowing as reported by Yadav *et al.* (2011).

Nandal *et al.* (2005) reported that maximum yield in cabbage was obtained with oxadiazon at 1 kgha^{-1} followed by oxadiazon at 0.75 kgha^{-1} along with pendimethalin 0.75 kgha^{-1}. They also reported a yield increase of 219 percent with the application of oxadiazon 1 kgha^{-1}.

Pre-emergence application of pendimethalin or metalachlor (2.00 kgha^{-1}), followed by hand weeding three weeks after sowing was found to be effective in controlling majority of weeds in okra throughout the season (Adejonwo *et al.*, 1990). Sheela *et al*. (2007) reported that fluchloralin 04 $kgha^{-1}$ were beneficial for weed control in okra.

Patel *et al*. (2004) reported that highest net profit in transplanted chilli was observed in three hand weedings, followed by pre-plant application of pendimethalin along with one handweeding.

Sha and Karuppaiah (2005) observed that integrated weed control treatment such as black polythene sheet mulching followed by 1.5 $kgha^{-1}$ fluchloralin along with sugarcane trash mulching 18 days after transplanting of brinjal increases its growth and yield.

2.5.2 Non chemical methods of weeds management in vegetables

2.5.2.1 Soil solarisation

The number of weeds in solarised plot of lettuce was lower compared to control plot as reported by Silveria *et al*. (1990). Alexander (1990) reported that soil solarisation increases the head weight and plant weight of broccoli. Soil solarisation for one month recorded the highest fruit yield in brinjal reported by Syriac and Geetha (2007).

Bawazir *et al*. (1995) reported that the available NPK content in solarised soil was higher and when compared with control, the weed dry weight was decreased by 97.1 per cent in solarised soil. The total number of weeds in all species was lowest in solarised soil when compared with non solarised soil (Arora and Tomar, 2012).

The use of soil solarisation is limited in many of the organic standards, as it has some negative effects on soil biology (Merfield, 2019).

2.5.2.2 Intercropping

According to Baumann *et al*. (2000) carried out experiment with intercropping leeks to weed control observed that the critical period for weed control was reduced in intercropping with celery when compared with pure crop of celery. Weed population and weed dry weight was reported to be lowest and weed control efficiency was highest for maize- cowpea and maize- French bean intercropping system as reported by Hugar and Palled (2008).

Intercropping in okra with cassava significantly reduced the weed growth (25-45%) without reducing the yield in okra (Olasantan, 2001). Okra planted at the rate of 50,000 plants per hectare shows best weed control when compared with 25,000 and 35,000 plants per hectare. Muoneke and Ndukwe (2008) conducted study on okra/amaranth intercrop and compared their growth and yield parameters with sole cropping. The study revealed a decrease in yield of both crops when intercropped (38 or 41% yield reduction) and cultural operations were also observed to be difficult in intercropped system due to less spacing between the plants.

2.5.2.3 Mulching

Bhardwaj (2013) stated that temperature moderation, weed control and salinity reduction was favoured by mulching the soil surface around the plants which provides conclusive effects such as earliness, high yield and better quality of crops.

Olasantan (1985) reported that the vegetative growth, yield and yield components of tomato were increased significantly by mulching. Liu *et al*. (1989) reported that when mulches were applied to soil, soil moisture losses through evaporation and growth of weeds were checked.

Pramanik *et al*. (2002) reported that water use efficiency in okra can be increased by 65.7 per cent by the process of mulching. Radwan and Hussain (2001) reported that mulching is more effective in controlling broad leaved weeds than grassy weeds. DenHollander *et al*. (2007) reported that mulches can lower the germination and development of weed seeds through mechanical and allelopathic effects as reported by Kruidhof *et al*. (2008).

2.5.2.4 Organic mulching

Organic mulches are proved to be better than plastic mulches because plastic mulches require higher cost of production and disposal of plastic after cropping is difficult (Hemphill, 1993). Mulching or covering the surface of soil can be effective for suppressing weed seed germination and its emergence. Organic materials like bark, straw, composted municipal green waste can be effectively used for weed control. (Merwin *et al*., 1995). Mulching reduces soil deterioration by preventing run off and soil loss, prevents evaporative loss and reduces weed infestation (Sarolia and Bharadwaj, 2012). Organic mulches of mango leaves can be effectively utilized for weed management in okra (Faras, 2015).

2.5.3 Stale seed bed method for weed control

Sheela *et al.* (2007) reported that stale seed bed is effective in suppressing the weeds and improving yield and economics of okra.

Once weeds are flushed out several methods may be used to kill emerged weeds and complete the stale seed bed technique by employing tillage or a non-selective herbicide (Hill *et al.*, 2006). According to Ameena *et al*. (2013) pre-plant application of glyphosate 1.5 kg/ha along with stale seed bed before sowing of okra followed either by polythene mulching or directed application of glyphosate 1.5 kg/ha between rows of okra was reported to be the most effective treatment in controlling purple nutsedge (*Cyperus rotundus* L.) in a non-organic production system .

2.5.4 Organic herbicides for weed management

Lanini *et al.* (2010) described plant oil-based herbicides as minimum risk pesticides which act only on small, newly emerged weeds. These have greater efficacy against broadleaf weeds than grasses and at warm temperatures but lack residual action.

2.5.4.1 Organic acids

Coconut vinegar (acetic acid) can be obtained from coconut water, which is a waste product from copra and desiccated coconut production. In the production of coconut vinegar, fermentation process takes place in two stages. In the first stage fermentable sugars are converted into ethanol by the action of yeast and in the second stage oxidation of ethanol to acetic acid by the action of acetic acid bacteria (AAB). Raw coconut water contains only 3 per cent (w/v) sugar, therefore up to 10percent (w/v) sugar is added to matured coconut water during the industrial production of coconut water vinegar.

Vinegar (acetic acid) is a non-selective contact herbicide. Typically, vinegar is less effective in controlling grasses than broadleaf weeds and more effective on annual species than perennials. In addition to application volumes and concentration, weed control by acetic acid is also dependent on the weed size and the species. (Webber and Shrefler, 2009a).

Chinery (2002) found that acetic acid treatment causes a quick dramatic discoloration and browning of plant foliage, which later turned out to be water soaked and blackened in a few hours and also 95 to 100 per cent control was found in all plots with acetic acid treatment. He pointed out that 5 per cent acetic acid gives 90 per cent control up to five weeks but was less effective at 9 and 13 weeks. Acetic acid at 5 per cent concentration gives only short term control of most perennial weeds, but effectively controls crab grass and plantain.

Greenhouse and field studies indicated that 5 percent vinegar solutions did not produce reliable weed control, while solutions of 10, 15, and 20 percent provided 80-100 percent control of certain annual weeds (foxtail, lambsquarters, pigweed, and velvetleaf). Perennial weeds (Canada thistle) treated with 5 percent vinegar showed 100 percent shoot burn down but roots were not affected, therefore shoots always re-grew (Daniels and Fults, 2002). Three applications of acetic acid were seen to be much more effective than one application in most cases (Chinery, 2002).

10 to 20 per cent acetic acid solutions provide greater than 80 per cent control of most small weeds. But the cost of applying acetic acid was 10 times more than the cost of using glyphosate (Young, 2004). Acetic acid affects the aerial portions of plants leaving the underground parts uncontrolled and thus the re-emergence of the plants occur after a few days or weeks from the root system. Malkomes (2005) reported that even though acetic acid is applied at relatively

higher concentrations it does not have long term negative influence on soil micro organisms. Dayan *et al.* (2009) reported that herbicidal activity of acetic acid does not significantly increase with the use of oil adjuvents.

Acetic acid can also be used to control invasive aquatic weeds like propagules of hydrilla (*Hydrilla verticilliata*), smooth cord grass (*Sartina alterniflora*) and sago pondweed (*Stuckenia pectinatus*) (Spencer and Ksander, 1999). Careful treatments of lake sediments with acetic acid may have utility as an alternative to foliar applied herbicides such as imazapyr and glyphosate. (Anderson, 2007).

2.5.4.2 Lemon extract

d-Limonene is a terpene found in the oil extracted from the peels of citrus fruits. Main *et al.* (2013) applied d-Limonene, clove oil and acetic acid to control weeds in carrot and observed that clove oil and d-limonene as citrus oil gave slightly better weed control and yield than acetic acid and flaming.

Barker and Prostak (2014) investigated on the management of vegetation by alternative practices in fields and roadsides and found that citric-acetic acid formulations and clove oil formulations applied as foliar sprays immediately desiccated foliage.

2.5.4.3 Essential oils as herbicide

Allelopathy can describe any direct or indirect effect of plant chemical compounds on another plant or microbe by allelochemicals released through leaching from leaves or through volatile emissions (Weir *et al.,* 2004).

Kohli *et al.* (1998) reported that the volatile oil from lemon-scented eucalypt (*E.citriodora* Hook) and Tasmanian blue gum inhibits the germination and early seedling growth of *Parthenium hysterophorus* L. and pointed that these could be used for weed management. The germination of the weed was inhibited and the chlorophyll content and cellular respiration of the mature plants exposed to eucalypt oils were reduced drastically. This was accompanied by increased water loss resulting in complete wilting of the plants after IS days of exposure to volatile oils. Volatile oil from *Artemisia ordosica* inhibits the growth and photosynthetic activity of *Palmellococcus miniatus* through the combined effects of components in volatile oil (Yang *et al*., 2012).

Singh *et al*. (2002) also found reduction in chlorophyll content of mature *C. occidentalis* and *E.cruss-galli* plants sprayed with eucalyptus oils. Kaur *et al*. (2010) observed that the application of *Artemisia* oils on 6-week-old weed plants caused losses in chlorophyll concentrations in the leaves and injuries, ranging from chlorosis to necrosis.

Clove oil is a post-emergence, non-selective, contact herbicide for the control of actively growing emerged annual and perennial grass and broadleaf weeds. As with the other contact herbicides, when weeds are of similar size, the broadleaf weeds are easier to control than the grasses (Webber and Shrefler, 2009b).

Boyd and Brennan (2006) conducted study on the response of clove oil herbicide in burning nettle, common purslane and rye and reported that clove oil have potential as a directed or spot application treatment in high value organic vegetables for the creation of stale seed beds and also reported that maximum weed kill was obtained at 10 to 40 percent clove oil.

Evans and Bellinder, (2009) conducted study on how the volume, concentration and application timing of vinegar and clove oil product affect the weed control and response on crop and they reported that weed control was greatest (83 percent, 1 DAT) with 20 per cent vinegar. Application of vinegar and clove oil through broadcasting is effective for use on young, actively growing onion, sweet corn and potato.

Abouziena *et al*. (2009) conducted greenhouse experiments to evaluate the effectiveness of acetic acid, citric acid, citric acid-garlic mixture and clove oil as natural product herbicides for weed control. The herbicides were applied at two weed growth stages, namely, two to four and four to six true-leaf stages of weeds. Acetic acid was phytotoxic to all broadleaf weeds and most narrow leaf weeds. The efficacy was reduced significantly in delayed application upto four to six leaf stage and when compared with other herbicides acetic acid was less sensitive to growth stages of weeds.

Evans and Bellinder (2009) assessed weed control, weed biomass, crop injury, and yield of sweet corn, potato, and onion when vinegar, clove oil and their mixture was applied at different growth stages. By fourth week after application much of the initial injury to the corn crop was outgrown. They also stated that the efficiency depend on the weed species and the size of weeds at the time of application.

Brainard *et al.* (2013) conducted study to evaluate the efficacy of clove oil and vinegar based herbicides on weeds and reported that 7.5 percent clove oil and 15 percent vinegar is the best for adequate control of mustard and observed poor control of annual grass weeds. They also reported that temperature has no effect on the weed control efficiency of clove oil, but higher temperature has a significant effect on the control of brown mustard by vinegar.

Ahuja *et al.* (2015) investigated the phytotoxic potential of eugenol which is a major component of the essential oil of clove [*Syzygium aromaticum* (L.) Merrill and Perry] towards grassy weeds. Eugenol at 1,000 μM caused 55–70 and 42–90 per cent decrease in percent germination in grassy and broad-leaved weeds, respectively. Likewise, root length declined by 55 to 90 and 57 to 71 per cent, whereas shoot length was decreased by 50 to 83 and 36 to 73 per cent in grassy and broad leaved weeds respectively, in treatment with 1,000 μM eugenol. The observed reduction in the plant growth was accompanied by a decline in the total chlorophyll content (37 to 53 per cent) and cellular respiration (36 to 57 per cent) in the test plants. However, the inhibitory effect was stronger in grassy weeds than that in broad leaved ones.

Johnson *et al*. (2012) conducted work on the integrated systems for weed management in organic sweet onion. They reported that clove oil herbicide shows weed control without affecting the yield of sweet onion.

Park *et al*. (2011) studied on the herbicidal action of clove oil in cucumber seedlings and they reported it as an effective organic herbicide. They also pointed out that light has no role in the herbicidal action of clove oil.

Chaturvedi *et al.* (2012) conducted study on the phytotoxic potential of Eucalyptus leaf essential oil to control *Parthenium hysterophorus* and observed that *Eucayptus citriodora* inhibits the growth of seedlings and biomass of Parthenium at a concentration of 0.25mgL^{-1}. It affected the growth, photosynthesis and energy metabolism of the treated plants.

2.5.4.4 Cashew nut shell liquid herbicide

The species *Anacardium occidentale* (Anacardiaceae) is found in tropical regions worldwide. It is common in Brazil, India, Mozambique, Tanzania, Kenya, Vietnam, Indonesia, and Thailand (Mazzetto *et al.*, 2009).

According to Ceruks, *et al.* (2007) different species of Anacardium group has high allelopathic effect, which is due to the presence of phenolic constituents.

Chemical structure of cardanol is similar to synthetic phenols (Santos and Magalhaes, 1999). CNSL is a mixture of 4 phenolic compounds namely anacardic acid, cardanol, cardol, 2 ethyl cardol.

Depending on the extraction method used, CNSL is classified into two categories. Natural CNSL (iCNSL), extracted with solvents and its main components are anacardic acid (62.9%), cardol (23.98%) and cardanol (6.99%) (Oliveira *et al.*, 2011).

Technical CNSL (tCNSL) is prepared by burning the nuts at high temperature in industries, containing cardanol (60-65%), cardol (15-20%), polymeric material (10%) and small amounts of metilcardol (Phanikumar *et al.*, 2002).

Cashew nut shell liquid contains approximately 90 per cent anacardic acid, a phenolic compound biosynthesized from fatty acids that can be phytotoxic (Martias *et al.*, 2017).

Anacardic acid is converted to cardanol by thermal decarboxylation and has antifeedent, repellent and arrestent effects, thus affecting the insects growth and development (Isman, 2006). Whereas more than 6 percent concentration cause phytotoxic symptoms in soya bean leaves (Andayanie *et al*., 2019).

2.6 EFFECT OF REPEATED APPLICATION OF ORGANIC HERBICIDES

Acetic acid is suggested to be applied five times per year (Young, 2004). Barker and Prostak (2009) conducted study on alternative management of roadside vegetation and stated that for the season long control of vegetation, repeated application of organic herbicides is required at an interval of 6 weeks or more often. They also reported that for improving the efficiency of herbicides, the citric acids- acetic acids formulations must be added without dilution (20% active ingredient).

2.7 PHYTOTOXIC EFFECT OF ORGANIC HERBICIDES ON SEEDLINGS

According to a study by Meyer *et al*. (2008), tomato seedlings were the most sensitive to clove oil. The 0.2 percent and 0.3 percent clove oil concentrations applied as drenches at transplant (0 day) were the most phytotoxic to seedlings of all the tested vegetable species, with only 0 percent to 50 percent seedling survival. Most of the clove oil concentrations applied as drenches at transplant decreased shoot heights and fresh shoot weights of all seedlings. Some applications of clove oil at 0.2 percent and 0.3 percent, applied 2, 5, or 7 days before transplant also significantly reduced shoot growth, especially of pepper and tomato.

2.8 EFFECT OF ORGANIC HERBICIDES ON SOIL PARAMETERS

Rui *et al*. (2014) conducted work on the effect of wood vinegar on the microbial characters on soil and reported that treatment with wood vinegar significantly increased the total number of bacteria especially *Bacillus* spp., Gram-positive and Gram-negative bacteria, aerobic and anaerobic and other non dominant bacteria in the soil. Whereas there was some inhibitory effect on the fungi population in soil.

Clove oil has the potential to reduce the population of *Phytophthora nicotianae* in soil after 21 days of treatment as reported by Bowers and Locke (2004). 97.5 per cent control of *Fusarium oxysporum* f. sp. Chrysanthemi with 10 per cent clove oil treatment was observed by Bowers and Locke (2000).

According to Behera and Sahani (2003), the soil microbial and fungal population was reported to be low in eucalyptus plantation. Eucalyptus essential oil suppresses the fungal population in soil as reported by Martins *et al.* (2013).

Gellerman *et al.* (1969) reported that anacardic acid has an inhibitory effect in the growth of most of the microorganisms, especially in the gram negative bacteria which were found to be more sensitive.

According to a study conducted by Radhakrishnan *et al.* (2003) the initial soil pH of 5.9 to 6.6 has declined to 4.7 to 5.2 one month after application of vinegar, but after five months it was observed to be 5.8 to 7.1.

2.9 ECONOMICS OF ORGANIC WEED MANAGEMENT

Bandyopadhyay *et al.* (2001) reported that mulching with green leaves of *Antigonon leptopus* gives higher pod yield of 17.1tha^{-1} and a B:C ratio of 4.86 and better growth attributing characters in okra.

In okra, mulching with black polythene resulted in 22.3tha^{-1} yield with the highest cost benefit ratio of 1:3.1 on comparison with control having 3.1tha^{-1} yield (Saikia *et al.*, 1997).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled 'Evaluation of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculentus* (L.) Moench]' was carried out at the Department of Vegetable Science, College of Agriculture, Vellayani during 2017-19. The materials used and the methodology adopted for the study is described in this chapter.

3.1 General Details

Location

The experiment was conducted at the Department of Vegetable Science, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. Geographically the field is situated at 8°25' 55.15" North latitude and 76°59' 14.51" East longitude, at an altitude of 29 m above mean sea level.

Soil

Predominant soil type of the experimental site was red loam of Vellayani series, texturally classified as sandy clay loam.

Crop and variety

Okra variety Anjitha, which is tolerent to yellow vein mosaic virus, was used for the experiment.

3.2 Experiment details

The experiment comprised of two parts. First part consisted of 5 experiments each having 5 treatments and 5 replications laid out in Completely Randomised Block Design (CRD). Second part consists of 13 treatments and 3 replications laid out in Randomised Block Design (RBD).

Part 1: Preliminary evaluation of horticultural crop products and by-products as herbicides.

Experiment 1. Coconut vinegar (CVH)

1. Design: CRD

2. Replication: 5

3: Treatments: 5 [4 different concentrations of coconut vinegar (5, 7.5, 10, 12.5 percent acetic acid equivalent) and control]

Commercially available coconut water vinegar was purchased and acetic acid content of coconut vinegar was enhanced from 4 to 5, 7.5, 10 and 12.5 percentage by freeze distillation. The four concentrations of acetic acid was applied on to the weeds and compared with unweeded control. Acetic acid having a melting point of 16.5°C (Eichelberger and Mer, 1933) will melt faster than water with 0°C melting point.

The experiment was conducted in Completely Randomised Block Design (CRD) replicated 5 times.

Experiment 2. Cashew Nut Shell Liquid (CNSLH)

1. Design: CRD

2. Replication: 5

3: Treatments: 5 [4 different concentrations of Cashew Nut Shell Liquid (5, 10, 15, 20 percent CNSL) and control]

Industrial grade cashew nut shell liquid was purchased from cashew factory in Kollam district. It was emulsified to 5, 10, 15 and 20 percent by using soap solution and alcohol to form a sprayable solution. The four concentrations of CNSL was applied on to the weeds and compared with unweeded control.

The experiment was conducted in Completely Randomised Block Design (CRD) replicated 5 times.

Experiment 3. Lemon Extract (LEH)

1. Design: CRD

2. Replication: 5

3: Treatments: 5 [4 different concentrations of lemon extract (2.5, 5, 7.5, 10 percent citric acid equivalent) and control]

Ordinary small lemon was purchased from the market. Lemon juice was squeezed out and the peel was cold pressed to obtain the peel extract. The citric acid content was enhanced to 2.5, 5, 7.5 and 10 percent by evaporation method. The four concentrations of citric acid was applied on to the weeds and compared with unweeded control.

The experiment was conducted in Completely Randomised Block Design (CRD) replicated 5 times.

Experiment 4. Coconut vinegar-clove leaf oil mixture (CLOH)

1. Design: CRD

2. Replication: 5

3: Treatments: 5 [4 different concentrations of coconut vinegar-clove leaf oil mixture (Best treatment of Experiment 1 + 1, 2, 3, 4 percent clove leaf oil) and control]

The best treatment of experiment 1 (Coconut vinegar herbicide) was mixed with 1, 2, 3 and 4 percent clove leaf oil purchased from Synthite Industries Ltd. The four concentrations of coconut vinegar-clove leaf oil mixture was applied on to the weeds and compared with unweeded control.

The experiment was conducted in Completely Randomised Block Design (CRD) replicated 5 times.

Experiment 5. Coconut vinegar-eucalyptus oil mixture (EOH)

1. Design: CRD

2. Replication: 5

3: Treatments: 5 [4 different concentrations of coconut vinegar-eucalyptus oil mixture (Best treatment of Experiment 1 + 1, 2, 3, 4 percent eucalyptus oil) and control]

The best treatment of experiment 1 (Coconut vinegar herbicide) was mixed with 1, 2, 3 and 4 percent eucalyptus oil purchased from Vanasree Products of Kerala Forest Department. The four concentrations of coconut vinegar-clove eucalyptus oil mixture was applied on to the weeds and compared with unweeded control.

The experiment was conducted in Completely Randomised Block Design (CRD) replicated 5 times.

Land preparation

Seed beds were prepared in a weedy area by tilling using a rotavator and weeds were flushed out. After 45 days, the emerged weeds (Plate 1) were smothered by value added extracts (Plate 2) at tested concentrations in randomly selected mini plots.

The best treatment of each experiment in part I was selected based on weed control efficiency and carried over to the field experiment in Part II (Plate 3)

Part II: Evaluation of herbicides in organic farming of okra.

Design : RBD

Treatments : 13

Plate 1: Plot at 45 days after seed bed preparation

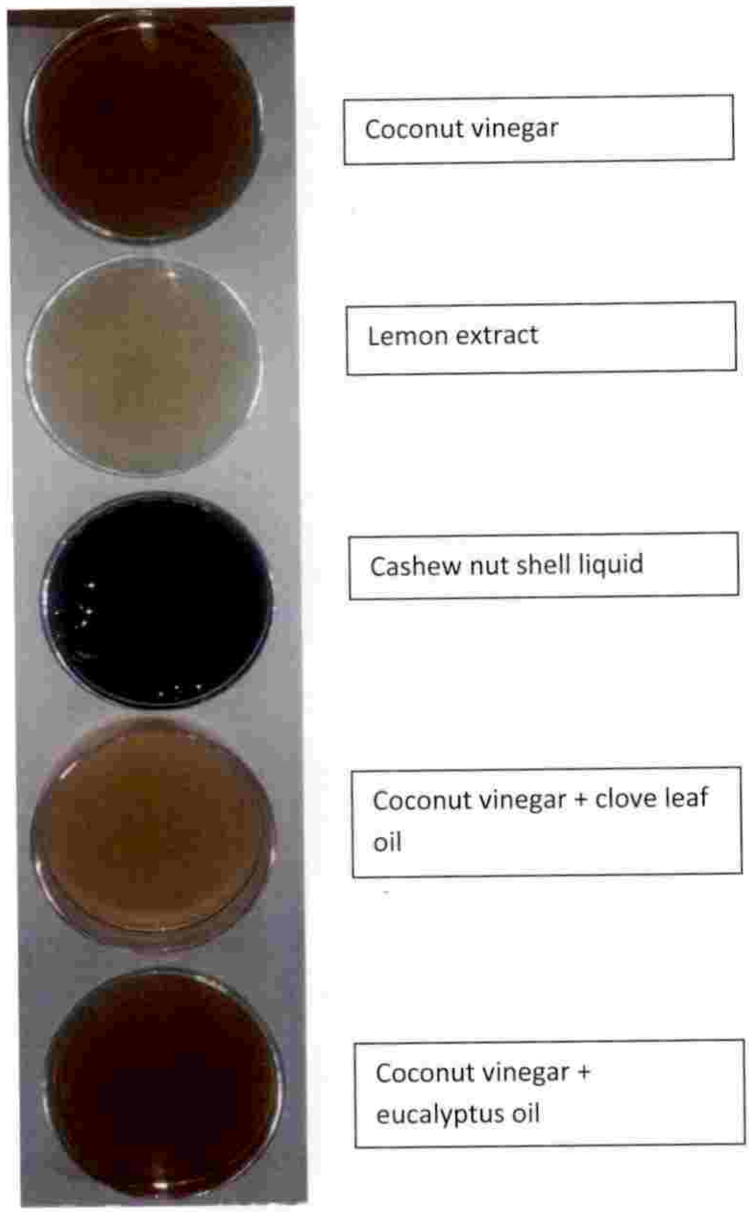


Plate 2: Herbicidal preparations

Plate 3: Field view of Part II

Replication : 3

Spacing : 60 cm x 45 cm

Plot size : 2.4 m x 2.7 m

Treatments

T_1- Stale seed bed with coconut vinegar herbicide (CVH)

T_2- Stale seed bed with cashew nut shell liquid herbicide (CNSLH)

T_3- Stale seed bed with lemon Extract herbicide (LEH)

T_4- Stale seed bed with coconut vinegar- clove leaf oil herbicide (CLOH)

T_5- Stale seed bed with coconut vinegar- eucalyptus oil herbicide (EOH)

T_6- T1+ Spray of CVH at 30 DAS

T_7- T2+ Spray of CNSLH at 30 DAS

T_8- T3+ Spray of LEH at 30 DAS

T_9- T4+ Spray of CLOH at 30 DAS

T_{10}- T5+ Spray of EOH at 30 DAS

T_{11}- Organic mulching with mango leaves

T_{12}- Hand weeding (Weed free till 7th week)

T_{13}- Control (Weedy Check)

Land preparation and sowing

Land was prepared thoroughly using rotavator to produce fine tilth (Plate 4). Plot size was 6.48 m^2. Ridges and furrows were taken at a spacing of 60 cm. Weeds were allowed to grow in the seed bed for 45 days. The above mentioned herbicides were applied in the individual plots as per the treatment. Pre-soaked

Plate 4: Stale seed bed before spraying

seeds treated with *Pseudomonas* (8g/kg seeds), were dibbled at a spacing of 60cm x 45 cm at the rate of one seed per hole. The seed rate was 8.5 $kgha^{-1}$. The variety used was Anjitha obtained from Department of Plant Breeding and Genetics, College of Agriculture, Vellayani.

Manuring

Manures were applied as per the Adhoc organic Package of Practices recommendation of KAU. Lime was applied based on the acidity of soil 15 days before sowing. FYM or compost @25t/ha was applied as basal dose along with *Pseudomonas* @ 2$kgha^{-1}$. Top dressing was carried out with the following manures at 10-15 days interval.

1. Soil application of fresh cowdung slurry @ 1 kg/10 litres (50 $kgha^{-1}$)

2. Application of cow's urine 500 litres/ha (8 times dilution)

3. Application of vermicompost - 1 t ha^{-1}

4. Application of groundnut cake-1 kg/10 litres (50 $kgha^{-1}$).

Weeding

Weeding was done as per the treatments in different plots. In the seed bed organic herbicides were applied at 45 days after weed emergence in T_1 to T_{10}. Repeated spraying was carried out at 30 days after sowing of crop in treatments T_5 to T_{10}. In T_{11} mango leaf mulching was carried out. In T_{12} hand weeding, where the plot was kept weed free till 7 weeks after sowing. No weeding was conducted in unweeded control plot.

Irrigation

Irrigation was given as and when required.

3.3 Observations

Part I

3.3.1 Floristic composition of weeds

The weed species infested the experimental cite were identified and recorded before application, 15 and 45 days after application.

3.3.2 Absolute density (Ad)

Absolute density of weeds were calculated by categorising the plants into sedges, broad leaf weeds and grasses in an area of 25cm x 25cm in 3 sites in each plot and taking the average. It was recorded before application, 15 and 45 days after application using the formula suggested by Philips (1959).

Ad = Total number of plants of a given species per m^2

3.3.3 Root and shoot biomass.

The shoot portion was clipped up to ground level and green weight recorded in gm^{-2} using an electric balance. The roots of each plant were washed with sprinkler on wire gauze mesh. A plastic sheet was kept below the mesh to collect the disconnected fine roots. The weight of root of weeds was recorded in gm^{-2}.

3.3.4 Weed control efficiency

The clipped material and the root of each plant was shade dried until the time, the weight remained constant for subsequent weighing. The shade dried weight of shoots/columns and roots of the individual plant were recorded in gm^{-2} using in electric balance.

Weed control efficiency was calculated based on the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{WDWC - WDWT}{WDWC} \times 100 \text{ where,}$$

WCE = Weed control efficiency

WDWC = weed dry weight in unweeded plot (control)

WDWT = weed dry weight in treated plot

Part II

3.3.5 Crop Growth characters

From each plot, 5 plants were selected at random and the following observations were taken from these sample plants and the mean values are recorded.

3.3.5.1 Germination percentage

Germination percentage of the seeds is calculated based on the number of seeds germinated per 100 seeds sown

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{total number of seeds sown}} \text{x} 100$$

3.3.5.2 Phytotoxicity rating

Phytotoxicity rating was done in the seedlings by visual observation after the application of herbicides and the rating was given according to the phytotoxicity rating chart given below (Rao, 1986).

Effect	Rating	Weed	Crop
None	0	No control	No injury, normal
Slight	1	Very poor control	Slight stunting, injury or discolouration
	2	Poor control	Some stand loss, stunting or discolouration
	3	Poor to deficient control	Injury more pronounced but not persistent

Moderate	4	Deficient control	Moderate injury, recovery possible
	5	Deficient to moderate control	Injury more persistent, recovery doubtful
	6	Moderate control	Near severe injury no recovery possible
Severe	7	Satisfactory control	Severe injury stand loss
	8	Good control	Almost destroyed a few plants surviving
	9	Good to excellent control	Very few plants alive
Complete	10	Complete control	Complete destruction

3.3.5.3 Plant height

The height of the plant was recorded at 60 days after sowing from the ground level to the growing tip and expressed in cm.

3.3.5.4 Number of branches per plant

The total number of branches at the maximum growing stage of each sample plant is counted and then the average is calculated.

3.3.5.5 Number of leaves per plant

Number of leaves of each sample plant was counted at 60 days after sowing and the mean number of leaves per plant worked out.

3.3.5.6 Node to first flower

The node at which the first flower emerged was recorded.

3.3.5.7 Days to 50 percent flowering

Number of days taken by 50 percent of the plants for the emergence of flowers in each treatment was recorded.

3.3.5.8 Crop duration

The number of days from sowing to harvesting is noted in days.

3.3.6 Yield and yield attributes

3.3.6.1 Number of flowers per plant

The number of flowers that are produced in the sample plants were counted and mean value was recorded.

3.3.6.2 Number of fruits per plant

The number of fruits that are produced in the sample plants were counted and mean value was recorded.

3.3.6.3 Number of harvest

The total number of harvest per plant was recorded

3.3.6.4 Percent fruit set

Based on the total number of fruits harvested per plant per plot and the total number of flowers produced per plant per plot, the percentage fruit set was worked out.

Percentage fruit set=

$$\frac{\text{Total number of fruits}}{\text{Total number of flowers}} \text{x100}$$

3.3.6.5 Yield

The weight of fruits from the net plot was recorded from each harvest. The total was worked out and expressed in t ha^{-1}.

3.3.7 Observation on weeds

3.3.7.1 Floristic composition of weeds

The weed species infested the experimental cite were identified and recorded before application, 15 and 45 days after application.

3.3.7.2 Absolute density (Ad)

Absolute density of weeds was calculated in an area of 25cm x 25cm in 3 sites in each plot and taking the average. It was recorded before application, 15 and 45 days after application using the formula suggested by Philips (1959).

Ad = Total number of plants of a given species m^{-2}

3.3.7.3 Root and shoot biomass.

The shoot portion was clipped up to ground level and green weight recorded in gm^{-2} using an electric balance. The roots of each plant were washed with sprinkler on wire gauze mesh. A plastic sheet was kept below the mesh to collect the disconnected fine roots. The weight of root of weeds was recorded in gm^{-2}.

3.3.7.4 Weed control efficiency

Weed control efficiency was calculated based on the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{WDWC - WDWT}{WDWC} \times 100$$ where,

WCE = Weed control efficiency

WDWC = weed dry weight in unweeded plot (control)

WDWT = weed dry weight in treated plot

3.3.7.5 Weed index

Weed index was calculated based on the formula suggested by Gill and Vijayakumar (1969).

$$WI = \frac{X-Y}{X} \times 100$$ where

X= yield from the weed free plot or the treatment which recorded the minimum number of weeds.

Y = yield from the plot for which the weed index is to be worked out.

3.3.8 Soil analysis

Soil analysis was carried out before and after the experiment. Soil samples were collected from different parts of the field and a representative soil sample was obtained by mixing the soil samples. The representative sample was used for the estimation of organic carbon status, available nitrogen, available phosphorus and available potassium of the site. Soil samples from individual plots were taken after the experiment and N, P, K status was analysed.

3.3.8.1 Organic carbon status of soil

The organic carbon status of soil was carried out by Walkley and Black rapid titration method (Walkley and Black, 1934)

3.3.8.2 Available nitrogen

Estimation of available nitrogen was carried out by alkaline permanganate method (Subbiah and Asija, 1956)

3.3.8.3 Available phosphorus

Available P_2O_5 was determined by Dickman and Bray's molybdenum blue method in a kletts summerson photoelectric colorimeter. The soil was extracted with Bray's reagent No. 1 (0.03 N ammonium fluride in 0.025 N hydrochloric acid) (Jackson, 1973).

3.3.8.4 Available potassium

Available K_2O was determined in the neutral normal ammonium acetate extract and estimated using EEL flame photometer (Jackson, 1973).

3.3.8.5 Microbial population in the soil

Total population of bacteria, fungi and actinomycetes were enumerated before and after the experiment. The media used are

Sl. No	Microbes	Medium	Reference
1	Bacteria	Nutrient agar	Atlas and Parks (1993)
2	Fungi	Martin's Rose Bengal Agar	Martin (1950)
3	Actinomycetes	Kenknight's Agar	Coppuccino and Sheman (1996)

The estimation was carried out by serial dilution of 1 mL aliquot and pour plate method was used.

3.3.8.6 Quantitative estimation of earthworms

Pits of one metre cube soil was excavated and examined for enumeration of earth worms and the method followed was direct counting method (Thakur, 2014).

3.3.8.7 Dehydrogenase enzyme activity of soil

Dehydrogenase enzyme activity was calculated by using spectrophotometric method expressed in μg of TPF g^{-1} soil $24h^{-1}$. (Casida *et al.*, 1964)

3.3.9 Nutrient uptake by crop and weeds

The plant samples were dried in an electric hot air oven to constant weight, which was ground and sieved through a 0.5 mm sieve. The sample was weighed in an electrical balance. The weighed samples are carried on to acid extraction and then chemical analysis was conducted.

The weed samples were collected at 30 and 60 days after sowing.

Total nitrogen content

Total nitrogen content was estimated by modified microkjeldal method. (Jackson, 1973).

Total phosphorus content

Total phosphorus content was found out using Vanadomolybdo phosphoric yellow colour method. (Jackson, 1973)

Total potassium content

Total potassium content was determined by EEL Flame Photometer (Jackson, 1973).

The N, P, K uptake by the crop and weeds were worked out as the product of content of these nutrients and the dry weight of weeds and expressed in kgha^{-1}.

3.3.10 B: C Ratio

The prevailing labour charge in the locality, cost of inputs and extra treatment costs were taken together and gross expenditure was computed and expressed in rupees per hectare. The price of okra at current local market price was taken as total receipts for computing gross return and expressed in rupees per hectare. The benefit cost ratio was calculated according to the formula given below

$$\text{BCR} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.3.11 Statistical Analysis

The data were subjected to analysis of variance using the statistical package "OP-STAT" (Sheoran *et al*., 1998). The data on absolute density of weeds and root and shoot biomass, which showed wide variation, were subjected to square root ($\sqrt{x+0.5}$) transformation to make analysis of variance valid (Gomez and Gomez, 1984).

Results

4. RESULTS

The results of the study on 'Evaluation of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculents* (L.) Moench]' conducted in the Department of Vegetable Science, College of Agriculture, Vellayani are presented below.

PART 1- Preliminary evaluation of horticultural crop products and by-products as herbicides.

Part 1 consisted of 5 experiments with Coconut vinegar herbicide (CVH) with 5, 7.5, 10 and 12.5 percent acetic acid, Cashew Nut Shell Liquid herbicide (CNSLH) with 5, 10, 15 and 20 percent CNSL, Lemon extract herbicide (LEH) with 2.5, 5, 7.5 and 10 percent citric acid, Coconut vinegar-clove leaf oil herbicide (CLOH), which is a mixture of best treatment of CVH with 1, 2, 3 and 4 percent clove leaf oil and Coconut vinegar-eucalyptus oil herbicide (EOH) which is a mixture of best treatment of CVH with 1, 2, 3 and 4 percent eucalyptus oil. The observations on weeds such as floristic composition, absolute density, root and shoot biomass, and weed control efficiency was taken and the results are presented below.

4.1. Experiment 1: Coconut vinegar

4.1.1. Observations on weeds

4.1.1.1. Floristic composition of weeds

Panicum maximum, *Setaria barbata* and *Cynodon dactylon* are the major grasses seen in the experimental area (Table 1). Sedges such as *Cyperus rotundus* and broad leaved weeds such as *Cleome viscose*, *Synedrella nodiflora*, *Euphorbia genniculata*, *Phyllanthus niruri*, *Gomphrena serrate*, *Commelina benghalensis*, *Evolvulus numularius* and *Vernonia cineria* are the common weed species observed.

Table 1: Effect of coconut vinegar herbicides (CVH) on floristic composition of weeds

Stage of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Evolvulus nummularius* *Vernonia cineria*
15 DAS	*Panicum maximum* *Setaria barbata*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Vernonia cineria*
45 DAS	*Panicum maximum* *Setaria barbata*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Commelina benghalensis* *Evolvulus nummularius* *Vernonia cineria*

At 15 days after spraying, grasses such as *Panicum maximum* and *Setaria barbata*, sedges such as *Cyperus rotundus*, and broad leaved weeds such as *Euphorbia genniculata*, *Gomphrena serrate* and *Vernonia cineria* was observed.

At 45 days after spraying, grasses such as *Panicum maximum* and *Setaria barbata*, sedges such as *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata*, *Gomphrena serrate*, *Commelina benghalensis*, *Evolvulus nummularius* and *Vernonia cineria* was observed.

4.1.1.2. Absolute density

Observations on the effect of coconut vinegar treatments on the absolute density of weeds are given in Table 2. At 15 days after spraying, coconut vinegar herbicide (CVH) with 12.5 percent acetic acid (T_4) recorded the lowest absolute density of grasses (153.19m^{-2}) compared to unweeded control (T_5) with 240.53m^{-2}, followed by coconut vinegar with 10 percent acetic acid (T_3) (215.35 m^{-2}) and higher absolute density (241.99 m^{-2}) was observed with coconut vinegar with 5 percent acetic acid (T_1) which was on par with unweeded control (240.53 m^{-2}). CVH with 12.5 percent acetic acid (T_4) recorded the lowest absolute density of sedges (9.18 m^{-2}), followed by CVH with 10 percent acetic acid (T_3) with absolute density of 12.35 m^{-2} and higher absolute density (21.22 m^{-2}) was observed in plot without any weeding (T_5) but at par with CVH with 5 percent acetic acid (T_1). CVH with 12.5 percent acetic acid (T_4) recorded the lowest absolute density of broad leaved weeds (29.06 m^{-2}) which was on par with CVH with 10 percent acetic acid (T_3) which recorded absolute density of 35.86 m^{-2} and higher absolute density (115.15 m^{-2}) was observed in plot without any weeding (T_5).

At 45 days after spraying, CVH with 12.5 percent acetic acid (T_4) recorded the lowest absolute density of grasses (158.36 m^{-2}), followed by CVH with 10 percent acetic acid (T_3) with 195.14 m^{-2} and the highest absolute density (248.29 m^{-2}) was in plot without any weeding (T_5). Lowest absolute density of sedges (16.07 m^{-2}) was observed in CVH with 12.5 percent acetic acid (T_4), followed by CVH with 10 percent acetic acid (16.56 m^{-2}) and highest absolute density (24.41

Table 2. Effect of coconut vinegar herbicides (CVH) on absolute density of grasses, sedges and broad leaved weeds at before spraying, 15 DAS and 45 DAS.

Treatments	Absolute density (no.m^{-2})								
	Before spraying			15 DAS			45 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1- CVH with 5 % acetic acid	241.49* (15.55)	16.09 (4.07)	95.74 (9.81)	241.99 (15.57)	18.13 (4.32)	71.46 (8.48)	246.52 (15.71)	21.41 (4.68)	69.11 (8.34)
T_2- CVH with 7.5% acetic acid	240.15 (15.51)	15.33 (3.98)	105.12 (10.28)	238.51 (15.46)	16.15 (4.08)	91.47 (9.59)	244.55 (15.65)	17.67 (4.26)	94.33 (9.74)
T_3- CVH with 10% acetic acid	244.08 (15.64)	16.07 (4.07)	103.34 (10.19)	215.35 (14.69)	12.35 (3.58)	35.86 (6.03)	195.14 (13.99)	16.56 (4.13)	43.98 (6.67)
T_4- CVH with 12.5% acetic acid	233.38 (15.29)	18.15 (4.32)	106.21 (10.33)	153.19 (12.40)	9.18 (3.11)	29.06 (5.44)	158.36 (12.60)	16.07 (4.07)	30.42 (5.56)
T_5- control	235.00 (15.34)	17.62 (4.26)	109.33 (10.48)	240.53 (15.53)	21.22 (4.66)	115.15 (10.75)	248.29 (15.77)	24.41 (4.99)	129.07 (11.38)
CD (0.05)	NS	NS	NS	0.98	0.34	1.95	1.47	0.66	1.38
SE(m)±	0.30	0.15	0.30	0.33	0.11	0.48	0.50	0.22	0.47

* Original values, square root transformed values are given in parenthesis

m^{-2}) was in unweeded control (T_5) and on par with CVH with 5 percent acetic acid (21.41 m^{-2}). CVH with 12.5 percent acetic acid (T_4) recorded the lowest absolute density of broad leaved weeds (30.42 m^{-2}), which was on par with CVH with 10 percent acetic acid (T_3) which shows absolute density of 43.98 m^{-2} and highest absolute density was in unweeded control (T_5) having a weed count of 129.07 m^{-2}.

4.1.1.3 Root and shoot biomass

Effect of coconut vinegar treatments on root and shoot biomass of weeds are given in Table 3. At 15 days after spraying, least root biomass (6.61 gm^{-2}) was observed in CVH with 12.5 percent acetic acid (T_4), followed by CVH with 10 percent acetic acid (T_3) with 18.61 gm^{-2}, whereas highest root biomass was recorded in unweeded control (51.61 gm^{-2}). Shoot biomass was also observed to be lowest (355.73 gm^{-2}) in treatment CVH with 12.5 percent acetic acid (T_4), followed by CVH with 10 percent acetic acid (T_3) having 688.62 gm^{-2}. The highest shoot biomass (1025.29 gm^{-2}) was observed with unweeded control (T_5).

At 45 days after spraying, lowest root biomass (11.18 gm^{-2}) was observed in treatment with CVH with 12.5 percent acetic acid (T_4) when compared to control (T_5) with 55.35 gm^{-2} followed by CVH with 10 percent acetic acid (T_3) with 24.39 gm^{-2}. Shoot biomass was observed to be lowest (401.66 gm^{-2}) in CVH with 12.5 percent acetic acid treatment (T_4) when compared to control (T_5) with 1192.65 gm^{-2}, followed by CVH with 10 percent acetic acid (T_3) with shoot biomass of 837.31 gm^{-2}.

4.1.1.4 Weed Control Efficiency

At 15 days after spraying, CVH with 12.5 percent acetic acid (T_4) recorded highest weed control efficiency of 70.37 percent (Table 4) when compared to control (T_5) with 0.00 percent weed control efficiency, followed by CVH with 10 percent acetic acid (T_3) (38.07%).

Table 3. Effect of coconut vinegar herbicides (CVH) on the root and shoot biomass of weeds at before spraying, 15 DAS and 45 DAS

Treatments	Root and shoot biomass (g m^{-2})					
	Before spraying		15 DAS		45 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot
T_1- CVH with 5 % acetic acid	32.24* (5.72)	950.24 (30.83)	35.34 (5.99)	1008.20 (31.76)	31.66 (5.67)	971.88 (31.18)
T_2- CVH with 7.5% acetic acid	32.33 (5.73)	956.78 (30.94)	38.59 (6.25)	970.13 (31.16)	37.19 (6.14)	978.25 (31.29)
T_3- CVH with 10% acetic acid	36.38 (6.07)	962.11 (31.03)	18.61 (4.37)	688.62 (26.25)	24.39 (4.99)	837.31 (28.95)
T_4- CVH with 12.5% acetic acid	34.52 (5.92)	958.33 (30.97)	6.61 (2.67)	355.73 (18.87)	11.18 (3.42)	401.66 (20.05)
T_5- control	39.00 (6.29)	990.74 (31.48)	51.61 (7.22)	1025.29 (32.03)	55.35 (7.47)	1192.65 (34.54)
CD (0.05)	NS	NS	0.51	1.224	0.82	2.31
SE (m)±	0.16	0.26	0.17	0.42	0.27	0.78

* Original values, square root transformed values are given in parenthesis

Table 4. Effect of coconut vinegar herbicides (CVH) on weed control efficiency at 15 DAS and 45 DAS.

Treatments	Weed Control Efficiency (%)	
	15 DAS	45 DAS
T_1- CVH with 5 % acetic acid	14.42	3.88
T_2- CVH with 7.5% acetic acid	16.39	17.40
T_3- CVH with 10% acetic acid	38.07	37.90
T_4- CVH with 12.5% acetic acid	70.37	56.31
T_5- control	0.00	0.00
CD (0.05)	9.437	8.66
SE (m)±	3.20	2.93

At 45 days after spraying weed control efficiency was highest in CVH with 12.5 percent acetic acid (T_4) with 56.31 percent when compared to unweeded control (T_5) with 0.00 percent weed control efficiency, followed by CVH with 10 percent acetic acid (T_3) with 37.90 percent weed control efficiency.

4.2 Experiment 2: Cashew Nut Shell Liquid

4.2.1 Observation on weeds

4.2.1.1 Floristic composition of weeds

Effect of CNSL herbicides (CNSLH) on the floristic composition of weeds are presented in Table 5. Control of grasses such as *Cynodon dactylon*, certain broad leaved weeds such as *Cleome viscose*, *Synedrella nodiflora*, *Phyllanthus niruri*, *Commelina benghalensis* and *Evolvulus numularius* was observed at 15 days after spraying. At 45 days after spraying regrowth of certain weeds such as *Commelina benghalensis* and *Evolvulus numularius* was also noticed.

4.2.1.2 Absolute density

Effect of CNSL treatments on the absolute density of grasses, sedges, and broad leaved weeds are given in Table 6. At 15 days after spraying, lowest absolute density of grasses (14.80 m^{-2}) was observed in 20 percent CNSL treatment (T_4), followed by 15 percent CNSL treatment (T_3) with absolute density of 55.47 m^{-2} and the highest absolute density (175.12 m^{-2}) was recorded by unweeded control (T_5). 20 percent CNSL (T_4) recorded the lowest absolute density of sedges (5.33 m^{-2}); followed by 15 percent CNSL (T_3) and unweeded control (T_5) recorded the highest number of sedges m^{-2} (23.76 m^{-2}). Absolute density of broad leaved weeds was found to be lowest (10.17 m^{-2}) in treatment with 20 percent CNSL (T_4), followed by 15 percent CNSL treatment (T_3) with 73.53 m^{-2} and the highest absolute density was observed in unweeded control (T_5) with 115.13 m^{-2}.

At 45 days after spraying, lowest absolute density of grasses (50.62 m^{-2}) was observed with 20 percent CNSL (T_4), followed by 15 percent CNSL(T_3) with

Table 5: Effect of Cashew Nut Shell Liquid (CNSLH) on floristic composition of weeds

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Evolvulus nummularius* *Vernonia cineria*
15 DAS	*Panicum maximum* *Setaria barbata*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Vernonia cineria*
45 DAS	*Panicum maximum* *Setaria barbata*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Commelina benghalensis* *Evolvulus nummularius* *Vernonia cineria*

Table 6. Effect of Cashew Nut Shell Liquid (CNSLH) on absolute density of grasses, sedges and broad leaved weeds at before spraying, 15 DAS and 45 DAS

Treatments	Absolute density (no.m^{-2})								
	Before spraying			15 DAS			45 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1- 5% CNSL	163.46* (12.80)	20.34 (4.57)	103.66 (10.21)	166.58 (12.93)	22.34 (4.78)	108.28 (10.43)	200.22 (14.15)	44.68 (6.72)	130.92 (11.46)
T_2- 10% CNSL	161.71 (12.74)	18.34 (4.34)	105.75 (10.31)	118.77 (10.92)	21.15 (4.65)	91.83 (9.61)	189.31 (13.76)	37.49 (6.16)	118.72 (10.92)
T_3- 15% CNSL	169.43 (13.04)	20.13 (4.54)	108.37 (10.43)	55.47 (7.48)	19.68 (4.49)	73.53 (8.60)	115.76 (10.76)	27.22 (5.27)	66.41 (8.18)
T_4- 20% CNSL	164.67 (12.85)	16.34 (4.10)	102.32 (10.14)	14.80 (3.91)	5.33 (2.42)	10.17 (3.27)	50.62 (7.12)	17.99 (4.30)	29.75 (5.50)
T_5- control	165.70 (12.89)	18.06 (4.31)	106.68 (10.53)	175.12 (13.25)	23.76 (4.93)	115.13 (10.75)	203.83 (14.28)	44.69 (6.72)	131.34 (11.48)
CD (0.05)	NS	NS	NS	0.73	0.39	0.55	0.88	0.77	0.77
SE(m)±	0.41	0.21	0.29	0.25	0.13	0.18	0.30	0.26	0.26

* Original values, square root transformed values are given in parenthesis

115.76 m^{-2} and the highest (203.83 m^{-2}) was recorded in unweeded control (T_5). Absolute density of sedges and broad leaved weeds was recorded to be lowest in 20 percent CNSL (T_4) with 17.99 m^{-2} and 29.75 m^{-2} respectively, followed by 15 percent CNSL (T_3) with 27.22 and 66.41 m^{-2} respectively. Highest absolute density of sedges and broad leaves weeds was observed in unweeded control (T_5) with 44.69 and 131.34 m^{-2} respectively.

4.2.1.3 Root and shoot biomass

Effect of CNSL treatments on the root and shoot biomass of weeds are given in Table 7. At 15 days after spraying the root and shoot biomass (2.53 and 47.58 gm^{-2} respectively) was observed to be lowest in 20 percent CNSL (T_4), followed by 15 percent CNSL (T_3) with 7.13 and 358.22 gm^{-2} respectively. The root and shoot biomass was observed to be highest (33.97 and 1070.43 gm^{-2} respectively) in unweeded control (T_5).

At 45 days after spraying, lowest root and shoot biomass (8.91 and 426.29 gm^{-2} respectively) was recorded in 20 percent CNSL treatment (T_4), followed by 15 percent CNSL (T_3) with 20.11 and 726.88 gm^{-2} respectively. Highest root and shoot biomass (42.86 and 1279.92 gm^{-2} respectively) was observed in unweeded control (T_5).

4.2.1.4 Weed Control Efficiency

Effect of CNSL treatments on weed control efficiency is given in Table 8. At 15 days after spraying, highest weed control efficiency (85.42%) was recorded by 20 percent CNSL (T_4), followed by 15 percent CNSL (T_3) with 60.72 percent and the lowest was recorded by unweeded control (T_5) with 0.00 percent.

At 45 days after spraying, highest weed control efficiency (54.39%) was observed with 20 percent CNSL treatment (T_4), followed by 15 percent CNSL (T_3) with 43.60 percent. Weed control efficiency was observed to be lowest (0.00%) in unweeded control (T_5).

Table 7: Effect of Cashew Nut Shell Liquid (CNSLH) on root and shoot biomass (g m^{-2}) of weeds before spraying, 15 days after spraying and 45 days after spraying.

Treatments	Root and shoot biomass (g m^{-2})					
	Before spraying		15 DAS		45 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot
T_1- 5% CNSL	27.58* (5.30)	948.88 (30.81)	27.70 (5.31)	1033.44 (32.16)	39.59 (6.33)	1199.22 (34.64)
T_2- 10% CNSL	25.85 (5.13)	949.87 (30.83)	17.41 (4.23)	671.14 (25.92)	30.54 (5.57)	912.63 (30.22)
T_3- 15% CNSL	25.59 (5.11)	954.80 (30.91)	7.13 (2.76)	358.22 (18.94)	20.11 (4.54)	726.88 (26.97)
T_4- 20% CNSL	25.83 (5.13)	949.06 (30.82)	2.53 (1.74)	47.58 (6.93)	8.91 (3.07)	426.29 (20.66)
T_5- control	26.14 (5.16)	957.84 (30.96)	33.97 (5.87)	1070.43 (32.73)	42.86 (6.59)	1279.92 (35.78)
CD (0.05)	NS	NS	0.45	1.19	0.43	1.67
SE (m)±	0.23	0.09	0.15	0.41	0.14	0.57

* Original values, square root transformed values are given in parenthesis

Table 8: Effect of Cashew Nut Shell Liquid (CNSL) treatments on weed control efficiency at 15 and 45 days after spraying.

Treatments	Weed Control Efficiency (%)	
	15 Days after spraying	45 Days after spraying
T_1- 5% CNSL	11.27	5.29
T_2- 10% CNSL	32.26	7.32
T_3- 15% CNSL	60.72	43.60
T_4- 20% CNSL	85.42	54.39
T_5- control	0.00	0.00
CD (0.05)	8.92	9.46
SE (m)±	3.02	3.22

4.3 Experiment 3: Lemon Extract

4.3.1 Observation on weeds

4.3.1.1 Floristic composition of weeds

None of the weed flora was observed to be controlled with lemon extract treatments (LEH). Partial control of certain broad leaved weeds was observed at 15 days after spraying (Table 9)

4.3.1.2 Absolute density

Effect of LEH treatments on the absolute density of grasses, sedges and broad leaved weeds are given in Table 10. At 15 days after spraying, there were no significant difference in the absolute density of grasses and sedges. LEH treatment with 10 percent citric acid (T_4) recorded the lowest number of broad leaved weeds (32.97 m^{-2}), followed by LEH with 7.5 percent citric acid (T_3) with 47.61 m^{-2}. Highest absolute density of broad leaved weeds (60.68 m^{-2}) was observed in unweeded control (T_5).

At 45 days after spraying, the treatments did not differ significantly in the absolute density of grasses, sedges and broad leaved weeds with control.

4.3.1.3 Root and shoot biomass

Effect of LEH treatments on the root and shoot biomass of weeds are given in Table 11. At 15 days after spraying, the root and shoot biomass was observed to be lowest (12.12 and 160.33 gm^{-2} respectively) in LEH treatment with 10 percent citric acid (T_4), followed by LEH with 7.5 percent citric acid (T_3) (15.25 and 333.04 gm^{-2} respectively). Highest root and shoot biomass (30.64 and 337.73 gm^{-2} respectively) was recorded by unweeded control (T_5).

At 45 days after spraying, the root and shoot biomass was observed to be lowest (17.47 and 287.38 gm^{-2} respectively) in LEH with 10 percent citric acid (T_4), the lowest root biomass was found to be on par with 2.5 percent, 5 percent

Table 9: Effect of lemon extract herbicides (LEH) on floristic composition of weeds.

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*
15 DAS	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*
45 DAS	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*

Table 10: Effect of lemon extract herbicides (LEH) on absolute density of grasses, sedges and broad leaved weeds at before spraying, 15 DAS and 45 DAS

Treatments	Absolute density (no.m^{-2})								
	Before spraying			15 DAS			45 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1- 2.5% citric acid	86.72* (9.34)	15.73 (4.03)	51.24 (7.19)	109.41 (10.48)	21.11 (4.65)	60.68 (7.82)	105.73 (10.31)	30.88 (5.60)	58.05 (7.65)
T_2- 5% citric acid	101.27 (10.09)	19.66 (4.49)	49.22 (7.05)	105.55 (10.30)	20.84 (4.62)	52.83 (7.30)	111.80 (10.60)	26.48 (5.19)	53.80 (7.37)
T_3- 7.5% citric acid	104.56 (10.25)	16.24 (4.09)	37.26 (6.15)	110.57 (10.54)	18.10 (4.31)	47.61 (6.94)	110.55 (10.54)	21.19 (4.66)	45.33 (6.77)
T_4- 10% citric acid	105.10 (10.28)	13.89 (3.79)	53.92 (7.38)	101.89 (10.12)	16.96 (4.18)	32.97 (5.79)	103.19 (10.18)	19.67 (4.49)	54.26 (7.4)
T_5- control	124.05 (11.16)	15.76 (4.03)	46.63 (6.87)	118.55 (10.91)	21.62 (4.70)	53.58 (7.35)	133.09 (11.56)	30.75 (5.59)	67.36 (8.24)
CD (0.05)	NS	NS	NS	NS	NS	0.69	NS	NS	NS
SE(m)±	0.59	0.21	0.40	0.29	0.23	0.23	0.46	0.33	0.32

* Original values, square root transformed values are given in parenthesis

Table 11: Effect of lemon extract herbicides (LEH) on root and shoot biomass (gm^{-2}) of weeds before spraying, 15 days after spraying and 45 days after spraying.

Treatments	Root and shoot biomass ($g\ m^{-2}$)					
	Before spraying		15 DAS		45 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot
T_1- 2.5% citric acid	16.64* (4.14)	334.35 (18.30)	17.03 (4.19)	354.26 (18.84)	18.51 (4.36)	395.31 (19.90)
T_2- 5% citric acid	14.55 (3.88)	343.71 (18.55)	17.12 (4.20)	352.00 (18.78)	22.32 (4.78)	396.70 (19.93)
T_3- 7.5% citric acid	15.00 (3.94)	332.34 (18.24)	15.25 (3.97)	333.04 (18.26)	17.57 (4.25)	347.70 (18.66)
T_4- 10% citric acid	17.56 (4.25)	350.84 (18.74)	12.12 (3.55)	160.33 (12.68)	17.47 (4.24)	287.38 (16.97)
T_5- control	15.24 (3.97)	304.60 (17.47)	30.64 (5.58)	337.73 (18.39)	34.04 (5.88)	419.87 (20.50)
CD (0.05)	NS	NS	0.569	1.20	0.65	1.61
SE (m)±	0.19	0.43	0.19	0.40	0.21	0.55

* Original values, square root transformed values are given in parenthesis

and 7.5 percent citric acid (T_3). Highest root and shoot biomass was observed in unweeded control (T_5) with 34.04 and 419.87 gm^{-2} respectively.

4.3.1.4 Weed Control Efficiency

Effect of LEH treatments on the weed control efficiency is given in Table 12. At 15 days after spraying highest weed control efficiency (40.01%) was observed with LEH with 10 percent citric acid (T_4), followed by LEH with 7.5 percent citric acid (T_3) with 16.55 percent and lowest weed control efficiency (0.00%) with unweeded control (T_5).

At 45 days after spraying, highest weed control efficiency (5.93%) was observed with LEH having 10 percent citric acid (T_4), followed by LEH with 7.5 percent citric acid (T_3) with 1.59 percent and the lowest weed control efficiency of 0.00 percent was observed with unweeded control plot(T_5).

4.4 Experiment- 4: Coconut vinegar- clove leaf oil

4.4.1 Observation on weeds

4.4.1.1 Floristic composition of weeds

At 15 days after spraying, grasses such as *Setaria barbata* and *Cynodon dactylon* was controlled and broad leaved weeds such as *Cleome viscose*, *Synedrella nodiflora*, *Phyllanthus niruri*, *Commelina benghalensis*, and *Vernonia cineria* are observed to be controlled to a great extent. Regrowth of some of the weeds such as *Cynodon dactylon*, *Commelina benghalensis* and *Vernonia cineria* was observed in the experimental plot at 45 days after spraying (Table 13).

4.4.1.2 Absolute density

Effect of coconut vinegar- clove leaf oil (CLOH) treatments on the absolute density of grasses, sedges and broad leaved weeds are given in Table 14. At 15 days after spraying, absolute density of grasses was observed to be lowest (10.10 m^{-2}) in treatment with CLOH with4 percent clove leaf oil (T_4), followed by CLOH with 3 percent clove leaf oil (T_3) with 27.63 m^{-2} and the highest absolute

Table 12: Effect of lemon extract herbicides (LEH) on weed control efficiency at 15 and 45 days after spraying.

Treatments	Weed Control Efficiency (%)	
	15 Days after spraying	45 Days after spraying
T_1- 2.5% citric acid	6.38	1.59
T_2- 5% citric acid	12.17	0.94
T_3- 7.5% citric acid	16.55	1.12
T_4- 10% citric acid	40.01	5.93
T_5- control	0.00	0.00
CD (0.05)	8.13	3.24
SE (m)±	2.76	1.10

Table 13: Effect of coconut vinegar + clove leaf oil herbicides (CLOH) on floristic composition of weeds.

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*
15 DAS	*Panicum maximum*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata*
45 DAS	*Panicum maximum* *Cynodon dactylon*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*

Table 14: Effect of coconut vinegar + clove leaf oil (CLOH) treatments on absolute density of grasses, sedges and broad leaved weeds at before spraying, 15 DAS and 45 DAS

Treatments	Absolute density (no.m^{-2})								
	Before spraying			15 DAS			45 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1- CLOH with 1% clove leaf oil	184.22* (13.59)	75.91 (8.74)	145.52 (12.08)	60.22 (7.79)	30.18 (5.54)	58.76 (7.70)	62.50 (7.91)	32.61 (5.75)	65.29 (8.11)
T_2- CLOH with 2% clove leaf oil	189.88 (13.80)	61.45 (7.87)	161.68 (12.74)	57.59 (7.62)	25.96 (5.14)	47.58 (6.93)	59.23 (7.70)	26.65 (5.21)	48.49 (6.99)
T_3- CLOH with 3% clove leaf oil	190.82 (13.83)	65.17 (8.10)	167.07 (12.95)	27.63 (5.30)	16.12 (4.08)	23.79 (4.93)	28.09 (5.3)	15.25 (3.97)	23.75 (4.92)
T_4- CLOH with 4% clove leaf oil	186.29 (13.67)	62.93 (7.97)	158.71 (12.62)	10.10 (3.26)	7.72 (2.87)	7.72 (2.87)	9.95 (3.16)	6.00 (2.55)	7.85 (2.89)
T_5- control	193.18 (13.92)	64.83 (8.08)	163.49 (12.81)	203.56 (14.29)	76.87 (8.80)	76.87 (8.80)	209.67 (14.48)	79.58 (8.95)	177.67 (13.35)
CD (0.05)	NS	NS	NS	0.45	0.63	0.38	0.72	0.78	0.61
SE(m)±	0.10	0.22	0.28	0.15	0.20	0.12	0.24	0.26	0.20

* Original values, square root transformed values are given in parenthesis

density was observed in unweeded control (T_5). Absolute density of sedges and broad leaved weeds (7.72 and 7.72 m^{-2} respectively) was observed to be lowest in CLOH with 4 percent clove leaf oil (T_4), followed by CLOH with 3 percent clove leaf oil (16.12 and 23.79 m^{-2} respectively). Unweeded control (T_5) recorded the highest absolute density of sedges and broad leaved weeds (76.87 m^{-2} and 76.87 m^{-2} respectively).

At 45 days after spraying, CLOH with 4 percent clove leaf oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds (9.95, 6.00, and 7.85 m^{-2} respectively), followed by CLOH with 3 percent clove leaf oil (T_3) with 28.09, 15.25 and 23.75 m^{-2} respectively. Unweeded control (T_5) recorded the highest absolute density of grasses, sedges and broad leaved weeds (209.67, 79.58 and 177.67 m^{-2} respectively).

4.4.1.3 Root and shoot biomass

Effect of coconut vinegar- clove leaf oil treatments on the root and shoot biomass of weeds are given in Table 15. At 15 days after spraying, CLOH with 4 percent clove leaf oil (T_4) recorded the lowest root and shoot biomass (1.16 and 36.18 gm^{-2} respectively), CLOH with3 percent clove leaf oil (T_3) was observed to be the next best treatment with root and shoot biomass of 5.19 and 201.08 gm^{-2} respectively. Unweeded control (T_5) recorded the highest root and shoot biomass (32.97 and 1010.49 gm^{-2} respectively).

At 45 days after spraying, CLOH with 4 percent clove leaf oil (T_4) recorded the lowest root and shoot biomass of weeds (3.86 and 81.62 gm^{-2} respectively), followed by CLOH with 3 percent clove leaf oil (T_3) with root and shoot biomass of 14.23 and 359.97 gm^{-2} respectively. Unweeded control (T_5) recorded the highest root and shoot biomass (40.69 and 1205.74 gm^{-2} respectively).

Table 15: Effect of coconut vinegar + clove leaf oil (CLOH) herbicides on root and shoot biomass (gm^{-2}) of weeds before spraying, 15 days after spraying and 45 days after spraying.

Treatments	Root and shoot biomass (g m^{-2})					
	Before spraying		15 DAS		45 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot
T_1- CLOH with 1% clove leaf oil	23.43* (4.89)	945.31 (30.75)	6.06 (2.56)	341.49 (18.49)	17.61 (4.26)	452.76 (21.29)
T_2- CLOH with 2% clove leaf oil	25.87 (5.14)	938.74 (30.65)	6.92 (2.72)	302.75 (17.41)	16.30 (4.10)	386.64 (19.68)
T_3- CLOH with 3% clove leaf oil	26.31 (5.18)	943.03 (30.72)	5.19 (2.39)	201.08 (14.20)	14.23 (3.84)	359.97 (18.99)
T_4- CLOH with 4% clove leaf oil	26.29 (5.18)	947.40 (30.79)	1.16 (1.29)	36.18 (6.06)	3.86 (2.09)	81.62 (9.06)
T_5- control	26.96 (5.24)	936.29 (30.61)	32.97 (5.79)	1010.49 (31.80)	40.69 (6.42)	1205.74 (34.73)
CD (0.05)	NS	NS	0.34	0.92	0.46	1.49
SE (m)±	0.21	0.13	0.11	0.31	0.15	0.50

* Original values, square root transformed values are given in parenthesis

4.4.1.4 Weed control efficiency

Effect of coconut vinegar- clove leaf oil treatments on weed control efficiency is given in Table 16. At 15 days after spraying highest weed control efficiency of 98.11 percent was observed in CLOH with 4 percent clove leaf oil (T_4), followed by CLOH with 3 percent clove leaf oil (T_3) with weed control efficiency of 86.60 percent and the least weed control efficiency (0.00%) was recorded by unweeded control (T_5).

At 45 days after spraying highest weed control efficiency (84.37%) was recorded by CLOH with 4 percent clove leaf oil (T_4), followed by CLOH with 3 percent clove leaf oil (T_3) with 63.61 percent. Lowest weed control efficiency (0.00%) was observed with unweeded control (T_5).

4.5 Experiment 5: Coconut vinegar- Eucalyptus oil

4.5.1 Observation on weeds

4.5.1.1 Floristic composition of weeds

Control of grasses such as *Setaria barbata*, *Cynodon dactylon* and broad leaved weeds such as *Cleome viscose*, *Synedrella nodiflora*, *Phyllanthus niruri*, *Commelina benghalensis*, *Vernonia cineria* are observed at 15 days after spraying. Regrowth of certain grasses such as *Cynodon dactylon* and *Eleusine indica* and broad leaved weeds such as *Commelina benghalensis* and *Vernonia cineria* are observed in the experimental plot (Table 17).

4.5.1.2 Absolute density

Effect of coconut vinegar- eucalyptus oil treatments on absolute density of grasses, sedges and broad leaved weeds are given in Table 18. At 15 days after spraying, absolute density of grasses was observed to be lowest (4.49 m^{-2}) in treatment with EOH with 4 percent eucalyptus oil (T_4), followed by coconut vinegar with 12.5 percent acetic acid and 3 percent eucalyptus oil (T_3) with 7.74 m^{-2} and the highest absolute density was observed in unweeded control (25.84 m^{-}

Table 16: Effect of coconut vinegar + clove leaf oil (CLOH) herbicides on weed control efficiency at 15 and 45 days after spraying.

Treatments	Weed Control Efficiency (%)	
	15 Days after spraying	45 Days after spraying
T_1- CLOH with 1% clove leaf oil	67.58	53.43
T_2- CLOH with 2% clove leaf oil	73.06	60.90
T_3- CLOH with 3% clove leaf oil	86.60	63.61
T_4- CLOH with 4% clove leaf oil	98.11	84.37
T_5- control	0.00	0.00
CD (0.05)	4.20	10.53
SE (m)±	1.43	3.57

Table 17: Effect of coconut vinegar + eucalyptus oil herbicides (EOH) on floristic composition of weeds.

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Setaria barbata* *Cynodon dactylon*	*Cyperus rotundus*	*Cleome viscosa* *Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*
15 DAS	*Panicum maximum*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata*
45 DAS	*Panicum maximum* *Cynodon dactylon* *Eleusine indica*	*Cyperus rotundus*	*Euphorbia genniculata* *Gomphrena serrata* *Commelina benghalensis* *Vernonia cineria*

Table 18: Effect of coconut vinegar + eucalyptus oil (EOH) treatments on absolute density of grasses, sedges and broad leaved weeds at before spraying, 15 DAS and 45 DAS

Treatments	Absolute density (no.m^{-2})								
	Before spraying			15 DAS			45 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1- EOH with 1% eucalyptus oil	20.47* (4.58)	253.93 (15.95)	175.01 (13.25)	10.33 (3.29)	125.57 (11.23)	92.58 (9.65)	16.53 (4.12)	126.45 (11.27)	93.32 (9.69)
T_2- EOH with 2% eucalyptus oil	18.57 (4.37)	269.21 (16.42)	169.33 (13.03)	9.59 (3.18)	119.92 (10.97)	85.36 (9.27)	14.54 (3.88)	121.98 (11.07)	90.76 (9.55)
T_3- EOH with 3% eucalyptus oil	18.94 (4.41)	252.21 (15.90)	173.48 (13.19)	7.74 (2.87)	38.93 (6.28)	59.44 (7.74)	13.47 (3.74)	42.51 (6.56)	64.99 (8.09)
T_4- EOH with 4% eucalyptus oil	19.10 (4.43)	270.79 (16.47)	179.62 (13.42)	4.49 (2.23)	9.82 (3.21)	5.87 (2.52)	7.79 (2.88)	24.5 (5.00)	10.85 (3.37)
T_5- control	20.41 (4.57)	276.06 (16.63)	169.85 (13.05)	25.84 (5.13)	287.96 (16.98)	186.75 (13.68)	30.65 (5.58)	288.67 (17.01)	191.74 (13.87)
CD (0.05)	NS	NS	NS	0.35	0.47	0.51	0.56	0.70	0.53
SE(m)±	0.16	0.24	0.19	0.12	0.17	0.19	0.18	0.24	0.17

* Original values, square root transformed values are given in parenthesis

^{2}). Absolute density of sedges and broad leaved weeds was observed to be lowest (9.82 and 5.87 m^{-2} respectively) in CLOH with 4 percent eucalyptus oil (T_4), followed by CLOH with3 percent eucalyptus oil (38.93 and 59.44 m^{-2} respectively). Unweeded control (T_5) recorded the highest absolute density of sedges and broad leaved weeds (287.96 and 186.75 m^{-2} respectively).

At 45 days after spraying, EOH with 4 percent eucalyptus oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds(7.79, 24.50, and 10.85 m^{-2} respectively), followed by EOH with 3 percent eucalyptus oil (T_3) (13.47, 42.51 and 64.99 m^{-2} respectively). Unweeded control (T_5) recorded the highest absolute density of grasses, sedges and broad leaved weeds (30.65, 288.67 and 191.74 m^{-2} respectively).

4.5.1.3 Root and shoot biomass

Effect of coconut vinegar- eucalyptus oil treatments on the root and shoot biomass of weeds are given in Table 19. At 15 days after spraying, EOH with 4 percent eucalyptus oil (T_4) recorded the lowest root and shoot biomass (1.74 and 32.75 gm^{-2} respectively), EOH with 3 percent eucalyptus oil (T_3) was observed to be the next best treatment with root and shoot biomass of 5.09 and 203.19 gm^{-2} respectively. Unweeded control (T_5) recorded the highest root and shoot biomass (30.60 and 993.96 gm^{-2} respectively).

At 45 days after spraying, EOH with 4 percent eucalyptus oil (T_4) recorded the lowest root and shoot biomass of weeds (3.44 and 83.97 gm^{-2} respectively), followed by EOH with 3 percent eucalyptus oil (T_3) (8.62 and 333.29 gm^{-2} respectively). Unweeded control (T_5) recorded the highest root and shoot biomass (38.25 and 1163.47 gm^{-2} respectively).

4.5.1.4 Weed control efficiency

Effect of coconut vinegar- eucalyptus oil treatments on weed control efficiency is given in Table 20. At 15 days after spraying highest weed control efficiency (96.96%) was observed in treatment EOH with4 percent eucalyptus oil

Table 19: Effect of coconut vinegar + eucalyptus oil (EOH) treatments on root and shoot biomass (g m^{-2}) of weeds before spraying, 15 days after spraying and 45 days after spraying.

Treatments	Root and shoot biomass (g m^{-2})					
	Before spraying		15 DAS		45 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot
T_1- EOH with 1% eucalyptus oil	28.07* (5.35)	940.33 (30.67)	6.58 (2.66)	396.86 (19.93)	16.02 (4.06)	672.80 (25.95)
T_2- EOH with 2% eucalyptus oil	30.08 (5.53)	937.27 (30.62)	5.81 (2.51)	316.16 (17.80)	11.16 (3.41)	555.75 (23.59)
T_3- EOH with 3% eucalyptus oil	22.89 (4.84)	946.11 (30.77)	5.09 (2.36)	203.19 (14.27)	8.62 (3.02)	333.29 (18.27)
T_4- EOH with 4% eucalyptus oil	26.60 (5.21)	936.96 (30.62)	1.74 (1.50)	32.75 (5.77)	3.44 (1.98)	83.97 (9.19)
T_5- control	22.73 (4.82)	964.97 (30.78)	30.60 (5.58)	993.96 (31.54)	38.25 (6.23)	1163.47 (34.12)
CD (0.05)	NS	NS	0.47	1.04	0.50	1.68
SE (m)±	0.19	0.13	0.15	0.35	0.16	0.57

* Original values, square root transformed values are given in parenthesis

Table 20: Effect of coconut vinegar + eucalyptus oil herbicides (EOH) on weed control efficiency at 15 and 45 days after spraying.

Treatments	Weed Control Efficiency (%)	
	15 Days after spraying	45 Days after spraying
T_1- EOH with 1% eucalyptus oil	52.10	51.22
T_2- EOH with 2% eucalyptus oil	52.34	50.75
T_3- EOH with 3% eucalyptus oil	73.65	63.53
T_4- EOH with 4% eucalyptus oil	96.96	67.46
T_5- control	0.00	0.00
CD (0.05)	5.53	10.98
SE (m)±	1.87	3.73

(T_4), followed by EOH with 3 percent eucalyptus oil (T_3) with 73.65 percent and the least weed control efficiency (0.00%) was recorded by unweeded control (T_5).

At 45 days after spraying, highest weed control efficiency (67.46%) was recorded by EOH with 4 percent eucalyptus oil (T_4), followed by EOH with 3 percent eucalyptus oil (T_3) (63.53%). Lowest weed control efficiency (0.00%) was observed with unweeded control (T_5).

PART 2- Evaluation of herbicides in organic farming of okra.

The best treatments of Part I based on the highest weed control efficiency, i.e. CVH with 12.5 percent acetic acid, 20 percent CNSLH, LEH with 10 percent citric acid, CLOH with 4 percent clove leaf oil and EOH with 4 percent eucalyptus oil was carried over to part II- Evaluation of herbicides in organic farming of okra. The following are the observations in part II

4.6 Plant Growth characters

4.6.1 Germination percentage

Effect of herbicides on the germination percentage of okra seeds are given in Table 21. All treatment plots except control shows more than 85 percent germination. Highest germination percentage was observed in hand weeded plot (T_{12}) with 93.06 percent, which was found to be on par with T_4 single spray of CLOH (T_4) with 91.67 percent germination, repeated spray of CLOH (T_9) with 90.97 percent and mango leaf mulching (T_{11}) with 90.97 percent.

4.6.2 Phytotoxicity Rating

Effect of herbicides on phytotoxicity rating of okra seedlings are given in Table 22. None of the seedlings showed any phytotoxicity symptoms. Up to 30 days after sowing, repeated spray of CLOH (T_9) recorded phytotoxicity rating of 4.33, followed by repeated spray of EOH(T_{10}) (4.00). Repeated spray of coconut CVH (T_6) and CNSLH (T_7) also shows slight phytotoxicity symptom (1.80 and 1.80 respectively).

Table 21: Effect of treatments on germination percentage of okra seeds

Treatments	Germination%
T_1	87.50
T_2	88.89
T_3	85.41
T_4	91.67
T_5	89.58
T_6	87.50
T_7	89.58
T_8	87.50
T_9	90.97
T_{10}	87.50
T_{11}	90.97
T_{12}	93.06
T_{13}	81.25
CD (0.05)	3.38
SE (m)±	1.16

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 22: Effect of treatments on phytotoxicity rating of seedlings 30 DAS

Treatments	Phytotoxicity rating in seedling
T_1	0.00
T_2	0.00
T_3	0.00
T_4	0.00
T_5	0.00
T_6	1.80
T_7	1.80
T_8	0.20
T_9	4.33
T_{10}	4.00
T_{11}	0.00
T_{12}	0.00
T_{13}	0.00
CD(0.05)	0.25
SE (m)±	0.09

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

4.6.3 Plant height

All treatments showed more plant height than that of unweeded control (Table 23). Plant height was observed to be more in hand weeded plot (T_{12}) with 124.60 cm, which was on par with single spray of CLOH (T_4) with plant height of 114.00 cm and repeated spray of CLOH (T_9) with 114.20 cm. Unweeded control plot (T_{13}) recorded the lowest plant height of 68.80 cm as given in Table which was on par with single spray and repeated spray of lemon extract herbicide (T_3 and T_8)

4.6.4 Number of branches per plant

All treatments except single and repeated spray of LEH recorded more number of branches than unweeded control. More number of branches was observed in hand weeded plot T_{12} with 3.00 branches and repeated spray of CLOH (T_9) was found to be on par (2.87) with hand weeded plot (T_{12}) as given in Table 23. Lowest number of branches (0.27) was observed in unweeded control (T_{13}) and single and repeated spray of lemon extract (T_3 and T_8) with 0.67 and 0.33 branches respectively was found to be on par with unweeded control (T_{13}).

4.6.5 Number of leaves per plant

Repeated spray of CLOH (T_9) recorded more number of leaves per plant (20.00), which was on par with single spray of CLOH (T_4) with 19.00 leaves per plant and hand weeded plot (19.60). Unweeded control (T_{13}) recorded the least number of leaves per plant (11.07) as given in Table 23.

4.6.6 Node to first flower

There was no significant difference among the treatments for the node to first flower.

4.6.7 Days to 50 percent flowering

All treatments took less number of days for 50 percent flowering than that of unweeded control. Unweeded control (T_{13}) recorded more days for 50 percent

Table 23: Effect of treatments on plant height, number of branches per plant and number of leaves per plant.

Treatments	Plant height (cm)	No. of branches per plant (At harvest)	No. of leaves per plant
T_1	102.00	2.00	16.13
T_2	85.80	1.33	13.33
T_3	80.60	0.67	12.67
T_4	114.00	1.73	19.00
T_5	102.00	1.80	16.60
T_6	101.00	1.33	18.33
T_7	87.40	1.07	13.60
T_8	78.00	0.33	12.80
T_9	114.20	2.87	20.00
T_{10}	99.60	2.07	16.73
T_{11}	102.80	2.13	14.00
T_{12}	124.60	3.00	19.60
T_{13}	68.80	0.27	11.07
CD (0.05)	14.63	0.44	1.24
SE (m)±	5.01	0.15	0.42

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

flowering (53.00) and hand weeded plot (T_{12}) shows less number of days (48.33) which was on par with repeated spray of CLOH (T_9) which took 49.20 days as given in Table 24.

4.6.8 Crop duration

Crop duration was observed to be higher in all treatments except single and repeated spray of LEH (T_3 and T_8) when compared to control (Table 26). Plants which receive hand weeding (T_{12}) recorded the highest duration of crop (106 days). Single and repeated spray of all other herbicides except lemon extract herbicide, was observed to be on par with hand weeded plot. Unweeded control (T_{13}) with duration of 75 days and single and repeated spray of lemon extract herbicide (T_3 and T_8) with 75.67 and 76 days respectively recorded the lowest crop duration.

4.7 Yield attributes

4.7.1 Number of flowers per plant

Highest number of flowers per plant (10.18) was observed in repeated spray of CLOH (T_9), which was on par with hand weeded plot (T_{12}) with 9.80 (Table 25). Single spray of lemon extract (T_3) recorded the lowest number of flowers per plant (3.40), on par with unweeded control (3.47), repeated spray of LEH (4.27), single and repeated spray of CNSLH (4.20 and 4.40 respectively).

4.7.2 Number of fruits per plant

The number of fruits per plant was higher in all treatments except single and repeated spray of LEH which was at par with unweeded control. Hand weeded plot (T_{12}) recorded the highest number of fruits per plant (9.07) which was at par with repeated spray of CLOH (T_9) with 8.9 number of fruits per plant as given in Table 25. Least number of fruits per plant (0.60) was observed in unweeded control (T_{13}), also, single and repeated spray of LEH (T_3 and T_8) was found to be on par with control having 0.80 and 0.87 fruits per plant respectively.

Table 24: Effect of treatments on days to 50 percent flowering and node to first flower.

Treatments	Days to 50 % flowering	Node to first flower
T_1	49.67	4.06
T_2	50.67	4.06
T_3	51.67	4.13
T_4	49.33	3.93
T_5	49.33	4.06
T_6	50.33	4.06
T_7	49.67	4.13
T_8	51.67	4.06
T_9	49.20	4.20
T_{10}	50.67	4.13
T_{11}	49.67	4.13
T_{12}	48.33	4.00
T_{13}	53.00	4.13
CD (0.05)	0.96	NS
SE (m)±	0.33	0.16

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

4.7.3 Percentage fruit set

The effect of treatments on the fruit set percentage is given in Table 25. Highest fruit set percentage (93.82) was observed in plants which receive repeated spray of EOH (T_{10}). Single spray of CVH (T_1) with 77.27 percentage, CNSLH (T_2) with 78.34 percentage, CLOH (T_4) with 92.51 percentage, EOH (T_5) with 88.11 percentage and repeated spray of CNSLH (T_7) with 85.26 percentage, CLOH (T_9) with 87.42 percentage, mango leaf mulching (T_{11}) with 84.68 percentage and hand weeding (T_{12}) with 92.43 percentage also recorded higher percentage fruit set. Unweeded control (T_{13}) and single and repeated spray of LEH (T_3 and T_8) recorded the lowest percentage fruit set (22.62 and 20.71 respectively).

4.7.5 Number of harvest

All treatments except single and repeated spray of LEH (T_3 and T_8) recorded more number of harvests (Table 26) than unweeded control (T_{13}). More number of harvests (17.00) was obtained from repeated spray of CLOH (T_9), and hand weeded plot (17.00). Unweeded control (T_{13}), single and repeated treatment with lemon extract herbicide (T_3 and T_8) recorded lesser number of harvests (6.67, 7.00 and 7.00 respectively).

4.7.6 Yield

Effect of treatments in the yield of okra is presented in Table 26. There was significant difference in the yield of okra with different treatments. Hand weeded plot (T_{12}) recorded the highest yield of 10.83 tha^{-1}, which was followed by repeated spray of CLOH (T_9) (9.89) and EOH herbicide (T_{10}) (9.55). The lowest yield was recorded from plots of unweeded control (T_{13}), single and repeated spray of lemon extract herbicide (T_3 and T_8) (0.63, 0.89 and 1.15 tha^{-1} respectively).

4.8 Observation on weeds

4.8.1 Floristic composition of weeds

Table 25: Effect of treatments on no of fruits per plant, no of flowers per plant and percent fruit set.

Treatments	No. of fruits per plant	No of flowers per plant	Percent fruit set
T_1	4.47	5.80	77.27
T_2	3.27	4.20	78.34
T_3	0.80	3.40	22.62
T_4	6.87	7.47	92.51
T_5	5.67	6.40	88.11
T_6	3.73	5.67	65.60
T_7	3.60	4.40	85.26
T_8	0.87	4.27	20.71
T_9	8.9	10.18	87.42
T_{10}	6.47	6.87	93.82
T_{11}	4.47	5.27	84.68
T_{12}	9.07	9.80	92.43
T_{13}	0.60	3.47	16.54
CD (0.05)	1.30	1.63	17.25
SE (m)±	0.45	0.56	5.91

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 26: Effect of treatments on crop duration (days), no. of harvests and yield (tha^{-1}).

Treatments	Crop duration (days)	No. of harvest	Yield(tha^{-1})
T_1	104.33	14.33	5.96
T_2	106	14.33	4.10
T_3	75.67	7.00	0.89
T_4	105	15.00	8.79
T_5	105	15.00	7.01
T_6	105.33	14.67	4.61
T_7	105.33	14.33	4.44
T_8	76	7.00	1.15
T_9	105	17.00	9.89
T_{10}	106	16.00	9.55
T_{11}	103	14.33	6.70
T_{12}	106	17.00	10.83
T_{13}	75	6.67	0.63
CD (0.05)	3.43	0.98	1.45
SE (m)±	1.17	0.33	0.49

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Grasses such as *Panicum maximum*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Eleusine indica* and *Setaria barbata* are the important grasses seen in the experimental plot. Sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora*, *Euphorbia genniculata*, *Phyllanthus niruri*, *Alternanthera sessilis*, *Cleome viscose*, *Tridax procumbens*, *Vernonia cinerea*, *Commelina benghalensis* are observed in the plot.

In coconut vinegar treated plot, at the time of sowing, grasses such as *Panicum maximum*, *Cynodon dactylon*, *Digitaria sanguinalis* and *Eleusine indica*, sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata*, *Alternanthera sessilis*, *Cleome viscose*, *Vernonia cinerea* and *Commelina benghalensis* (Table 27). At 30 days after sowing regrowth of grasses such as *Dactyloctenium aegyptium*, *Digitaria bicornis* and *Setaria barbata*, broad leaved weeds such as *Synedrella nodiflora*, *Phyllanthus niruri* and *Tridax procumbens*. At 60 days after sowing, regrowth of certain broad leaved weeds was observed, such as *Oldenlandia umbellate*, *Oxalis corniculata*, *Cleome rutidosperma and Scoparia dulcis* was observed.

In CNSLH treated plot (Table 28), at the time of sowing, grasses such as *Panicum maximum*, *Cynodon dactylon*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis* and *Digitaria bicornis*, sedges such as *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata*, *Alternanthera sessilis*, *Vernonia cinerea* and *Commelina benghalensis*. At 30 days after sowing regrowth of grasses such as *Eleusine indica* and *Setaria barbata*, sedges such as *Kyllinga monocephala* and broad leaved weeds such as *Synedrella nodiflora*, *Phyllanthus niruri*, *Cleome viscosa* and *Tridax procumbens*. At 60 days after sowing, regrowth of certain broad leaved weeds was observed, such as *Oldenlandia umbellate*, *Oxalis corniculata*, *Cleome rutidosperma and Scoparia dulcis*.

In LEH treated plot, at the time of sowing, grasses such as *Panicum maximum*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Digitaria bicornis*, *Setaria barbata* and *Eleusine indica*, sedges such as *Kyllinga monocephala* and *Cyperus*

Table 27: Floristic composition of weeds in T_1 - CVH treated plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Digitaria sanguinalis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
At sowing	*Panicum maximum* *Cynodon dactylon* *Digitaria sanguinalis* *Eleusine indica*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis* *Cleome rutidosperma* *Scoparia dulcis*

Table 28: Floristic composition of weeds in T_2 - CNSLH treated plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis* *Cleome rutidosperma*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis*	*Cyperus rotundus*	*Euphorbia genniculata* *Alternanthera sessilis* *Vernonia cinerea* *Commelina benghalensis*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Cleome rutidosperma* *Scoparia dulcis*

rotundus and broad leaved weeds such as *Synedrella nodiflora, Euphorbia genniculata, Alternanthera sessilis, Cleome viscose, Vernonia cinerea, Commelina benghalensis* and *Cleome rutidosperma* (Table 29). At 30 days after sowing regrowth of grasses such as *Dactyloctenium aegyptium,* broad leaved weeds such as *Phyllanthus niruri* and *Tridax procumbens.* At 60 days after sowing, regrowth of certain broad leaved weeds such as *Oldenlandia umbellate, Oxalis corniculata, Cleome rutidosperma and Scoparia dulcis* was observed

In CLOH treated plot, at the time of sowing, grasses such as *Panicum maximum*, *Dactyloctenium aegyptium*, sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata* was observed (Table 30). At 30 days after sowing regrowth of grasses such as *Cynodon dactylon* and broad leaved weeds such as *Synedrella nodiflora, Phyllanthus niruri, Tridax procumbens, Alternanthera sessilis, Vernonia cinerea* and *Commelina benghalensis.* At 60 days after sowing, regrowth of certain grasses such as *Digitaria sanguinalis, Digitaria bicornis, Eleusine indica* and *Setaria barbata,* broad leaved weeds such as *Oldenlandia umbellate* was observed.

In EOH treated plot, at the time of sowing, grasses such as *Panicum maximum* and *Dactyloctenium aegyptium*, sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata* was observed (Table 31). At 30 days after sowing regrowth of grasses such as *Cynodon dactylon* and broad leaved weeds such as *Synedrella nodiflora, Phyllanthus niruri, Alternanthera sessilis, Tridax procumbens, Vernonia cinerea* and *Commelina benghalensis.* At 60 days after sowing, regrowth of certain grasses such as *Digitaria sanguinalis, Digitaria bicornis, Eleusine indica* and *Setaria barbata,* broad leaved weeds such as *Oldenlandia umbellate* was observed.

In plot with repeated spray of CVH at 30 days after sowing, grasses such as *Panicum maximum, Cynodon dactylon , Digitaria sanguinalis, Eleusine indica,*

Table 29: Floristic composition of weeds in T3 - LEH treated plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria bicornis* *Eleusine indica*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Commelina benghalensis* *Cleome rutidosperma*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis* *Cleome rutidosperma* *Scoparia dulcis*

Table 30: Floristic composition of weeds in T_4 - CLOH treated plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata*
At sowing	*Panicum maximum* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Alternanthera sessilis* *Phyllanthus niruri* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*

Table 31: Floristic composition of weeds in T_5 - EOH treated plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata*
At sowing	*Panicum maximum* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*

sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata*, *Alternanthera sessilis, Cleome viscose*, *Vernonia cinerea* and *Commelina benghalensis* was observed (Table 32) at the time of sowing. At 30 days after sowing regrowth of grasses such as *Dactyloctenium aegyptium, Digitaria bicornis, Setaria barbata* and broad leaved weeds such as *Synedrella nodiflora, Phyllanthus niruri, Alternanthera sessilis* and *Tridax procumbens.* At 60 days after sowing, regrowth of certain broad leaved weeds such as *Oxalis corniculata* was observed.

In plot with repeated spray of CNSLH at 30 days after sowing, grasses such as *Panicum maximum*, *Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Digitaria bicornis, Eleusine indica* and *Setaria barbata* sedges such as *Kyllinga monocephala* and *Cyperus rotundus* and broad leaved weeds such as *Euphorbia genniculata*, *Alternanthera sessilis, Vernonia cinerea* and *Commelina benghalensis* was observed at the time of sowing (Table 33). At 30 days after sowing regrowth of broad leaved weeds such as *Synedrella nodiflora, Phyllanthus niruri, Cleome viscose* and *Tridax procumbens.* At 60 days after sowing, regrowth of certain broad leaved weeds such as *Oldenlandia umbellate* was observed.

In plot with repeated spray of LEH at 30 days after sowing, grasses such as *Panicum maximum*, *Cynodon dactylon* , *Dactyloctenium aegyptium, Digitaria bicornis* and *Eleusine indica* sedges such as *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora, Euphorbia genniculata*, *Alternanthera sessilis, Cleome viscose, Commelina benghalensis* and *Cleome rutidosperma* was observed at the time of sowing (Table 34). At 30 days after sowing regrowth of grasses such as *Digitaria sanguinalis* and *Setaria barbata*, sedges such as *Kyllinga monocephala*, broad leaved weeds such as *Phyllanthus niruri, Vernonia cinerea* and *Tridax procumbens.* At 60 days after sowing, regrowth of certain broad leaved weeds such as *Oxalis corniculata, Cleome rutidosperma* and *Scoparia dulcis* was observed.

Table 32: Floristic composition of weeds in T_6 - CVH repeated spray 30 DAS

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Digitaria sanguinalis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
At sowing	*Panicum maximum* *Cynodon dactylon* *Digitaria sanguinalis* *Eleusine indica*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis*

Table 33: Floristic composition of weeds in T_7 - CNSLH repeated spray 30 DAS

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis* *Cleome rutidosperma*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata* *Alternanthera sessilis* *Vernonia cinerea* *Commelina benghalensis*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*

Table 34: Floristic composition of weeds in T_8 - LEH repeated spraying 30 DAS

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria bicornis* *Eleusine indica*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Commelina benghalensis* *Cleome rutidosperma*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis* *Cleome rutidosperma* *Scoparia dulcis*

In plot with repeated spray of CLOH at 30 days after sowing, grasses such as *Panicum maximum,* sedges such as *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora* and *Euphorbia genniculata* was observed at the time of sowing (Table 35). At 30 days after sowing regrowth of grasses such as *Cynodon dactylon and Dactyloctenium aegyptium* sedges such as *Kyllinga monocephala*, broad leaved weeds such as *Phyllanthus niruri, Vernonia cinerea, Tridax procumbens, Alternanthera sessilis and Commelina benghalensis.* At 60 days after sowing, regrowth of certain grasses such as *Digitaria sanguinalis, Eleusine indica* and *Setaria barbata* and broad leaved weeds such as *Oxalis corniculata, Peperomia reflexa* and *Oldenlandia umbellate* was observed.

In plot with repeated spray of EOH at 30 days after sowing, grasses such as *Panicum maximum* sedges such as *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora* and *Euphorbia genniculata* was observed at the time of sowing (Table 36). At 30 days after sowing regrowth of grasses such as *Cynodon dactylon and Dactyloctenium aegyptium* sedges such as *Kyllinga monocephala*, broad leaved weeds such as *Phyllanthus niruri, Vernonia cinerea, Tridax procumbens, Alternanthera sessilis and Commelina benghalensis.* At 60 days after sowing, regrowth of certain grasses such as *Digitaria sanguinalis, Eleusine indica* and *Setaria barbata* and broad leaved weeds such as *Oxalis corniculata, Peperomia reflexa* and *Oldenlandia umbellate* was observed.

In mango leaf mulched plot, grasses such as *Panicum maximum, Cynodon dactylon* and *Dactyloctenium aegyptium*, sedges such as *Cyperus rotundus* and *Kyllinga monocephala* and broad leaved weeds such as *Synedrella nodiflora, Euphorbia genniculata, Cleome viscose, Vernonia cinerea* and *Commelina benghalensis* was observed at the time of sowing (Table 37). At 30 days after sowing regrowth of grasses such as *Digitaria sanguinalis, Digitaria bicornis, Eleusine indica* and *Setaria barbata,* broad leaved weeds such as *Alternanthera sessilis.* At 60 days after sowing, regrowth of certain sedges such as *Kyllinga monocephala* and broad leaved weeds such as *Phyllanthus niruri, Oxalis corniculata, Peperomia reflexa* and *Oldenlandia umbellate* was observed.

Table 35: Floristic composition of weeds in T_9 - CLOH repeated spaying 30 DAS

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Cleome viscose*
At sowing	*Panicum maximum*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata* *Oldenlandia umbellate* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis*

Table 36: Floristic composition of weeds in T_{10} - EOH repeated spaying 30 DAS

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Cleome viscose*
At sowing	*Panicum maximum*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Euphorbia genniculata* *Oldenlandia umbellate* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis*

Table 37: Floristic composition of weeds in T_{11} - mango leaf mulched plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis*

In hand weeded plot, grasses such as *Panicum maximum, Cynodon dactylon* and *Dactyloctenium aegyptium* and *Digitaria sanguinalis,* sedges such as *Cyperus rotundus* and *Kyllinga monocephala* and broad leaved weeds such as *Synedrella nodiflora, Alternanthera sessilis, Phyllanthus niruri, Cleome viscose, Vernonia cinerea* and *Commelina benghalensis* was observed at 30 days after sowing (Table 38). At 60 days after sowing regrowth of grasses such as *Digitaria bicornis, Eleusine indica* and *Setaria barbata,* broad leaved weeds such as *Alternanthera sessilis, Oxalis corniculata, Peperomia reflexa* and *Oldenlandia umbellate* was observed.

4.8.2 Absolute density

Absolute density of grasses, sedges and broad leaved weeds are given in Table 40. At sowing, the absolute density of grasses was lowest in hand weeded plot (T_{12}) (0.00 m^{-2}), followed by repeated spray of coconut vinegar clove leaf oil herbicide (T_9) (9.22). Same trend was observed in absolute density of sedges with 0.00 m^{-2} in hand weeded plot(T_{12}), followed by repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (8.01). Absolute density of broad leaved weeds was lowest in hand weeded plot (T_{12}) (0.00 m^{-2}), followed by single spray of coconut vinegar-clove leaf oil herbicide (T_4) and coconut vinegar-eucalyptus oil herbicide (T_5) with absolute density of 7.17 and 5.40 m^{-2} respectively and repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) and coconut vinegar-eucalyptus oil herbicide (T_{10}) with absolute density of 5.66 and 5.34 m^{-2} respectively. Absolute density of grasses, sedges and broad leaved weeds was found to be highest in unweeded control (T_{13}) with 147.71, 83.88 and 103.27 m^{-2} respectively.

At 30 days after sowing lowest absolute density of grasses was observed in hand weeded plot (T_{12}) (11.69), followed by repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (56.43) and highest was observed in repeated spray of lemon extract herbicide(T_8). Unweeded control (T_{13}), single spray of lemon extract herbicide (T_3) and single spray of coconut vinegar herbicide (T_1) also recorded highest absolute density of grasses. Absolute density of sedges was

Table 38: Floristic composition of weeds in T_{12} - hand weeded plot

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri*
At sowing	-	-	-
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Cleome rutidosperma*

Table 39: Floristic composition of weeds in T_{13} - weedy check

Stages of spraying	Grasses	Sedges	Broad leaved weeds
Before spraying	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose*
At sowing	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria bicornis* *Eleusine indica*	*Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis* *Cleome rutidosperma*
30 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Vernonia cinerea* *Commelina benghalensis*
60 DAS	*Panicum maximum* *Cynodon dactylon* *Dactyloctenium aegyptium* *Digitaria sanguinalis* *Digitaria bicornis* *Eleusine indica* *Setaria barbata*	*Kyllinga monocephala* *Cyperus rotundus*	*Synedrella nodiflora* *Euphorbia genniculata* *Oldenlandia umbellate* *Phyllanthus niruri* *Alternanthera sessilis* *Cleome viscose* *Tridax procumbens* *Peperomia reflexa* *Vernonia cinerea* *Oxalis corniculata* *Commelina benghalensis* *Cleome rutidosperma* *Scoparia dulcis*

lowest in hand weeded plot (T_{12}) (6.79), followed by coconut vinegar-clove leaf oil herbicide (T_9) with 22.37 m^{-2}. Highest absolute density of sedges was recorded by unweeded control (T_{13}) with 93.47 m^{-2}. Absolute density of broad leaved weeds was observed to be lowest in hand weeded plot (T_{12}) (5.56), followed by single and repeated spray of CNSL herbicide (T_2 and T_7) (9.92 and 19.11 respectively), coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (14.23 and 7.14 respectively) and coconut vinegar eucalyptus oil herbicide (T_5 and T_{10}) (21.15 and 18.66 respectively). Highest absolute density of broad leaved weeds was observed in unweeded control (T_{13}) with 93.61, followed by single and repeated spray of lemon extract herbicide(T_3 and T_8) (60.09 and 58.54 respectively).

At 60 days after sowing, absolute density of grasses was lowest in T_9 repeated spray of coconut vinegar-clove leaf oil herbicide (67.95), on par with mango leaf mulching (T_{11}), hand weeding (T_{12}) and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) with 71.30, 80.07 and 91.60 respectively. Highest absolute density of grasses was observed in unweeded control (T_{13}) with 180.82, followed by single and repeated spray of lemon extract herbicide (T_3 and T_8) (178.60 and 165.79 respectively). Absolute density of sedges was lowest in T_9 repeated spray of coconut vinegar clove leaf oil herbicide with 19.84, on par with repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (27.16), mango leaf mulching (T_{11}) (26.85), hand weeding (T_{12}) (22.19), single spray of coconut vinegar clove leaf oil herbicide (T_4) (28.44) and CNSL herbicide (T_2) (29.31). Absolute density of broad leaved weeds was lowest in T_9 repeated spray of coconut vinegar with cove leaf oil herbicide (11.27), which was on par with repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (24.08), mango leaf mulching (T_{11}) (25.39), hand weeding (T_{12}) (22.73), single spray of coconut vinegar- clove leaf oil herbicide (T_4) (12.80) and single spray of coconut vinegar-eucalyptus oil herbicide (T_5) (29.59). Lowest absolute density of broad leaved weeds was observed with unweeded control (T_{13}) (64.69).

Table 40: Effect of treatments on absolute density (no. m^{-2}) of grasses, sedges and broad leaved weeds at before, at sowing, 30 days after sowing and 60 days after sowing.

Treatments	Before			At sowing			30 DAS			60 DAS		
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW
T_1	150.70* (12.28)	52.82 (7.27)	60.78 (7.80)	94.25 (9.73)	38.03 (6.21)	27.67 (5.31)	128.60* (11.34)	35.80 (5.98)	26.40 (5.14)	106.89 (10.34)	38.01 (6.17)	43.35 (6.58)
T_2	141.49 (11.89)	43.94 (6.63)	72.59 (8.52)	65.29 (8.11)	32.08 (5.71)	26.65 (5.21)	83.01 (9.11)	27.18 (5.21)	9.92 (3.15)	104.12 (10.20)	29.31 (5.41)	35.00 (5.92)
T_3	122.66 (11.08)	27.46 (5.24)	67.77 (8.23)	130.28 (11.44)	29.75 (5.50)	31.19 (5.63)	137.36 (11.72)	46.36 (6.81)	60.09 (7.75)	178.60 (13.36)	62.25 (7.89)	53.49 (7.31)
T_4	127.87 (11.31)	62.49 (7.91)	51.34 (7.17)	33.86 (5.86)	24.46 (4.99)	7.17 (2.77)	87.27 (9.34)	35.02 (5.92)	14.23 (3.77)	125.37 (11.20)	28.44 (5.33)	12.80 (3.58)
T_5	161.24 (12.70)	40.90 (6.39)	47.68 (6.91)	39.52 (6.33)	17.28 (4.22)	5.40 (2.43)	85.75 (9.26)	34.40 (5.87)	21.15 (4.60)	132.92 (11.53)	37.59 (6.13)	29.59 (5.44)
T_6	129.28 (11.37)	60.42 (7.77)	54.20 (7.36)	77.79 (8.85)	32.01 (5.70)	39.24 (6.30)	104.18 (10.21)	34.47 (5.87)	33.98 (5.83)	100.36 (10.02)	39.79 (6.31)	34.46 (5.87)
T_7	116.34 (10.79)	49.73 (7.05)	46.99 (6.86)	67.71 (8.26)	29.27 (5.46)	24.95 (5.05)	88.60 (9.41)	33.64 (5.80)	19.11 (4.37)	96.12 (9.80)	45.32 (6.73)	64.95 (8.06)

Table 40 contd...

T_8	145.03	76.83	30.55	147.49	77.50	21.51	153.64	50.01	58.54	165.79	41.33	29.60
	(12.04)	(8.76)	(5.23)	(12.17)	(8.83)	(4.69)	(12.40)	(7.07)	(7.65)	(12.88)	(6.43)	(5.44)
T_9	113.29*	41.27	68.36	9.22	8.01	5.66	56.43*	22.37	7.14	67.95	19.84	11.27
	(10.64)	(6.42)	(8.27)	(3.12)	(2.92)	(2.48)	(7.51)	(4.73)	(2.67)	(8.24)	(4.45)	(3.36)
T_{10}	126.77	41.53	75.69	20.04	11.35	5.34	72.32	31.10	18.66	91.60	27.16	24.08
	(11.26)	(6.44)	(8.70)	(4.53)	(3.44)	(2.42)	(8.50)	(5.58)	(4.32)	(9.57)	(5.21)	(4.91)
T_{11}	133.82	43.09	50.20	26.75	11.57	11.15	69.74	34.64	37.55	71.30	26.85	25.39
	(11.57)	(6.56)	(7.09)	(5.22)	(3.47)	(3.41)	(8.35)	(5.89)	(6.13)	(8.44)	(5.18)	(5.04)
T_{12}	144.24	37.56	35.77	0.00	0.00	0.00	11.69	6.79	5.56	80.07	22.19	22.73
	(12.01)	(6.13)	(5.98)	(0.70)	(0.70)	(0.70)	(3.42)	(2.61)	(2.36)	(8.95)	(4.71)	(4.77)
T_{13}	138.93	54.73	46.06	147.71	83.88	103.27	147.28	93.47	93.61	180.82	63.35	64.69
	(11.79)	(7.40)	(6.79)	(12.17)	(9.19)	(10.19)	(12.14)	(9.67)	(9.68)	(13.45)	(7.96)	(8.04)
CD (0.05)	NS	NS	NS	1.90	1.75	2.24	1.78	1.89	2.70	1.38	1.58	2.36
SE (m)±	0.95	0.64	1.08	0.65	0.59	0.74	0.60	0.64	0.91	0.47	0.53	0.80

* Original values, square root transformed values are given in parenthesis

4.8.3 Root and shoot biomass

At sowing, hand weeding (T_{12}) was observed to be the best treatment with root and shoot biomass 0.00 gm^{-2} (Table 41). Repeated spray of coconut vinegar with 12.5 percent acetic acid and 4 percent clove leaf oil (T_9) recorded the next best treatment in root biomass control (2.40) and repeated spray of EOH (T_{10}) recorded the next best treatment in control of shoot biomass (223.66). Root and shoot biomass was observed to be highest in unweeded control (T_{13}) (25.18) and repeated spray of lemon extract herbicide (T_8) (740.54) respectively.

At 30 days after sowing, root and shoot biomass was observed to be lower in hand weeded plot (T_{12}) (2.86 and 283.19 respectively). Single spray of CNSL herbicide (T_2) (290.34 gm^{-2}) and repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (341.01 gm^{-2}) was observed to be on par with hand weeding (T_{12}) (283.19 gm^{-2}) for shoot biomass of weeds. Repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) was observed to be the next best treatment (9.28 gm^{-2}) to hand weeding (T_{12}) (2.86 gm^{-2}) in control of root biomass. The root biomass was found to be lowest in unweeded control (T_{13}) (30.11 gm^{-2}) and shoot biomass in repeated spray of lemon extract herbicide (T_8) (857.17 gm^{-2}).

At 60 days after sowing, lowest root biomass was observed with hand weeded plot (T_{12}) (9.32), followed by T_9 repeated spray of coconut vinegar clove leaf oil herbicide (14.21) and T_{11} mango leaf mulching with 12.43 gm^{-2}. T_{13} unweeded control recorded highest root biomass (28.53). Lowest shoot biomass was observed in hand weeded plot (T_{12}) (424.48), repeated spray of coconut vinegar clove leaf oil herbicide (T_9) (427.16), mango leaf mulching (T_{11}) (485.66), repeated spray of coconut vinegar eucalyptus oil herbicide (T_{10}) (514.65), repeated spray of coconut vinegar herbicide (T_6) (546.97), repeated spray of CNSL herbicide (T_{10}) (559.48) and single spray of coconut vinegar herbicide (T_1) and coconut vinegar-clove leaf oil herbicide (T_4) (597.79 and 545.19 respectively). Highest shoot biomass was observed in unweeded control (T_{13}) (1387.58).

Table 41: Effect of treatments on root and shoot biomass of weeds (g m^{-2})

Treatments	root and shoot biomass of weeds (g m^{-2})							
	Before		At sowing		30 DAS		60 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
T_1	22.39* (4.78)	663.37 (25.76)	16.87 (4.17)	295.96 (17.22)	24.79 (5.03)	472.26 (21.74)	26.78 (5.22)	597.79 (24.46)
T_2	27.45 (5.29)	712.41 (26.69)	11.83 (3.51)	417.87 (20.45)	17.88 (4.29)	290.34 (17.05)	20.68 (4.60)	639.99 (25.31)
T_3	20.28 (4.56)	631.27 (25.13)	19.64 (4.49)	642.83 (25.36)	25.20 (5.02)	797.39 (28.25)	25.63 (5.11)	998.38 (31.61)
T_4	26.20 (5.17)	691.74 (26.30)	5.76 (2.50)	331.03 (18.21)	15.31 (3.98)	579.64 (24.09)	21.72 (4.71)	545.19 (23.36)
T_5	23.07 (4.86)	712.20 (26.69)	6.52 (2.65)	245.64 (15.69)	16.14 (4.08)	426.13 (20.66)	24.73 (5.02)	624.05 (24.99)
T_6	21.94 (4.74)	680.17 (26.08)	14.62 (3.89)	499.78 (22.37)	18.50 (4.36)	559.20 (23.66)	17.50 (4.24)	546.97 (23.40)
T_7	24.05 (4.96)	653.21 (25.56)	13.27 (3.71)	345.65 (18.61)	22.53 (4.80)	583.35 (24.16)	20.67 (4.60)	559.48 (23.66)

* Original values, square root transformed values are given in parenthesis

T_1- Stale seed bed (SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS

Table 41(contd.): Effect of treatments on root and shoot biomass of weeds (gm^{-2})

Treatments	Before		At sowing		30 DAS		60 DAS	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
T_8	25.08* (5.06)	668.22 (25.85)	23.80 (4.93)	740.54 (27.22)	25.20 (5.02)	857.17 (29.29)	24.03 (4.95)	1058.35 (32.54)
T_9	27.81 (5.32)	643.79 (25.37)	2.40 (1.70)	247.78 (15.76)	9.28 (3.13)	341.01 (18.48)	14.21 (3.84)	427.16 (20.68)
T_{10}	21.36 (4.68)	650.10 (25.50)	5.23 (2.39)	223.66 (14.97)	15.57 (4.01)	387.55 (19.70)	16.51 (4.12)	514.65 (22.70)
T_{11}	26.16 (5.16)	653.62 (25.57)	8.08 (2.93)	224.50 (15.00)	14.78 (3.91)	438.86 (20.96)	12.43 (3.60)	485.66 (22.05)
T_{12}	23.00 (4.85)	679.59 (26.07)	0.00 (0.70)	0.00 (0.70)	2.86 (1.83)	283.19 (16.84)	9.32 (3.13)	424.48 (20.62)
T_{13}	22.66 (4.81)	676.42 (26.01)	25.18 (5.07)	714.21 (26.73)	30.11 (5.53)	744.13 (27.28)	28.53 (5.39)	1387.58 (37.26)
CD (0.05)	NA	NA	0.69	3.42	0.52	2.62	0.86	4.09
SE (m)±	0.29	0.49	0.23	1.17	0.17	0.90	0.29	1.40

* Original values, square root transformed values are given in parenthesis

T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

4.8.4 Weed control efficiency

A similar trend was observed in weed control efficiency (Table 42). Hand weeding (T_{12}) recorded the highest weed control efficiency of 100 percent at the time of sowing, which was on par with single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (92.26 and 90.89 respectively) and coconut vinegar-eucalyptus oil herbicide (T_{10}) (90.16).

At 30 days after sowing, weed control efficiency was highest in hand weeded plot (T_{12}) (71.99), which was on par with single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (61.28 and 70.04 respectively), repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (53.71) and single spray of coconut vinegar herbicide (T_1) (59.84).

At 60 days after sowing repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) recorded highest weed control efficiency of 61.89 percent, followed by hand weeding (T_{12}) (59.17), single spray of coconut vinegar-clove leaf oil herbicide (T_4) (57.34) and mango leaf mulching (T_{11}) (54.14). Unweeded control (T_{13}) recorded the lowest weed control efficiency of 0.00 percent at sowing, 30 and 60 days after sowing.

4.8.5 Weed index

Effect of different herbicide treatments on the weed index is given in Table 42. Highest weed index of 94.2 was recorded by unweeded control (T_{13}), which was on par with single and repeated spray of lemon extract herbicide (T_3 and T_8) (91.92 and 89.55 respectively). Lowest weed index was observed with hand weeded plot (T_9) (0.00), on par with repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) and coconut vinegar-eucalyptus oil herbicide (T_{10}) (8.68 and 12.00 respectively).

4.9 Organic carbon status of soil

Table 42: Effect of treatments on weed control efficiency (%) and weed index

Treatments	Weed Control Efficiency (%)			Weed index
	At sowing	30 DAS	60 DAS	
T_1	51.13	59.84	37.89	45.15
T_2	40.36	25.81	46.53	62.05
T_3	16.88	2.26	3.79	91.92
T_4	92.26	61.28	57.34	18.77
T_5	85.95	49.43	31.38	34.73
T_6	40.08	55.46	48.25	57.18
T_7	53.53	38.07	38.53	58.38
T_8	10.09	2.26	0.33	89.55
T_9	90.89	70.04	61.89	8.68
T_{10}	90.16	53.71	44.53	12.00
T_{11}	72.65	61.51	54.14	37.75
T_{12}	100.00	71.99	59.17	0.00
T_{13}	0.00	0.00	0.00	94.2
CD (0.05)	10.44	12.35	12.13	12.86
SE (m)±	3.58	4.23	4.16	4.41

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Organic carbon percentage was found to be highest in plot which receives repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (2.50 per cent), repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) and unweeded control plot (T_{13}) was on par with T_9 (Table 43). Treatments with lemon extract herbicide (T_3), CNSL herbicide (T_7), hand weeding (T_{12}) and single spray of coconut vinegar (T_1) recorded lowest organic carbon status in soil.

4.10 Soil pH

The data regarding soil pH are given in Table 44. The soil pH in general was acidic. There was an increase in soil pH in all the treatments as compared to pre experimental soil. Higher pH of 5.85 was observed in hand weeded plot (T_{12}), mango leaf mulching (T_{12}), unweeded control (T_{13}), single spray of CNSL herbicide (T_2) and lemon extract herbicide (T_3) were on par. Repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5) recorded the lowest soil pH after the experiment (5.33). All treatments with coconut vinegar herbicide recorded lower soil pH after the experiment.

4.11 Soil EC

The data pertaining soil electrical conductivity is depicted in Table 44. Higher EC of 0.26 dSm^{-2} was observed in single spray of lemon extract herbicide (T_3) and unweeded control (T_{13}) with 0.24 dSm^{-2}. Lowest soil EC was recorded by CNSL herbicide (T_7) (0.08 dSm^{-2}).

4.12 Available NPK status of soil

The data showing the effect of treatments on the status of available nutrients in soil is given in Table 45. Available nitrogen in soil was observed to be higher in plot received repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (338.69 kg/ha), followed by unweeded control (T_{13}) (326.14 kg/ha). Available nitrogen was lowest in plot with single spray of coconut vinegar treatment (T_1) (263.42 kg/ha).

Table 43: Effect of treatments on organic carbon status of soil

Treatments	Soil organic carbon (%)
T_1	1.82
T_2	1.80
T_3	1.78
T_4	2.13
T_5	2.11
T_6	2.22
T_7	2.03
T_8	1.79
T_9	2.50
T_{10}	2.36
T_{11}	2.09
T_{12}	2.36
T_{13}	1.85
Pre experiment	1.19
CD (0.05)	0.30
SE (m)±	0.11

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 44: Effect of treatments on soil pH and EC

Treatments	Soil pH	Soil EC (dSm^{-2})
T_1	5.46	0.09
T_2	5.66	0.08
T_3	5.64	0.26
T_4	5.43	0.10
T_5	5.42	0.10
T_6	5.38	0.09
T_7	5.60	0.12
T_8	5.58	0.20
T_9	5.34	0.15
T_{10}	5.33	0.09
T_{11}	5.76	0.10
T_{12}	5.85	0.13
T_{13}	5.81	0.24
Pre experiment	5.89	0.09
Before liming	4.8	-
CD (0.05)	0.20	0.06
SE (m)±	0.08	0.02

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 45: Effect of treatments on available N, P and K status of soil 60 DAS

Treatments	Available nutrients (kg/ha)		
	N	P	K
T_1	263.42	115.36	302.40
T_2	313.60	141.12	392.00
T_3	275.97	109.76	347.20
T_4	275.97	109.76	358.40
T_5	301.06	162.40	347.20
T_6	288.51	110.88	358.40
T_7	313.60	113.12	324.80
T_8	275.97	110.88	324.80
T_9	338.69	132.16	459.20
T_{10}	275.97	148.96	380.80
T_{11}	301.06	92.96	403.20
T_{12}	313.60	141.12	324.80
T_{13}	326.14	108.64	336.00
Pre experiment	186.22	76.18	258.98
CD(0.05)	11.97	8.17	12.25
SE (m)±	4.10	2.80	4.20

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Available phosphorus in soil was observed to be higher in single spray of coconut vinegar-eucalyptus oil herbicide (T_5) (162.40 kg/ha), followed by repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}). Mango leaf mulched plot (T_{11}) recorded the lowest phosphorus content in soil (92.96 kg/ha).

Available potassium content was observed to be highest in plot with repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (459.20 kg/ha), followed by mango leaf mulching (T_{11}) (403.20 kg/ha). Single spray of coconut vinegar herbicide (T_1) recorded the lowest available potassium content in soil (302.40 kg/ha).

4.13 Nutrient uptake by weeds

Uptake of major nutrients such as nitroegen, phosphorus and potassium at 30 and 60 days after sowing is depicted in Table 46. At 30 days after sowing, the uptake of nitrogen was observed to be higher in unweeded control (T_{13}) (43.17 kg/ha), on par with single and repeated spray of lemon extract herbicide (T_3 and T_8) (42.49 and 37.20 kg/ha). Hand weeded plot (T_{12}) (0.61 kg/ha), single and repeated spray of coconut vinegar herbicide (T_1 and T_6) (5.18 and 4.15 kg/ha respectively), single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (3.34 and 1.59 kg/ha respectively), single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) (2.54 and 2.80 kg/ha respectively) and mango leaf mulching (T_{11}) (5.38 kg/ha) recorded the lowest uptake of nitrogen at this stage. Similarly at 60 days after sowing, highest N uptake was observed in unweeded control (T_{13}) (51.97 kg/ha), on par with single spray of lemon extract herbicide (T_3) (51.01 kg/ha). Hand weeded plot (T_{12}) (4.08 kg/ha), single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (7.19 and 4.98 kg/ha respectively), single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) (8.95 and 7.84 kg/ha respectively) and repeated spray of coconut vinegar herbicide (T_6) (8.87 kg/ha) recorded the lowest uptake of N at 60 days after sowing.

The highest uptake of P was observed in unweeded control (T_{13}) with 18.86 kg/ha at 30 days after sowing, followed by single spray of lemon extract herbicide (T_3) (13.28 kg/ha). Single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (1.86, 0.65), single and repeated spray of coconut vinegar herbicide (T_1 and T_6) (1.56 and 1.09 kg/ha respectively), single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) (2.95 and 0.93 kg/ha respectively), repeated spray of CNSL herbicide (T_7) (2.53 kg/ha) and mango leaf mulching (T_{11}) (2.43 kg/ha) recorded the lowest uptake of P at 30 days after sowing. At 60 DAS, unweeded control (T_{13}) recorded highest P uptake by weeds (19.54 kg/ha), followed by single spray of lemon extract herbicide (T_3) (14.39 kg/ha). Lowest uptake of P was observed in repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (0.73 kg/ha), followed by T_1, T_4, T_5, T_6, T_7, T_{10}, T_{11}.

Similar trend was observed in case of K uptake by weeds. Unweeded control (T_{13}) recorded the highest uptake of K (41.54 kg/ha), followed by single spray of lemon extract treatment (T_3) (28.93 kg/ha). Repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (4.63kg/ha) recorded the lowest uptake of K by weeds at 30 DAS, which was on par with single spray of coconut vinegar-clove leaf oil herbicide (T_4) (10.97 kg/ha), single and repeated spray of coconut vinegar herbicide (T_1 and T_6) (7.71 and 8.37 kg/ha respectively), single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) (9.95 and 8.25 kg/ha respectively), mango leaf mulching(T_{11}) (9.45 kg/ha) and hand weeding (T_{12}) (5.53 kg/ha). At 60 DAS, highest K uptake by weeds was observed in unweeded control (T_{13}) (45.91 kg/ha), followed by repeated spray of lemon extract herbicide (T_8) (31.42 kg/ha). The lowest K uptake was observed in coconut vinegar-clove leaf oil herbicide (T_9) (7.04 kg/ha), on par with single and repeated spray of coconut vinegar herbicide (T_1 and T_6) (13.58 and 11.17 respectively), single spray of CNSL herbicide (T_2) (11.78 kg/ha), repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (12.07 kg/ha), mango leaf mulching (T_{11}) (12.94 kg/ha) and hand weeded plot (T_{12}) (9.30 kg/ha).

Table 46: Effect of treatments on nutrient uptake by weeds (30 and 60 DAS)

Treatments	Nutrient uptake by weeds (kg/ha)					
	N		P		K	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
T_1	5.18	12.78	1.56	2.95	7.71	13.58
T_2	12.16	13.09	6.61	3.75	14.87	11.78
T_3	42.49	51.01	13.28	14.39	28.93	30.81
T_4	3.34	7.19	1.86	1.75	10.97	13.99
T_5	2.54	8.95	2.95	2.46	9.95	15.93
T_6	4.15	8.87	1.09	1.58	8.37	11.17
T_7	13.97	19.22	2.53	2.94	13.56	14.70
T_8	37.20	46.44	10.11	11.71	28.57	31.42
T_9	1.59	4.98	0.65	0.73	4.63	7.04
T_{10}	2.80	7.84	0.93	1.54	8.25	12.07
T_{11}	5.38	10.34	2.43	3.40	9.45	12.94
T_{12}	0.61	4.08	2.42	3.95	5.53	9.30
T_{13}	43.17	51.97	18.86	19.54	41.54	45.91
CD (0.05)	6.96	5.23	4.13	3.21	6.37	6.62
SE (m)±	2.39	1.79	1.42	1.10	2.18	2.27

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

4.14 Nutrient uptake by crop

The data regarding the effect of treatments on the uptake of NPK by crop is depicted in Table 47. Highest uptake of N was observed in repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) with 26.55 kg/ha, on par with single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) with 21.86 and 25.93 kg/ha respectively, mango leaf mulching (T_{11}) with 21.12 kg/ha and hand weeded plot (T_{12}) with 26.53 kg/ha. Lowest N uptake by crop was observed in unweeded control (T_{13}) with 4.55 kg/ha, on par with single and repeated spray of lemon extract herbicide (7.90 and 7.83 kg/ha) and repeated spray of CNSL herbicide (13.13 kg/ha).

Highest uptake of P was observed in hand weeded plot (T_{12}) with 6.84 kg/ha, single and repeated spray of coconut vinegar-clove leaf oil herbicide (4.16 and 4.42 kg/ha), single and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_5 and T_{10}) with 4.18 and 4.18 kg/ha respectively and single spray of coconut vinegar herbicide (T_1) with 5.21 kg/ha. Lowest uptake of P was recorded by unweeded control (T_{12}) with 0.33 kg/ha, on par with single and repeated spray of lemon extract herbicide (0.66 and 0.80 kg/ha), single and repeated spray of CNSL herbicide (T_2 and T_7) with 1.86 and 2.03 kg/ha and repeated spray of coconut vinegar herbicide (3.17 kg/ha).

Potassium uptake was observed to be highest in coconut vinegar-clove leaf oil herbicide (T_9) (27.38 kg/ha), which was on par with repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (25.55 kg/ha) and hand weeded plot (T_{12}) (25.76 kg/ha). Unweeded control (T_{13}) recorded the lowest uptake of K by plants (1.35 kg/ha), on par with single and repeated spray of lemon extract herbicide (T_3 and T_8) (2.91 and 4.07 kg/ha).

4.15 Microbial population in soil

Effect of treatments on the microbial population of soil is given in Table 48. All treatments improved the bacterial population in soil than before experiment, except mango leaf mulching (T_{11}) (7.04), on par with repeated spray

Table 47: Effect of treatments on nutrient uptake by crop (kg/ha)

Treatments	Nutrient uptake by crop (kg/ha)		
	N	P	K
T_1	17.06	5.21	11.97
T_2	14.44	1.86	8.92
T_3	7.90	0.66	2.91
T_4	18.71	4.16	15.20
T_5	21.86	4.18	16.95
T_6	17.12	3.17	10.51
T_7	13.13	2.03	10.93
T_8	7.83	0.80	4.07
T_9	26.55	4.42	27.38
T_{10}	25.93	4.18	25.55
T_{11}	21.12	3.60	12.95
T_{12}	26.53	6.84	25.76
T_{13}	4.55	0.33	1.35
CD(0.05)	7.65	3.08	4.32
SE (m)±	2.62	1.05	1.48

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

of CNSL herbicide (T_7). Bacterial population was observed to be higher in coconut vinegar treatment (T_6) (7.90 log cfu g^{-1} of soil), which was on par with single and repeated spray of coconut vinegar-clove leaf oil herbicide (T_4 and T_9) (7.43 and 7.43 log cfu g^{-1} of soil respectively), single spray of coconut vinegar-eucalyptus oil herbicide (T_5) (7.52 log cfu g^{-1} of soil), single and repeated spray of lemon extract herbicide (T_3 and T_8) (7.6 and 7.70 log cfu g^{-1} of soil respectively), repeated spray of coconut vinegar herbicide (T_6) (7.88 log cfu g^{-1} of soil) and unweeded control (7.71 log cfu g^{-1} of soil).

All the treatments improved the fungal population in soil than before experiment, except repeated spray of CNSL herbicide (T_7) (4.74 log cfu g^{-1} of soil), which recorded the lowest fungal population in soil, on par with hand weeded plot (T_{12}) (4.85 log cfu g^{-1} of soil). highest fungal population was observed in repeated spray of coconut vinegar-clove leaf oil herbicide (T_9) (5.43 log cfu g^{-1} of soil), on par with single and repeated spray of coconut vinegar herbicide (T_1 and T_6) (5.28 and 5.42 log cfu g^{-1} of soil respectively), single spray of CNSL herbicide (T_2) (5.37 log cfu g^{-1} of soil), single spray of coconut vinegar-clove leaf oil herbicide (T_4) (5.31), repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (5.34 log cfu g^{-1} of soil) and unweeded control (T_{13}) (5.24 log cfu g^{-1} of soil).

It was observed that all the treatments reduced the actinomycetes population in soil when compared to before experiment (5.32 log cfu g^{-1} of soil). Single spray of coconut vinegar-clove leaf oil (T_4) recorded the highest actinomycetes population (5.22 log cfu g^{-1} of soil) after the experiment, which was on par with single spray of coconut vinegar (5.02 log cfu g^{-1} of soil) and single spray of lemon extract herbicide (5.15 log cfu g^{-1} of soil). Lowest population of actinomycetes was observed in repeated spray of coconut vinegar-eucalyptus oil herbicide (4.52 log cfu g^{-1} of soil), on par with repeated spray of lemon extract herbicide (4.66 log cfu g^{-1} of soil).

Table 48: Effect of treatments on microbial population in soil 60 DAS

Treatments	Microbial Population (log cfu/g soil)		
	Bacteria	Fungi	Actinomycetes
T_1	7.90	5.28	5.02
T_2	7.16	5.37	4.99
T_3	7.61	5.07	5.15
T_4	7.43	5.31	5.22
T_5	7.52	5.22	4.92
T_6	7.88	5.42	4.95
T_7	7.04	4.74	4.99
T_8	7.70	5.10	4.66
T_9	7.43	5.43	4.81
T_{10}	7.35	5.34	4.52
T_{11}	7.04	5.17	4.85
T_{12}	7.25	4.85	4.94
T_{13}	7.71	5.24	4.85
before	7.11	4.83	5.32
CD (0.05)	0.51	0.21	0.21
SE (m)±	0.18	0.07	0.07

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

4.16 Quantitative estimation of earthworms

There was no significant difference among the treatments in the number of earthworms per square metre of soil (Table 49).

4.17 Dehydrogenase enzyme activity of soil

All the treatments recorded improved dehydrogenase enzyme activity when compared to before experiment (Table 50). Highest dehydrogenase enzyme activity was observed in single spray of coconut vinegar herbicide (T_1) (97.06 μg of TPF g^{-1} soil $24h^{-1}$), single spray of coconut vinegar-clove leaf oil herbicide (T_4) (89.64 μg of TPF g^{-1} soil $24h^{-1}$) and repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) (87.27 μg of TPF g^{-1} soil $24h^{-1}$). Unweeded control (T_{13}) recorded the lowest dehydrogenase enzyme activity (8.70 μg of TPF g^{-1} soil $24h^{-1}$), on par with single spray of CNSL herbicide (T_2) (18.81 μg of TPF g^{-1} soil $24h^{-1}$) and mango leaf mulching (T_{11}) (10.18 μg of TPF g^{-1} soil $24h^{-1}$).

4.18 B:C ratio

Effect of treatments on B:C ratio is depicted in Table 51. Highest B:C ratio was observed in single spray of coconut vinegar-clove leaf oil herbicide (T_4) treatment (1.54), followed by repeated spray of coconut vinegar-eucalyptus oil herbicide (T_{10}) with 1.47. Lowest B:C ratio was observed in single and repeated spray of lemon extract herbicide (0.15 and 0.15 respectively).

Table 49: Effect of treatments on the quantitative estimation of earthworms

Treatments	Earthworms (no. m^{-3})
T_1	74.67
T_2	73.33
T_3	96.00
T_4	80.00
T_5	72.00
T_6	73.33
T_7	80.00
T_8	98.67
T_9	72.00
T_{10}	73.33
T_{11}	96.00
T_{12}	77.33
T_{13}	98.67
CD(0.05)	NS
SE (m)±	10.00

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 50: Effect of treatments on dehydrogenase enzyme activity of soil

Treatments	Dehydrogenase enzyme activity (µg of TPF g^{-1} soil $24h^{-1}$)
T_1	97.06
T_2	18.81
T_3	39.16
T_4	89.64
T_5	75.81
T_6	74.48
T_7	62.44
T_8	78.50
T_9	75.94
T_{10}	87.27
T_{11}	10.18
T_{12}	35.58
T_{13}	8.70
Before experiment	6.37
CD (0.05)	15.34
SE (m)±	5.25

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T_5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Table 51: Effect of treatments on B:C ratio

Treatments	Benefit (Rs)	Cost (Rs)	B:C ratio
T_1	178800	150468	1.19
T_2	123000	130489	0.94
T_3	26700	180723	0.15
T_4	263700	170867	1.54
T_5	210300	160465	1.31
T_6	138300	175623	0.79
T_7	133200	135729	0.98
T_8	34500	235336	0.15
T_9	296700	215447	1.38
T_{10}	286500	195556	1.47
T_{11}	201000	140722	1.43
T_{12}	324900	297236	1.09
T_{13}	18900	105889	0.18

T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T_1+ Spray of CVH at 30 DAS; T_7- T_2+ Spray of CNSLH at 30 DAS; T_8- T_3+ Spray of LEH at 30 DAS; T_9- T_4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Discussion

5. DISCUSSION

The experiment entitled 'Evaluation of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculentus* (L.) Moench] was conducted in the Department of Vegetable Science, College of Agriculture, Vellayani during 2018-19. The results of the experiment presented in the previous chapter are discussed below.

5.1 PART1- PRELIMINARY EVALUATION OF HORTICULTURAL CROP PRODUCTS AND BY-PRODUCTS AS HERBICIDES.

Part 1 of investigation consisted of 5 experiments with Coconut vinegar herbicide (CVH), Cashew Nut Shell Liquid herbicide (CNSLH), Lemon extract herbicide (LEH), Coconut vinegar-clove leaf oil herbicide (CLOH), and Coconut vinegar-eucalyptus oil herbicide (EOH). The observations on weeds such as floristic composition, absolute density, root and shoot biomass, and weed control efficiency was taken and the results are discussed below.

Mainly upland weeds were observed in the experiment plot. Grasses such *as Panicum maximum, Setaria barbata* and *Cynodon dactyon* were predominantly seen. *Cyperus rotundus* was the only sedge found in the experimental plot. Broad leaved weeds such as *Cleome viscose, Synedrella nodiflora, Euphorbia genniculata, Phyllanthus niruri, Gomphrena serrata, Commelina benghalensis, Evolvulus numularius* and *Vernonia cineria* were observed predominantly.

5.1.1 Experiment 1- coconut vinegar (CVH)

Coconut vinegar with 4 different concentrations of acetic acid (5, 7.5, 10 and 12.5 percent) and unweeded control were taken as the treatments. The results obtained from the experiment 1 are discussed below.

Among the different concentrations of acetic acid, CVH with 12.5 per cent acetic acid (T_1) consistently reduced the absolute density of weeds until 45 days after spraying (Plate 5). It recorded the lowest absolute density of grasses, sedges and broad leaved weeds (153.19 m^{-2}, 9.18 m^{-2}, 29.06 m^{-2} respectively), which

Plate 5: Effect of CVH with12.5% acetic acid treatment at before spraying, 15 and 45 days after spraying.

accounted for 36.31 percent reduction in absolute density of grasses, 56.73 percent in sedges and 74.76 percent in broad leaved weeds when compared to un weeded control at 15 days after spraying. At 45 days after spraying, lowest absolute density of grasses with 158.36 m^{-2}, sedges with 16.07 m^{-2}, broad leaved weeds with 30.42 m^{-2}, which accounted for 36.21 percent reduction of grasses, 34.41 percent reduction of sedges and 76.43 percent reduction of broad leaved weeds when compared to un weeded control (T_5).

Chinery (2002) observed that acetic acid treatments cause a quick discoloration and browning of plant foliage, later turned into water soaked and blackened in a few hours, which was also observed in this study.

CVH with 12.5 percent acetic acid (T_4) consistently reduced the root biomass at 15 and 45 days after spraying when compared to the unweeded control. CVH with 12.5 percent acetic acid (T_4) recorded a root biomass of 6.61 gm^{-2} which accounted for 87.19 percent reduction at 15 days after spraying compared to unweeded control. At 45 days after spraying, the root biomass was 11.18 gm^{-2} which accounted for 79.80 percent reduction when compared to unweeded control. The shoot biomass was also reduced consistently at 15 and 45 days after spraying with CVH 12.5 percent acetic acid (355.73 and 401.66 gm^{-2} respectively) which accounted for 65.30 percent and 66.32 percent reduction respectively over unweeded control plot.

At 15 days after spraying, all the treatments recorded significantly higher weed control efficiency (Fig.1) as compared to unweeded control and CVH with 12.5 percent acetic acid (T_4) recorded the highest weed control efficiency of 70.37 percent. At 45 days after spraying, all treatments except CVH with 5 percent acetic acid recorded higher weed control efficiency when compared to unweeded control and CVH with 12.5 percent acetic acid (T_4) recorded highest weed control efficiency. The weed control efficiency decreased from 15 days after spraying (70.37%) to 45 days after spraying (56.31%).

These observations were in agreement with the findings of Daniels and Fults (2002), five per cent vinegar solution did not cause any weed control and 80-100 per cent control of certain species of annual weeds was observed with 10, 15 and 20 per cent vinegar. Perennial weeds when treated with vinegar showed burn down of shoot, but roots were not affected, so re growth of weeds occured.

These observations were in line with the findings of Webber and Shrefler, (2009a) that the weed control by acetic acid not only depend on the application volume and concentration, but also the weed size and species.

5.1.2 Experiment 2- Cashew nut shell liquid (CNSLH)

CNSLH with 4 concentrations of CNSL (5, 10, 15 and 20% CNSL) and unweeded control were the treatments. The results obtained from experiment 2 are discussed below.

Among the different concentrations of CNSL, 20 per cent CNSL (T_4) consistently reduced the absolute density of weeds upto 45 days after spraying (Plate 6). It recorded the lowest absolute density of grasses, sedges and broad leaved weeds (14.80 m^{-2}, 5.33 m^{-2} and 10.17 m^{-2} respectively) which accounted for 91.54, 77.57, 91.16 percent reduction in absolute density of grasses, sedges and broad leaved weeds in comparison to unweeded control at 15 days after spraying. At 45 days after spraying, lowest absolute density of grasses, sedges and broad leaved weeds were recorded in 20 percent CNSL (50.62 m^{-2}, 17.99 m^{-2} and 29.75 m^{-2} respectively) which accounted for 75.16 percent reduction in absolute density of grasses, 59.74 percent in sedges and 77.34 percent in broad leaved weeds when compared to unweeded control.

Five percent CNSL (T_1) did not significantly reduce the absolute density of grasses, sedges and broadleaved weeds consistently upto 45 days of spraying than unweeded control, whereas 10 percent CNSL (T_2) significantly reduced the absolute density of grasses and broad leaved weeds at 15 days after spraying. This falls in line with the inference of Anadayanie *et al.*, (2019) that less than six

Plate 6: Effect of 20% CNSLH at before spraying, 15 and 45 days after spraying.

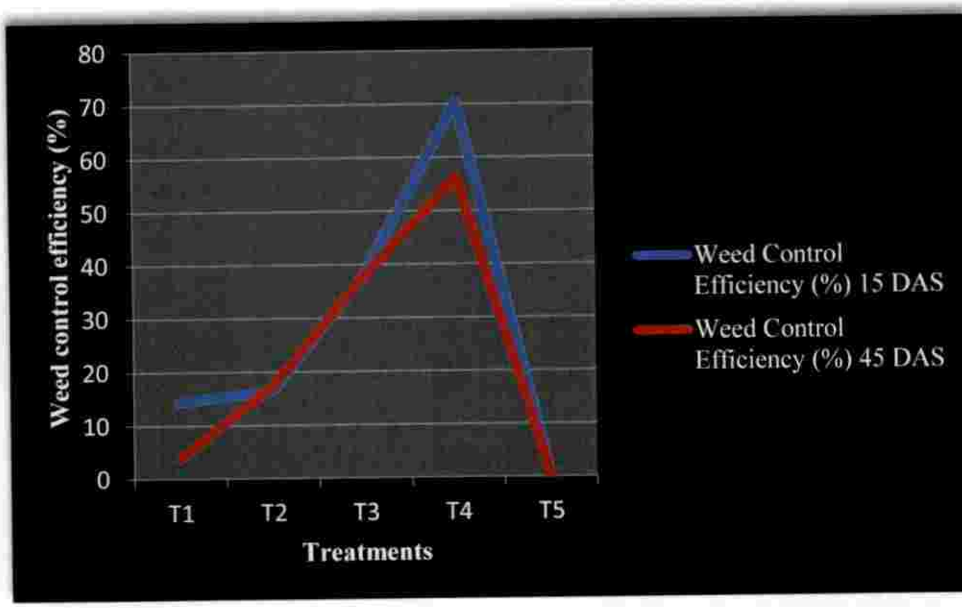
percent concentration of CNSL acts only as an insecticide and more than six percent concentration of CNSL causes phytotoxicity symptoms.

All treatments significantly reduced the root biomass at 15 days after spraying in comparison with unweeded control. At 45 days after spraying, all treatments except five percent CNSL (T_1) significantly reduced root biomass, when compared to unweeded control. 20 percent CNSL (T_4) consistently reduced the root biomass upto 45 days after spraying. It recorded the lowest root biomass of 2.53 gm^{-2}, which accounted for 92.55 percent reduction than that of unweeded control at 15 days after spraying. At 45 days after spraying, lowest root biomass of 8.91 gm^{-2} was observed with 20 percent CNSL (T_4), which accounted for 79.21 percent reduction in comparison to unweeded control.

All treatments except five percent CNSL (T_1) significantly reduced shoot biomass than that of unweeded control until 45 days after spraying. Among all the treatments 20 percent CNSL (T_4) consistently reduced shoot biomass of weeds upto 45 days after spraying. The lowest shoot biomass of 47.58 gm^{-2} was observed with 20 percent CNSL (T_4) treatment at 15 days after spraying, which accounted for 95.55 percent reduction in the shoot biomass when compared to unweeded control (T_5). At 45 days after spraying, lowest shoot biomass of 426.29gm^{-2} was observed with 20 percent CNSL (T_4), which accounted for 66.69 percent reduction in shoot biomass when compared to unweeded control (T_5).

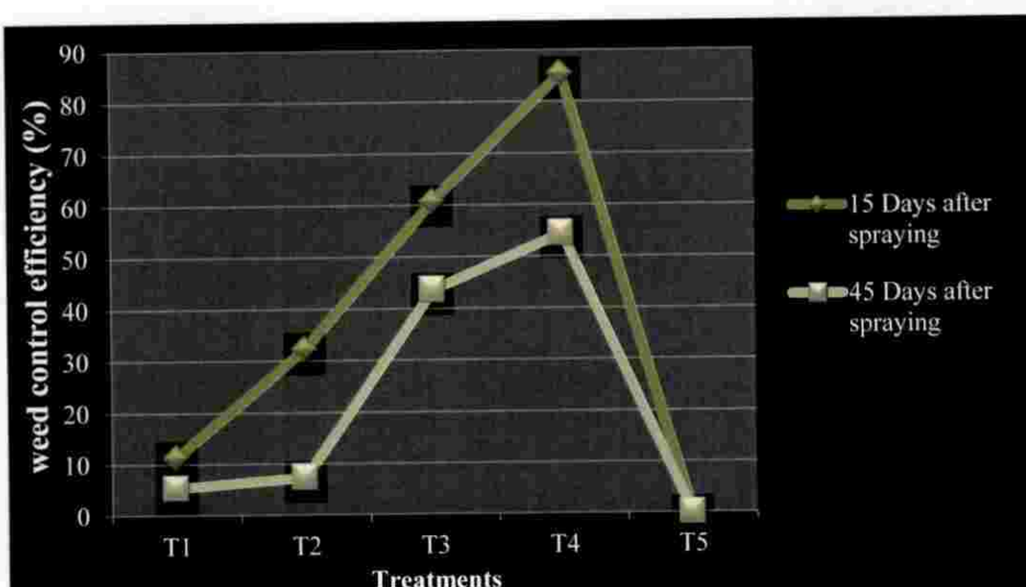
At 15 days after spraying, all treatments recorded significantly higher weed control efficiency (Fig.2) compared to unweeded control (T_5) and 20 percent CNSL (T_4) recorded the highest weed control efficiency of 85.42 percent. All treatments except 5 and 10 percent CNSL recorded higher weed control efficiency than that of unweeded control, wherein 20 percent CNSL (T_4) recorded the highest weed control efficiency of 54.39 percent at 45 days after spraying. The weed control efficiency reduced from 15 to 45 days after spraying, which may be due to the regrowth of certain perennial weeds.

Figure 1: Effect of CVH on weed control efficiency at 15 days after spraying and 45 days after spraying.



T_1- CVH with 5 % acetic acid; T_2- CVH with 7.5% acetic acid; T_3- CVH with 10% acetic acid; T_4- CVH with 12.5% acetic acid; T_5- control.

Figure 2: Effect of CNSLH on weed control efficiency at 15 days after spraying and 45 days after spraying.



T_1- 5% CNSL; T_2- 10% CNSL; T_3- 15% CNSL; T_4- 20% CNSL; T_5- control

5.1.3 Experiment 3- Lemon extract (LEH)

Lemon extract with four concentration of citric acid (2.5, 5, 7.5 and 10 percent citric acid) and unweeded control was the treatments in experiment 3. The results of the observations in experiment 3 are discussed below.

None of the treatments significantly reduced the absolute density of grasses and sedges at 15 days after spraying. LEH with 10 percent citric acid (T_4) recorded the lowest absolute density of broad leaved weeds (32.97 m^{-2}) at 15 days after spraying, which accounted for 38.46 percent reduction compared to unweeded control (Plate 7). At 45 days after spraying, there was no significant difference between the treatments for the reduction of absolute density of grasses, sedges and broad leaved weeds.

Among all the treatments, LEH with 7.5 percent citric acid (T_3) and 10 percent citric acid (T_4) consistently reduced the root biomass upto 45 days after spraying. At 15 days after spraying, the lowest root biomass was observed in LEH with 7.5 percent citric acid (15.25 gm^{-2}) and 10 percent citric acid (12.12 gm^{-2}) which accounted for 50.23 and 60.44 percent reduction respectively in comparison to unweeded control. At 45 days after spraying, all treatments significantly reduced the root biomass when compared to unweeded control.

Among all the treatments, LEH with 10 percent citric acid (T_4) consistently reduced the shoot biomass upto 45 days after spraying. At 15 days after spraying, lowest shoot biomass was observed in LEH with 10 percent citric acid (160.33 gm^{-2}) which accounted for 52.57 percent reduction over unweeded control. At 45 days after spraying, LEH with 10 percent citric acid (T_4) recorded the lowest shoot biomass of 287.38 gm^{-2}, which accounted for 31.56 percent reduction in shoot biomass when compared to unweeded control.

At 15 days after spraying, all the treatments except LEH with 2.5 percent citric acid (T_1) recorded higher weed control efficiency (Fig.3) compared to unweeded control, among which LEH with 10 percent citric acid recorded the highest weed control efficiency of 40.01 percent. At 45 days after spraying, only

Plate 7: Effect of LEH with 10% citric acid treatment at before spraying, 15 and 45 days after spraying.

LEH with 10 percent citric acid (T_4) recorded significantly higher weed control efficiency (5.93 %) compared to unweeded control. Weed control efficiency decreases from 15 days after spraying to 45 days after spraying.

These results are in contrast with the findings of Main *et al.* (2013), that d-limonene as citrus oil gave better weed control and yield than acetic acid.

5.1.4 Experiment 4- Coconut vinegar-clove leaf oil mixture (CLOH)

In experiment 4, a mixture of coconut vinegar and clove leaf oil was used. The best treatment of experiment 1 (CVH with 12.5% acetic acid) was mixed with 4 different concentrations of clove leaf oil (1, 2, 3 and 4 % clove leaf oil) were applied on to the weeds and compared with unweeded control. The results obtained are discussed below.

All the treatments consistently reduced the absolute density of grasses, sedges and broad leaved weeds upto 45 days after spraying compared to unweeded control. Among the treatments CLOH with 4 percent clove leaf oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds (10.10, 7.72, 7.72 m^{-2} respectively) which accounted for 95.03 percent reduction in absolute density of grasses, 89.96 percent in sedges and 89.96 percent in broad leaved weeds compared to unweeded control at 15 days after spraying (Plate 8 and Plate 9). Among the treatments, CLOH with 4 percent clove leaf oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds (9.95, 6.00 and 7.85 m^{-2} respectively) which accounted for 95.25 percent reduction in absolute density of grasses, 92.46 percent in sedges and 95.58 percent in broad leaved weeds in comparison to unweeded control.

All treatments significantly reduced the root biomass of weeds when compared to unweeded control (T_5). Among the treatments, CLOH with 4 percent clove leaf oil (T_4) recorded the lowest root biomass (1.16 gm^{-2}) at 15 days after spraying which accounted for 96.48 percent reduction in root biomass compared to un weeded control at 15 days after spraying. At 45 days after spraying also all the treatments significantly reduced the root biomass compared to unweeded

Plate 8: Effect of CLOH with 4% clove leaf oil treatment at before, 15 and 45 days after spraying.

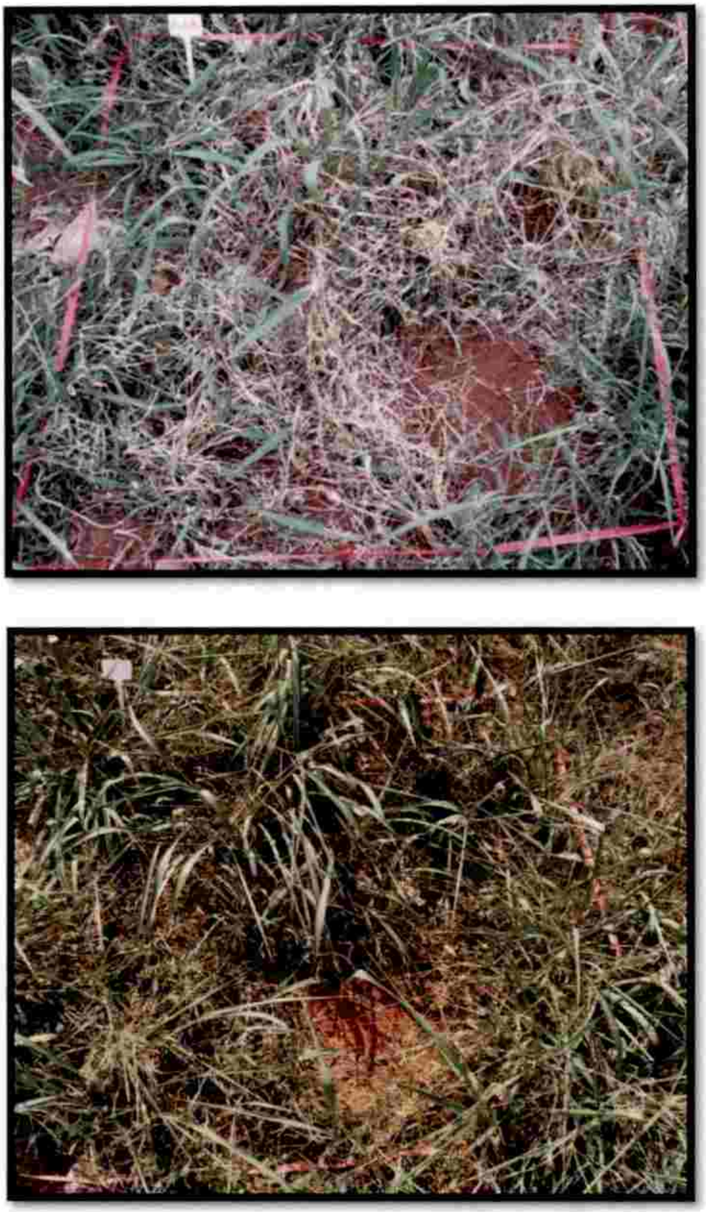


Plate 9: Effect of CLOH with 4% clove leaf oil treatment at 15 and 45 days after spraying.

control. Among the treatments CLOH with 4 percent clove leaf oil (T_4) recorded the lowest root biomass (3.86 gm^{-2}) which accounted for 90.51 percent reduction than unweeded control.

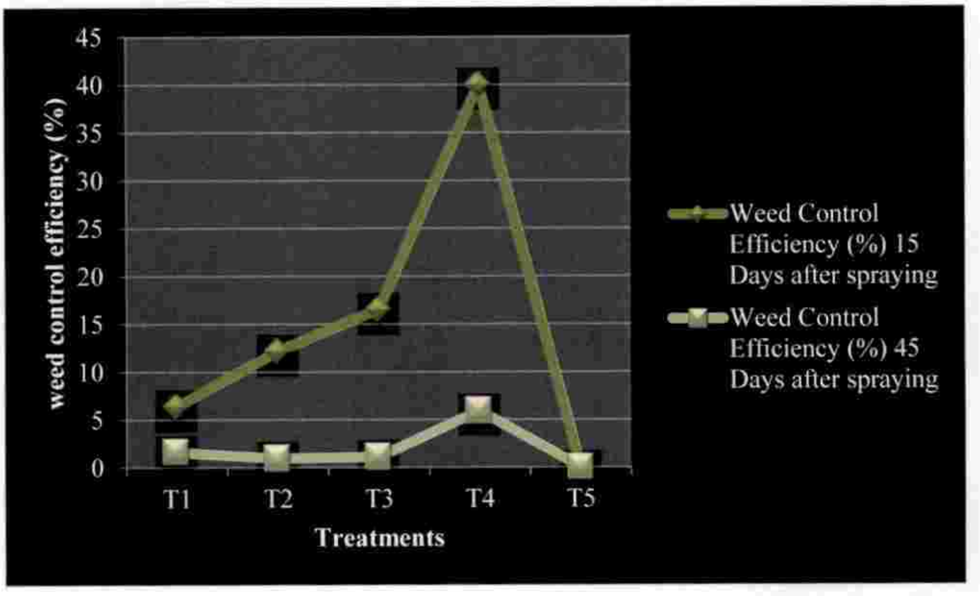
All treatments significantly reduced the shoot biomass of weeds when compared to unweeded control. Among the treatments CLOH with 4 percent clove leaf oil (T_4) recorded the lowest shoot biomass (36.18 gm^{-2}) at 15 days after spraying which accounted for 96.41 percent reduction in comparison to unweeded control. At 45 days after spraying, all the treatments significantly reduced the shoot biomass compared to unweeded control. Among the treatments CLOH with 4 percent clove leaf oil (T_4) recorded the lowest shoot biomass (81.62 gm^{-2}) which accounted for 93.23 percent reduction in shoot biomass compared to unweeded control.

All treatments recorded higher weed control efficiency (Fig.4) compared to unweeded control at 15 and 45 days after spraying. Among the treatments, CLOH with 4 percent clove leaf oil (T_4) consistently recorded the highest weed control efficiency of 98.11 percent at 15 days after spraying and 84.37 percent at 45 days after spraying.

The results from the study conducted by de Oleveira *et al*. (2016), proves that the major phytotoxic activity promoting agent in clove oil is eugenol, which inhibits the seed germination and elongation of hypocotyls and radical part of seedlings. Webber and Shrefler (2009b) reported that clove oil is a post emergent, non selective, contact herbicide for controlling actively growing annual and perennial grass and broad leaved weeds. Clove oil consisted of 77.10 percent eugenol, whereas clove leaf oil consisted of 94.4 percent eugenol (Razafimamonjison *et al*., 2014).

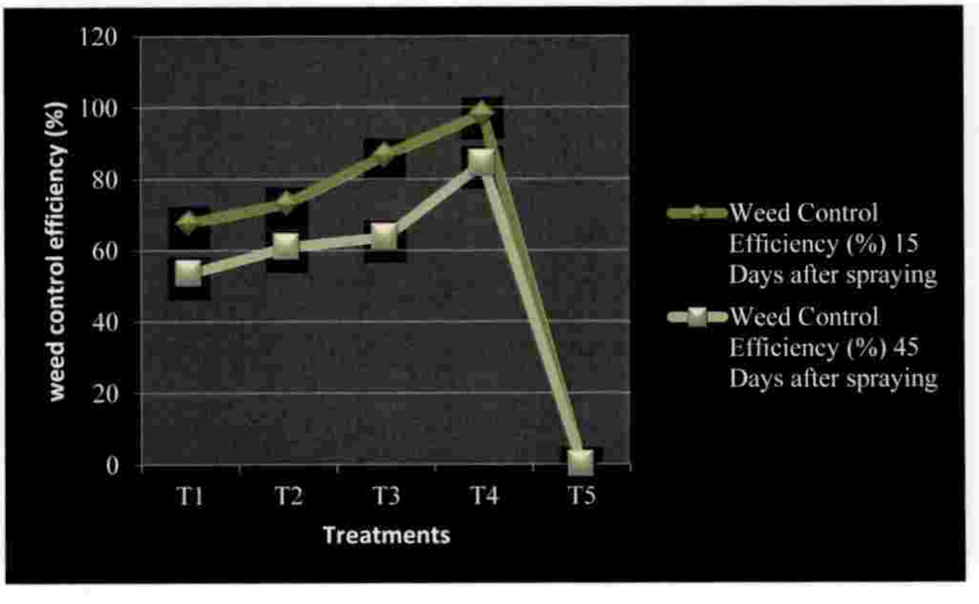
This fall in line with the findings of Brainard, 2013, who reported that combination of 15 per cent vinegar and 7.5 per cent clove leaf oil was best for control of mustard.

Figure 3: Effect of LEH on weed control efficiency at 15 days after spraying and 45 days after spraying.



T_1- 2.5% citric acid; T_2- 5% citric acid; T_3- 7.5% citric acid; T_4- 10% citric acid; T_5- control.

Figure 4: Effect of coconut vinegar + clove leaf oil on weed control efficiency at 15 days after spraying and 45 days after spraying.



T_1- CLOH with 1% clove leaf oil; T_2- CLOH with 2% clove leaf oil; T_3- CLOH with 3% clove leaf oil; T_4- CLOH with 4% clove leaf oil; T_5- control

5.1.5 Experiment 5- coconut vinegar-eucalyptus oil mixture (EOH)

In experiment 4, a mixture of coconut vinegar and eucalyptus oil was used. The best treatment of experiment 1 was mixed with 4 different concentrations of eucalyptus oil (1, 2, 3 and 4 % eucalyptus oil) applied on to the weeds and compared with unweeded control. The results obtained are discussed below.

All the treatments consistently reduced the absolute density of grasses, sedges and broad leaved weeds upto 45 days after spraying. At 15 days after spraying all the treatments significantly reduced the absolute density of grasses sedges and broad leaved weeds compared to unweeded control. Among the treatments EOH with 4 percent eucalyptus oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds (4.49, 9.82 and 5.87 m^{-2} respectively) which accounted for 82.62 percent reduction in absolute density of grasses, 96.58 percent in sedges and 96.85 percent in broad leaved weeds compared to unweeded control (Plate 10). Among the treatments, EOH with 4 percent eucalyptus oil (T_4) recorded the lowest absolute density of grasses, sedges and broad leaved weeds (7.79, 24.50 and 10.85 m^{-2} respectively) which accounted for 74.50 percent reduction in the absolute density of grasses, 91.50 percent in sedges and 94.34 percent in broad leaved weeds in comparison to unweeded control at 45 days after spraying.

All treatments significantly reduced the root biomass of weeds when compared to unweeded control. Among the treatments, EOH with 4 percent eucalyptus oil (T_4) recorded the lowest root biomass (1.74 gm^{-2}) at 15 days after spraying which accounted for 94.31 percent reduction in root biomass compared to unweeded control (T_5) at 15 days after spraying. At 45 days after spraying also all the treatments significantly reduced the root biomass compared to unweeded control. Among the treatments EOH with 4 percent eucalyptus oil (T_4) recorded the lowest root biomass (3.44 gm^{-2}) which accounted for 91.00 percent reduction than unweeded control (T_5).

Plate 10: Effect of EOH with 4% eucalyptus oil treatment at
before spraying, 15 and 45 days after spraying

All treatments significantly reduced the shoot biomass of weeds when compared to unweeded control. Among the treatments EOH with 4 percent eucalyptus oil (T_4) recorded the lowest shoot biomass (32.75 gm^{-2}) at 15 days after spraying which accounted for 96.70 percent reduction in comparison to unweeded control at 15 days after spraying. At 45 days after spraying, all the treatments significantly reduced the shoot biomass compared to unweeded control (T_5). Among the treatments EOH with 4 percent eucalyptus oil (T_4) recorded the lowest shoot biomass (83.97 gm^{-2}) which accounted for 92.78 percent reduction than unweeded control.

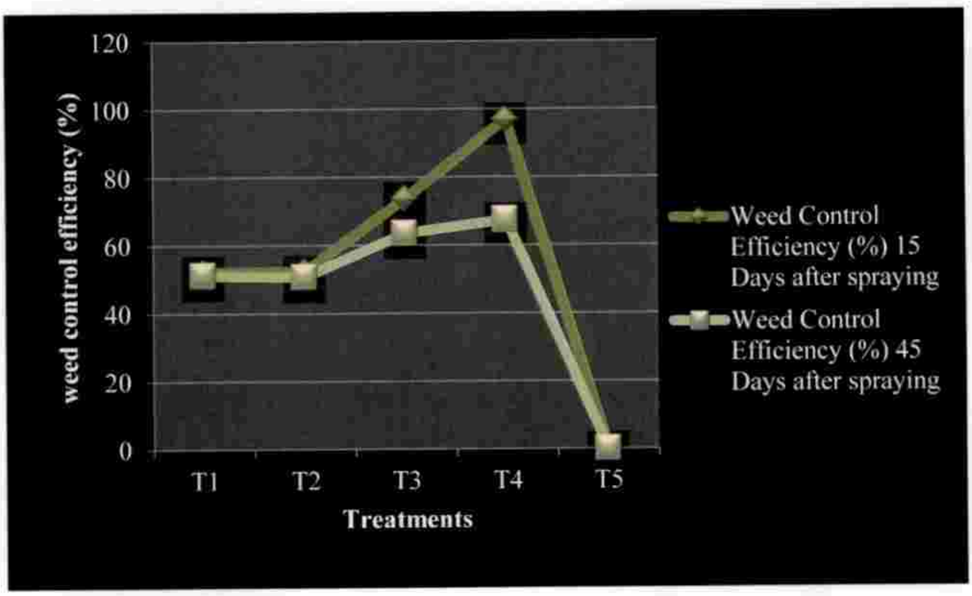
All treatments recorded higher weed control efficiency (Fig.5) compared to unweeded control at 15 and 45 days after spraying. Among the treatments, EOH with 4 percent eucalyptus oil (T_4) consistently recorded the highest weed control efficiency of 96.96 percent at 15 days after spraying and 67.46 percent at 45 days after spraying.

Kohli *et al.*, (1998) reported that the germination of weed *Parthenium hysterophorus* was inhibited by exposure to Eucalyptus oil and the chlorophyll content and cellular respiration rate was found to reduce which was accompanied by increased water loss resulting in complete wilting of plants after 15 days of treatment with volatile oils. Singh *et al.,* (2002) also found reduction in chlorophyll content of mature *C. occidentalis* and *E. cruss-galli* plants sprayed with eucalyptus oils.

5.1.6 Selection of best treatment

The best treatments of each experiment was selected based on the weed control efficiency i.e, 12.5 percent CVH, 20 percent CNSL, 10 percent LEH, 4 percent CLOH and 4 percent EOH and carried over to part II for evaluation of herbicides in organic farming of okra.

Figure 5: Effect of coconut vinegar + eucalyptus oil treatments on weed control efficiency at 15 and 45 days after spraying.



T_1- EOH with 1% eucalyptus oil; T_2- EOH with 2% eucalyptus oil; T_3- EOH with 3% eucalyptus oil; T_4- EOH with 4% eucalyptus oil; T_5- control.

5.2 PART II- EVALUATION OF HERBICIDES IN ORGANIC FARMING OF OKRA.

CVH with 12.5% acetic acid, CNSLH with 20% concentration, LEH with 10 % citric acid, CLOH with 4% clove leaf oil, and EOH with 4% eucalyptus oil were sprayed on the 45 day old weeds on stale seed bed, repeated application thirty days after sowing of okra variety Anjitha seeds in comparison to organic mulching with mango leaves, hand weeding till 7th week and weedy check. Results on crop growth characters, yield attributes, weed growth characters, soil parameters and economics of cultivation are discussed below.

5.2.1 Effect of treatments on the crop growth and yield characters

5.2.1.1 Germination percentage

All the organic herbicidal treatments and mulching recorded significantly higher germination percentage of okra seeds when compared to unweeded control. Germination percentage ranged from 81.25 per cent in unweeded control (T_{13}) to 93.06 per cent in hand weeded plot (T_{12}). This indicated that application of organic herbicides did not affect germination of okra seeds. This was in contrast with the findings of Shiralipour *et al.*, (1997) that 0.05 mM concentration of acetic acid inhibited germination up to 50 percent. This may be due to sowing of seeds after 15 days of organic herbicide treatment in the present study.

5.2.1.2 Phytotoxicity rating

The results obtained for the phytotoxicity rating in okra seedlings is given in figure . It is observed that there were no phytotoxicity symptoms observed in the seedlings when sown after 15 days of treatment (in T_1 to T_5). But in repeated application at 30 days after sowing of crop, all the herbicides showed some phytotoxicity symptoms ranging from 0.20, which indicates normal or no injury, in repeated spraying of lemon extract to 4.33 (Plate 11), which indicates moderate injury and recovery is possible, in repeated spraying of CLOH (T_9). Meyer *et al.*, (2008) reported similar effect of phytotoxicity with 0.2% and 0.3% clove oil

Plate 11: Phytotoxic effect of CLOH on okra seedling at repeated spray after 30 days of sowing

applied as drenches at transplant (0 day). These concentrations were observed to be the most phytotoxic to seedlings of all the tested vegetable species. EOH also exhibited phytotoxicity rating of 4.00 which indicated moderate injury and recovery is possible. Coconut vinegar and clove leaf oil are organic herbicides with contact herbicidal action as reported by Webber and Shrefler, 2009a andWebber and Shrefler, 2009b. The contact herbicidal action of vinegar wasreported by webber and Shrefler (2009a) and that of clove leaf oil was reported by Webber and Shrefler (2009b). Thus the drifting of these contact organic herbicides while spraying in a crop stand may cause phytotoxicity symptoms in seedlings. Prevention of drifting while spraying is labour intensive and is a cumbersome process.

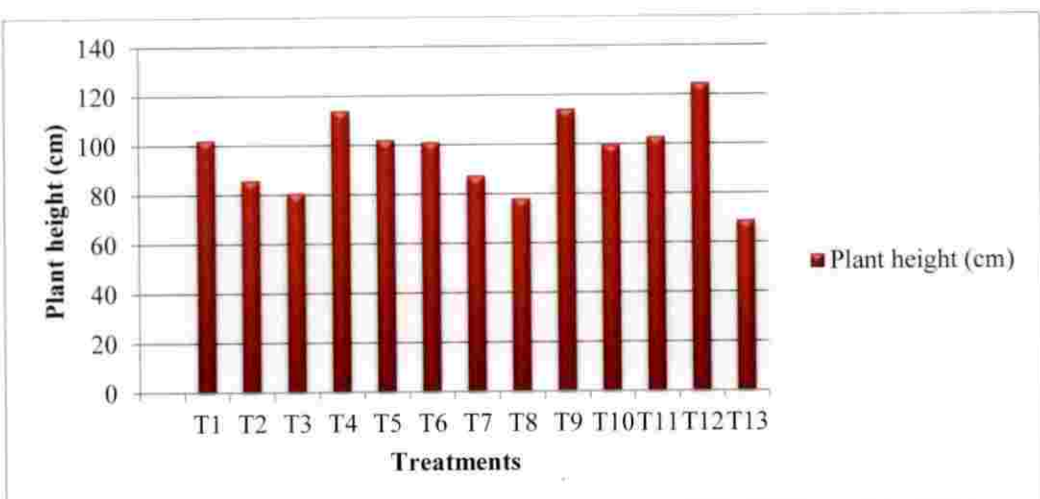
5.2.1.3 Plant height

Plant height (Fig.6) ranged from 68.60 cm in unweeded control (T_{13}) to 124.60 cm in hand weeded plot (T_{12}). All the organic herbicide treatments and mango leaf mulching except LEH (T_3 and T_8) produced taller plants when compared to unweeded control. This falls in line with the findings of Usman *et al.* (2005), that the height of okra is reduced due to increased crop weed competition. Among the plots treated with organic herbicides, single and repeated spray of CLOH (T_4 and T_9) produced taller plants similar to hand weeded plot. Repeated application of CLOH did not significantly influence the plant height in okra compared to single spray.

5.2.1.4 Number of branches per plant

All the treatments including mulching showed significantly higher number of branches except LEH (Fig.7). Among the organic herbicide treated plots, repeated spray of CLOH recorded the highest number of branches per plant similar to hand weeded plot.

Figure 6: Effect of treatments on plant height



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

5.2.1.5 *Number of leaves per plant*

The number of leaves per plant (Fig.7) ranged from 11.07 in unweeded control (T_{13}) to 20.00 in repeated spray of CLOH (T_9). All the treatments significantly improved the number of leaves per plant compared to unweeded control. CLOH recorded similar effect in improving the number of leaves per plant with hand weeded plot (T_{12}) and repeated application did not influence the number of leaves per plant.

5.2.1.6 *Days to 50 percent flowering*

Days to 50 per cent flowering ranged from 48.33 to 53.00 days. All the treatments significantly reduced the number of days for 50 percent flowering when compared to unweeded control (T_{13}). More number of days was required for flowering in plots which did not receive any weeding and less number of days was required when hand weeding (T_{12}) and repeated spraying of CLOH (T_9) was done. Repeated spraying of CLOH at 30 days after sowing did not significantly reduced the number of days for 50 percent flowering compared to single spraying.

5.2.1.7 *Node to first flower*

The node at which the first flower appeared was observed to be non significant among the treatments.

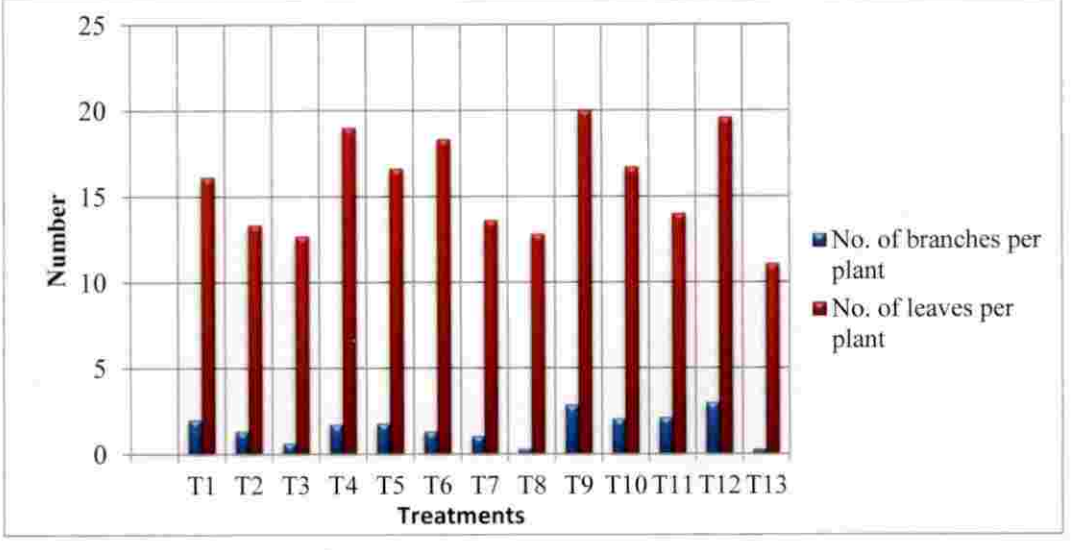
5.2.1.8 *Number of fruits per plant*

All the treatments except LEH significantly increased the number of fruits per plant compared to unweeded control (Fig.8). Repeated spraying of CLOH (T_9) recorded similar number of fruits per plant (8.9) as that of hand weeded plot (9.07). The number of fruits improved with repeated spraying of CLOH (T_9) compared to single spraying (6.87).

5.2.1.9 *Number of flowers per plant*

All treatments except LEH (T_3 and T_8) and CNSLH (T_2 and T_7) recorded significantly higher number of flowers per plant compared to unweeded control

Figure 7: Effect of treatments on number of branches per plant and number of leaves per plant



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

(Fig.8). Repeated spraying of CLOH at 30 days after sowing (T_9) recorded similar number of flowers per plant (10.18) as that of hand weeded plot (9.80). The number of flowers improved with repeated spraying of CLOH compared to single spraying (7.47).

5.2.1.10 Percentage fruit set

Almost all the treatments except single (T_3) and repeated spray of LEH (T_8) recorded higher percentage fruit set (Fig.8), when compared to unweeded control (T_{13}). Repeated spraying of organic herbicides did not affect the percentage fruit set when compared to single spraying.

5.2.1.11 Crop duration

All treatments except LEH recorded longer crop duration compared to unweeded control (Fig.9). Severe weed infestation may lead to increased crop weed competition, thereby reduces the nutrient uptake of crops leading to reduced crop duration in unweeded control (75 days) and single and repeated spray of LEH (75.67 and 76 days respectively). Repeated spraying of organic herbicides did not affect the duration of crop compared to single spraying.

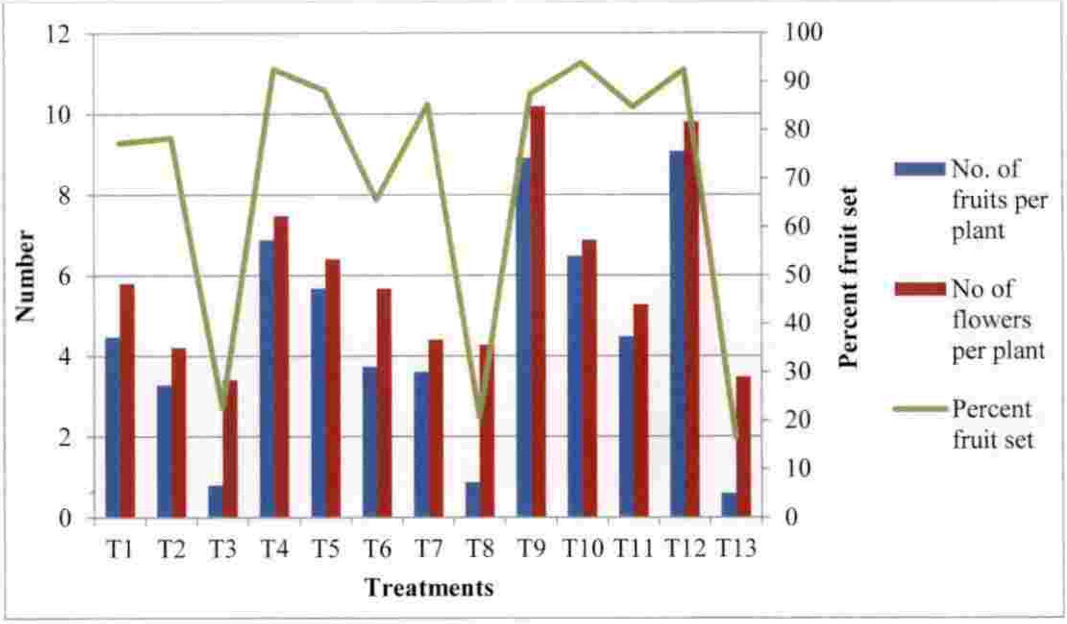
5.2.1.12 Number of harvest

All treatments except LEH significantly recorded more number of harvests compared to unweeded control (Fig.10). Repeated spraying of CLOH significantly influenced the number of harvest. Repeated spraying of CLOH performed similar to hand weeded plot in improving the number of harvest. Increased crop duration may lead to more number of harvests.

5.2.1.13 Yield

All treatments except LEH improved the yield of okra (Plate 12) compared to unweeded control (Fig.11). Repeated spraying of CLOH (T_9) and EOH (T_{10}) performed similar to hand weeded plot (T_{912}) in improving the yield. This comes in agreement with the findings of Gogoi *et al*. (1996) that the first to seven weeks

Figure 8: Effect of treatments on no of fruits per plant, no of flowers per plant and percent fruit set



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Figure 9: Effect of treatments on crop duration (days)

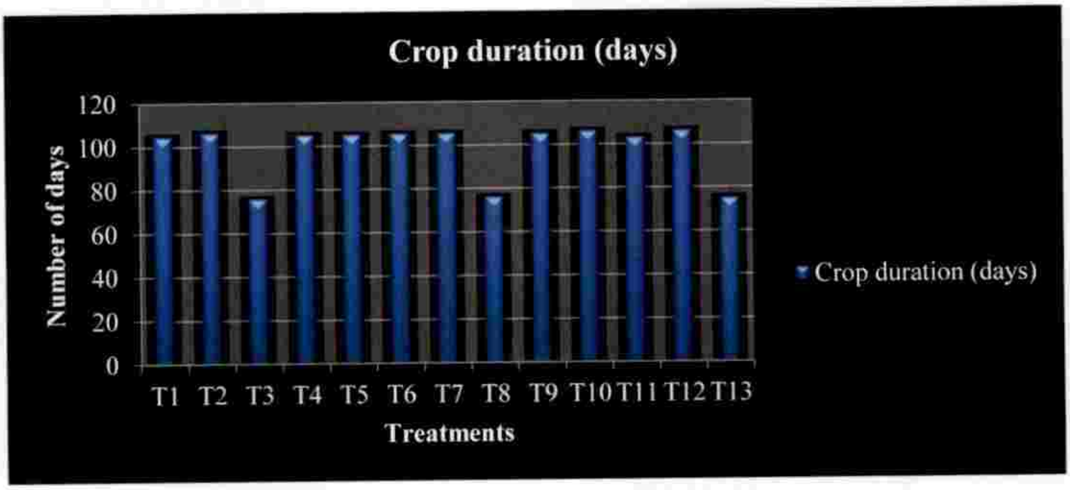
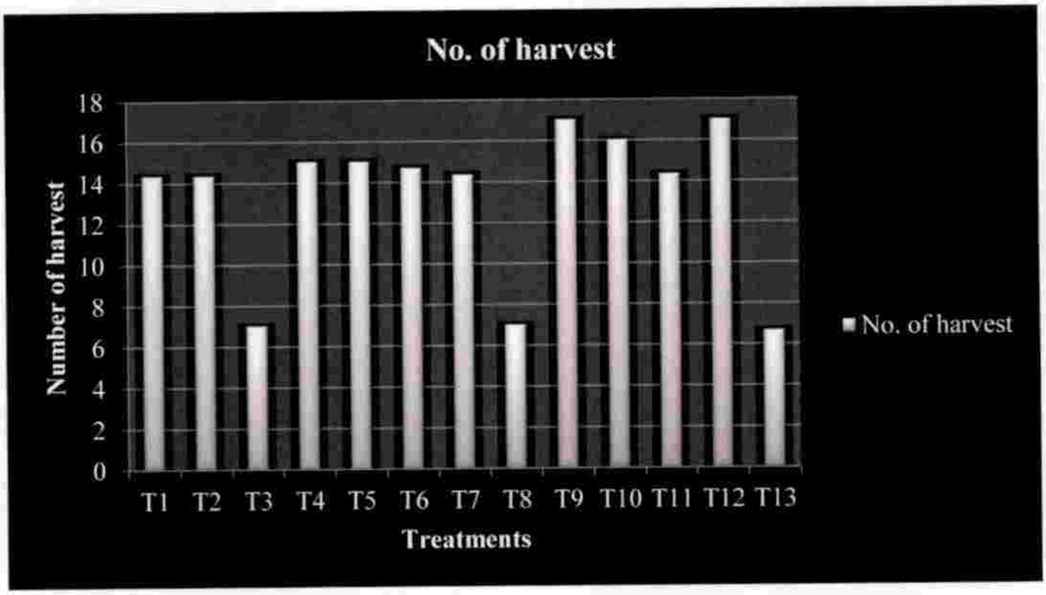


Figure 10: Effect of treatments on no. of harvests



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

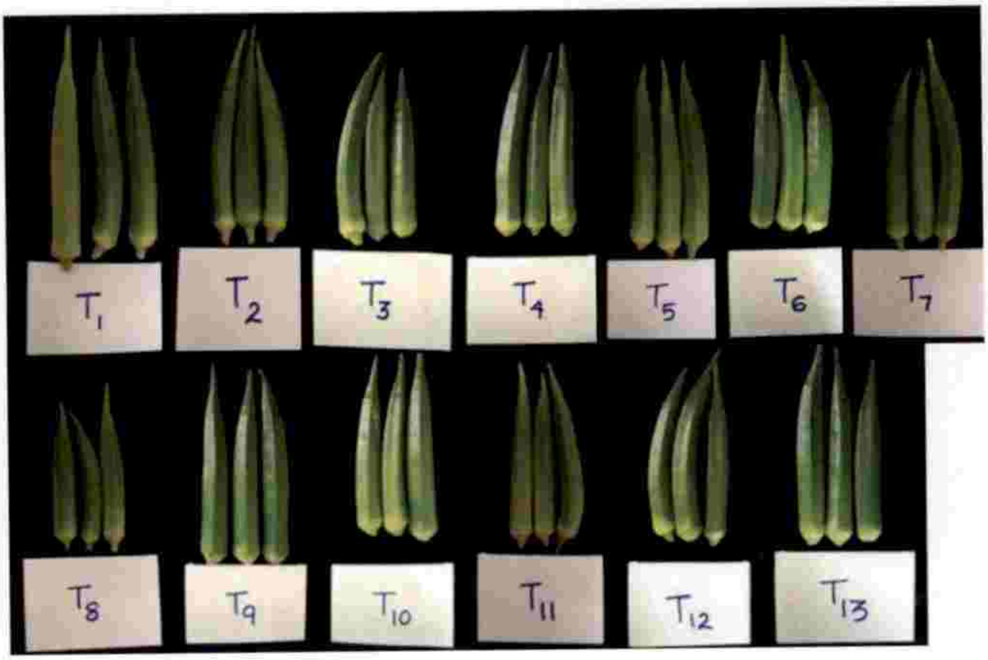
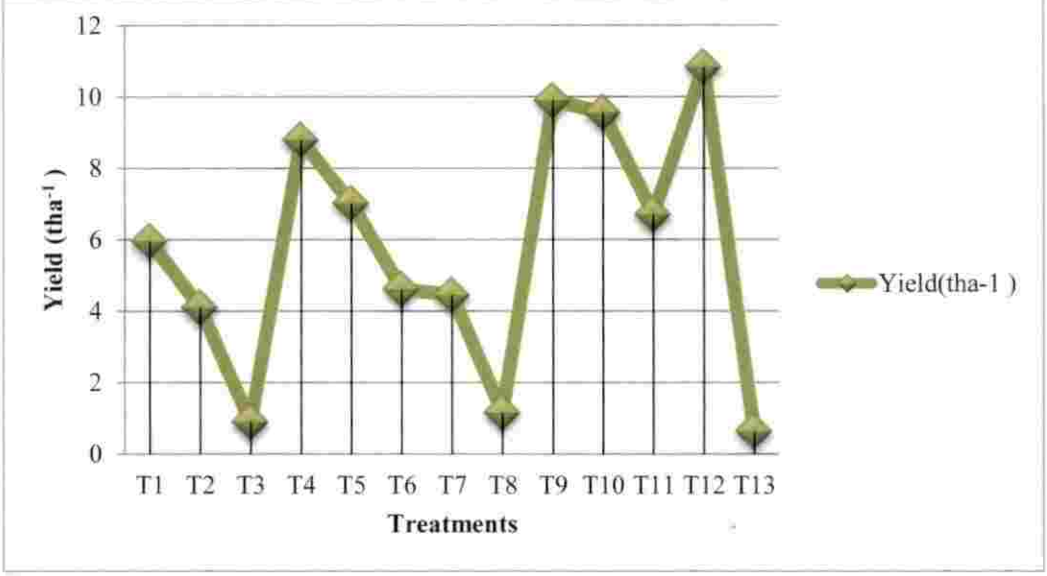


Plate 12: Effect of treatments on yield of okra

Figure 11: Effect of treatments on yield (tha^{-1})



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

after planting is the most critical period for weed control in okra. A weed free period upto seven weeks from sowing resulted in yield comparable with those obtained in a weed free situation. There was significantly higher yield when repeated spraying of CLOH (T_9) was given compared to single spraying of the same.

The yield reduction due to weed competition was 94.18 percent in unweeded control (0.63 tha^{-1}), 91.78 in single spray of LEH (0.89 tha^{-1}) and 89.38 percent in repeated spray of LEH (1.15 tha^{-1}) when compared to hand weeded plot (T_{12}). In okra yield reduction due to weed competition ranges from 59 per cent to 90 per cent as reported by Singh *et al*. (1982).

5.2.2 Observations on weeds

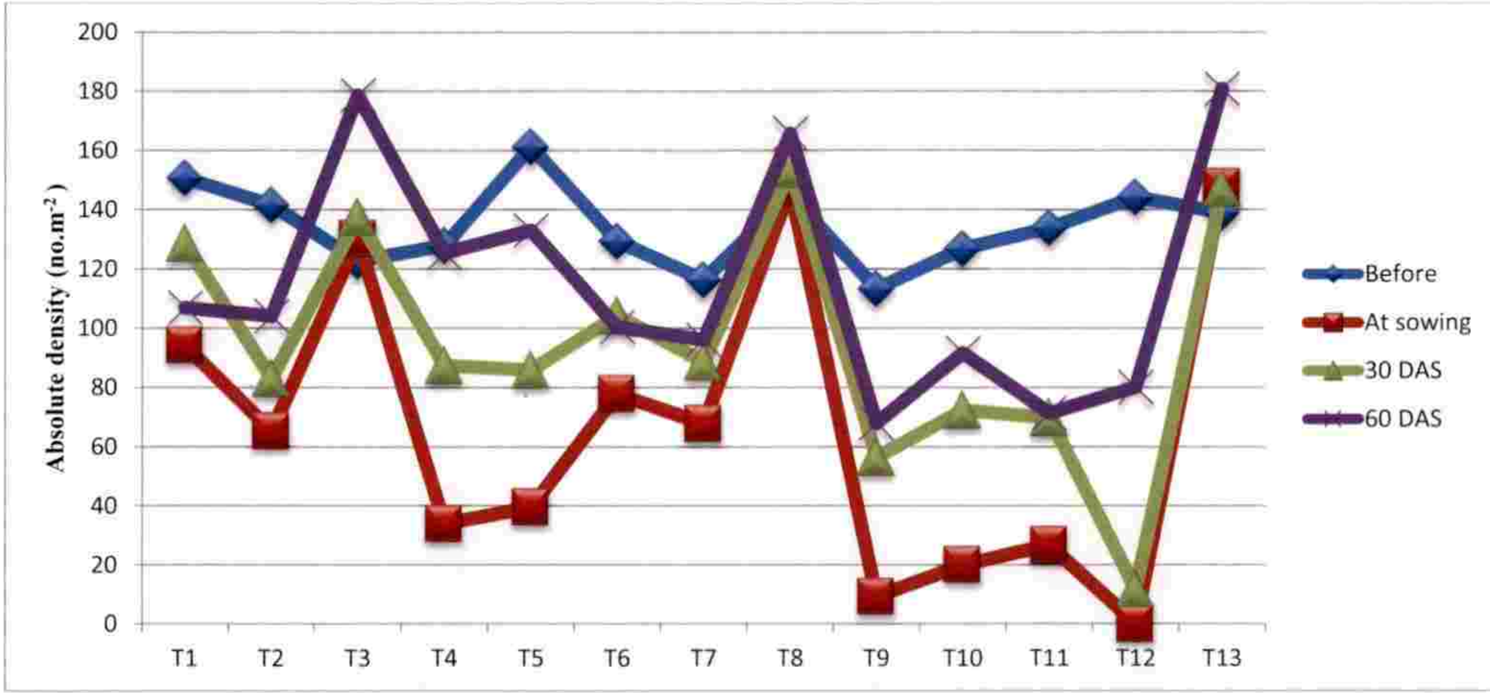
5.2.2.1 Floristic composition of weeds

Grasses such as *Panicum maximum*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Eleusine indica*, *Setaria barbata*, sedges such as *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora*, *Euphorbia genniculata*, *Phyllanthus niruri*, *Alternanthera sessilis*, *Cleome viscose*, *Tridax procumbens*, *Vernonia cinerea*, and *Commelina benghalensis* were the weeds species observed in the experimental plots. With the application of herbicides, some of the weed species got reduced at the time of sowing. At 30 days after sowing and 60 days after sowing, regrowth of certain weed species was observed, which may be due to the lack of complete emergence of weed seed bank at stale seed bed that might have germinated during the intercultural operations carried out for the crop or due to enhanced moisture availability due to heavy rains being located in deeper layers of earth. Hence further modification to stale seed bed is needed to flush out the weed seed bank.

5.2.2.2 Absolute density of weeds

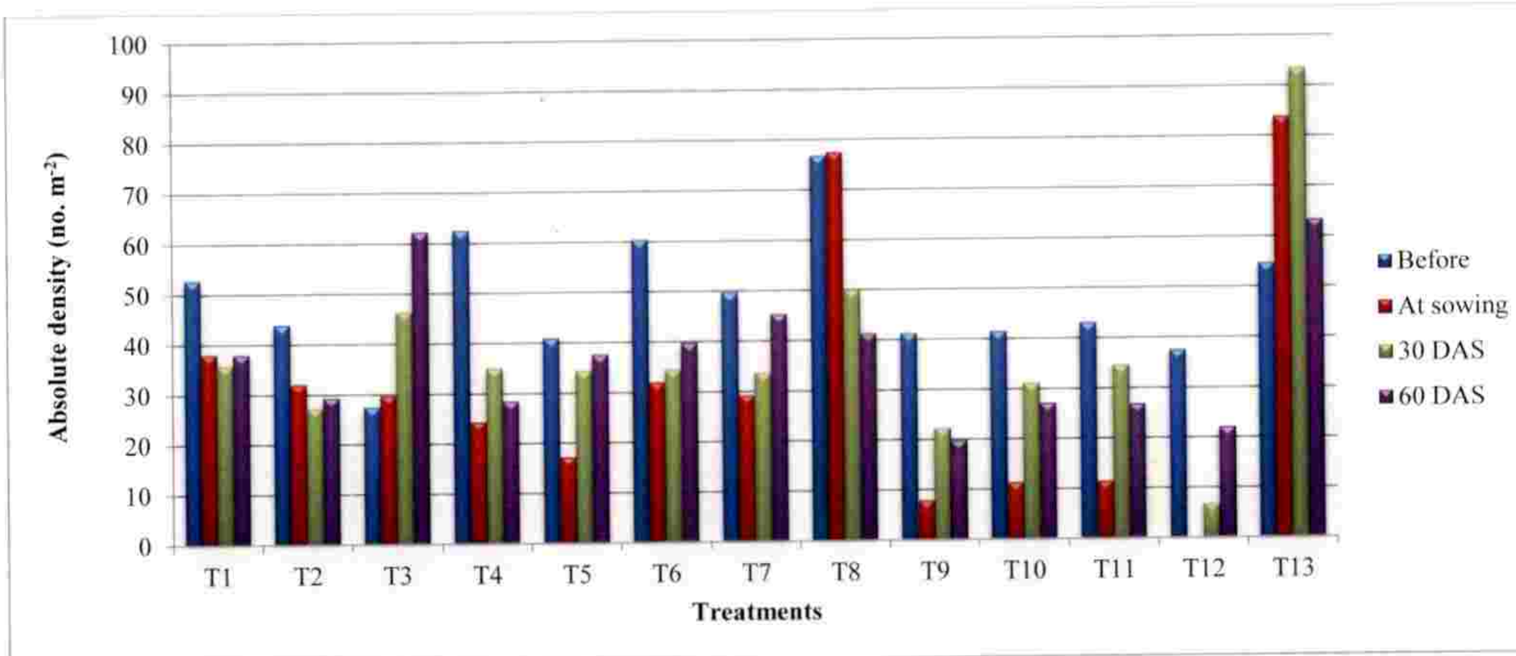
At the time of sowing, all treatments except LEH significantly reduced the absolute density of grasses (Fig.12) and sedges (Fig.13) when compared to

Figure 12: Effect of treatments on absolute density (no. m^{-2}) of grasses at before, at sowing, 30 days after sowing and 60 days after sowing.



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Figure 13: Effect of treatments on absolute density (no. m^{-2}) of sedges at before, at sowing, 30 days after sowing and 60 days after sowing.



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

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unweeded control. All treatments significantly exhibited lower absolute density of broad leaved weeds when compared to unweeded control (Fig.14). Organic herbicide treatment with CLOH (T_4 and T_9) and EOH (T_5 and T_{10}) recorded similar effect of hand weeding in the reduction of absolute density of broad leaved weeds at sowing.

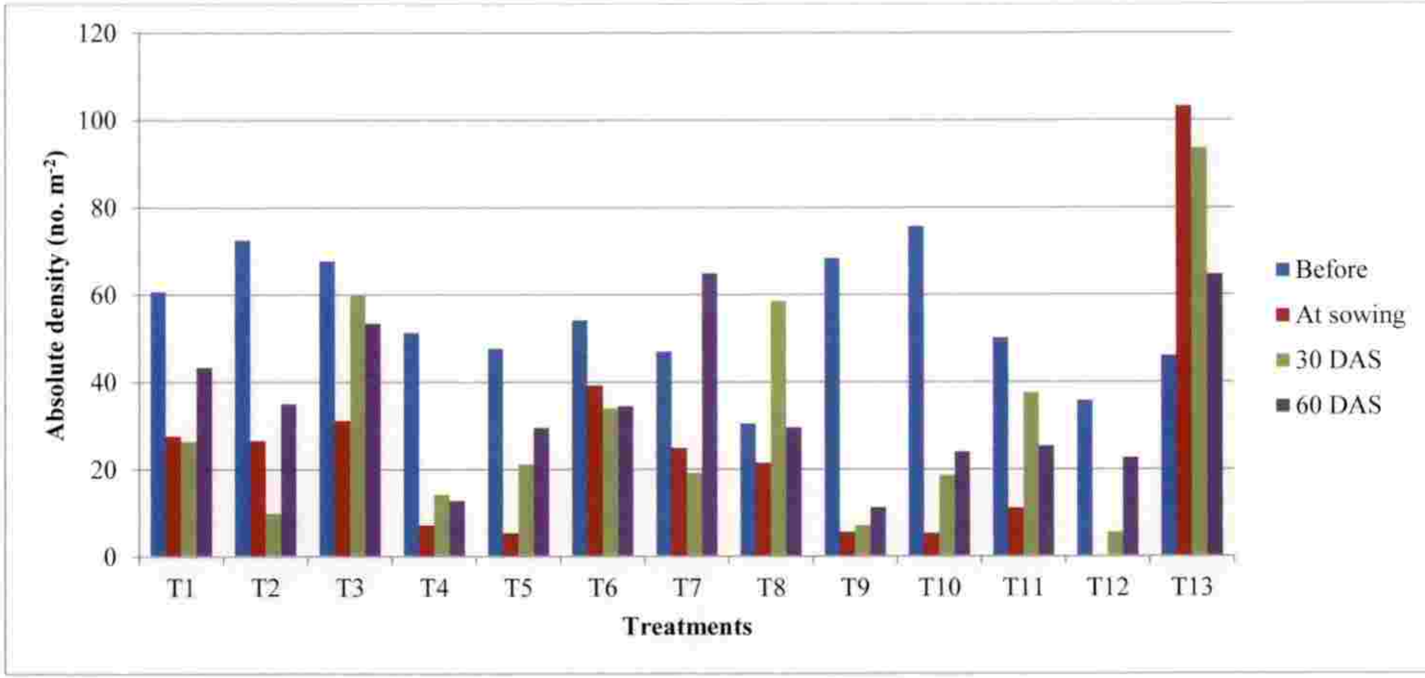
At 30 days after sowing, all treatments except LEH and single spray of CVH significantly reduced the absolute density of grasses compared to unweeded plot. All treatments significantly reduced the absolute density of sedges at 30 days after sowing. All treatments except LEH significantly reduced the absolute density of broad leaved weeds compared to unweeded control. Organic herbicidal treatments such as CNSLH, CLOH and EOH recorded similar effect in reducing absolute density of broad leaved weeds at 30 days after sowing. The findings of Abouziena *et al.* (2009) were in agreement with these observations. They reported that acetic acid was phytotoxic to all broad leaved weeds and most narrow leaved weeds. Moreover, acetic acid was less sensitive to growth stages of weeds when compared to other herbicides.

At 60 days after sowing, repeated spraying of CLOH (T_9) and EOH (T_{10}) and mango leaf mulching (T_{11}) recorded the lowest absolute density of grasses, sedges and broad leaved weeds similar to hand weeding. These results support the findings of Faras, (2015) that organic mulches with mango leaves can also be effectively used for weed management in okra. Lowest absolute density of grasses, sedges and broad leaved weeds (67.95, 19.84 and 11.27 m^{-2}) was observed in repeated spray of CLOH which accounted for 62.42 percent reduction in absolute density of grasses, 68.68 percent in sedges and 82.57 percent in broad leaved weeds when compared to unweeded control.

5.2.2.3 Root and shoot biomass

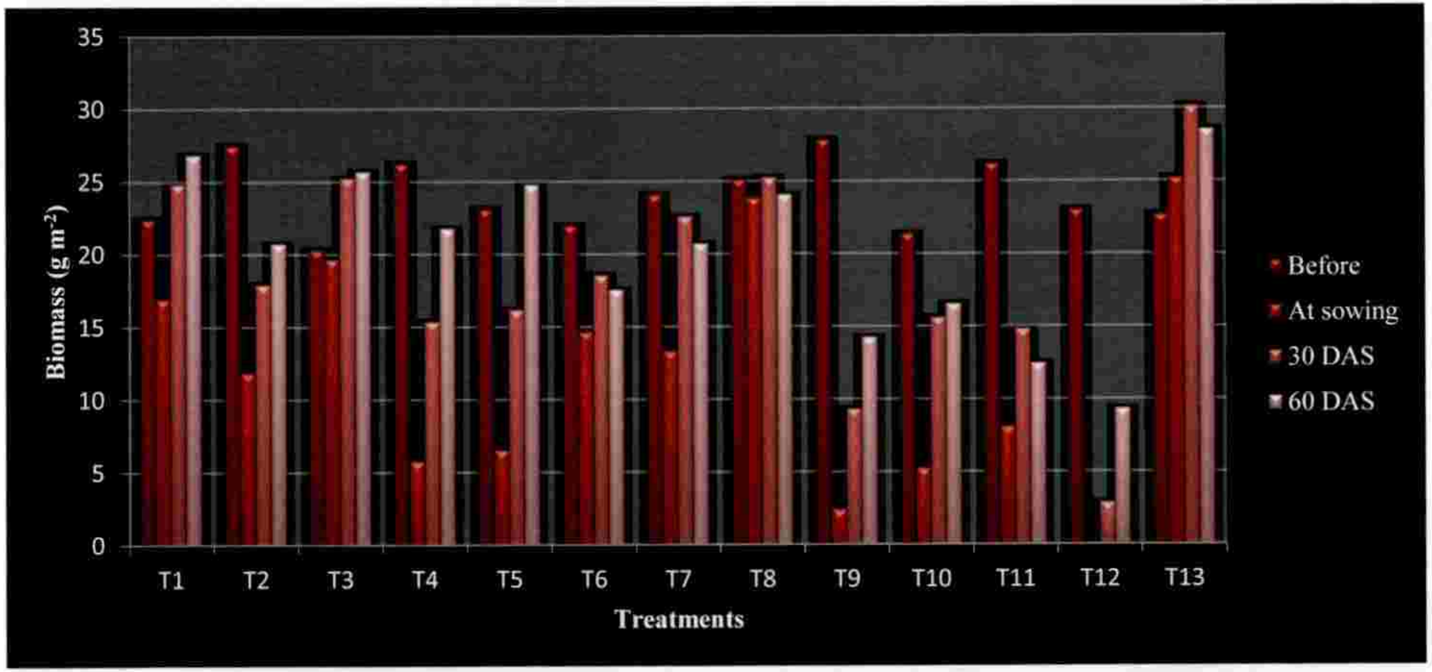
At the time of sowing, all the treatments except LEH recorded significantly lower root biomass compared to unweeded control (Fig.15). Repeated spraying of CLOH and mango leaf mulching exhibited similar effect of

Figure 14: Effect of treatments on absolute density (no.m^{-2}) of broad leaved weeds at before, at sowing, 30 days after sowing and 60 days after sowing.



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Figure 15: Effect of treatments on root biomass of weeds (g m^{-2})



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

hand weeding in reducing the root biomass at 60 days after sowing which accounted for 50.19 percent and 56.43 percent reduction respectively when compared to unweeded control.

At the time of sowing, all treatments except LEH recorded lower shoot biomass as compared to unweeded control (Fig.16). CLOH recorded lowest shoot biomass consistently upto 60 days after sowing similar to hand weeded plot. Mango leaf mulching also exhibited similar effect of hand weeding at 60 days after sowing for reducing the shoot biomass of weeds. Repeated spraying of CVH and CLOH did not exhibit any effect in reducing the shoot biomass at 60 days after sowing when compared to single spraying of the same.

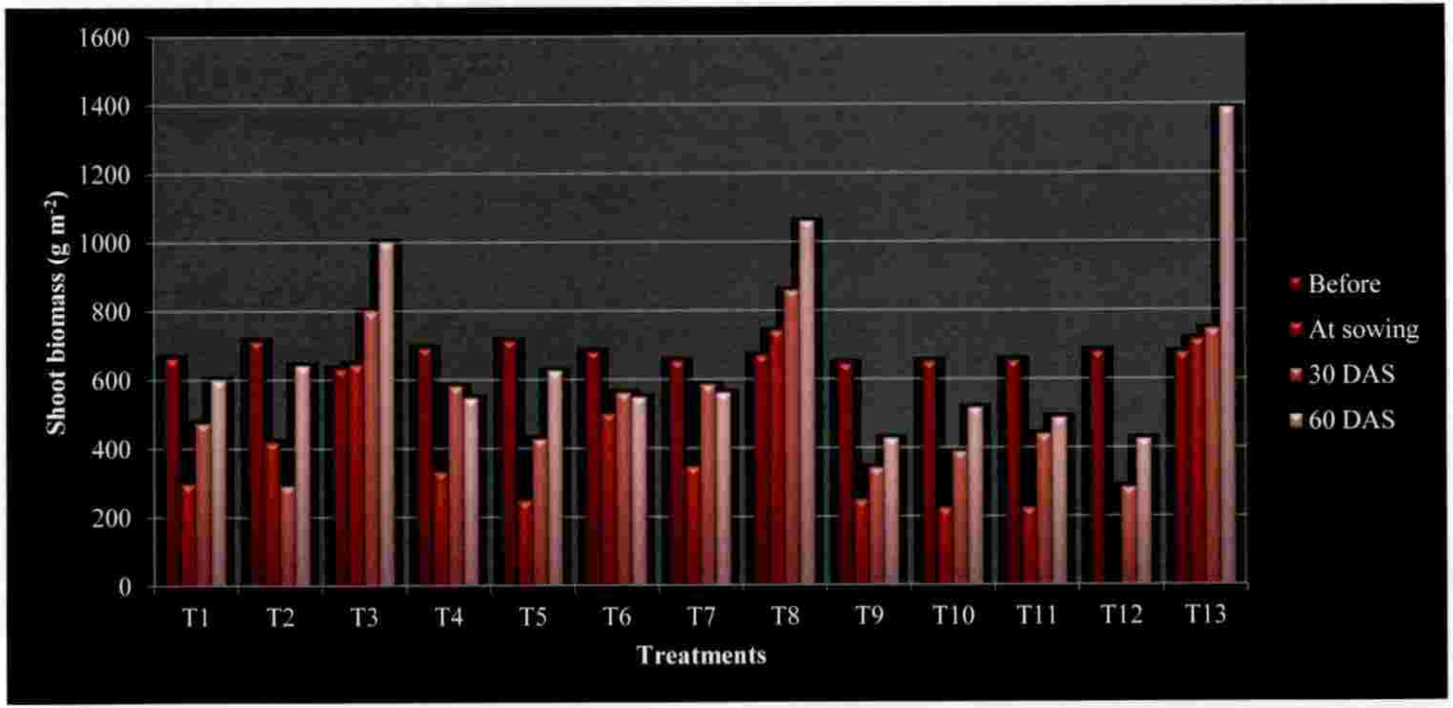
5.2.2.4 Weed control efficiency

All treatments except LEH significantly recorded higher weed control efficiency at the time of sowing, when compared to unweeded control (Fig.17). Organic herbicides such as CLOH and EOH recorded significantly similar weed control efficiency compared to hand weeded plot until 30 days after sowing. Single and repeated spray of CLOH and hand weeded plot consistently exhibited higher weed control efficiency upto 60 days after sowing (Plate 13).

5.2.2.5 Weed index

Weed index is defined as the magnitude of yield reduction due to presence of weeds in comparison with weed free check (Gill and Vijayakumar, 1969). It was observed to be higher in unweeded control with weed index of 94.2 and single and repeated spray of LEH with weed index of 91.92 and 89.55 respectively, which indicates higher yield reduction in these plots as compared to hand weeded plot (Fig.18). Repeated spray of CLOH and EOH recorded the lowest weed index of 8.68 and 12.00 respectively and it was significantly similar to weed index of hand weeded plot.

Figure 16: Effect of treatments on shoot biomass of weeds (g m^{-2})



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

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Plate 13: Effect of 12.5% coconut vinegar + 4 % clove leaf oil herbicide at before spraying, five days after spraying and 15 days after spraying.

Figure 17: Effect of treatments on weed control efficiency (%)

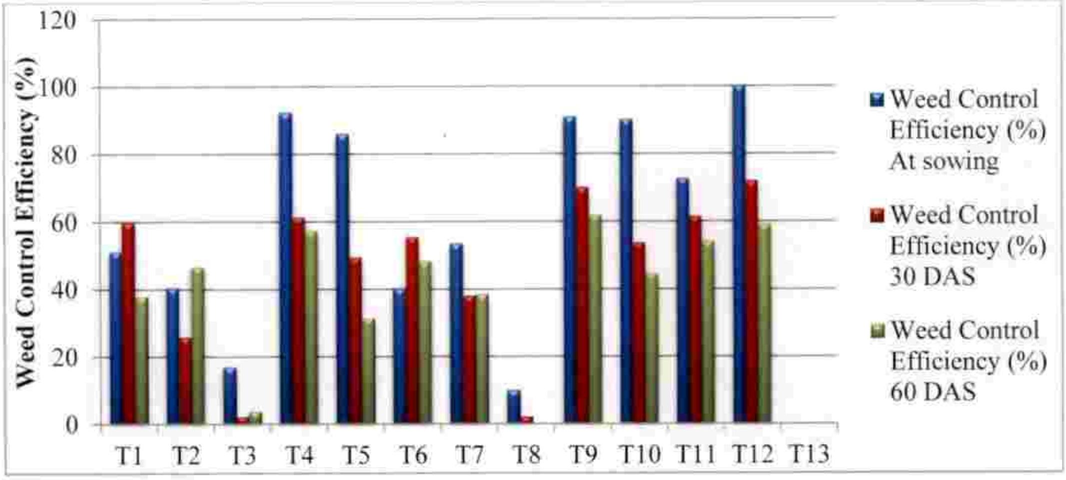
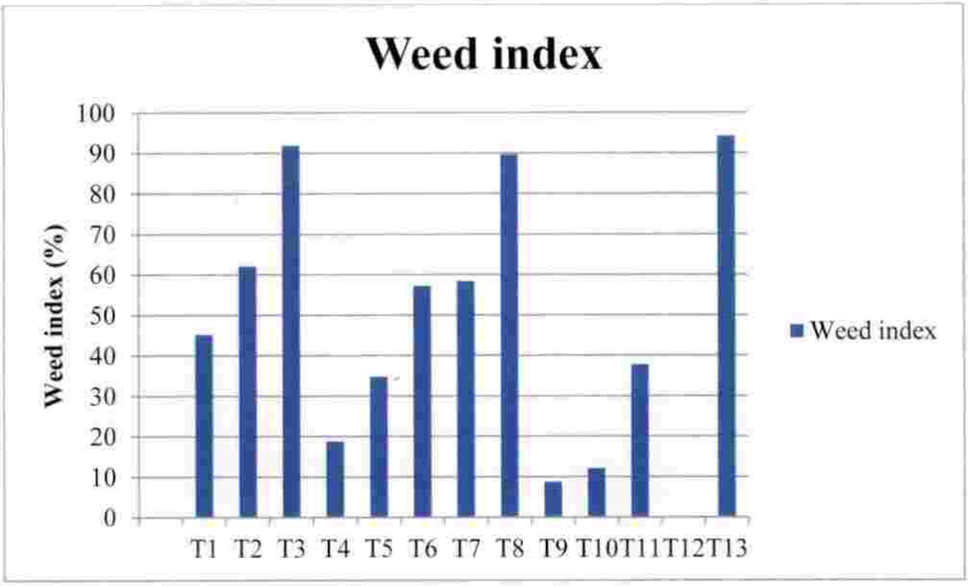


Figure 18: Effect of treatments on weed index (%)



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

5.2.3 Organic carbon status of soil

Soil organic carbon percentage ranged from 1.78 to 2.50 per cent. All the treatments improved the soil organic carbon content compared to the pre experiment plot (Fig.19). Among all the herbicide treated plots, soil organic carbon percentage was observed to be higher in repeated spray of CLOH (2.50%) and EOH (2.36%) and hand weeded plot (2.36%), which may be due to the decomposition of destroyed weeds to the soil along with added organic manures. This falls in line with the findings of Shivaprasad *et al*. (2005) that soil organic carbon depletion occurred due to heavy dry matter production.

5.2.4 Effect of treatments on soil pH

Before liming, the soil pH was 4.8 and after liming it increased to 5.89. With the application of organic herbicides, there was a slight decrease in the soil pH ranges from 5.33 in repeated spray of EOH to 5.85 in hand weeded plot (Fig.20). All the organic herbicide treatments that contained acetic acid such as CVH, CLOH, EOH recorded lowest soil pH values. However, only a narrow range of reduction in pH was observed with the organic herbicide treatments, which can be improved by liming. Higher pH was observed in hand weeded plot, where no herbicide was used.

Similar finding was observed by Radhakrishnan *et al.* (2003) that there was a reduction in soil pH from 5.9 to 4.7 with the application of vinegar at 30 days after treatment, but increased to 5.8 at 6 months after application.

5.2.5 Soil Electrical conductivity

Soil electrical conductivity ranges from 0.08dSm^{-2} in single spray of CNSL to 0.26 in single spray of LEH (Fig.20). All other treatments including mango leaf mulching recorded significantly lowest soil EC. It is a measure of the amount of salts in soil. EC less than 1 dSm^{-2} are considered as saline soil and it will not impact crops and soil microbial processes (Smith and Doran, 1996).

Figure 19: Effect of treatments on organic carbon status of soil

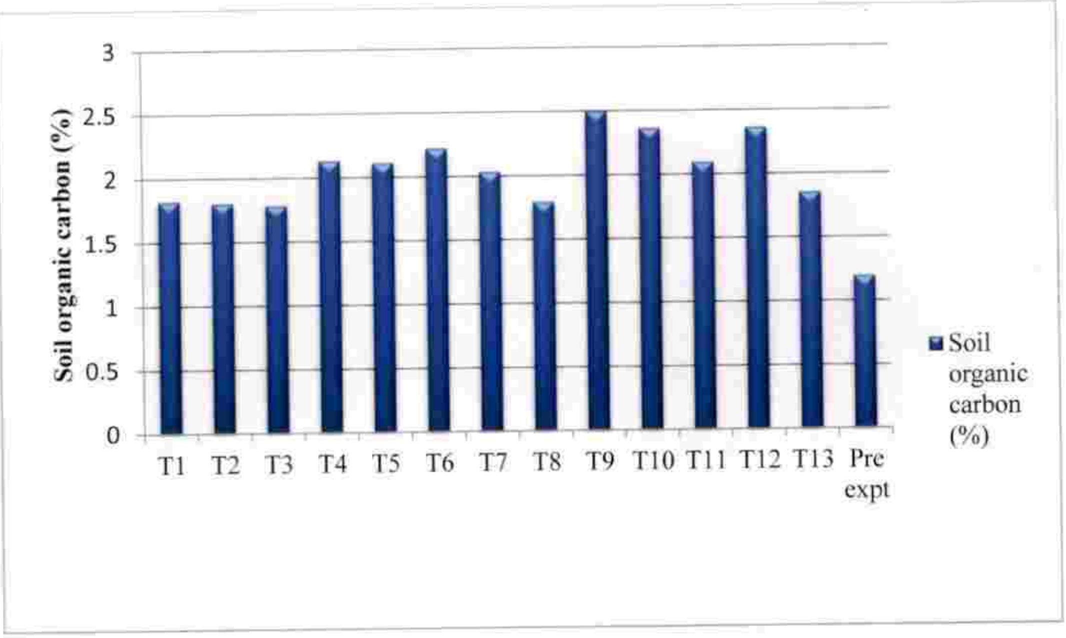
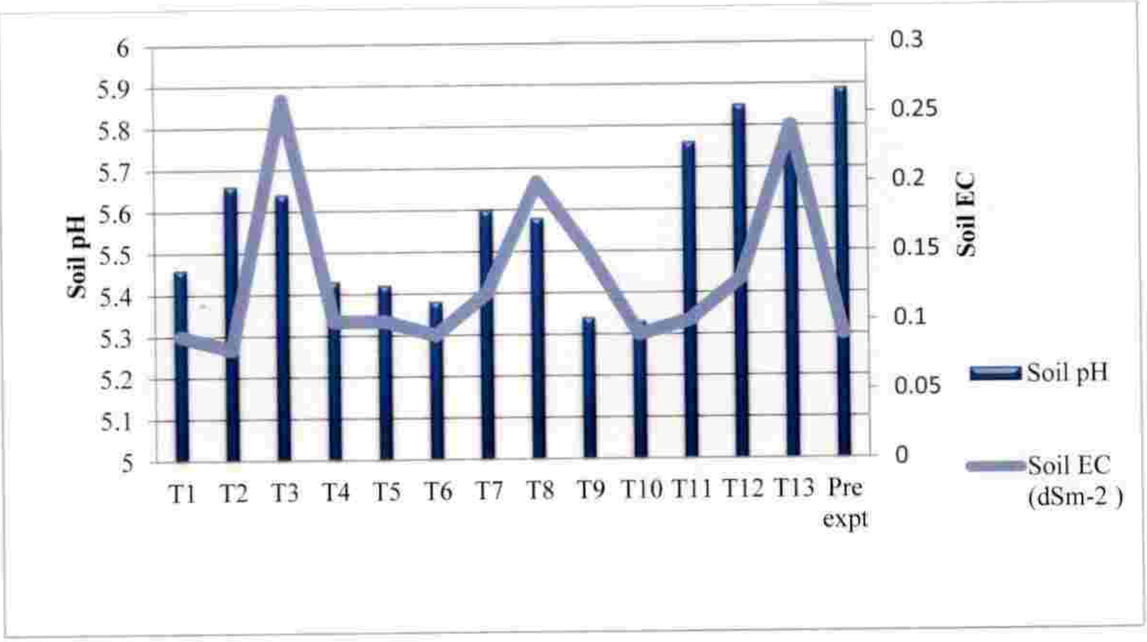


Figure 20: Effect of treatments on soil pH and EC



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

5.2.6 Available NPK status of soil

All the treatments recorded higher amount of available nitrogen in soil when compared to pre experiment values (Fig.21). The available nitrogen content in soil ranged from 263.42 kg ha^{-1} in single spray of CVH to 338.69 kg ha^{-1} in repeated spray of CLOH.

All the treatments recorded higher amount of available phosphorus (Fig.21) as compared to pre experiment plot. It ranges from 92.96 kg ha^{-1} in mango leaf mulched plot and 162.40 kg ha^{-1} in single spray of EOH treated plot.

All the treatments recorded higher amount of available potassium (Fig.21) when compared to pre experiment plot. It ranges from 302.40 in single spray of CVH treated plot to 459.20 kg ha^{-1} in repeated spray of CLOH treated plot.

5.2.7 Nutrient uptake by weeds

Lowest nutrient uptake by weeds was recorded consistently upto 60 days after sowing in repeated spraying of CVH, CLOH and EOH (Fig.22). Nutrient uptake by weeds was observed to be consistently higher upto 60 days after sowing in unweeded control plot, which may be due to the highest biomass of weeds observed in unweeded control. This falls in line with the findings of Suresh (1984) that weeds in unweeded plot removed more nutrients than that of plots with weed control measures.

5.2.8 Nutrient uptake by crop

All the treatments except LEH significantly increased the N, P and K uptake by crop when compared to unweeded control (Fig.23). Higher nutrient uptake was observed in plots with lower weed density, such as hand weeded plot (26.53 kg ha^{-1} N, 6.84 kg ha^{-1} P and 27.38 kg ha^{-1} K), repeated spray of CLOH (26.55 kg ha^{-1} N, 4.42 kg ha^{-1} P and 27.38 kg ha^{-1} K), repeated spray of EOH (25.93 kg ha^{-1} N, 4.18 kg ha^{-1} P and 25.55 kg ha^{-1} K). It was observed that there was an inverse relation between the nutrient uptake by weeds and that by crop. Lower crop weed competition may result in higher uptake of nutrients by crop.

Figure 21: Effect of treatments on available N, P and K status of soil 60 DAS

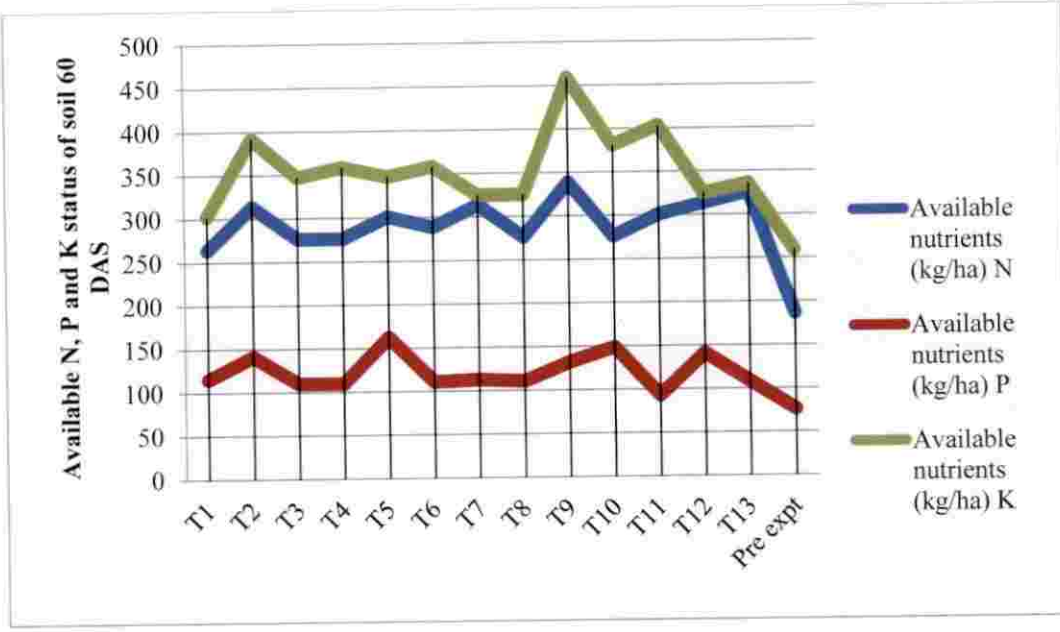
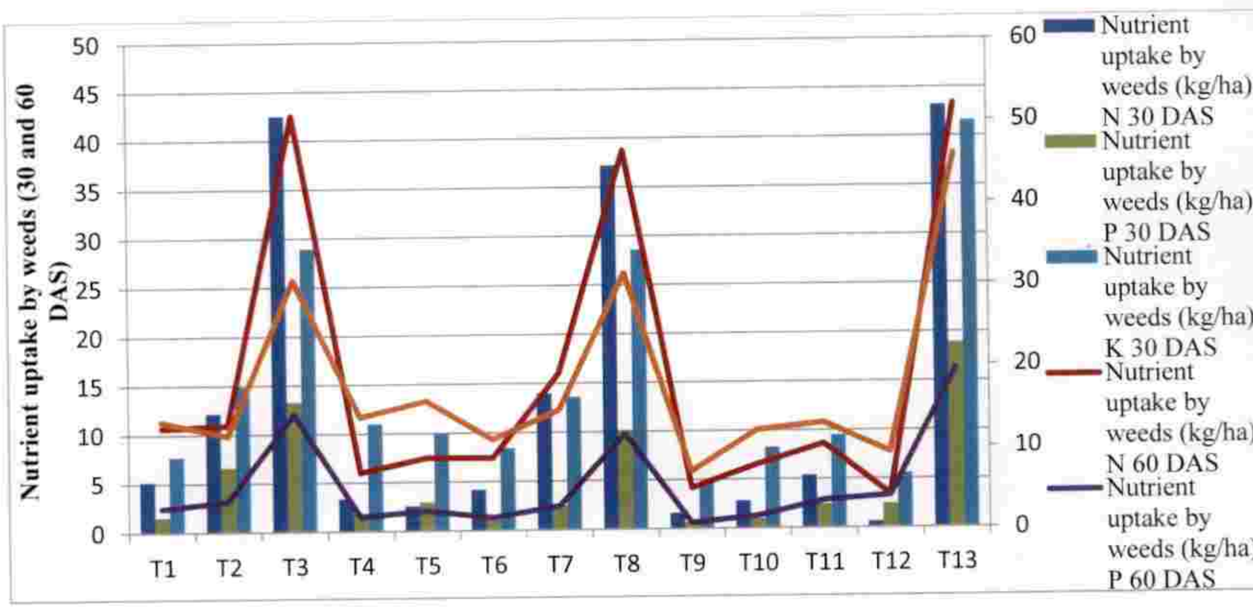
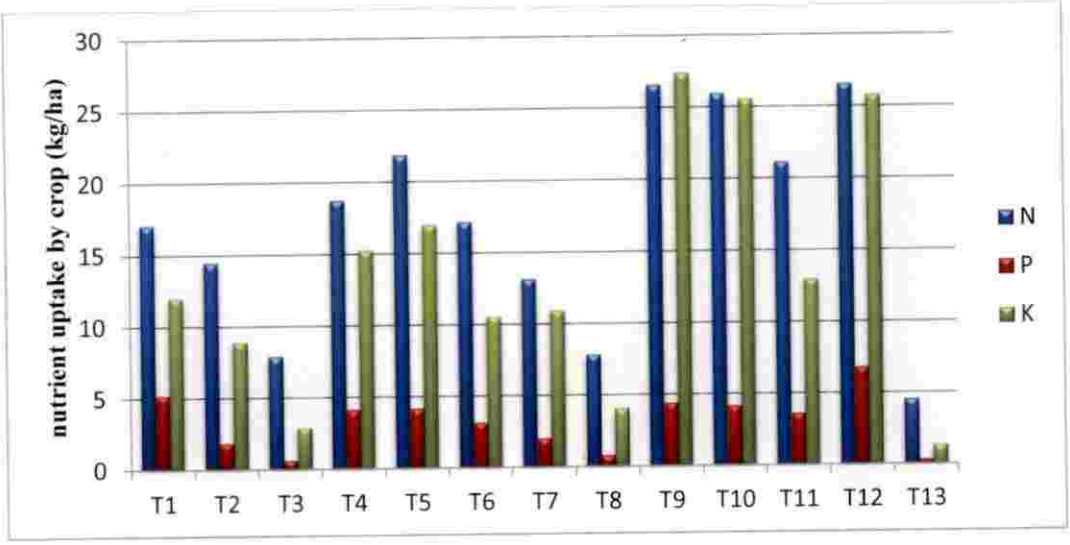


Figure 22: Effect of treatments on nutrient uptake by weeds (30 and 60 DAS)



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

Figure 23: Effect of treatments on nutrient uptake by crop (kg/ha)



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

5.2.9 Microbial population in soil

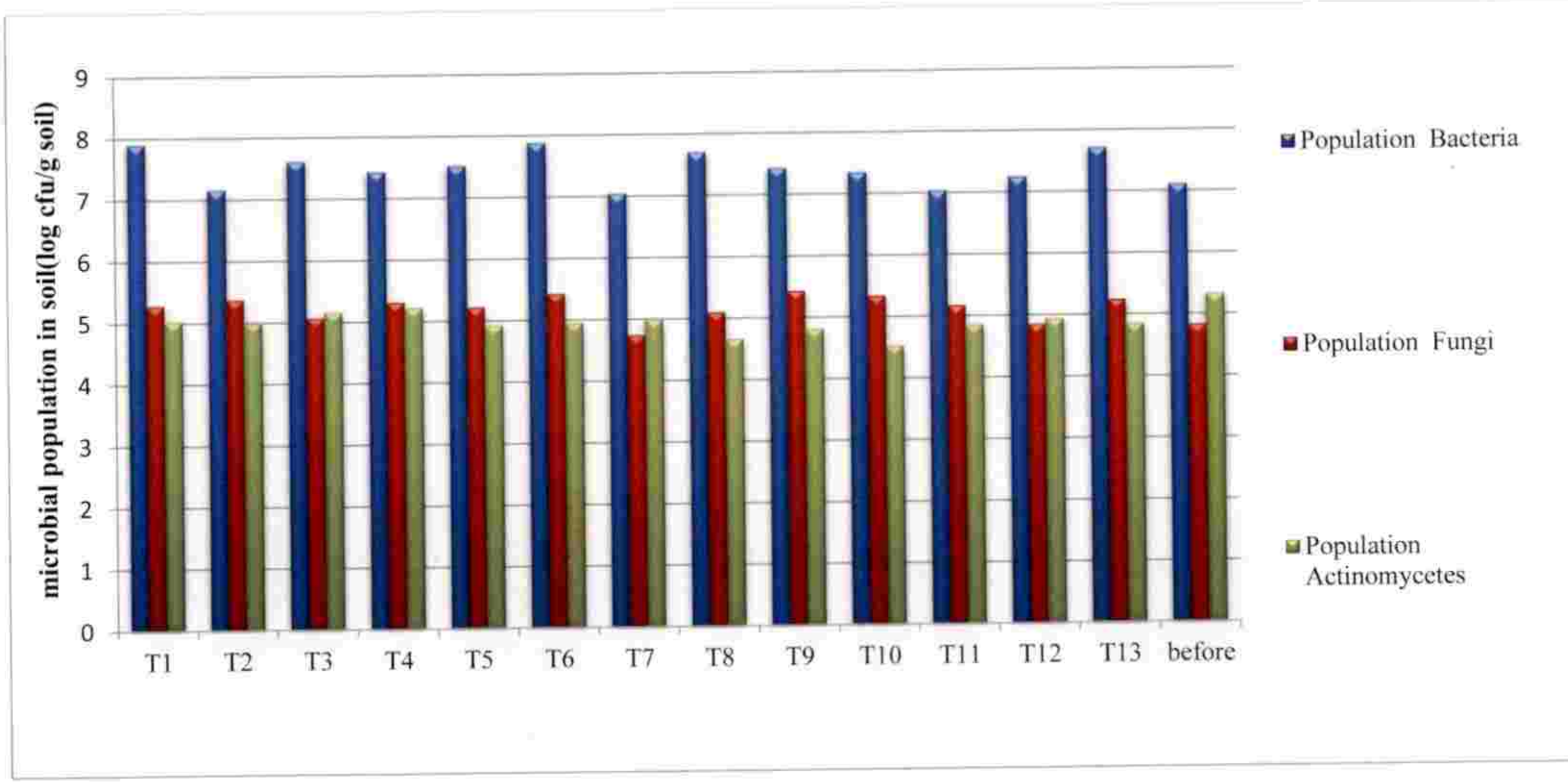
All the treatments significantly improved the bacterial population when compared to pre experiment plot. CVH and CLOH treated plot recorded the highest population of bacteria, fungi and actinomycetes.

Bacterial population was observed to be higher in coconut vinegar treated plots. This was in line with the findings of Rui *et al.* (2014), who reported that treatment with wood vinegar significantly increased the total bacteria in soil. Also, Malkomes (2005) reported that even though acetic acid is applied at relatively higher concentrations, it does not have long term negative influence on soil micro organisms. Lowest bacterial population was observed in mango leaf mulching and CNSL treated plot. This was in agreement with the findings of Faras (2015) that the soil bacterial population decreased from sowing to 60 days after sowing of okra in mango leaf mulching @ 5 t ha^{-1}. Also, inhibitory effect of anacardic acid in CNSL in the growth of bacteria was reported by Gellerman *et al.* (1969).

All the treatments except CNSLH and hand weeded plot recorded significantly higher fungal population than that of pre experiment plot. Highest fungal population was observed in repeated spray of CLOH. Fungal population in all the treatments that contains acetic acid was comparable to that of unweeded control plot.

All the treatments significantly reduced the actinomycetes population compared to pre experiment (Fig.24). Highest actinomycetes population was observed in single spray of CLOH, single spray of LEH and single spray of CVH. While repeated spray of lemon extract herbicide recorded lowest actinomycetes population. The soil microbial and fungal population was observed to be low in eucalyptus plantation (Behera and Sahani, 2003).

Figure 24: Effect of treatments on microbial population in soil 60 DAS



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

5.2.10 Quantitative estimation of earthworms

There was no significant difference between the treatments for the number of earthworms per m^3. This leads to the conclusion that the soil chemical parameters did not varied adversely because of organic herbicide application. Also, this may be due to the presence of potent defense mechanism of earthworms which help them to survive in varying soil conditions as reported by Roubalova *et al.* (2015).

5.2.11 Dehydrogenase enzyme activity

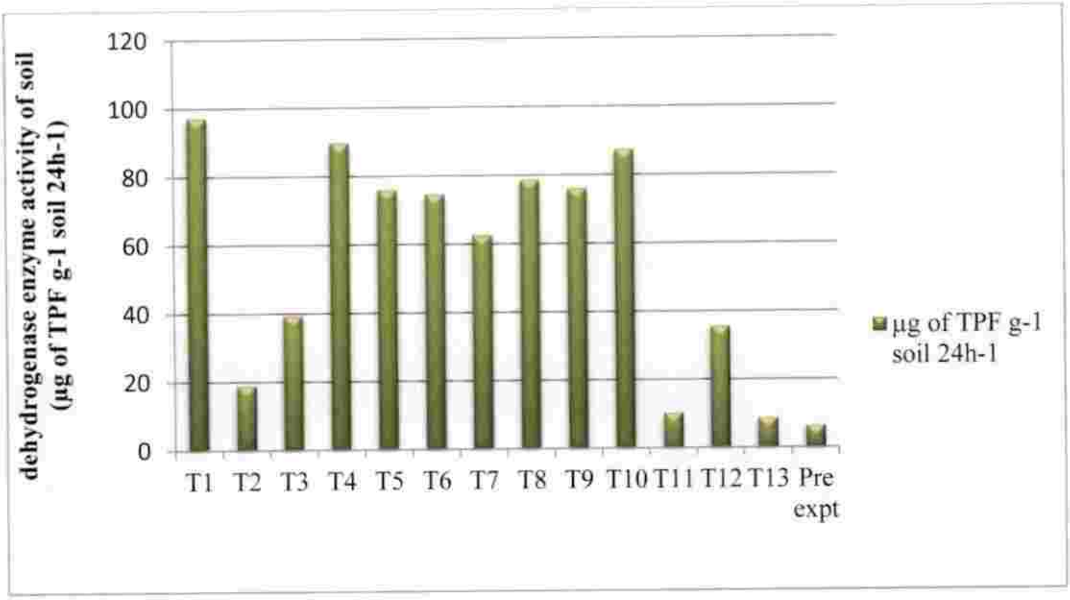
All the treatments significantly increased the dehydrogenase enzyme activity of soil as compared to pre experiment plot (6.37 µg of TPF g^{-1} soil $24h^{-1}$). The dehydrogenase enzyme activity was observed to be higher in CVH treated plots (Fig.25), where the microbial population was also observed to be highest. Unweeded control, mango leaf mulched plots and single spray of CNSLH treated plots recorded the lowest activity of dehydrogenase enzyme. CNSL has an inhibitory effect in the growth of soil microorganisms as reported by Gellerman *et al.* (1969). This may be the reason for reducing the dehydrogenase enzyme activity of CNSLH treated plot.

5.2.12 B:C ratio

B:C ratio ranges from 0.15 in LEH treatments to 1.54 in single spray of CLOH. Even though the benefit was higher for hand weeded plot, the cost of cultivation was also higher in the same due to higher labour charges compared to the cost and application of other organic herbicides. Repeated spray of CLOH recorded higher benefit than that of single spraying, but the cost of herbicide as well as repeated application charges makes the cost of cultivation higher. Hence B:C ratio was higher for single spray of CLOH compared to repeated spraying.

This may be in conformity with the findings of Singh *et al.* (1982) that 59 to 90 per cent yield reduction due to weed competition in okra. Stale seed bed

Figure 25: Effect of treatments on dehydrogenase enzyme activity of soil



T_1- Stale seed bed(SSB) with CVH; T_2- SSB with CNSLH; T_3- SSB with LEH; T_4- SSB with CLOH; T_5- SSB with EOH; T_6- T1+ Spray of CVH at 30 DAS; T_7- T2+ Spray of CNSLH at 30 DAS; T_8- T3+ Spray of LEH at 30 DAS; T_9- T4+ Spray of CLOH at 30 DAS; T_{10}- T5+ Spray of EOH at 30 DAS; T_{11}- Organic mulching with mango leaves; T_{12}- Hand weeding (Weed free till 7th week); T_{13}- Control (Weedy Check).

method improved the yield and economics of okra as reported by Sheela *et al.* (2007).

Summary

6. SUMMARY

Weeds are a major constraint in the production of vegetables that leads to yield reduction. The ill effects of modern agricultural chemicals raise serious question about the quality of protective foods like vegetables. Avoidance of synthetic substances for pest management forms the key to organic farming. To study the herbicidal efficacy of horticultural crop products and by-products and its evaluation as herbicides in organic farming of okra and to assess its effect on the soil properties when compared to unweeded condition, a field study was conducted using different organic herbicides and mulching as treatments. The study entitled "Evaluation of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculentus* (L.) Moench]" was conducted in the Department of Vegetable Science, College of Agriculture, Vellayani during 2018-19. The study aimed to evaluate the herbicidal properties of different horticultural crop products and by-products such as coconut vinegar, cashew nut shell liquid, lemon extract, clove leaf oil and eucalyptus oil and to study their herbicidal efficacy in organic farming of okra. The study was conducted in two parts: 1) Preliminary evaluation of horticultural crop products and by-products as herbicides and 2) Evaluation of herbicides in organic farming of okra.

PART I

For preliminary evaluation of herbicides, seed beds were prepared by tilling with rotavator and weeds were allowed to grow for 45 days. The emerged weeds were smothered by herbicide preparations in randomly selected mini plots in separate experiments for each horticultural product and by product in Completely Randomised Design replicated five times.

For preliminary evaluation as herbicides, acetic acid content of coconut vinegar was enhanced from 4 to 5, 7.5,10 and 12.5 percent by freeze distillation (CVH), cashew nut shell liquid was emulsified to 5, 10, 15 and 20 percent (CNSLH), citric acid in lemon extract was enhanced to 2.5, 5, 7.5 and 10 percent by evaporation (LEH) and sprayed on weeds @ 50ml/m^2.

Among the different concentrations of acetic acid, CVH with 12.5 per cent acetic acid consistently reduced the absolute density of weeds until 45 days after spraying when compared to unweeded control at 15 days after spraying. CVH with 12.5 percent acetic acid consistently reduced the root and shoot biomass at 15 and 45 days after spraying when compared to the unweeded control. At 15 days after spraying, all the treatments recorded significantly higher weed control efficiency as compared to unweeded control and CVH with 12.5 percent acetic acid recorded the highest weed control efficiency of 70.37 percent. At 45 days after spraying, all treatments except CVH with 5 percent acetic acid recorded higher weed control efficiency when compared to unweeded control and CVH with 12.5 percent acetic acid recorded highest weed control efficiency. The weed control efficiency decreased from 15 days after spraying to 45 days after spraying.

Among the different concentrations of CNSL, 20 per cent CNSL consistently reduced the absolute density of weeds upto 45 days after spraying when compared to unweeded control. All treatments significantly reduced the root biomass at 15 days after spraying in comparison with unweeded control. At 45 days after spraying, all treatments except five percent CNSL significantly reduced root biomass, when compared to unweeded control. All treatments except five percent CNSL significantly reduced shoot biomass than that of unweeded control until 45 days after spraying. 20 percent CNSL consistently reduced the root and shoot biomass upto 45 days after spraying and it recorded the lowest root and biomass upto 45 days after spraying.

At 15 days after spraying, all treatments recorded significantly higher weed control efficiency compared to unweeded control and 20 percent CNSL recorded the highest weed control efficiency of 85.42 percent. All treatments except 5 and 10 percent CNSL recorded higher weed control efficiency than that of unweeded control, wherein 20 percent CNSL recorded the highest weed control efficiency of 54.39 percent at 45 days after spraying. The weed control efficiency reduced from 15 to 45 days after spraying, which may be due to the regrowth of certain perennial weeds.

None of the treatments of LEH significantly reduced the absolute density of grasses and sedges at 15 days after spraying. LEH with 10 percent citric acid recorded the lowest absolute density of broad leaved weeds at 15 days after spraying. At 45 days after spraying, there was no significant difference between the treatments for the reduction of absolute density of grasses, sedges and broad leaved weeds.

Among all the treatments, LEH with 7.5 percent citric acid and 10 percent citric acid consistently reduced the root biomass upto 45 days after spraying. LEH with 10 percent citric acid consistently reduced the shoot biomass upto 45 days after spraying. At 15 days after spraying, the lowest root biomass was observed in LEH with 7.5 percent citric acid and 10 percent citric acid, whereas, lowest shoot biomass was observed in LEH with 10 percent citric acid in comparison to unweeded control. At 45 days after spraying, all treatments significantly reduced the root biomass when compared to unweeded control, whereas, LEH with 10 percent citric acid recorded the lowest shoot biomass.At 15 and 45 days after spraying, LEH with 10 percent citric acid recorded the highest weed control efficiency of 40.01 percent. Weed control efficiency decreases from 15 days after spraying to 45 days after spraying.

All the treatments of CLOH consistently reduced the absolute density of grasses, sedges and broad leaved weeds upto 45 days after spraying compared to unweeded control. Among the treatments CLOH with 4 percent clove leaf oil recorded the lowest absolute density of grasses, sedges and broad leaved weeds compared to unweeded control at 15 and 45 days after spraying. All treatments significantly reduced the root and shoot biomass of weeds when compared to unweeded control. Among the treatments, CLOH with 4 percent clove leaf oil recorded the lowest root and shoot biomass at 15 and 45 days after spraying. All treatments recorded higher weed control efficiency compared to unweeded control at 15 and 45 days after spraying. Among the treatments, CLOH with 4 percent clove leaf oil consistently recorded the highest weed control efficiency of 98.11 percent at 15 days after spraying and 84.37 percent at 45 days after spraying.

All the treatments of EOH consistently reduced the absolute density of grasses, sedges and broad leaved weeds upto 45 days after spraying. At 15 and 45 days after spraying all the treatments significantly reduced the absolute density of grasses, sedges and broad leaved weeds compared to unweeded control. Among the treatments EOH with 4 percent eucalyptus oil recorded the lowest absolute density of grasses, sedges and broad leaved weeds at 15 and 45 days after spraying.

All treatments significantly reduced the root and shoot biomass of weeds when compared to unweeded control. Among the treatments, EOH with 4 percent eucalyptus oil recorded the lowest root and shoot biomass at 15 and 45 days after spraying. All treatments recorded higher weed control efficiency compared to unweeded control at 15 and 45 days after spraying. Among the treatments, EOH with 4 percent eucalyptus oil consistently recorded the highest weed control efficiency of 96.96 percent at 15 days after spraying and 67.46 percent at 45 days after spraying.

The best treatments of each experiment was selected based on the weed control efficiency i.e, 12.5 percent CVH, 20 percent CNSL, 10 percent LEH, 4 percent CLOH and 4 percent EOH and carried over to part II for evaluation of herbicides in organic farming of okra.

PART II

CVH with 12.5% acetic acid, CNSLH with 20% concentration, LEH with 10 % citric acid, CLOH with 4% clove leaf oil, and EOH with 4% eucalyptus oil were sprayed on the 45 day old weeds on stale seed bed, repeated application thirty days after sowing of okra variety Anjitha seeds in comparison to organic mulching with mango leaves, hand weeding till 7th week and weedy check.

All the organic herbicidal treatments and mulching recorded significantly higher germination percentage of okra seeds when compared to unweeded control. This indicated that application of organic herbicides did not affect germination of okra seeds.

It was observed that there was no phytotoxicity symptoms observed in the seedlings when sown after 15 days of treatment. But in repeated application at 30 days after sowing of crop, all the herbicides exhibited some phytotoxicity symptoms ranging from 0.20, which indicates normal or no injury, in repeated spraying of lemon extract to 4.33, which indicates moderate injury and recovery is possible, in repeated spraying of CLOH.

All the organic herbicide treatments and mulching except LEH produced taller plants when compared to unweeded control. Among the plots treated with organic herbicides, single and repeated spray of CLOH produced taller plants similar to hand weeded plot. Repeated application of CLOH did not significantly influence the plant height in okra compared to single spray. All the treatments including mulching showed significantly higher number of branches except LEH. Among the organic herbicide treated plots, repeated spray of CLOH recorded the highest number of branches per plant similar to hand weeded plot. All the treatments significantly improved the number of leaves per plant compared to unweeded control. CLOH recorded similar effect of hand weeded plot in improving the number of leaves per plant and repeated application did not influence the number of leaves per plant.

Days to 50 per cent flowering ranged from 48.33 to 53.00 days. All the treatments significantly reduced the number of days for 50 percent flowering when compared to unweeded control. More number of days was required for flowering in plots which did not receive any weeding and less number of days was required when hand weeding and repeated spraying of CLOH was done. Repeated spraying of CLOH at 30 days after sowing did not significantly reduced the number of days for 50 percent flowering compared to single spraying. The node at which the first flower appeared was observed to be non significant among the treatments.

All the treatments except LEH significantly increased the number of fruits per plant compared to unweeded control. Repeated spraying of CLOH recorded similar number of fruits per plant as that of hand weeded plot. The number of fruits improved with repeated spraying of CLOH compared to single spraying. All treatments except LEH and CNSLH recorded significantly higher number of flowers per plant compared to unweeded control. Repeated spraying of CLOH at 30 days after sowing recorded similar number of flowers per plant as that of hand weeded plot. The number of flowers improved with repeated spraying of CLOH compared to single spraying. All the treatments except single and repeated spray of LEH recorded higher percentage fruit set, when compared to unweeded control. Repeated spraying of organic herbicides did not affect the percentage fruit set when compared to single spraying.

All treatments except LEH recorded longer crop duration compared to unweeded control. Severe weed infestation may lead to increased crop weed competition, thereby reduces the nutrient uptake of crops leading to reduced crop duration in unweeded control and single and repeated spray of LEH. Repeated spraying of organic herbicides did not affect the duration of crop compared to single spraying. All treatments except LEH significantly recorded more number of harvests compared to unweeded control. Repeated spraying of CLOH significantly influenced the number of harvest compared to single spraying. Repeated spraying of CLOH performed similar to hand weeded plot in improving the number of harvest. Increased crop duration may lead to more number of harvests.

Number of fruits per plant was significantly higher in all treatments except LEH when compared to unweeded control. Repeated spraying of CLOH significantly improved the number of fruits per plant compared to single spraying and it performed similar to hand weeded plot.

All treatments except LEH improved the yield of okra compared to unweeded control. Repeated spraying of CLOH and EOH performed similar to hand weeded plot in improving the yield. A weed free period upto seven weeks from sowing resulted in yield comparable with those obtained in a weed free situation. There was significantly higher yield when repeated spraying of CLOH was given compared to single spraying of the same.

Grasses such as *Panicum maximum*, *Cynodon dactylon*, *Digitaria sanguinalis*, *Eleusine indica*, *Setaria barbata*, sedges such as *Cyperus rotundus* and broad leaved weeds such as *Synedrella nodiflora*, *Euphorbia genniculata*, *Phyllanthus niruri*, *Alternanthera sessilis*, *Cleome viscose*, *Tridax procumbens*, *Vernonia cinerea*, and *Commelina benghalensis* were the weeds species observed in the experimental plots. With the application of herbicides, some of the weed species got reduced at the time of sowing. At 30 days after sowing and 60 days after sowing, regrowth of certain weed species was observed, which may be due to the lack of complete emergence of weed seed bank at stale seed bed that might have germinated during the intercultural operations carried out for the crop or due to enhanced moisture availability due to heavy rains being located in deeper layers of earth. Hence further modification to stale seed bed is needed to flush out the weed seed bank.

At the time of sowing, all treatments except LEH significantly reduced the absolute density of grasses and sedges when compared to unweeded control. All treatments significantly exhibited lower absolute density of broad leaved weeds when compared to unweeded control. Organic herbicide treatment with CLOH and EOH recorded similar effect of hand weeding in the reduction of absolute density of broad leaved weeds at sowing. At 30 days after sowing, all treatments except LEH and single spray of CVH significantly reduced the absolute density of grasses compared to unweeded plot. All treatments significantly reduced the absolute density of sedges at 30 days after sowing. All treatments except LEH significantly reduced the absolute density of broad leaved weeds compared to unweeded control. Organic herbicidal treatments such as CNSLH, CLOH and EOH recorded similar effect in reducing absolute density of broad leaved weeds at 30 days after sowing. At 60 days after sowing, repeated spraying of CLOH and EOH and mango leaf mulching recorded the lowest absolute density of grasses, sedges and broad leaved weeds similar to hand weeding. Lowest absolute density of grasses, sedges and broad leaved weeds was observed in repeated spray of CLOH. At the time of sowing, all the treatments except LEH recorded significantly lower root and shoot biomass compared to unweeded control. Hand weeded plot consistently recorded lowest root and shoot biomass of weeds until 60 days after sowing. At 60 days after sowing, repeated spraying of CLOH and mango leaf mulching exhibited similar effect of hand weeding in reducing the root biomass. CLOH recorded lowest shoot biomass consistently from 30 to 60 days after sowing similar to hand weeded plot. Repeated spraying of CVH and CLOH did not exhibit any effect in reducing the shoot biomass at 60 days after sowing compared to single spraying. Mango leaf mulching also exhibited similar effect of hand weeding at 60 days after sowing for reducing the shoot biomass of weeds.

All treatments except LEH significantly recorded higher weed control efficiency at the time of sowing, when compared to unweeded control. Single and repeated spray of CLOH and hand weeded plot consistently exhibited higher weed control efficiency upto 60 days after sowing. Organic herbicides such as CLOH and EOH recorded significantly similar weed control efficiency compared to hand weeded plot until 30 days after sowing.

Weed index was observed to be higher in unweeded control and single and repeated spray of LEH which indicates higher yield reduction in these plots as compared to hand weeded plot. Repeated spray of CLOH and EOH recorded the lowest weed index and it was significantly similar to weed index of hand weeded plot.

All the treatments improved the soil organic carbon percentage compared to the pre experiment plot. Among all the herbicide treated plots, soil organic carbon percentage was observed to be higher in repeated spray of CLOH and EOH and hand weeded plot, which may be due to the decomposition of destroyed weeds to the soil along with added organic manures. Soil pH was observed to be lowered after the experiment in all the plots when compared to pre experiment plot after liming. Among the different organic herbicides, plots treated with acetic acid based herbicides gave lower pH. Higher pH was observed in hand weeded plot, where no herbicide was used. Single spray of both CNSL herbicide and LEH also recorded higher pH. Highest soil electrical conductivity was observed in unweeded control and LEH treated plot, where the weed growth was observed to be highest. All other treatments including mango leaf mulching recorded lowest soil EC.

All the treatments recorded higher amount of available N, P and K in soil when compared to pre experiment. Nutrient uptake by weeds was observed to be consistently higher in unweeded control plot, which may be due to the highest biomass of weeds observed in unweeded control. Lowest nutrient uptake by weeds was recorded consistently upto 60 days after sowing in repeated spraying of CVH, CLOH and EOH. All the treatments except LEH significantly increased the N, P and K uptake by crop when compared to unweeded control. Higher nutrient uptake was observed in plots with lower weed density, such as hand weeded plot, repeated spray of CLOH, repeated spray of EOH. It was observed that there was an inverse relation between the nutrient uptake by weeds and that by crop. Lower crop weed competition may result in higher uptake of nutrients by crop.

All the treatments significantly improved the bacterial population when compared to pre experiment plot. CVH and CLOH treated plot recorded the highest population of bacteria, fungi and actinomycetes. Bacterial population was observed to be higher in coconut vinegar treated plots. Lowest bacterial population was observed in mango leaf mulching and CNSL treated plot. All the treatments except CNSLH and hand weeded plot recorded significantly higher fungal population than that of pre experiment plot. Highest fungal population was observed in repeated spray of CLOH. All the treatments significantly reduced the actinomycetes population compared to pre experiment. Highest actinomycetes population was observed in single spray of CLOH, single spray of LEH and single spray of CVH. While repeated spray of lemon extract herbicide recorded lowest actinomycetes population.

There was no significant difference between the treatments for the number of earthworms per m^3. This leads to the conclusion that the soil chemical parameters did not varied adversely because of organic herbicide application.

All the treatments significantly increased the dehydrogenase enzyme acticity of soil as compared to pre experiment plot. The dehydrogenase enzyme activity was observed to be higher in coconut vinegar treated plots, where the microbial population was also observed to be highest. Unweeded control, mango leaf mulched plots and single spray of CNSLH treated plots recorded the lowest activity of dehydrogenase enzyme.

B:C ratio ranges from 0.15 in LEH treatments to 1.54 in single spray of CLOH. Even though the benefit was higher for hand weeded plot, the cost of cultivation was also higher in the same due to higher labour charges compared to the cost of other organic herbicides. Repeated spray of CLOH recorded higher benefit than that of single spraying, but the cost of herbicide for repeated spraying makes the cost of cultivation higher. Hence B:C ratio was higher for single spray of CLOH compared to repeated spraying.

In conclusion, Clove Leaf Oil Herbicide (mixture of coconut vinegar with 12.5% acetic acid and 4% clove leaf oil) performed on par with hand weeding for improving major growth and yield parameters, control of grasses, sedges and broad leaved weeds with similar weed control efficiency, weed index without adversely affecting the organic carbon content, EC, nutrient and microbial composition of soil when sprayed on stale seed bed 15 days before and 30 days after sowing but highest B:C ratio was obtained for single spray at 15 days before sowing in organic okra.

References

7. REFERENCES

Abouziena, H. F. H., Ahmad A. M., Omar, A. A. M., Sharma, S.D., and Singh, M. 2009. Efficacy comparison of some new natural-product herbicides for weed control at two growth stages. *Weed Technol.* 23(3): 431-437.

Adejonwo, K. O., Ahmed, M. K., Lagoke, S. T. O., and Karikari, S. K. 1990. Herbicide evaluation studies in rainfed okra at Samaru, Nigeria. *Nigeria J. Weed Sci.* 3: 51-58.

Ahuja, N., Batish, D. R., Singh, H. P., and Kohli, R. K. 2015. Herbicidal activity of eugenol towards some grassy and broad leaved weeds. *J. Pest Sci.* 88(1): 209-218.

Alexander, R. T. 1990. The effect of solarization on vegetable crop production. *Proc. 43rd New Zealand Weed and Pest Control Conf.* pp. 270-273.

Al-Khathiri, C. R. 1994. Weeds: A factor limiting crop production in Yemen. *Indian J. Plant Prot.* 22(1): 5-8.

Ameena, M., Kumari, V. L. G., and George, S. 2013. Control of purple nutsedge in okra through integrated management. *Indian J. Weed Sci.* 45(1): 51-54.

Andayanie, W. R., Nuriana, W., and Ermawaty, N. 2019. Bioactive compounds and their antifeedant activity in the cashew nut (*Anacardium occidentale* L.) shell extract against *Bemisia tabaci*, (Gennadius, 1889) (Hemiptera: Aleyrodidae). *Acta agriculturae Slovenica* 113(2): 281-288.

Anderson, L. W. 2007. Potential for sediment-applied acetic acid for control of invasive *Spartina alterniflora*. *J. Aquat. Plant Manage.* 45: 100-105.

APEDA [Agricultural and Processed Food Products Export Development Authority]. 2018. APEDA [online]. Available: http://apeda.gov.in/apedawebsite/FFV.htm. [16 Nov.2018]

Arora, A. and Tomar, S. S. 2012. Effect of soil solarization on weed seed bank in soil. *Indian J. Weed Sci.* 44(2): 122-123.

Atlas, R. M. and Parks, L. C. 1993. *Handbook of Microbiological Media*. CRC Press, Inc. London, 529p.

Bandyopadhyay, S., Chakraborty, T. and Poddar, P. 2001. Effect of polythene and organic mulching under different levels of manuring practices of growth and yield of okra (*Abelmoschus esculentus* L. Moench). Environment-and-Ecology, 19(2): 261-264.

Barker, A. V. and Prostak, R. G. 2009. Alternative management of roadside vegetation. *Hortic. Technol.* 19(2): 346-352.

Barker, A. V. and Prostak, R. G. 2014. Management of vegetation by alternative practices in fields and roadsides. *Int. J. Agron.* 2014: 1-12.

Baumann, D. T., Kropff, M. J., and Bastiaans, L. 2000. Intercropping leeks to suppress weeds. *Weed Res.* 40(4): 359-374.

Bawazir, A. A., Rowaished, A. K., Bayounis, A. A., and Al-Jounaid, A. M. 1995. Influence of soil mulching with sawdust and transparent polyethylene on growth and yield of okra and weed control. *Arab J. Plant Protection*. 13(2): 89-93.

Behera, N. and Sahani, U. 2003. Soil microbial biomass and activity in response to Eucalyptus plantation and natural regeneration on tropical soil. *Forest Ecol. Manage.* 174(1-3): 1-11.

Beste, C. E. 1979. Yellow nutsedge competition in seeded tomatoes. *Proc. North Eastern Weed Sci. Soc.* 2: 107-109.

Bhalla, P. L. and Pramar, R. P. 1982. Study on effectiveness of pre-emergent herbicide on weed control and seed yield of okra [abstract]. In: *Abstract Papers, Annual Weed Science Conference*; 3-4 March, 1992, Hisar. Indian Society of Weed Science, Hisar, 34p.

Bhardwaj, R. 2013. Effect of mulching on crop production under rainfed condition-a review. *Agricultural Reviews*, 34(3).

Bhowmik, P. C. and Reddy, K. N. 1988. Interference of common lambsqarters (*Chenopodium album*) in transplanted tomato (*Lycopersicon esculentum*). *Weed Technol*. 2(1): 505–508.

Bottenberg, H., Masiunas, J., Eastman, C., and Eastburn, D. 1997. Weed management effects on insects and diseases of cabbage and snapbean. *Hortic. Technol.* 7(4): 400-403.

Bowers, J. H. and Locke, J. C. 2000. Effect of botanical extracts on the population density of *Fusarium oxysporum* in soil and control of fusarium wilt in the greenhouse. *Plant Disease* 84(3): 300-305.

Bowers, J. H. and Locke, J. C. 2004. Effect of formulated plant extracts and oils on population density of *Phytophthora nicotianae* in soil and control of phytophthora blight in the greenhouse. *Plant Disease* 88(1): 11-16.

Boyd, N. S. and Brennan, E. B. 2006. Burning nettle, common purslane, and rye response to a clove oil herbicide. *Weed Technol.* 20(3): 646-650.

Brainard, D. C., Curran, W. S., Bellinder, R. R., Ngouajio, M., VanGessel, M. J., Haar, M. J., Lanini, W. T., and Masiunas, J. B. 2013. Temperature and relative humidity affect weed response to vinegar and clove oil. *Weed Technol.* 27(1): 156-164.

Casida, L. E., Klein, D. A., and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98: 371-376.

Ceruks, M., Romoff, P., Fávero, O. A., and Lago, J. H. G. 2007. Constituintes fenólicos polares de *Schinus terebinthifolius* Raddi (Anacardiaceae). *Química Nova* 30(3): 597-601.

Chaturvedi, S., Pandey, J., Dhyani, V. C., Guru, S. K., and Kaushal, R. 2012. Phytotoxic potential of Eucalyptus leaf essential oil to control *Parthenium hysterophorus* L. *Allelopathy J.* 29(2): 315-324.

Chinery, D. 2002. *Using Acetic Acid (Vinegar) as a Broad-Spectrum Herbicide*. Cooperatif Extension Educator, Cornell Cooperative Extension of Rensselaer Country, 61p.

Coppuccino and Sheman. 1996. *Microbiology – A laboratory manual* (4^{th} Ed). The Benjamin/ Cummings Publishing Company Inc. 213p.

Daniels, C. H. and Fults, J. 2002. Fact sheet for vinegar/acetic acid recommendations. Oregon Department of Agriculture Factsheet No. PIC-01002, Salem, OR, 11p.

Dayan, F. E., Cantrell, C. L., and Duke, S. O. 2009. Natural products in crop protection. *Bioorganic Med. Chem.* 17(12): 4022-4034.

de Oliveira, M. S., da Costa, W. A., Pereira, D. S., Botelho, J. R. S., de Alencar Menezes, T. O., de Aguiar Andrade, E. H., da Silva, S. H. M., da Silva Sousa Filho, A. P. and de Carvalho Junior, R. N. 2016. Chemical composition and phytotoxic activity of clove (*Syzygium aromaticum*) essential oil obtained with supercritical CO2. *J. Supercritical Fluids* 118: 185-193.

DenHollander, N. G., Bastiaans, l. and Kropff, M. J. 2007. Clover as a cover crop for weed suppression in an intercropping design. I. Characteristics of several clovers species. *Eur. J. Agron.* 26: 92–103.

Dhaker, H., Mundra, S. L., and Jain, N. K. 2009. Weed management in clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.]. *Indian J. Weed Sci.* 41(3&4): 224-227.

Eichelberger, W. C. and Mer, V. K. L. 1933. Preparation and properties of anhydrous acetic acid. *J. Am. Chem. Soc.* 55(9): 3633-3634.

Evans G. J. and Bellinder, R. R 2009. The potential use of vinegar and a clove oil herbicide for weed control in sweet corn, potato, and onion. *Weed Technol.* 23(1): 120-128.

Fajinmi, A. A. and Fajinmi, O. B. 2010. Epidemiology of okra mosaic virus on okra under tropical conditions. *Int. J. Veg. Sci.* 16(3): 287-296.

Faras, B. M. U. P. 2015. Efficiency of mulches for weed management in okra (*Abelmoschus esculentus* (L.) Moench.). M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 95p.

Gambhir, O. P., Malik, Y. S., and Pandita, M. L. 1983. Chemical weed control in seed crop of radish. *Indian J. Weed Sci.* 15(1): 74-76.

Gellerman, J. L., Walsh, N. J., Werner, N. K., and Schlenk, H. 1969. Antimicrobial effects of anacardic acids. *Can. J. Microbiol.* 15(10): 1219-1223.

Gill, H. S. and Vijaykumar. 1969. Weed index a new method for reporting weed control trials. *Indian J. Agron.* 14: 96-98.

Gogoi, S., Hatibarua, P., Mazumder, A., and Shadeque, A. 1996. Effect of period of weed interference on growth and fruit formation in okra. *J. Agri. Sci. Soc. North East India* 9(2): 115-118.

GOI. 2017. Pocket book of labour statistics. [Government of India] Labour Bureau. Shimla. 283p.

Gomez, K. A. and Gomez, A. A. 1984. *Statistical Procedures for Agricultural Research* (2nd Ed.). John Willey and sons, New York, 680p.

Hemphill, D. D.1993. Agricultural plastics as solid waste: What are the options for disposal? *Hortic. Technol.* 3: 70-73.

Hewson, R. T. and Roberts, H. A., 1973. Effects of weed competition for different periods on the growth and yield of red beet. *Journal of Horticultural Science*, *48*(3): 281-292.

Hill, J., Williams, J., Mutters, R., and Greer, C. 2006. The California rice cropping system: Agronomic and natural resource issues for long-term sustainability. *Paddy Water Environ*. 4: 13-19.

Hugar, H. Y. and Palled, Y. B. 2008. Effect of intercropped vegetables on maize and associated weeds in maize-vegetable intercropping systems. *Karnataka J. Agric. Sci.* 21(2): 159-161.

Isman, M. B. 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annu. Rev. Entomol. 51*: 45-66.

Jackson, M. L. 1973. *Soil Chemical Analysis* (2nd ed.). Prentice Hall of India, New Delhi, 498p.

Johnson, W. C., Langston, D. B., MacLean, D. D., Sanders, F. H., Torrance, R. L., and Davis, J. W. 2012. Integrated systems of weed management in organic transplanted vidalia sweet onion production. *Hortic. Technol.* 22(1): 64-69.

KAU [Kerala Agricultural University]. 1992. Kerala Agricultural University. Annual Report of the AICVIP, Vellanikkara, Thrissur, 15p.

KAU [Kerala Agricultural University]. 2017. *Package of practices recommendations (organic): Crops.* Kerala Agricultural University, Thrissur, 327p.

KAU [Kerala Agricultural University]. 2012. *Annual Report (2011-12)- Krishi Vigyan Kendra, Kannur.* Kerala Agricultural University, Kannur, 137p.

Kaur, S., Singh, H. P., Mittal, S., Batish, D. R., and Kohli, R. K. 2010. Phytotoxic effects of volatile oil from *Artemisia scoparia* against weeds and its possible use as a bioherbicide. *Ind. Crops Products* 32(1): 54-61.

Khalil, I. A. and Jan, A. 2002. *Cropping Technology*. National Book Foundation Islamabad Pak. 130p.

Kohli, R. K., Batish, D. R. and Singh, H. P. 1998. Eucalypt oils for the control of parthenium (*Parthenium hysterophorus* L.). *Crop Protection*, 17(2):119-122.

Kostov, T. and Pacanoski, Z. 2007. Weeds with major economic impact on agriculture in Republic of Macedonia. *Pak. J. Weed Sci. Res*. 13(3-4): 227-239.

Kruidhof, H. M., Bastiaans, L. and Kropff. M. J. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. *Weed Res*. 48: 492–502.

Kusvuran, S. 2012. Influence of drought stress on growth, ion accumulation and antioxidative enzymes in okra genotypes. *Int. J. Agric. Biol*. 14(3): 199-201.

Lanini, W. T., Capps, L., and Roncoroni, J. A. 2010. Field testing of organic herbicides. In: *Proceedings of the Western Society of Weed Science*. Waikoloa, Hawaii, USA. March. 63:13.

Leela, D. 1987. Weed control by herbicides in knol khol and radish. *Int. J. Pest Manage*. 33(3): 214-219.

Leela, D. 2003. Weed management in vegetable crops and orchards. In: Saraswat, V. N., Bhan, V. M. and Yaduraju, N. T. (eds.). *Weed management*. Indian Council of Agricultural Research, New Delhi. 241-272.

Liu, L. C., Padilla, M. A., Goyal, M. R. and Ibanez, J. G. 1989. Integrated weed management in transplanted tomatoes and peppers under drip irrigation. *J. Agric*. 71: 349-358.

Main, D. C., Sanderson, K. R., Fillmore, S. A. E. and Ivany, J. A. 2013. Comparison of synthetic and organic herbicides applied banded for weed control in carrots (*Daucus carota* L.). *Can. J. Plant Sci*. 93: 857-861.

Malkomes, H. P. 2005. Influence of higher dosages of an acetic acid-based herbicide, which are necessary for weed control, on soil microorganisms and the microbial activity in soil. *J. Plant Diseases Prot.* 112(5): 457-471.

Mani, V. S., Mala, M. L., Gautan, K. G., and Bhagavandas. 1973. Weed killing chemical in potato cultivation. *Ind. Fmg.* 23(1): 17-18.

Martias, R., Rosa, A. C., Oliveira, A. K. M., Pereira, K. C. L., Rizzi, E. S. and Machado, A. A. 2017. Cashew nut shell liquid and formulation: Toxicity during the germination of lettuce, tomato seeds and coffee senna and seedling formation. *Acta Sci. Agron.* 39(4):487-495.

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

Martins, C., Natal-da-Luz, T., Sousa, J. P., Gonçalves, M. J., Salgueiro, L., and Canhoto, C. 2013. Effects of essential oils from *Eucalyptus globulus* leaves on soil organisms involved in leaf degradation. *PloS One* 8(4): 15-19.

Mazzetto, S. E., Lomonaco, D., and Mele, G. 2009. Cashew nut oil: Opportunities and challenges in the context of sustainable industrial development. *Quimica Nova,* 32(3): 732-741.

Merfield, C. N. 2019. Integrated Weed Management in Organic Farming. In: *Organic Farming*. Woodhead Publishing, pp.117-180.

Merwin, I. A., Rosenberger, D. A., Engle, C. A., Rist, D. L., and Fargione, M. 1995. Comparing mulches, herbicides, and cultivation as orchard groundcover management systems. *Hortic. Technol.* 5(2): 151-158.

Meyer, S. L., Lakshman, D. K., Zasada, I. A., Vinyard, B. T., and Chitwood, D. J. 2008. Phytotoxicity of clove oil to vegetable crop seedlings and nematotoxicity to root-knot nematodes. *Hortic. Technol.* 18(4): 631-638.

Muoneke, C. O. and Ndukwe, O. O. 2008. Effect of plant population and spatial arrangement on the productivity of okra/amaranthus intercropping system. *Agro-Sci.* 7(1): 15-21.

Nandal, T. R. and Pandita, M. L. 1988. Chemical weed control in brinjal (*Solanum melongena* L.). *Indian J. Weed Sci.* 20(3): 55-59.

Nandal, T. R. Dhiman, N. K., and Sharma, R. 2005. Integrated weed management in cabbage (*Brassica oleracea* var. capitata L.). *Indian J. Weed Sci.* 37(3and4): 240-243.

Nazir, J., Khan, S. H., Praveen, K., Afroza, B., and Shabir, A. 2016. A review on organic farming in vegetable crops. *Asian J. Hortic.* 11(1): 208-217.

NHB [National Horticulture Board]. 2018. *Annual Report 2017-2018.* National Horticulture Board, Haryana, 170p.

Norman, J. C., Opata, J., and Ofori, E. 2011. Growth and yield of okra and hot pepper as influenced by mulching. *Ghana J. Hortic.* 9(1): 35-42.

Olasantan, F. O. 1985. Effects of intercropping, mulching and staking on growth and yield of tomatoes. *Exp. Agric.* 21(2): 135-144.

Olasantan, F. O. 2001. Optimum plant populations for okra (*Abelmoschus esculentus*) in a mixture with cassava (*Manihot esculenta*) and its relevance to rainy season-based cropping systems in south-western Nigeria. *J. Agric. Sci.* 136(2): 207-214.

Oliveira, M. S. C., de Morais, S. M., Magalhães, D. V., Batista, W. P., Vieira, Í. G. P., Craveiro, A. A., de Manezes, J. E. S. A., Carvalho, A. F. U. and de Lima, G. P. G. 2011. Antioxidant, larvicidal and antiacetylcholinesterase activities of cashew nut shell liquid constituents. *Acta Tropica*, 117(3): 165-170.

Paller, E. C., Guantes, M. M., Soriano, J. M. & Vega, M. R. 1973. Duration of weed competition and weed control and yield. II. Transplanted onions. The Philippine Agriculturist, IV(5/6): 2214.

Pandey, J. and Pandey, U. 2009. Accumulation of heavy metals in dietary vegetables and cultivated soil horizon in organic farming system in relation to atmospheric deposition in a seasonally dry tropical region of India. *Environ. Monitoring Assess.* 148(1-4): 61-74.

Park, K. W., Choi, S. H., Ahn, J. Y., Sohn, Y. G., Kim, C. G., and Lee, J. J. 2011. Herbicidal action of clove oil on cucumber seedlings. *Weed Biol.Manage.* 11(4): 235-240.

Patel, R. B., Barevadia, T. N., Patel, B. B., and Meisuriya, M. 2004. Effect of cultural and chemical methods on weed and fruit yield of green chilli. *Indian J. Weed Sci.* 36(3&4): 300-301.

Phanikumar, P., Paramashivappa, R., Vithayathil, P. J., Subba Rao, P. V., and Srinivasa Rao, A. 2002. Process for isolation of cardanol from technical cashew (*Anacardium occidentale* L.) nut shell liquid. *J. Agric. Food Chem.* 50(16): 4705-4708.

Philips, E. A. 1959. Methods of vegetation study. *Ecology Work Book.* Henry Holt and Co. Inc, 44p.

Ponchio, JA-de-R., Fravarin, J. L., Louro, M. P., Portugal-Junior-A., Minami, H., and Victoria-Filho-R. 1984. Competition between purple nutsedge (*Cyperus rotundus* L.) summer squash (*Cucurbita moschata* L.) cv. Menina Brasileira. *Solo,* 76(1): 5-10.

Prakash, V., Pandey, A. K., Singh, R. D., and Mani, V. P. 1999. Integrated weed management in chilli (*Capsicum annuum* L.) under mid-hill conditions of North-Western Himalayas. *Indian J. Weed Sci.* 31(3 & 4): 164-166.

Pramanik, S. C., Chaudhuri, S. G., Nair, A. K. and Dinesh, R. 2002. Conjunctive use of irrigation and mulching on growth, yield and water use efficiency of okra in Bay Islands. *Indian J. Soil Conserv.* 30(3): 236-239.

Qasem, J. R. 1993. Root growth, development and nutrient uptake of tomato (*Lycopersicon esculentum*) and *Chenopodium album*. *Weed Res*. 33(1): 35-42.

Qasem, J. R. and Hill, T. A. 1993. Nutrient accumulation of tomato (*Lycopersicon esculentum*), fat-hen (*Chenopodium album*) and groundsel (*Senecio vulgaris*) in relation to root characteristics. *Dirasat. Ser. Pure Appl. Sci.* 20(3): 195-207.

Radhakrishnan, J., Teasdale, J. R., and Coffman, C. B. 2003, January. Agricultural applications of vinegar. In: *Proc. Northeast. Weed Sci. Soc*. 57: 63-64.

Radwan, S. M. A. and Hussein, H. F. 2001. Response of onion, *Allium cepa*, L. plants and associated weeds to biofertilization under some plant mulches. *Annals of Agricultural Science*, 32(1): 135-162.

Rajagopal, A. and Sankaran, S. 1979. Crop-weed competition in tomato. *Madrasagric.J.* 67(1): 1-8.

Rajput, H. D., Singh, K., and Kushwha, H. S. 2003. Integrated weed management in chilli (*Capsicum annuum*). *Indian J. Agron.* 48(2): 136-138.

Ramappa, H. K., Muniyappa, V., and Colvin, J. 1998. The contribution of tomato and alternative host plants to tomato leaf curl virus inoculum pressure in different areas of South India. *Ann. Appl. Biol.* 133(2): 187-198.

Rana, M. K., Sood, S., and Sood, R. 2011. Weed management in vegetable crops. In: Rana, M. K. (Ed.) *Fundamentals of Vegetable Production*. New India Publishing Agency, New Delhi, pp. 484-528.

Rao, V. S. 1986. *Principles of Weed Science*. Oxford and IBH Publishing Co. Private Limited, New Delhi. 450p.

Razafimamonjison, G., Jahiel, M., Duclos, T., Ramanoelina, P., Fawbush, F., and Danthu, P. 2014. Bud, leaf and stem essential oil composition of *Syzygium aromaticum* from Madagascar, Indonesia and Zanzibar. *Int. J. Basic Appl. Sci.* 3(3): 224-228.

Roubalová, R., Procházková, P., Dvořák, J., Škanta, F., and Bilej, M. 2015. The role of earthworm defense mechanisms in ecotoxicity studies. *Invertebrate Survival J.* 12(1): 203-213.

Rui, Z., Wei, D., Zhibin, Y., Chao, Z., and Xiaojuan, A. 2014. Effects of wood vinegar on the soil microbial characteristics. *J. Chem. Pharma. Res.* 6(3): 1254-1260.

Saikia, S., Saikia, A., Shadeque, A. and Gogoi, S. 1997. Field performance of okra as influenced by low density plastic mulches. *Annals of Biology*, 13: 253-258.

Saimbhi, M. S., Sandhu, K. S., Singh, D., Kooner, K. S., and Dhillon, N. P. S. 1994. Chemical weed control studies in okra. *Journal of Research Punjab Agricultural University*. 14:178-190.

Sainudheen, K. 2000. Integrated weed management in okra [*Abelmoschus esculentus* (L.) Moench.]. M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 97p.

Santos, M. L. D. and Magalhães, G. C. D. 1999. Utilisation of cashew nut shell liquid from *Anacardium occidentale* as starting material for organic synthesis: A novel route to lasiodiplodin from cardols. *J. Brazilian Chem. Soc.* 10(1): 13-20.

Sarolia, D. K. and Bhardwaj, R. L. 2012. Effect of mulching on crop production under rainfed condition: a review. *Int. J. Res. Chem. Environ.* 2: 8-20.

Sastry, K. S. 1984. Strains of tomato leaf curl virus and its perpetuation under field conditions. *J. Turkish Phytopathol.* 13(2/3): 87-90.

Sha, K. and Karuppaiah, P. 2005. Integrated weed management in brinjal (*Solanum melongena* L.). *Indian J. Weed Sci.* 37(1/2): 137-138.

Sheela, K. R., Nandakumar, C., and Pushpakumari, R. 2007. Integrated weed management in bhindi (*Abelmoschus esculentus*). *ActaHortic.* 752:549-552.

Sheoran, O. P., Tonk, D. S., Kaushik, L. S., Hasija, R. C. and Pannu, R. S. 1998. Statistical Software Package for Agricultural Research Workers. Recent Advances in information theory, Statistics & Computer Applications by D. S. Hooda & R. C. Hasija Department of Mathematics Statistics, CCS HAU, Hisar: 139-143.

Shiralipour, A., McConnell, D. B., and Smith, W. H. 1997. Phytotoxic effects of a short-chain fatty acid on seed germination and root length of *Cucumis sativus* cv.'Poinset'. *Compost Sci. Utilization* 5(2): 47-52.

Shivaprasad, P., Biradar, I. B., Salakinkop, S. R., Raghuramulu, Y., D'Souza, M. V., Hariyappa, N., Hareesh, S. B. and Murthy, M. A. 2005. Influence of soil cultivation methods in young coffee on soil moisture, weed suppression and organic matter. *Journal of Coffee Research*, 33(1/2):1-14.

Silveria, H. L., Gomes, R., Aguiar, L., Caixinhas, M. L., Bica, J., and Bica, M. 1990. Soil solarisation under polyethylene film: Cultivation of lettuce and onions. *Plasticulture,* (85): 35-42.

Singh, G., Bhan, V. M., and Tripati, S. S. 1982. Weed control in okra (*Abelmoschus esculentus* (L.) Moench). *Indian J. Weed Sci.* 14(1): 19-23.

Singh, H. P., Batish, D. R., Kaur, S., Ramezani, H., and Kohli, R. K. 2002. Comparative phytotoxicity of four monoterpenes against *Cassia occidentalis*. *Ann. Appl. Biol.* 141(2):111-116.

Smith, J. L. and Doran, J. W. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. *Methods for assessing soil quality*, 49.

Spencer, D. F. and Ksander, G. G. 1999. Influence of dilute acetic acid treatments on survival of monoecious hydrilla tubers in the Oregon House Canal, California. *J. Aquatic Plant Manage.* 37:67-71.

Subbiah, B. V. and Asija, L. L. K. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci.* 25: 259-260.

Syriac, E. K. and Geetha, K. 2007. Evaluation of pre-emergence herbicides and soil solarization for weed management in brinjal (*Solanum melongena* L.). *Indian J. Weed Sci.* 39(1and2): 109-111.

Thakur, J. K. 2014. Analytical techniques for Analysis of Soil Biological Parameters. In: ICAR short course on '*Advances in Nutrient Dynamics in Soil-Plant Atmosphere System for Improving Nutrient Use Efficiency*', 02-11 Sept 2014, Bhopal [on-line]. Available: http://www.iiss.nic.in/publication/ICAR%20Short%20course%20manual%20211%20Sep%202014.pdf [08 March 2019].

Usman, K., Ejaz, A., Khan, M. U., Atiq, A., Adeel, I., and Javed, I. 2005. Integrated weed management in okra. *Pak. J. Weed Sci. Res.* 11(1/2): 55-60.

Usoroh, N. J. 1981. Weed problems and control strategies in fruit and vegetable production in Nigeria. *African Symposium Hortic. Crops.* 123: 299-304.

Varghese, A. and Nair, K. P. M. 1986. Competition for nutrients by rice and weeds. *Agric. Res. J.* 24(1): 38-42.

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 39: 29-38.

Webber, C. L.and Shrefler, J. W. 2009a. Broadcast application of vinegar for broadleaf weed control in spring- transplanted onions. In: 2008. Weed Control Report. Brandenberger, L. and Wells, L. (eds.). 162: 26-28.

Webber, C. L.III and Shrefler, J. W. 2009b. Broadcast application of Matran for broadleaf weed control in spring- transplanted onions. In: 2008 Weed Control Report. Brandenberger, L. and Wells, L. (eds.). 162:17-19.

Webber, C. L.III, Shrefler, W. J., and Brandenberger, P. L. 2012. Organic weed control, In: Herbicides- Environmental Impact Studies and Management Approaches, Dr. Ruben Alvarez- Fernandez (Ed.). p. 185-198.

Weir, T. L., Park, S. W., and Vivanco, J. M. 2004. Biochemical and physiological mechanisms mediated by allelochemicals. *Curr.Opinion Plant Biol.* 7(4): 472-479.

Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables, and grains. *J. Alternative Complementary Med.* 7(2): 161-173.

Yadav, S. L., Koushik, M. K. and Mundra, S. L. 2011. Effect of weed control practices on weed dry weight, nutrient uptake and yield of cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] under rainfed condition. *Indian J. Weed Sci.* 43(1&2): 81-84.

Yang, X., Deng, S., De Philippis, R., Chen, L., Hu, C., and Zhang, W. 2012. Chemical composition of volatile oil from *Artemisia ordosica* and its allelopathic effects on desert soil microalgae, *Palmellococcus miniatus*. *Plant Physiol. Biochem.* 51: 153-158.

Young, S. L. 2004. Natural products for control of annual vegetation along roadsides. *Weed Technol*. 18(3):580–587.

Zareen, S., Khan, S., Ahmad, I., Haroon, M., Khan, I., and Ullah, I. 2017. Effect of various weed infested periods on okra under agro-climatic conditions of DI Khan, Pakistan. *Pak. J. Weed Sci. Res.* 23(1): 25-29.

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Abstract

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EVALUATION OF HERBICIDAL PROPERTIES OF HORTICULTURAL CROP PRODUCTS AND BY-PRODUCTS IN ORGANIC FARMING OF OKRA [*Abelmoschus esculentus* (L.) Moench]

by

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ABSTRACT

The study entitled "Evaluation of herbicidal properties of horticultural crop products and by-products in organic farming of okra [*Abelmoschus esculentus* (L.) Moench]" was conducted in the Department of Vegetable Science, College of Agriculture, Vellayani during 2018-19. The study aims to evaluate the herbicidal properties of different horticultural crop products and by-products such as coconut vinegar, cashew nut shell liquid, lemon extract, clove leaf oil and eucalyptus oil and to study their herbicidal efficacy in organic farming of okra. The study was conducted in two parts: 1) Preliminary evaluation of horticultural crop products and by-products as herbicides and 2) Evaluation of herbicides in organic farming of okra.

For preliminary evaluation of herbicides, seed beds were prepared by tilling with rotavator and weeds were allowed to grow for 45 days. The emerged weeds were smothered by herbicide preparations in randomly selected mini plots in separate experiments for each horticultural product and by product in Completely Randomised Design replicated five times.

For preliminary evaluation as herbicides, acetic acid content of coconut vinegar was enhanced from 4 to 5, 7.5,10 and 12.5 percent by freeze distillation (CVH), cashew nut shell liquid was emulsified to 5, 10, 15 and 20 percent (CNSLH), citric acid in lemon extract was enhanced to 2.5, 5, 7.5 and 10 percent by evaporation (LEH) and sprayed on weeds @ 50mlm^{-2}. CVH at 12.5 percent consistently reduced absolute density of grasses, sedges and broad leaved weeds at 15 and 45 days after spraying as well as lower root biomass, shoot biomass and higher weed control efficiency (70.37 and 56.3% at 15 and 45 DAS). Among CNSL emulsions 20 percent CNSLH consistently reduced absolute density of grasses, sedges and broad leaved weeds as well as recorded lower root biomass, shoot biomass and higher weed control efficiency. Among LEH though, absolute density of grasses and sedges were not significantly reduced by any of the concentrations. 10 percent lemon extract significantly reduced absolute density of broad leaved weeds at 15 DAS (32.97) at 15 and 45 DAS as well as recorded

lower root biomass and shoot biomass and weed control efficiency. Enhanced weed growth at 45 days compared to 15 days after spraying warrant repeated application of herbicides for adequate control.

CVH with 12.5percent acetic acid along with 1, 2, 3 and 4 percent clove leaf oil (CLOH) was sprayed on weeds @ 50mlm^{-2}. CLOH consisting 4 percent clove leaf oil consistently reduced absolute density of grasses, sedges and broad leaved weeds at 15 and 45 DAS as well as recorded lower root biomass, shoot biomass and weed control efficiency. CVH with 12.5 percent acetic acid along with 1, 2, 3, 4 percent eucalyptus oil (EOH) was sprayed on weeds @ 50mlm^{-2}. EOH consisting 4 percent eucalyptus oil consistently reduced absolute density of grasses, sedges and broad leaved weeds at 15 and 45 DAS as well as recorded lower root biomass, shoot biomass and weed control efficiency (96.96 and 67.46% at 15 and 45 DAS).

In part II of the study 12.5 percent CVH, 20 percent CNSLH, 10 percent LEH, 4 percent CLOH and 4 percent EOH were sprayed on the 45 day old weeds on stale seed bed, repeated application thirty days after sowing of okra variety Anjitha seeds in comparison to organic mulching with mango leaves, hand weeding till 7th week and weedy check. All treatments controlled weeds compared to weedy check with regard to growth parameters and CLOH spray at 15 days before and 30 days after sowing, performed on par with hand weeded plot for higher germination of okra (90.97%), plant height (114.20cm), branches (2.87), number of leaves (20) and lower duration for 50 percent flowering (49.20 days). All treatments improved yield parameters compared to weedy check except number of flowers per plant wherein lemon extract did not differ. CLOH performed on par to hand weeding for more harvests (17), flowers per plant (10.18), fruit set (87.42%), number of fruits per plant (8.90) yield (9.89tha^{-1}) and extended crop duration (105 days). All treatments reduced absolute density of grasses, sedges and broad leaved weeds except LEH on entire crop duration. Hand weeding reduced absolute density of grasses and sedges up to 30 days after sowing but CLOH and EOH were on par for control of broad leaved weeds only. After the second spraying at 30 days after sowing, CLOH and EOH performed on par with hand weeding for controlling grasses, sedges and broad leaved weeds. Hand weeding reduced root and shoot biomass up to 60 days after sowing but CLOH performed on par after second spray at 30 days after sowing. Hand weeding and CLOH were on par for weed control efficiency, weed index, lower nutrient uptake by weeds and higher nutrient uptake by okra. CLOH reduced pH, but on par for organic carbon content and EC of soil compared to hand weeding. CVH improved microbial population of soil, but on par with CLOH for fungi. Herbicide application did not change population of earthworms but improved dehydrogenase activity over weedy check. Single spray of CLOH 15 days before sowing recorded highest B:C ratio (1.54)

In conclusion, Clove Leaf Oil Herbicide (mixture of coconut vinegar with 12.5% acetic acid and 4% clove leaf oil) performed on par with hand weeding for improving major growth and yield parameters, control of grasses, sedges and broad leaved weeds with similar weed control efficiency, weed index without adversely affecting the organic carbon content, EC, nutrient and microbial composition of soil when sprayed on stale seed bed 15 days before and 30 days after sowing but highest B:C ratio was obtained for single spray at 15 days before sowing in organic okra. Hence, strategies to flush out maximum weeds out of weed seed bank for smothering in the stale seed bed itself and technologies for reducing cost of herbicidal components are essential. Moreover, long term impact on ecosystem need to be assessed.