Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)

MINU MARIYA ISSAC

(2018-11-061)

THESIS

Department of Agronomy

COLLEGE OF AGRICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)

By

MINU MARIYA ISSAC

(2018-11-061)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Agronomy

COLLEGE OF AGRICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

DECLARATION

I, Minu Mariya Issac (2018-11-061), hereby declare that the thesis entitled **"Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me any degree, diploma, fellowship or other similar title of any other university or society.

Place : Vellanikkara

Date : 24|04|2021

Minu Mariya Issac

(2018-11-061)

CERTIFICATE

Certified that this thesis entitled **"Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)"** is a record of research work done independently by Ms. Minu Mariya Issac (2018-11-061) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship to her.

Place : Vellanikkara

Date : 24/04/2021

Dr. Mini Abraham

Major Advisor, Advisory Committee

Professor (Agronomy)

Agronomic Research Station,

Chalakudy

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Minu Mariya Issac, a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that the thesis entitled **"Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)"** may be submitted by Ms. Minu Mariya Issac, in partial fulfilment of the requirement for the degree.

Dr. Mini Abraham
(Chairman, Advisory Committee)
Professor (Agronomy)
Agronomic Research Station, Chalakudy

Dr. P. Prameela
24/4/2021
(Member, Advisory Committee)
Professor and Head (Agronomy)
College of Agriculture, Vellanikkara

Dr. Kurien E. K.
(Member, Advisory Committee)
Professor (SWE)
College of Forestry, Vellanikkara

Dr. Anitha S.
(Member, Advisory Committee)
Professor and Head
Instructional Farm, Vellanikkara

ACKNOWLEDGEMENT

It is with great respect and devotion, I express my deep sense of gratitude and indebtedness to my major advisor Dr. Mini Abraham, Professor, Agronomic Research Station, Chalakudy for her expert advice, inspiring guidance and valuable suggestions rendered throughout the course of my study.

I consider it as my privilege to express my deep-felt gratitude to Dr. Meera V. Menon, Professor and Head, Dept. of Agronomy for her constant support, valuable suggestions, cooperation throughout the research programme and critical scrutiny of the manuscript.

No words can truly express my esteemed gratitude to Dr. George C. Thomas, Professor, Department of Agronomy for his constant help and valuable suggestions from beginning to the end of this study.

I am deeply obliged to Dr. Kurien E. K., Professor, Department of Soil Water and Engineering and Dr. Anitha S., Professor and Head Instructional farm, Vellanikkara for their invaluable help, guidance and critical assessment throughout the period of work.

My heartfelt thanks to my beloved teachers Dr. P. Prameela, Dr. P.V. Sindhu, Dr. Syama S. Nair, Dr. Savitha Antony, Dr. Sreelakshmi K., Dr. Bhindu P. S., and Dr. Susha K. S., for their encouragement, valuable help and advice rendered during the course of my study.

I also thank Gayathri, Athira, Ashok, Sijith, Omana, Sunitha, Babu, Biju, Vijaya, and Sheela for their co-operation and constant support during the conduct of field experiment. The help rendered by the labourers of the Water Management Research Unit are also very much appreciated.

I duly acknowledge the encouragement, moral support and timely persuasions by my dear seniors Anasooya, Athira, Emily, Vidhupriyadarshini, Arya, Sabika, Kishore, Saravanan, Sobha, Durga, Daly, Akhila, Venkateswara Reddy and my classmates Suhas, Mounisha, Nengparmoi, Liz, Basila and my loving juniors for their love, moral support and encouragement.

My sincere thanks to Jeena Mary, Anjali and Ajmal Fayique for their patience, timely help and kind cooperation.

My special thanks to Sreela, Shyamala and Agronomic Research Station, Chalakudy for their immense help and cooperation during the laboratory work.

I am in dearth of words to express my love towards my parents and my loving brother for their boundless affection, moral support, eternal love, deep concern, prayers and personal sacrifices which sustain peace in my life.

MINU MARIYA ISSAC

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIX

LIST OF ABBREVIATIONS

a.i	: active ingredient
@	: at the rate of
B: C	: Benefit Cost ratio
BLW	: Broad leaf weeds
cm	: centimetre
DAP	; Days after planting
DAS	: Days after sowing
DAT	; Days after transplanting
EC	: Emulsifiable Concentration
et al	: and others
fb	: followed by
Fig	: Figure
g	: gram
HW	: Hand weeding
i.e	: that is
K	: Potassium
kg	: kilo gram
L	: Litre
m	: metre

m^2	: metre square
N	: Nitrogen
OC	: Organic Carbon
P	: Phosphorus
RBD	: Randomized Block Design
t/ha	: tonnes per hectare
WAP	: Weeks After Planting
WAS	:Weeks After Sowing
WCE	: Weed Control Efficiency
WI	: Weed Index
°C	: Degree Celsius
%	: per cent

1. Introduction

1. Introduction

Weeds are the most severe and widespread biological constraint to crop production in India, and alone cause 33 per cent loss out of total losses due to pests (Verma *et al*., 2015). The cultivation of high yielding crop varieties responsive to fertilizers, irrigation and the new intensive cropping systems have brought to the forefront the problem of weeds, which cause tremendous losses to crops and their produce. Weed management is one of the factors having huge impact on agricultural productivity. It includes a combination of chemical, cultural and mechanical practices to control weeds. Herbicides are widely used in the developed countries and are becoming increasingly important in the developing countries because of the increasing cost of manual labour.

Herbigation is the application of herbicide through irrigation water and can be done effectively through micro irrigation. Through micro irrigation, the right quantity of water can be applied at the right time in the active root zone of the crop. Also it offers the facility for applying fertilizer and herbicide through irrigation water to the root zone. Conventional method of herbicide application takes considerable time and is expensive due to the increasing cost of manual labour. Also, heavy wind at the time of spraying and improper application causes herbicide loss, environmental pollution and drift injury to the nearby fields, especially on sensitive crops. Herbigation ensures no additional costs of application. The extent of movement of herbicides through irrigation water is a function of solubility, adsorption and volatility, and no herbicide residues have been detected in both the soil and crop in herbigation. (Hariharasudhan *et al.,* 2017). Use of micro irrigation not only helps in increasing the water use efficiency but also helps in achieving more weed control efficiency through non availability of irrigation water to the weeds (Sivanappan, 1994). Among micro irrigation methods, drip irrigation is the most efficient method of irrigation with high water use efficiency.

Okra is one of the important vegetable crops of Kerala. It is a warm season crop well adapted to most areas. It is grown all over India for its tender fruits. In Kerala it is grown in all seasons with both conventional irrigation and drip irrigation.

Weed competition during early stage of crop growth significantly lowers the crop yields. Heavy weed infestation in okra is mainly due to wider spacing, slower crop growth during early stages, higher fertilizer use and frequent irrigation. Manual weeding is difficult as it is highly labour intensive and time consuming. In Kerala, non-availability of manpower for weeding makes timely weed control a costly affair. A proper weed control method including herbicide use is a prime need.

Uniform application of herbicides is necessary to ensure considerable increase in vegetable production and real decrease in production costs. Generally herbigation is not done in any crop on a large scale. The present study was proposed with the following objectives:

1. To find out the effect of herbigation in okra
2. To evaluate the economic feasibility of the system

2. Review of literature

2. Review of Literature

Vegetable cultivation needs a special weed management approach. They are high value crops in terms of total calorific production, nutritional security, export market and food consumption. If the weeds are left uncontrolled in vegetables they can cause 70 – 80 per cent yield loss (Rana *et al.,* 2011). Weeds cause severe problems in vegetables than in field crops due to several reasons. Some of them are slow initial growth, more nutrient requirement, frequent irrigation and wider spacing.

A brief review of relevant and recent research work related to the research topic entitled 'Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)' has been done and presented in this chapter. The available literature pertaining to the aspect under investigation is reviewed under the following headings.

2.1. Weed flora in okra field

Weeds are integral part of each and every crop and cropping system. It is well known that weeds are very well adapted to the crop that they infest, because of their morphological and phenological characteristics. Because of high competitiveness and allelopathic effect, weeds cause much damage to the crops. Knowledge on the composition of weed flora and its correct identification is important for formulation of effective control measures. Weeds serve as alternate hosts for many insects and disease causing organisms so it is very much needed to manage them in time. Many weed species have been reported in okra from different geographical locations.

In an experiment conducted by Sainudheen (2000) at vegetable research farm of College of Horticulture at Vellanikkara, *Cynodon dactylon, Cyperus rotundus, Cyperus iria, Ludwigia parviflora, Digitaria ciliaris, Dactyloctenium aegyptium, Ischaemum rugosum, Echinochloa colona, Phyllanthus niruri* and *Physalis minima* were reported as major weeds in okra.

Basha (2001) carried out an experiment in summer season at S. V. Agricultural College, Tirupati. He observed heavy infestation of *Cyperus rotundus, Cynodon dactylon, Dactyloctenium aegyptium, Cleome viscosa, Tridax procumbens, Euphorbia hirta* and *Acanthospermum hispidum* in the okra field.

An experiment was conducted by Kumar and Choudhary (2004) to study the effect of pendimethalin singly and in combination with hand weeding in okra. They observed that *Cynodon dactylon, Digeria arvensis, Euphorbia hirta, Phyllanthus niruri, Portulaca oleraceae* and *Sorghum halapense* were dominant weeds in their experimental field.

In a field trial done by Amin and Limbani (2007) at University of Ghana Farm, Legon in the year 2004 and 2005, they noted the most problematic weeds in okra viz., *Cyperus rotundus, Trianthema portulacastrum, Croton spp., Euphorbia leptophylla, Cleome viscosa* and *Celosia laxa.*

According to Syriac and Geetha (2007) the major grassy weeds in vegetable fields of Kerala were *Eleusine indica, Digitaria sanguinalis, Paspalum* sp., and *Eragrostis* sp. Major broad leaved weeds were *Ageratum conyzoides, Leucas aspera, Ludwigia perennis, Commelina benghalensis, Cleome viscosa, Phyllanthus niruri* and *Vernonia cinerea,* and sedges were *Cyperus rotundus, Cyperus iria* and *Kyllinga monocephala.*

Smith (2009) conducted a field experiment at Akure, in the rainforest zone of southwestern Nigeria. They found that the major weed flora in okra field were *Celosia argentea, Synedrella nodiflora, Euphorbia heterophylla, Calopogonium mucunoides, Digitaria horizontalis, Sorghum arundinaceum, Portulaca oleracea* and *Talinum triangulare.*

Major problematic identified in okra fields were *Echinochloa spp., Cyperus rotundus, Celosia argentea, Cleome viscosa, Cynodon dactylon, Dactyloctenium aegyptium* and *Alternanthera sessilis, Eleusine indica, Digitaria sanguinalis, Phyllanthus niruri, Boerhavia repanda, Digeria arvensis (*Singh *et al.,*2010,Sharma and Patel (2011)

Iyagba *et al*. (2012) conducted a field experiment at Nigeria and reported that the composition of weed flora in the experimental field of okra were *Chromolaena odorata, Cyperus rotundus, Euphorbia heterophylla, Axonopus compressus, Eleusine* *indica, Eragrostis atrovirens, Celosia loxa, Panicum maximum, Laportea aestuans, Talinum triangulare, Mitrocarpus villosus* and *Cyperus tuberosus.*

Dilip (2013) reported major weed species present in the okra field at US Virgin Islands as *Sorghum halepense, Eleusine indica, Cyperus rotundus, Phyllanthus niruri, Portulaca oleraceae* and *Corchorus hirsutus.*

The prevalent weed flora infesting okra crop in the experimental field was *Digeria arvensis, Urena lobata, Cynodon dactylon, Cyperus iria, Commelina benghalensis, Amaranthus viridis, Amaranthus spinosus, Euphorbia hirta* and *Echinochloa colona* (Sah *et al*., 2018)

2.2. Critical period of weed competition

Weeds are competitive and adaptable to all adverse environments. It is the most important factor which impairs agricultural production. Usually, the critical period of weed competition is longer in direct seeded than in transplanted crops. For each and every crop there is a stage before which the crop weed competition will be maximum. The removal of weeds before this stage is very much needed to achieve the maximum growth and yield of the crop.

Gogoi *et al*. (1996) found that the most critical period of crop weed competition was 4 to 7 weeks after sowing (WAS) and the yield obtained was comparable with that obtained in a weed free situation in okra. While in a field experiment conducted by Ajeyalemi (2007) concluded that critical time for crop weed competition in okra as 2 to 6 WAS.

Weed infestation in okra from 2 weeks after planting (WAP) resulted in 79.8 per cent and 72.5 per cent fresh fruit yield reduction and weed infestation in okra from 8 WAP resulted in 19.8 per cent and 19.6 per cent yield losses in 2006 and 2007 respectively. (Rasheed and Oluseun, 2009). Iyagba et al. (2012) observed that the critical period of weed interference in okra was 3 WAS. Also, Elamin *et al.* (2019) found critical period for weed control in okra as between 6 and 8 WAS.

2.3. Losses caused by weeds

The quick germination and fast growth of weeds reduce the growth and yield of okra. Huge losses in okra yield have been reported where the weeds are not controlled during critical period of weed competition. Generally, these losses occur as a result of reduced yield, quality, harbouring of pests or diseases, allelopathic effects etc. The extent of yield losses depends on weed flora, their intensity, duration of weed competition, soil and climatic factors.

Okra being a widely spaced rainy season crop, faces severe problem of wide variety of both grass and broad leaved weeds which may cause more than 70 per cent reduction in yield of green fruits (Singh and Tripati, 1990). Field experiment conducted during the year 1990 -1991 at Vegetable Research Station, Jalandhar and Ludhiana showed that weeds reduced the yield by 54 to 90 per cent in okra crop (Saimbhai *et al*., 1994).

Unchecked weed growth has reduced the yield to an extent of 78.2 per cent in okra (Gogoi *et al*., 1997). Reddy *et al*. (1998) revealed that weed infestation causes 33 – 40 per cent yield reduction in vegetable crops. Similarly, Shaikh *et al*. (2002) recorded yield reduction to the extent of 68 per cent due to unchecked weeds in okra crop.

Jain and Tomar (2005) conducted a field experiment during kharif season of the year 2003-2004 at AICRP on weed control, College of Agriculture, Gwalior. They noticed that uncontrolled weeds resulted in 58 per cent reduction in seed yield of okra as compared to weed free treatment. Similarly, Olabode *et al*. (2006) reported 85 per cent yield loss in okra in unweeded plots when compared with mulched plots in southern Guinea savanna of Nigeria.

Kumar *et al*. (2011) conducted a field experiment at Palampur during the year 2007 and 2008. From the result they inferred that uncontrolled weeds reduced the seed yield of okra by 68 per cent compared to weed free treatment. Also, Sharma and Patel (2011) noted that the weed competition with the crop resulted in yield losses varying between 40 per cent to 80 per cent which depends on the type of weed flora and their intensity.

2.4 Methods of weed control

There are different methods for weed control in okra and each one have merits and demerits. Among the methods mechanical method and cultural methods are the most common methods. Although herbicides are replacing other methods, still the farmers practice these methods of weed control due to prohibitive cost of herbicides and lack of know-how to use the herbicides.

2.4.1 Non chemical methods of weed control.

The farmer's practice consisting of five hoeings was equally effective in controlling weeds compared to two hoeings along with basalin (2.5 l ha^{-1}) upto 40 days of sowing in okra (Kumar and Singh, 1986). According to Iremiren (1988) weeding once within the first four weeks was beneficial to okra in terms of growth and yield than the two or three weedings given later in the 12 week period. Highest pod yield ha^{-1} was obtained from plots with two hand weedings and it was on par with basalin (1.5 l ha^{-1}) treatment in bhendi (Vidya and Singh, 1990).

Prakash *et al.* (2001) reported that repeated weeding recorded the highest plant height, fruits per plant and fruit weight per plant. The highest fruit yield (13630 kg ha^{-1}) was obtained with weeding at 20, 40, 60 and 80 days after sowing (DAS). Also, the repeated hand weeding was on par with pre emergence application of fluchloralin along with one hand weeding at 30 DAS.

Jain and Tomar (2005) conducted a field experiment at All India Coordinated Research Project (AICRP) on Weed Control, Gwalior during the year 2003-2004. They reported higher seed yield in the treatment with three hand weedings at 3, 6, and 9 WAS. Also found that uncontrolled weeds unweeded plot resulted upto 58 per cent reduction in seed yield of okra as compared to the weed free treatment

John and Mini (2005) conducted a field experiment on development of an okra based cropping system at Kerala Agricultural University, Vellanikkara. The results indicated that okra when intercropped with cowpea produced highest fruit yield as well as net and gross returns.

An experiment was conducted by Singh *et al*. (2005) at Punjab Agricultural University, Ludhiana and found that all weed management practices significantly improved the seed yield of okra over control. Among the treatments, three hand weedings recorded highest seed yield and lowest weed density compared to other treatments.

Shinde *et al.* (2006) carried out a field trial to study the role of micro irrigation and polythene mulch on growth, yield and economics of okra var. Arka Anamika on lateritic soils of Maharashtra. The results indicated that white polythene mulch significantly recorded superior plant height, number of leaves, number of branches and dry matter per plant over rest of the mulches i.e. black polythene, straw mulch and no mulch treatment.

Sheela *et al.* (2007) conducted a field experiment at Farming System Research Station, Kottarakkara, Kerala to examine the effect of different weed management practices on yield and economics of okra. Among the treatments, the farmer's practice (four inter cultivation with spade) recorded the highest yield and it was on par with stale seed bed practice, pre emergence application of fluchloralin and mulching.

Warde *et al.* (2008) reported that the farmer's practice of handweeding at 20, 40 and 60 days after transplanting (DAT) gave higher yield (68.0 t ha^{-1}) and it is on par with oxyfluorfen @ 0.10 kg ha^{-1} followed by two hand weedings at 30 and 60 DAT in onion crop.

Patel *et al*. (2009) carried out an experiment at AICRP on weed control, Anand Agricultural University, Anand during kharif season of 2007 and 2008. The data showed that plant height was significantly higher in mulching with green and dry leaves treatments and was on par with wheat straw mulching. However fruit yield of okra was found significantly highest in weed free treatment.

Pandey and Mishra (2013) conducted a field experiment at Jharkhand during summer season of the year 2011 and 2012. They found that hand weeding at 15, 30 and 45 DAS gave maximum fruit yield (7.1t ha^{-1}) of okra, but this treatment was not economic because of more labour requirement.

2.4.2 Chemical weed control

The use of herbicides offer a great way for minimizing the cost of weed control irrespective of the situation and offer a weed control alternative to mechanical or cultural methods of weed control. During past few years the arena of weed control has undergone drastic change due to the invention of new herbicides for achieving best results. For effective use of this herbicides, one should be thorough about the conditions under which these herbicides work efficiently. The major factors affecting herbicide efficiency are weather, soil moisture, rainfall, humidity and wind. The herbicides act as a boon under adverse weather and soil conditions when the use of cultural methods become difficult.

Khurana *et al*. (1986) examined chemical method with manual method of weed control and reported that application of pendimethalin 1.0 kg ha^{-1} as pre-emergence had a good control of weeds, which ultimately lead to increased yield of okra fruits. Excellent growth, yield and quality of fruits and better soil conditions was obtained by pre emergence application of fluchloralin @ 2 kg ha^{-1} (Vethamani, 1988).

The use of pre emergence herbicides, thiobencarb @ 1.0 – 2.0 kg ha^{-1}, fluchloralin @ 0.75 – 1.25 kg ha^{-1} and butachlor @ 1.0 – 2.0 kg ha^{-1} recorded weed control efficiency (WCE) of 84.20 - 92.9 per cent which was comparable to hand weeding (94.20 %) (Ramamoorthy and Jayapal, 1990). Leela (1993) studied the effect of herbicides on vegetables at Hessarghatta, Karnataka and observed that the yield of okra, tomato, pea and amaranthus were increased with herbicide treatments and found more economical than hand weeding.

Basha (2001) reported that the chemical treatment alone or in combination with hand weeding improved growth and yield of okra. Hand weeding in combination with metolachlor as pre emergence spray gave higher plant height, dry matter at harvest, number of pods per plant, pod yield per plant and fruit yield.

An experiment was conducted by Trivedi *et al.* (2001) at AICRP on weed control, Anand to find out best integrated managements in okra crop. Six herbicides viz., alachlor, fluchloralin, trifluralin, pendimethalin, metolachlor and butachlor were tried at different concentrations and compared with two hand weedings (3 and 6 WAS), three hand weedings (3, 6 and 9 WAS) and weedy check. Among herbicidal treatments, pendimethalin @ 1 kg ha^{-1} showed maximum WCE (85 %) as compared to other treatments.

2.4.3. Herbigation

Herbigation is an effective method of applying herbicides through irrigation systems. Weed control has been equal or better with herbigation than application with ground or aerial sprayers. It provides greater flexibility in weed control programs. Sujith *et al.* (2003) reported that the use of irrigation systems to apply herbicides is a relatively recent development in weed control methods and observed that some of the herbicides exhibit good activity by controlling target weeds when applied with irrigation water.

2.4.3.1 Effect of herbigation on weed population and dry weight

In potato, application of EPTC herbicides through overhead micro sprinkler irrigation system after 40 DAS reduced weed population and dry weight as compared to conventional method of weed control (Saito and Santos, 1980). Also, El-Gindy, (1988) reported that the use of herbicides mixed with irrigation water for tomato reduced the weed growth by 55.50 per cent in furrow, 68 per cent in sprinkler and 65.9 per cent in drip irrigation systems.

Gruzdev *et al.* (1990) reported the effectiveness of weed control in maize and after harvest of soybean crops when herbicides were applied together with irrigation water in 200 m^3 water ha^{-1} compared to traditional boom sprayer method in 300 liters spray. Herbigation with oxadiazon @ 1.4 kg ha^{-1} and simazine @ 3 kg ha^{-1} in vineyard recorded lower weed population compared to unweeded control both after 30 and 60 days of application (Fourie, 1992).

Sujith (1997) mentioned that application of alachlor @ 2 kg ha^{-1} in groundnut through irrigation water recorded lower weed population irrespective of weeds compared to alachlor at same rate as soil spray. Also, Velayatham *et al*. (2001) reported that pre-emergent herbicide metolachlor @ 1 kg ha^{-1} applied as herbigation recorded lowest total weed dry matter production of 31.90 kg ha^{-1} and 36.60 kg ha^{-1} in two successive years.

Kohansal *et al*. (2010) noticed that herbigation of alachlor @ 5 lit ha^{-1} + metribuzin @ 300 g ha^{-1} reduced the weed population and weed dry weight as compared to unweeded check in maize. Nalayini *et al.* (2013) studied that herbicide rotation of pre emergence application of pendimethalin 1.0 kg ha^{-1} followed by hand weeding and application of metolachlor 1.0 kg ha^{-1} as an early post emergence herbicide on 30 DAS resulted in the lowest dry matter production by weeds when compared to hand weeding thrice.

Hakoomat *et al*. (2017) conducted an experiment at Central Cotton Research Institute, Multan, Pakistan to evaluate the impact of herbicide application under different irrigation practices. They found that all treatments with drip irrigation tends to decrease the weed density (upto 24 %) when compared with furrow irrigation method.

2.4.3.2 Effect of herbigation on weed control efficiency

Sujith (1997) noticed that application of alachlor @ 2 kg a.i. ha^{-1} through irrigation water reported higher weed control efficiency (80.9 %) compared to soil application (79.8 %) and control (17.9 %) in groundnut.

Rankova *et al*. (2009) reported that micro-sprinkling can be successfully used for the application of soil herbicide pendimethalin with the irrigation water. It led to increased WCE and found to be economical without causing any negative effect on crops and environment.

Nalayini *et al*. (2013) reported that the weed control efficiency was higher in case of weed control through herbigation (88.4 %) as compared to conventional spraying of herbicides (86.5 %) in cotton.

Elsayed *et al.* (2019) carried out an experiment to evaluate herbigation method for maximizing green beans productivity under drip irrigation system. The results showed that the highest weed control efficiency (WCE) of 82 per cent was achieved with injection of herbicide through sub surface drip irrigation system with 75 per cent of the recommended herbicide dose and achieved maximum benefit from the applied herbicides.

Kanimozhi *et al.*(2019) reported that the weed control efficiency of 80.8 per cent was recorded in pre emergence application of oxyfluorfen @ 0.188 kg a.i ha^{-1} under herbigation through microsprinkler.

2.4.3.3 Effect of herbigation on growth and yield of crops

Sujith (1997) noticed that application of alachlor at 2 kg a.i. ha^{-1} through irrigation water recorded higher pod yield (25.39 q ha^{-1}) of groundnut compared to conventional methods of herbicide spray.

Charlotte *et al.* (2000) reported higher tuber yield of potato in weed free condition (43.3 t ha^{-1}) compared to herbigated plot (42.1 t ha^{-1}) and no herbicide application treatment (12.9 t ha^{-1}).

Velayatham *et al.* (2001) noticed that pre-emergent herbicide metalachlor 1 kg a.i. ha^{-1} applied as herbigation registered higher grain yield of cowpea (311 kg ha^{-1}) and soybean (443.87 kg ha^{-1}) as compared to unweeded check in cotton based cropping system.

Abbasi *et al.* (2008) revealed that application of trifluralin (1920 g ha^{-1}) through drip irrigation followed by bentazon (960 g ha^{-1}) in soybean recorded higher grain yield (2143 kg ha^{-1}), biomass (9410 kg ha^{-1}) and harvest index (23 %) when compared to weedy check .

The highest grain yield (10.6 t ha^{-1}) of corn was recorded in the treatment applying eradicane (2 kg a.i. ha^{-1}) as herbigation at second irrigation as compared to conventional irrigated (7.5 t ha^{-1}) corn (Kesthkar *et al.*, 2010).

Nalayini *et al.* (2013) reported higher yield of cotton in herbigation (3998 kg ha^{-1}) over conventional spray (3498 kg ha^{-1}).Similarly, Jagadish (2015) reported that in aerobic rice, herbigation of pre-emergent herbicide pretilachlor + bensulfuron methyl followed by post emergent herbicide bispyribac sodium at 20 DAS recorded higher yield parameters like productive tillers, panicle length, panicle weight, grain yield and straw yield after weed free check.

2.4.3.4 Residual effect

Abdel-Aziz (2006) reported no residues of butralin herbicide in the soil after 15 days from application under different herbigation as well as conventional spraying treatments. Sahhar and El-Bagoury (2006) reported that conventional spraying resulted in higher contamination with herbicide residues than herbigation treatment on tomato in newly reclaimed lands of Egypt.

Micro irrigation systems especially micro-sprinkling can be successfully used for the application of soil herbicides with the irrigation water. The herbigation increases the herbicide efficiency and does not have a negative effect on the fruit trees and the environment (Rankova *et al*., 2009). The germination of bio assay crop of green gram raised immediately after the harvest of cotton was not affected by any of the herbicides tested or method of application. Hence herbigation found safe to be used in cotton based cropping system (Nalayini *et al*., 2013).

2.4.3.5 Effect of herbigation on soil micro-organisms

Rankova *et al.* (2009) found that soil respiration (microbial activity) increased in case of micro sprinkling compared to other methods of herbicide application. The microbial population was higher in herbigated weed control and as compared to the conventional sprayed treatment at 90 days after sowing in cotton. However the initial set back in microbial population was recovered after a period of time as the toxicity level decreased with time (Nalayini *et al*., 2013).

According to Nalayini *et al*. (2013) there was significant reduction in microbial population at initial stage (30 DAS) which is recovered at later stages (90

DAS) in cotton. Also the herbicidal treatments did not affect the succeeding crop green gram.

2.4.4 Pre-emergent herbicide - Oxyfluorfen

Oxyfluorfen is a diphenyl ether herbicide used for broad spectrum pre and post emergent control of annual broadleaf and grassy weeds. It is a selective contact herbicide. It is basically a soil applied herbicide readily absorbed by roots, but low humidity may reduce absorption. The shoots absorb very little oxyfluorfen (Rao, 1986).

2.4.4.1 Chemical weed control with oxyfluorfen

Porwal and Singh (1993) observed that the most effective and feasible method of controlling weeds in cauliflower was pre emergence application of oxyfluorfen @ 0.1 kg ha^{-1} followed by one hand weeding at 45 days after planting. In the case of onion, Kolhe (2001) found that the pre emergence application of oxyfluorfen @ 0.15 kg ha^{-1} followed by one hand weeding at 35 DAT was effective in controlling weed population and weed dry weight.

An experiment was conducted by Shylaja and Thomas (2004) at College of Horticulture, Thrissur to study the efficacy of commonly used pre emergence herbicides for the control of weeds in cocoa seedling nursery. It was found that oxyfluorfen (0.3 kg ha^{-1}), pendimethalin (1.5 kg ha^{-1}) and diuron (2 kg ha^{-1}) applied one day after sowing of seeds in polythene bags were effective in controlling the weeds upto 90 DAS.

Sheikh (2005) reported more than 80 per cent weed control efficiency in hand weeding, oxyfluorfen @ 0.10 kg ha^{-1} and pendimethalin 0.75 kg ha^{-1} supplemented with hand weeding in chilly. Also maximum weed control efficiency was found on pre emergence application of oxyfluorfen @ 0.2 kg ha^{-1} in cabbage (Anuradha *et al*., 2006).

Pre emergence application of oxyfluorfen along with one hand weeding at 35 days after transplanting was superior to the use of herbicides viz, pendimethalin, fluchloralin and alachlor when applied alone and also with one hand weeding at 35 days after transplanting in onion (Nisha, 2007).

Sharma *et al*. (2009) recorded that pendimethalin @ 0.5 kg ha^{-1} and oxyfluorfen @ 0.125 kg ha^{-1} resulted in better weed control and seedling production in onion nursery. Also, an experiment conducted by Abraham *et al*. (2010) revealed that oxyfluorfen 150 – 200 g ha^{-1} could effectively control weeds of rice such as grasses, sedges and broadleaved weeds if applied as pre emergence spray four days after transplanting.

An experiment conducted by Sathyapriya *et al.* (2012) to evaluate the influence of oxyfluorfen on weed control in onion and their residual effect on succeeding crops. It was reported that oxyfluorfen @ 400 g ha^{-1} gave lower weed density, weed dry weight and higher weed control efficiency at all stages. Succeeding crops like sunflower and pearl millet were not affected by the residue of the herbicide.

Sathyapriya *et al.* (2017b) conducted an experiment to evaluate the effect of oxyfluorfen for weed control in groundnut. They found that pre emergence application of oxyfluorfen @ 250 g ha^{-1} resulted in lower weed density and dry weight and enhanced the productivity of groundnut which resulted in higher economic returns. Application of oxyfluorfen 480 g ha^{-1} significantly reduced the weed dry weight till 56 days after transplanting and did not cause any injury to broccoli. Also, the yield obtained from this treatment 15.18 t ha^{-1} was on par with the yield in weed free treatment (Widaryanto and Roviyanti, 2017).

2.4.4.2 Effect of oxyfluorfen on growth, yield and quality of crops

Under rainfed conditions and with heavy infestation of wild oats, only oxyfluorfen gave higher garlic yield when compared with oxadiazon, pendimethalin and methabenzthiazuron (Qasem, 1996).

Gilreath and Santos (2005) reported that napropamide plus oxyfluorfen treatment resulted in highest fruit number and weight, increased yield by 20 per cent when compared to non-treated control in strawberry.

Kolse *et al.* (2010) concluded that oxyfluorfen @ 0.1875 kg ha^{-1} along with one hand weeding at 30 DAS was most effective in controlling weeds and increasing bulb yield thus the monetary returns.

Sathyapriya *et al.* (2017a) revealed that pre emergence application of oxyfluorfen @ 250 g ha^{-1} recorded higher grain yield of 6642 kg ha^{-1} in transplanted rice due better control of weeds at critical stages. Higher yield and quality of chickpea can be achieved by application of oxyfluorfen 0.18 kg ha^{-1} as pre emergence followed by pre mix (imazamox + imazethapyr) 0.03 kg ha^{-1} as post emergence at 40 DAS (Rupareliya *et al*., 2017).

2.5 Nutrient removal by weeds

Weeds compete heavily with the crop for nutrients, water, space and light.

Warde *et al.* (2007) found that lowest uptake of phosphorous by weed and higher uptake by onion crop was observed in plots which received herbicides along with two hand weedings as compared to other treatments.

An experiment was conducted by Borah *et al.* (2008) at Assam Agricultural University, Jorhat to study the nutrient removal by crop and weeds under different weed and nutrient management practices in transplanted autumn rice – winter rice cropping sequence. Among the treatments, highest nutrient removal (N, P and K) by weeds was observed with one hand weeding at tillering stage (farmer’s practice). Also, rotation of herbicide without nutrient substitution resulted in lowest nutrient removal by weeds at harvest stage of the crop.

In an experiment conducted by Gaikwad *et al.* (2010), they reported that the application of pre emergence herbicides such as oxyfluorfen, fluchloralin and oxadiargyl along with one hand weeding at 30 days after planting were effective in reducing the nutrient loss from the soil by weeds than the herbicides alone. Raj kumara *et al.* (2010) observed that throughout the crop period unweeded control removed 141.52 kg ha^{-1} of nitrogen.

Chander *et al.* (2013) carried out an experiment at Palampur, to evaluate the nutrient removal by weeds in soybean – wheat cropping system. The highest removal of N, P and K (71.5 kg, 6.9 kg and 97.4 kg) was from the unweeded check, thus depriving crops for that much amount of available nutrients. The lowest removal of nutrients by weeds (23.4 kg, 4.0 kg and 31.4 kg) was observed in application of pendimethalin @ 1.5 kg ha^{-1} (pre emergence) followed by chlorimuron – ethyl @ 4 g ha^{-1} (early post emergence).

Parameswari and Srinivas (2014) found out that the farmer's practice of hand weeding in rice resulted in lower removal of N, P and K compared to other treatments. This was on par with use of bensulfuron methyl 60 g ha^{-1} + pretilachlor 600 g ha^{-1} followed by hand weeding at 30 DAT.

2.6. Economics

Prakash *et al.* (2001) carried out an experiment at Vivekananda Partvatiya Krishi Anusandhan, Almora, Uttaranchal to study on integrated weed management in okra under mid hill condition of North West Himalayas. The highest crop yield, net profit and benefit cost ratios were recorded in hand weeding at 20, 40, 60 and 80 DAS treatment.

An experiment was conducted during kharif season at Navsari, Gujarat to study response of kharif okra to spacing and weed management under south Gujarat condition. They found that highest net profit was obtained from application of pendimethalin 1.0 kg ha^{-1} (Rs. 89198/ha) which was followed by alachlor 1.0 kg ha^{-1} (Rs 51304/ha) (Patel *et al*., 2004).

Sharma and Patel (2011) observed that the B:C ratio was higher under the treatment of interculturing + hand weeding at 30 and 60 DAS followed by pre emergence application of pendimethalin @ 1 kg ha^{-1} followed by hand weeding at 30 DAS and quizalofop-ethyl 75 g ha^{-1} as post emergence followed by hand weeding at 30 DAS.

Jalendhar (2012) observed that among different herbicides used, the gross returns, net returns and B: C ratio was highest with the application of oxyfluorfen as pre emergence @ 0.15 kg/ha followed by one hand weeding at 30 DAS.

Rajashree (2017) concluded that pre emergence application of pendimethalin @ 1 kg ha^{-1} along with one hand weeding recorded highest B:C ratio of 2.88 when compared with application of pendimethalin alone and post emergent herbicides such as metribuzin and glyphosate.

3. Materials & Methods

3. MATERIALS AND METHODS

An experiment on ‘Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)’ was carried out at Water Management Research Unit, Vellanikkara, Thrissur in 2019 - 2020. The details of materials used and the methodology adopted for the study are described in this chapter.

3.1. General Details

3.1.1. Location

The experiment was conducted at Water Management Research Unit, Vellanikkara, Thrissur, Kerala. The experimental field is geographically located at 13^0 32' N latitude and 76^0 26' E longitude. The experimental field lies at an altitude of 40.3 m above mean sea level.

3.1.2. Season of the experiment

The season selected for the experiment was summer. Sowing was done in December 2019 and crop duration was up to April 2020.

3.1.3. Weather condition during the experimental period

The area experiences a typical humid tropical climate. The meteorological data for the period of investigation are given in Fig.1 and Appendix 1. The prevailing weather during this period was normal. The maximum temperature, minimum temperature and average relative humidity recorded during the cropping period were 34.74 ^{0} C, 23.14 ^{0} C and 61.20 per cent respectively. No rainfall was recorded during the experimental period.

3.1.4. Soil characters

The soil of the experimental field was sandy loam in texture belonging to the order Ultisol. The data on pre-experimental physical and chemical properties of the soil are presented in the Table 1.

3.1.6. Cropping history of the experimental site

The experimental field was under okra, amaranth and chilly cultivation during previous years.

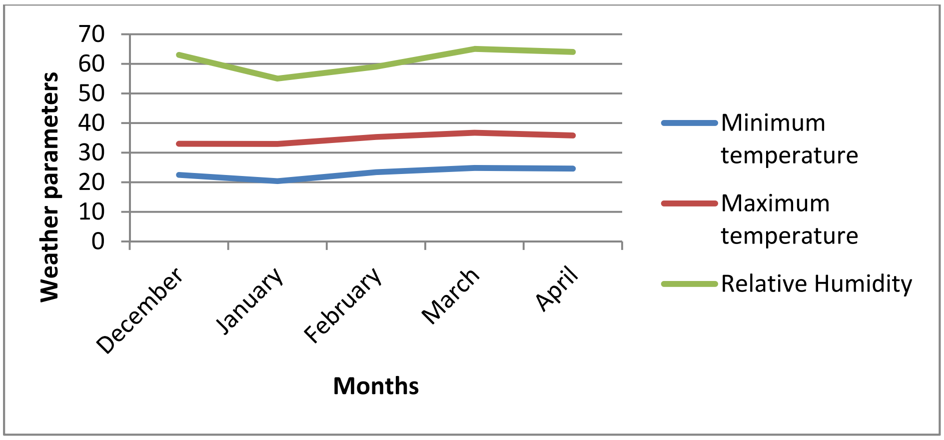

Fig 1. Mean monthly weather data on maximum temperature, minimum temperature and relative humidity

R_1T_1	R_2T_9	R_3T_6
R_1T_6	R_2T_7	R_3T_8
R_1T_7	R_2T_1	R_3T_3
R_1T_5	R_2T_2	R_3T_5
R_1T_8	R_2T_8	R_3T_{10}
R_1T_{10}	R_2T_5	R_3T_9
R_1T_3	R_2T_6	R_3T_4
R_1T_4	R_2T_{10}	R_3T_7
R_1T_2	R_2T_3	R_3T_1
R_1T_9	R_2T_4	R_3T_2

Fig 2. Layout of the experimental field

3.2. Materials used

3.2.1. Crop and variety

The okra variety used for this study was Arka Anamika. Plants are tall, well branched and the stem is green with purple shade. Purple pigment is present on both sides of the petal base. The fruits are green in colour and long. This variety is resistant to yellow vein mosaic disease. The yield potential of okra is 10 – 15 t ha^{-1} under good management practices with duration of 110 days.

3.2.2. Seed rate

A seed rate of 8.5 kg ha^{-1} was adopted as per POP recommendation of Kerala Agricultural University (KAU, 2016).

3.2.3. Source of nutrients

The organic source used was farm yard manure @ 20 t ha^{-1}. The nutrient content of farm yard manure was 0.5 % N, 0.4 % P and 0.3 % K.

Fertilizers containing the following nutrients were also used for the study.

Urea	-	46 % N
Factamphos	-	20 % N , 20 % P_2O_5
Muriate of Potash	-	60 % K_2O_5
19:19:19	-	19 % N, 19 % P_2O_5, 19 % K_2O

3.2.4. Lime

Lime @ 350 kg ha^{-1} was applied uniformly to all the treatment plots one week before sowing.

3.2.5. Plant protection chemicals

Pesticides were applied as and when necessary as per the recommendation of the Kerala Agricultural University (KAU, 2016).

3.2.6 Herbigation equipment

Fertilizer injector pump was used for herbicide injection to the irrigation system. Pressure gauge was attached in the system to observe the water pressure.

3.3. Experimental Details

3.3.1. Design and layout

The experiment was laid out in Randomized Block Design (RBD) with ten treatments replicated three times. The experiment consisted of four treatments with herbigation, four with conventional application of herbicides, one hand weeded control and one unweeded control. The plot size was 4m x 2.4m. The treatment details are given in Table 2 and lay out of the experiment is given in Figure 2.

Table 1. Physico – chemical properties of soil

Parameters	Value	Method used
1. Particle size composition of soil		
Sand (%)	52	Robinson's International Pipette method (Piper, 1996)
Silt (%)	23.5	
Clay (%)	24.5	
2. Chemical properties		
1. pH	6.08	1:2.5 soil water ratio (Jackson, 1958)
2. Organic carbon (%)	1.52	Walkley and Black method (Walkley and Black, 1934)
3. Available N (kg/ha)	182.20	Alkaline permanganate method (Subbiah and Asija, 1956)
4. Available P (kg/ha)	76.14	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz,1945; Watanabe and Olsen,1965)
5. Available K (kg/ha)	181.43	Neutral Normal NH_4OAC extract method using flame photometry (Jackson, 1958)

3.3.2. Treatments

Table 2. Details of treatments in the experiment

Treatments	
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb HW at 30 DAS
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb HW at 30 DAS
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb HW at 50 DAS
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb HW at 50 DAS
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb HW at 30 DAS
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb HW at 30 DAS
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb HW at 50 DAS
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb HW at 50 DAS
T_9	Hand weeded control
T_{10}	Unweeded control

*fb - followed by * - HW – Hand weeding

3.4. Field operations

3.4.1. Land preparation

The experimental area was ploughed twice to get a fine tilth and levelled. Raised beds of size 4 m x 2.4 m size were formed.

3.4.2. Sowing

Pre-soaked okra seeds were dibbled uniformly in the beds at a spacing of 60 cm x 30 cm. Sowing was done on 13-12-2019.

3.4.3. Manures and fertilizer

In all the treatments manures and fertilizers were applied as per Package of Practices Recommendations (KAU, 2016). FYM was applied at the rate of 20 t ha^{-1} incorporated before sowing. N, P, and K were applied based on KAU recommendation.

Table 3. KAU Package of Practices Recommendation of Fertilizers

	N (kg/ha)	P (kg/ha)	K (kg/ha)
Basal application	55	35	70
Top dressing @ 30 DAS	55	-	-

3.4.4. Irrigation

For drip irrigation, drip lines were laid in such a way that each plant was provided with one emitter with a discharge rate of 2 liters per hour. Irrigation was given daily at the rate of 125 per cent pan evaporation. The volume of water applied was calculated based on the formula

$$\text{Volume (l)} = \text{Pan evaporation [Epan (mm)]} \times \text{Area } (m^2)$$

The time of operation for drip irrigation system to deliver the required volume of water per plot was computed based on the formula.

$$\text{Time of application (h)} = \frac{\text{Volume of water (L)}}{\text{Discharge rate of emitter (Lph)} * \text{Number of emitters}}$$

The volume of water calculated for each plot was 48 litres and time of operation for drip as 24 minutes.

3.4.5 Herbigation

Herbicide was introduced into the irrigation system using fertilizer injection pump. The quantity of herbicide required was calculated based on the treatment and area.

3.4.6 Weeding

Hand weeding was done as per the treatments. The hand weeded control was kept weed free till 50 DAS. No weeding was done in unweeded control.

3.4.7 Plant protection measures

Need based application of plant protection chemicals was done whenever required to control sucking pests and caterpillars.

3.4.8 Harvesting of fruits

Harvesting of tender fruits was started at 45 DAS and done on alternate days manually.

Plate 1. General view of the experimental field

Plate 2. Seedling stage

Plate 3. Flowering Plate 4. Fruiting

Plate 5. Toxicity observed in crop during conventional spraying

Plate 6. Fertilizer injector used for herbigation

Plate 7. Wetted area during herbigation

3.5 Observations

From each plot five plants were selected and labelled. Biometric observations were recorded at 30 DAS, 60 DAS and 90 DAS.

3.5.1. Biometric observations on crop

3.5.1.1. Plant height

Height of the plant was measured from base of the plant to the tip. Height of observation plants was taken and its mean was recorded in cm.

3.5.1.2. Number of leaves per plant

The total number of leaves produced on observation plants was noted and the average was calculated.

3.5.1.3. Leaf area

The length and breadth of five leaves from each plant were measured and leaf area was calculated by using factor method.

$$\text{Leaf area (cm}^2\text{)} = \text{Length x breadth x k}$$

Where k is leaf area constant and is the ratio of actual leaf area to the apparent leaf area.

3.5.1.4. Days to first flower opening

The number of days to first flower opening from date of sowing was recorded from each plot.

3.5.1.5. Node at which first flower was formed

The node at which the first flower was formed was recorded on observation plants.

3.5.2. Yield and yield attributes

3.5.2.1. Number of fruits per plant

Total number of fruits from five plants in all harvests was taken and the average was calculated.

3.5.2.2. Average fruit weight

The weight of five randomly selected fruits from all harvests was recorded and then mean was calculated and expressed in grams.

3.5.2.3. Fruit yield per plant

Average fruit yield of five plants from all harvests was taken and expressed in grams per plant.

3.5.2.4. Fruit yield

Yield from net plot was calculated and was expressed in t ha^{-1}.

3.5.3. Observations on weeds

3.5.3.1. Weed species composition

Species identification was done using 50 cm ^{x} 50 cm (0.25 m^2) quadrat. The quadrat was placed at random inside the plot and observations were recorded at 20 DAS, 50 DAS and 80 DAS. The weed species were identified and recorded.

3.5.3.2. Weed count

Species wise weed count was recorded using 50 cm ^{x} 50 cm (0.25 m^2) quadrat. The quadrat was placed at random inside the sampling strip and observations were taken from the plot at 20 DAS, 50 DAS and 80 DAS. It was expressed in numbers per m^2.

3.5.3.3. Weed dry matter production

The weeds collected from the quadrat were uprooted, cleaned, shade dried and then dried to constant weight at 80°C. The dry weight was expressed in kg ha^{-1}.

3.5.3.4. Weed control efficiency (WCE)

The weed control efficiency was worked out using the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{\text{Weed dry weight in unweeded plot} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in unweeded plot}} \times 100$$

3.5.3.5. Weed index (WI)

Weed index was worked out using the formula suggested by Gill and Vijayakumar (1969).

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

X = Yield from treatment with least weeds

Y = Yield from treated plots

3.5.4. Plant analysis

For estimating content and uptake of macronutrients, destructive sampling was done at 20, 50 and 80 DAS from each treatment. The collected samples were shade dried first and then oven dried at 80^0C. These samples were ground and 0.2g samples were taken, digested and nutrient content was estimated as per standard procedures (Table 4). Plant uptake of macronutrients was calculated by multiplying nutrient content of plant samples with total dry weight of the plants. The uptake values were expressed in kg ha^{-1}.

Table 4. Methods used for analysis of plant samples

Sl. No.	Nutrient	Method
1	N	Microkjeldhal method (Jackson, 1958)
2	P	Diacid extract estimated colorimetrically in Spectrophotometer (Jackson, 1958)
3	K	Diacid extract method using Flame Photometer (Jackson, 1958)

3.5.8 Soil analysis

Soil analysis was done for estimating pH, organic carbon, available N, P, and K. For soil analysis, soil samples were collected from each plot, shade dried, powdered and sieved. For organic carbon estimation, soil was ground and passed through 0.5mm sieve. For reading soil pH, soil water suspension of 1:2.5 was taken. Samples passed through 2 mm sieve were used for estimation of macronutrients. Estimation of macronutrients was done using standard procedures (Table 1). The available N, P and K were expressed in kg ha^{-1}.

3.6 Economics

Cost of cultivation was computed by adding prevailing labour charge in the area, input costs and treatment costs. Gross return was calculated based on the market price of okra. Net returns is the difference between gross returns and cost of cultivation. It was expressed in rupees per ha. The ratio of gross return to cost of cultivation was the benefit: cost ratio.

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

3.7. Statistical analysis

The data related to different characters were tabulated and statistically analysed by using the technique of analysis of variance using the statistical package WASP 2.0. The significance of difference among treatments was estimated by using Duncan's Multiple Range Test (DMRT) at 5 % level of probability (Gomez and Gomez, 1984). Square root transformation was done for the weed count data.

4. Results

4. RESULTS

The experiment titled ‘Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)’ was conducted in Water Management Research Unit, Vellanikkara during the year 2019-2020. It was conducted to study the effect of herbigation in okra and also to evaluate the economic feasibility of the system. The observations collected were statistically analysed and the results obtained are presented below.

4.1. Growth characters

4.1.1. Plant height

The treatments showed no significant influence on plant height at 30 days after sowing (DAS), but had significant influence at 60 DAS and at 90 DAS (Table 5). The greatest plant height at 60 DAS was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS (76.27 cm). At 90 DAS, conventional spraying @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS (86.87cm) recorded greatest plant height. At 60 DAS and 90 DAS, all herbicide treatments except T_3 and T_4 had significantly taller plants which were on par. T_3 and T_4 recorded lower height and were on par with unweeded control. At all the stages the lowest plant height was recorded in unweeded control (T_{10}) (57.13 cm).

4.1.2. Number of leaves per plant

The treatments showed no significant influence on number of leaves of okra at 30 DAS, but significant effect was observed at 60 and 90 DAS (Table 6). This showed same trend as plant height. At 60 DAS, the highest number of leaves was recorded in the treatment which received conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (19.00). At 90 DAS, the highest number of leaves per plant was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (30.07). At 60 DAS and 90 DAS, all herbicide treatments except T_3 and T_4 had significantly more number of leaves which were on par. T_3 and T_4 recorded lower number of leaves and was on par with unweeded control. Lowest number of leaves was observed in unweeded control.

4.1.3. Leaf area (cm^2)

Leaf area was significantly influenced by the treatments and the data pertaining to leaf area at different stages of crop growth is presented in Table 7.

At 30 DAS, the leaf area was not significantly different among the treatments. At 60 and at 90 DAS statistical analysis of the data showed that different treatments had significant influence on leaf area of the crop. At 60 DAS, significantly higher leaf area (330.88 cm^2) was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS. This was on par with both treatments of herbigation @ 0.15 kg ha^{-1} and 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, all conventional spraying treatments and hand weeded control. The lowest leaf area was recorded in unweeded control (160.29 cm^2), which was on par with T_3 and T_4.

At 90 DAS, significantly higher leaf area was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS (267.78 cm^2). It was on par with herbigation @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, all conventional spraying treatments and hand weeded control. The lowest leaf area was recorded in unweeded control which was on par with T_3.

4.1.4. Days to first flower opening

The data pertaining to number of days taken for first flower opening is presented in Table 8. Statistical analysis of the data showed that in all the treatments the number of days taken for first flowering did not significantly differ. All the treatments except T_5 and T_8 flowered at 35 DAS whereas T_5 and T_8 flowered at 36 DAS. More number of days (37 DAS) were taken by plants grown in unweeded control (T_{10}).

4.1.5. Node at which first flower is formed

Observations on node at which first flower was formed is given in Table 8. Statistical analysis of the data showed no significant difference between the treatments, in all the treatments first flower appeared on fourth node.

Table 5. Effect of the treatments on plant height of okra

Treatments		Plant height (cm)		
		30 DAS*	60 DAS	90 DAS
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	48.75	76.27^{a}	86.80^{a}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	38.46	67.13^{a}	76.33^{ab}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	39.87	47.87^{b}	59.80^{bc}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	31.91	47.93^{b}	59.40^{bc}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	40.31	73.73^{a}	83.80^{a}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	38.69	68.07^{a}	78.53^{a}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	40.05	73.20^{a}	86.87^{a}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	36.49	66.93^{a}	79.20^{a}
T_9	Hand weeded control	38.07	60.73^{ab}	71.73^{abc}
T_{10}	Unweeded control	37.76	48.07^{b}	57.13^{c}

* - Non significant

Mean value with common superscripts do not differ significantly.

Table 6. Effect of the treatments on number of leaves per plant

Treatments		Number of leaves per plant		
		30 DAS *	60 DAS	90 DAS
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	7.47	11.73^{ab}	19.47^{cde}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	6.60	15.73^{ab}	25.13^{abc}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	7.13	8.93^{c}	16.47^{e}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	7.33	8.93^{c}	16.70^{e}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	8.60	19.00^{a}	30.07^{a}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	7.93	15.60^{ab}	22.67^{bcde}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	7.87	14.13^{abc}	20.80^{bcde}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	7.20	15.73^{ab}	26.93^{ab}
T_9	Hand weeded control	6.87	16.87^{ab}	23.80^{abcd}
T_{10}	Unweeded control	6.60	8.87^{c}	17.40^{de}

* - Non significant

Mean value with common superscripts do not differ significantly

Table 7. Effect of treatments on leaf area of okra at different growth stages

Treatments		Leaf area (cm^2)		
		30 DAS *	60 DAS	90 DAS
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	198.52	326.16^{a}	267.78^{a}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	171.01	320.27^{a}	267.09^{a}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	120.78	164.33^{cd}	128.49^{b}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	124.68	187.14^{bcd}	189.00^{ab}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	192.73	293.25^{a}	242.56^{a}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	159.42	282.82^{ab}	236.87^{a}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	173.75	330.88^{a}	264.32^{a}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	149.43	259.04^{abc}	210.14^{a}
T_9	Hand weeded control	151.36	329.64^{a}	246.48^{a}
T_{10}	Unweeded control	117.77	160.29^{d}	123.90^{b}

* - Non significant

Mean value with common superscripts do not differ significantly

Table 8. Effect of the treatments on number of days to first flower opening and node at which first flower is formed

Treatments		Days to first flower opening (DAS)*	Node at which first flower is formed *
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	35.33	4.33
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	35.33	4.33
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	35.33	4.33
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	35.33	4.67
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	35.67	4.33
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	35.33	4.67
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	35.33	4.00
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	36.00	4.67
T_9	Hand weeded control	35.33	4.67
T_{10}	Unweeded control	37.00	4.67

* - Non significant

Mean value with common superscripts do not differ significantly

4.2. Yield and yield attributes

4.2.1. Number of fruits per plant

The data related to number of fruits per plant are given in Table 9. The highest number of fruits per plant was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS (17.8). It was on par with herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, both treatments of conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1}, conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS and hand weeded control. The lowest number of fruits per plant was recorded in unweeded control (9.31).

4.2.2. Fruit yield per plant (g)

The data of fruit yield per plant presented in Table 9 indicated that there was significant difference among the various treatments. Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS resulted in higher fruit yield per plant (243.90 g). It was on par with herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and hand weeded control. The lowest fruit yield per plant was recorded in unweeded control. Also, both treatments of herbigation @ 0.15 kg ha^{-1} and 0.20 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS recorded poor fruit yield per plant.

4.2.3. Average fruit weight (g)

The data related to average fruit weight given in Table 9 indicated significant differences among the treatments. The highest average fruit weight was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (14.58 g). It was on par with all other conventional spraying treatments, both treatments of herbigation with oxyfluorfen @ 0.20 kg ha^{-1}, herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and hand weeded control. The lowest average fruit weight was recorded in unweeded control and herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS.

4.2.4. Fruit yield (t ha^{-1})

The data related to the fruit yield are given in Table 9. Hand weeded control recorded highest fruit yield (13.04 t ha^{-1}). It was on par with herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. The lowest value was recorded in unweeded control (5.35 t ha^{-1}).

Table 9. Effect of treatments on number of fruits per plant, fruit yield per plant, average fruit weight and fruit yield.

Treatments		Fruit yield per plant (g)	Average fruit weight (g)	Fruit yield (t ha^{-1})	Number of fruits per plant
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	243.90^{a}	13.73^{a}	13.02^{a}	17.8^{a}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	218.50^{abc}	13.84^{a}	12.14^{abc}	15.85^{ab}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	140.30^{ef}	11.19^{bc}	7.79^{de}	12.53^{bcd}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	128.90^{fg}	12.26^{abc}	7.16^{ef}	10.60^{cd}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	228.54^{ab}	14.20^{a}	12.70^{ab}	16.15^{ab}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	175.14^{de}	14.58^{a}	9.73^{cd}	12.59^{bcd}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	184.70^{cd}	13.43^{ab}	10.26^{c}	14.05^{abc}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	189.74^{bcd}	12.90^{abc}	10.54^{bc}	14.70^{ab}
T_9	Hand weeded control	220.32^{ab}	13.16^{ab}	13.04^{a}	15.92^{ab}
T_{10}	Unweeded control	96.30^{g}	10.42^{c}	5.35^{f}	9.31^{d}

Mean value with common superscripts do not differ significantly

4.3. Observations on weeds

4.3.1. Weed species composition

The weed flora of experimental field consisted of grasses, sedges, and broad leaved weeds (Table 10). The observations showed that there were 27 species of weeds, of which seven species were grasses, two were sedges and 18 species were broad leaved weeds. The predominant weeds were *Cyperus rotundus, Digitaria sanguinalis, Panicum maximum, Alternanthera bettzickiana, Mitracarpus verticillatus* and *Trianthema portulacastrum*.

Table 10. Weed species composition

Sl. No.	Grasses	Sl. No.	Broad leaved weeds
1	*Panicum maximum*	1	*Mimosa pudica*
2	*Digitaria sanguinalis*	2	*Ageratum conyzoides*
3	*Stenotaphrum secundatum*	3	*Euphorbia hirta*
4	*Pennisettum pedicillatum*	4	*Mollugo disticha*
5	*Brachiaria miliformis*	5	*Mitracarpus verticillatus*
6	*Digitaria bicornis*	6	*Cleome burmanii*
7	*Axonopus compressus*	7	*Phyllanthus niruri*
		8	*Trianthema portulacastrum*
	Sedges	9	*Portulaca oleracea*
1	*Cyperus sp.*	10	*Cassia tora*
2	*Bulbostylis barbata*	11	*Leucas aspera*
		12	*Alternanthera bettzickiana*
		13	*Melochia corchorifolia*
		14	*Ludwigia parviflora*
		15	*Cleome viscosa*
		16	*Scoparia dulcis*
		17	*Synedrella nodiflora*
		18	*Biophytum sensitivum*

4.3.2. Weed count at 20 DAS (no. /m^2)

Data on effect of treatments on weed count in the experiment field are presented in Table 11. Observations on total weed count and species wise weed count were also recorded.

4.3.2.1. Grasses

The different treatments applied had significant influence on grass weed population in the field. The treatment which received conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS recorded lowest number of grass weeds (2.08). It was on par with all other conventional spraying treatments The highest weed count was recorded in unweeded control (8.21).

4.3.2.2. Sedges

Different treatments had significant influence on sedges weed count also. Significantly lower number of sedges were recorded in both treatments of conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} and conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS (0.71). Highest number of sedges was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_3) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (3.93).

4.3.2.3. Broad leaved weeds

Significantly lower number of broad leaved weeds (4.04) was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS. It was on par with all conventional spraying treatments and hand weeded control. The highest number of broad leaved weeds (13.08) was observed in unweeded control.

4.3.2.4. Total weed count

Analysis showed that significantly lower weed count was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (21.33). It was on par with all conventional spraying treatments and hand weeded control. Highest weed count (256.00) was recorded in unweeded control.

4.3.3. Weed count at 50 DAS (no. /m^2)

The data pertaining to weed count at 50 DAS are presented in Table 12.

4.3.3.1. Grasses

Conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (3.50) recorded the lowest number of weeds. It was on par with all other conventional spraying treatments, herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. The highest weed count (7.64) was recorded in unweeded control.

4.3.3.2. Sedges

Considering all the treatments, conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS recorded (0.71) lowest weed count of sedges. Unweeded control recorded highest number of sedges (3.93) and it was on par with herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS and hand weeded control.

4.3.3.3. Broad leaved weeds

Significantly lower number of broad leaved weeds was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (3.91). It was on par with all other conventional spraying treatments.. T_3 and T_4 recorded higher number of broad leaved weeds and was on par with unweeded control (T_{10}) (14.81).

4.3.3.4. Total weed count

The lowest weed count (5.56) was significantly recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_8) two days before sowing and 25 DAS followed by hand weeding at 50 DAS. It was on par with all other conventional spraying treatments. Highest total weed count was recorded in unweeded control (17.15).

4.3.4. Weed count at 80 DAS (no. /m^2)

Data on effect of treatments on weed count at 80 DAS are given in Table 13.

4.3.4.1. Grasses

Significantly lower number of grass weeds was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (2.97). It was on par with all other conventional spraying treatments, herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. Unweeded control recorded highest number of grass weeds (8.55), followed by treatments involving herbigation twice.

4.3.4.2. Sedges

The treatments showed no significant influence on number of sedges grown in the experiment field.

4.3.4.3. Broad leaved weeds

The lowest number of broad leaved weeds was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (4.37). It was on par with all other conventional spraying treatments and hand weeded control. Unweeded control recorded highest number of broad leaved weeds (16.95).

4.3.4.4. Total weed count

Significantly minimum number of weeds (5.87) was found in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS. It was on par with all other conventional spraying treatments. All other treatments reduced the weed population and were significantly superior to unweeded control (19.39).

Table 11. Effect of treatments on weed count at 20 DAS

Treatments		Grasses	Sedges	BLWs	Total
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	6.72^{ab}	3.12^{ab}	8.39^{abcd}	11.46^{b}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	5.62^{bc}	3.03^{ab}	8.60^{abcd}	11.22^{b}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	4.80^{bcd}	3.93^{a}	10.97^{ab}	12.71^{ab}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	6.07^{bc}	1.65^{bc}	10.02^{abc}	11.91^{ab}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.10^{de}	2.56^{ab}	4.84^{cd}	6.75^{cd}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	2.08^{e}	0.71^{c}	4.04^{d}	4.55^{d}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	4.16^{cd}	0.71^{c}	4.32^{d}	6.15^{cd}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	2.94^{de}	0.71^{c}	4.82^{d}	5.73^{cd}
T_9	Hand weeded control	5.73^{bc}	2.56^{ab}	6.86^{bcd}	9.48^{bc}
T_{10}	Unweeded control	8.21^{a}	2.59^{ab}	13.08^{a}	15.75^{a}

Mean value with common superscripts do not differ significantly

Table 12. Effect of treatments on weed count at 50 DAS

Treatments		Grasses	Sedges	BLWs	Total
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	4.14^{bcd}	2.77^{ab}	9.30^{b}	10.58^{b}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	4.04^{cd}	2.56^{abc}	8.22^{bc}	9.60^{bc}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	6.44^{ab}	1.44^{bc}	13.26^{a}	14.90^{a}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	7.24^{a}	3.89^{a}	13.06^{a}	15.50^{a}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	4.20^{bcd}	2.77^{ab}	6.49^{bcd}	8.57^{bc}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.50^{d}	1.18^{bc}	5.91^{cd}	7.07^{cd}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	4.28^{bcd}	0.71^{c}	3.91^{d}	5.87^{d}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	3.52^{d}	1.18^{bc}	4.07^{d}	5.56^{d}
T_9	Hand weeded control	6.28^{abc}	3.67^{a}	7.62^{bc}	10.65^{b}
T_{10}	Unweeded control	7.64^{a}	3.93^{a}	14.81^{a}	17.15^{a}

Mean value with common superscripts do not differ significantly

Table 13. Effect of treatments on weed count at 80 DAS

Treatments		Grasses	Sedges	BLWs	Total
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	4.21^{cd}	2.65^{a}	11.25^{b}	12.32^{b}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.82^{cd}	1.92^{a}	9.38^{bc}	10.34^{bc}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	4.98^{bc}	2.39^{a}	9.99^{b}	11.47^{b}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	5.76^{b}	2.30^{a}	10.52^{b}	12.27^{b}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	4.12^{cd}	2.56^{a}	7.15^{cd}	8.83^{cd}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	2.97^{d}	1.18^{a}	6.08^{de}	6.94^{de}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	3.77^{cd}	0.71^{a}	4.37^{e}	5.87^{e}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	3.45^{d}	1.18^{a}	4.89^{e}	6.17^{e}
T_9	Hand weeded control	5.65^{b}	4.13^{a}	6.04^{de}	9.28^{c}
T_{10}	Unweeded control	8.55^{a}	3.79^{a}	16.95^{a}	19.39^{a}

Mean value with common superscripts do not differ significantly

4.3.5. Weed dry matter production (kg ha^{-1})

Observations on effect of treatments on dry matter production of weeds at different growth stages of the crop showed significant difference (Table 14).

At 20 DAS, significantly lower dry weight of weeds was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (8.1 kg ha^{-1}). It was on par with treatments of conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} & 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and hand weeded control. The highest dry weight of weeds observed in unweeded control (93.2 kg ha^{-1}), followed by herbigation treatments.

At 50 DAS, the lowest dry weight of weeds was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (83.3 kg ha^{-1}) and was on par with treatments T_1, T_2, T_4, T_6, T_7, T_8, T_9. The highest dry weight of weeds was recorded in unweeded control (840.0 kg ha^{-1}). At 80 DAS, the lowest dry weight of weeds recorded in hand weeded control (126.7), which was on par with all treatments except T_6 and T_{10}. The highest dry weight of weeds observed in unweeded control (1346.7 kg ha^{-1}).

4.3.6. Weed control efficiency (%)

Weed control efficiency was calculated on the basis of dry weight of weeds recorded in different treatments at different stages of crop growth in comparison to unweeded control. The data are presented in Table 15.

At 20 DAS, highest weed control efficiency (WCE) was observed in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (91.31%) followed by conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1}) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (87.54%). However lowest WCE was in the treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS (40.77%).

At 50 DAS, conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS recorded highest WCE (90.08 %). However, lowest WCE was in the treatment (T_3) herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS (61.90 %).

At 80 DAS, significantly the highest WCE was observed in the treatment hand weeded control (90.59 %) closely followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (90.10 %). The treatment conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_8) two days before sowing and 25 DAS followed by hand weeding at 50 DAS recorded minimum WCE (81.19 %).

4.3.7. Weed index (%)

The Table 16 shows the effect of different weed control measures on weed index. Regarding weed index the lowest value was recorded in the treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS and it was followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. However highest weed index was recorded in unweeded control (58.97 %).

Table 14. Effect of treatments on weed dry matter production

Treatments		Weed dry matter production (kg ha^{-1})		
		20 DAS	50 DAS	80 DAS
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	55.2^{bc}	110.0^{c}	200.0^{bc}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	51.5^{bc}	140.0^{c}	203.3^{bc}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	55.1^{bc}	320.0^{b}	240.0^{bc}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	59.7^{b}	240.0^{bc}	206.7^{bc}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	28.1^{cd}	83.3^{c}	133.3^{c}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	8.1^{d}	116.7^{c}	296.7^{b}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	13.2^{d}	153.3^{c}	243.3^{bc}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	11.6^{d}	180.0^{bc}	253.3^{bc}
T_9	Hand weeded control	13.8^{d}	126.7^{c}	126.7^{c}
T_{10}	Unweeded control	93.2^{a}	840.0^{a}	1346.7^{a}

Mean value with common superscripts do not differ significantly

Table 15. Effect of treatments on weed control efficiency

Treatments		Weed Control Efficiency (%)		
		20 DAS	50 DAS	80 DAS
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	40.77	86.90	85.15
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	44.74	83.33	84.90
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	40.88	61.90	82.18
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	35.94	71.43	84.65
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	69.88	90.08	90.10
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	91.31	86.11	77.97
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	85.82	81.75	81.93
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	87.54	78.57	81.19
T_9	Hand weeded control	85.20	84.92	90.59
T_{10}	Unweeded control	0.00	0.00	0.00

Table 16. Effect of treatments on weed index

Treatments		Weed Index (%)
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	0.15
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	6.90
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	40.26
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	45.09
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	2.61
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	25.38
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	21.32
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	19.17
T_9	Hand weeded control	0.00
T_{10}	Unweeded control	58.97

4.3.8. Nutrient removal by weeds at 20 DAS (kg ha^{-1})

The data related to nutrient removal by weeds at 20 DAS are given in Table 17.

4.3.8.1. Nitrogen

Weeds of the treatment unweeded control recorded highest removal of nitrogen (1.45 kg ha^{-1}). The lowest nitrogen removal was observed in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_2) two days before sowing followed by hand weeding at 30 DAS and conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_3) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (0.11 kg ha^{-1}). These were on par with all other conventional spraying treatments and hand weeded control.

4.3.8.2. Phosphorus

Highest phosphorus was removed by the weeds in unweeded control (0.31 kg ha^{-1}). Lowest phosphorus uptake by weeds was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (0.02 kg ha^{-1}). It was on par with all other conventional spraying treatments, hand weeded control, and treatments involving herbigation twice.

4.3.8.3. Potassium

Weeds of unweeded control (2.11 kg ha^{-1}) recorded the highest removal of potassium. Least potassium uptake by weeds was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (0.03 kg ha^{-1}). It was on par with all other conventional spraying treatments, hand weeded control and herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS.

4.3.9. Nutrient removal by weeds at 50 DAS (kg ha^{-1})

The data pertaining to nutrient removal by weeds at 50 DAS is given in Table 18.

4.3.9.1. Nitrogen

Highest nitrogen was removed by weeds in unweeded control (17.95 kg ha^{-1}). The lowest nitrogen was removed by weeds in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS (1.37 kg ha^{-1}). It was on par with all other conventional spraying treatments, hand weeded control and treatments involving herbigation once.

4.3.9.2. Phosphorus

Weeds of the treatment herbigation with oxyfluorfen @ 0.20 kg ha^{-1} (T_4) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (6.22 kg ha^{-1}) recorded highest removal of phosphorus. It was on par with the unweeded control. The lowest phosphorus uptake was observed in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (0.44 kg ha^{-1}) .

4.3.9.3. Potassium

Weeds of unweeded control recorded the highest removal of potassium (22.75 kg ha^{-1}) and it is followed by herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS. Lowest potassium uptake by weeds was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (1.82 kg ha^{-1}). It was on par with all other conventional spraying treatments, hand weeded control and treatments involving herbigation once.

4.3.10. Nutrient removal by weeds at 80 DAS (kg ha^{-1})

The data related to nutrient removal by weeds at 80 DAS are given in Table 19.

4.3.10.1. Nitrogen

Weeds of unweeded control (31.16 kg ha^{-1}) recorded highest removal of nitrogen. The lowest nitrogen uptake was observed in hand weeded control (1.51 kg ha^{-1}) and all other treatments were on par with hand weeded control.

4.3.10.2. Phosphorus

Highest phosphorus was removed by the weeds in unweeded control (18.33 kg ha^{-1}). Least phosphorus uptake by weeds was recorded in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_8) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (0.77 kg ha^{-1}) and all other treatments were on par with this treatment.

4.3.10.3. Potassium

Weeds of unweeded control (46.13 kg ha^{-1}) recorded highest removal of potassium. Least potassium uptake by weeds was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_3) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (1.22 kg ha^{-1}) and all other treatments were on par with this treatment.

Table 17. Effect of treatments on nutrient removal by weeds at 20 DAS

Treatments		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	0.61^{bc}	0.14^{bc}	0.92^{b}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	0.63^{b}	0.18^{b}	0.73^{bc}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	1.22^{a}	0.10^{bcd}	0.78^{bc}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	0.59^{bc}	0.08^{cd}	0.36^{cd}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	0.23^{bcd}	0.03^{d}	0.14^{d}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	0.11^{d}	0.02^{d}	0.03^{d}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	0.11^{d}	0.07^{cd}	0.10^{d}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	0.22^{bcd}	0.06^{cd}	0.08^{d}
T_9	Hand weeded control	0.18^{cd}	0.04^{d}	0.21^{d}
T_{10}	Unweeded control	1.45^{a}	0.31^{a}	2.11^{a}

Mean value with common superscripts do not differ significantly

Table 18. Effect of treatments on nutrient removal by weeds at 50 DAS

Treatments		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.44^{c}	0.74^{c}	2.81^{cd}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.51^{c}	1.2^{bc}	3.37^{cd}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	17.00^{a}	5.56^{a}	19.88^{ab}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	11.67^{b}	6.22^{a}	16.03^{b}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	1.56^{c}	0.44^{c}	1.82^{d}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	1.37^{c}	0.48^{c}	2.35^{cd}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	3.26^{c}	1.70^{bc}	4.94^{cd}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	5.18^{c}	2.58^{b}	7.36^{c}
T_9	Hand weeded control	2.35^{c}	0.81^{c}	3.85^{cd}
T_{10}	Unweeded control	17.95^{a}	5.10^{a}	22.75^{a}

Mean value with common superscripts do not differ significantly

Table 19. Effect of treatments on nutrient removal by weeds at 80 DAS

Treatments		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.41^{b}	1.15^{b}	2.29^{b}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	2.42^{b}	1.35^{b}	2.22^{b}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	1.62^{b}	0.82^{b}	1.22^{b}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	2.55^{b}	1.43^{b}	2.97^{b}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.78^{b}	1.53^{b}	4.45^{b}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	3.78^{b}	1.57^{b}	5.70^{b}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	3.01^{b}	0.83^{b}	4.44^{b}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	1.65^{b}	0.77^{b}	2.38^{b}
T_9	Hand weeded control	1.51^{b}	0.87^{b}	1.93^{b}
T_{10}	Unweeded control	31.16^{a}	18.33^{a}	46.13^{a}

Mean value with common superscripts do not differ significantly

4.4. Soil analysis

4.4.1. Soil pH

The data regarding soil pH are depicted in Table 20. In general, the soil was acidic. Higher pH of 6.49 was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS. Conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} (T_6) two days before sowing followed by hand weeding at 30 DAS recorded lowest pH of 5.81 after the experiment.

4.4.2. Soil organic carbon (%)

The data containing soil organic carbon are presented in Table 20. The organic carbon decreased after the experiment when compared to the pre experiment status except in unweeded control. Higher percentage of organic carbon was recorded in unweeded control (1.72 %). Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_3) two days before sowing and 25 DAS followed by hand weeding at 50 DAS recorded lowest content of organic carbon (0.68 %).

4.4.3. Nutrient content in soil (kg ha^{-1})

The data related to nutrient content in soil are given in Table 21.

4.4.3.1. Nitrogen

The nitrogen content was highest in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (236.60 kg ha^{-1}). The content of nitrogen was lowest in the treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_3) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (182.00 kg ha^{-1}).

4.4.3.2. Phosphorus

The phosphorus content was highest in (T_1) herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (80.64 kg ha^{-1}) which is followed by hand weeded control (79.01 kg ha^{-1}). The content of phosphorus was least in the treatment (T_4) herbigation with oxyfluorfen @ 0.20 kg

ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS (61.40 kg ha^{-1}).

4.4.3.3. Potassium

Conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_7) two days before sowing and 25 DAS followed by hand weeding at 50 DAS (191.60 kg ha^{-1}) recorded highest amount of potassium in the soil. Herbigation @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (102.03) registered (T_2) lowest amount of potassium in soil.

4.5 Economics

An appraisal of data shown in Table 22 indicated that treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} (T_1) two days before sowing followed by hand weeding at 30 DAS secured highest B:C ratio of 1.97 followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} (T_5) two days before sowing followed by hand weeding at 30 DAS (1.89). The unweeded control registered the lowest B:C ratio of 0.85.

Table 20. Effect of treatments on soil pH and organic carbon

Treatments		Soil pH	Organic carbon (%)
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	6.49^{a}	1.34^{c}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	6.06^{c}	1.28^{d}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	5.88^{g}	0.68^{h}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	6.04^{d}	1.54^{b}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	5.95^{e}	1.22^{e}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	5.81^{i}	1.19^{f}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	6.06^{c}	0.96^{g}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	5.90^{f}	1.34^{c}
T_9	Hand weeded control	5.84^{h}	1.21^{ef}
T_{10}	Unweeded control	6.10^{b}	1.72^{a}
Pre experiment		6.08	1.52

Mean value with common superscripts do not differ significantly

Table 21. Effect of treatments on available N, P and K in soil

Treatments		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	216.40^{e}	80.64^{a}	103.19^{i}
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	199.80^{g}	64.27^{i}	102.03^{j}
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	182.00^{i}	74.50^{d}	157.10^{d}
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	192.20^{h}	61.40^{j}	168.78^{b}
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	236.80^{a}	65.50^{g}	127.98^{h}
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	226.80^{c}	78.19^{c}	139.74^{g}
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	231.80^{b}	71.64^{e}	191.60^{a}
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	218.90^{d}	65.09^{h}	158.59^{c}
T_9	Hand weeded control	200.80^{f}	79.01^{b}	155.64^{e}
T_{10}	Unweeded control	191.80^{h}	67.54^{f}	146.98^{f}
Pre-experiment		182.20	76.14	181.43

Mean value with common superscripts do not differ significantly

Table 22. Economics of okra cultivation as influenced by various treatments

Treatments		Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	132253	260400	128147	1.97
T_2	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	132773	242800	110027	1.83
T_3	Herbigation with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	133785	155800	22015	1.17
T_4	Herbigation with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	134806	143200	17394	1.06
T_5	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	134653	254000	119347	1.89
T_6	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing fb hand weeding at 30 DAS	135164	194600	59436	1.44
T_7	Conventional spraying with oxyfluorfen 23.5 EC @ 0.15 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	136185	205200	68385	1.51
T_8	Conventional spraying with oxyfluorfen 23.5 EC @ 0.20 kg ha^{-1} 2 days before sowing and 25 DAS fb hand weeding at 50 DAS	137025	210800	73775	1.54
T_9	Hand weeded control	141521	260800	119279	1.84
T_{10}	Unweeded control	126521	107000	-10521	0.85

5. Discussion

5. DISCUSSION

An experiment entitled 'Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)' was conducted to evaluate the effect of herbigation as a weed management method in okra. The important results of the experiment are discussed in this chapter under the following major sections.

1. Effect of herbigation on plant growth and yield
2. Effect of herbigation on weed growth
3. Effect of herbigation on soil chemical properties
4. Effect of herbigation on nutrient removal by weeds
5. Economics

5.1. Effect of treatments on plant growth and yield

The result of the study revealed that herbigation had significant effect on growth and yield of okra. The plant height of okra was in the range from 31.91 cm to 48.75 cm, 48.07 cm to 76.27 cm and 57.13 cm to 86.87 cm at 30 DAS, 60 DAS and at 90 DAS respectively (Table 5 and Fig. 3). Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS recorded greatest plant height throughout the crop growth period. The lowest plant height (59.10 cm) was recorded in unweeded control. The greatest plant height recorded was mainly due to lower crop-weed competition i.e., the plant attained height and properly utilized sunlight and solar radiation. Due to more crop-weed competition in unweeded control, plants were unable to get light and nutrients and therefore attained lower height. Reduction in plant height due to competition by weeds in okra was reported by Narayanan *et al.* (2020). Sah *et al.* (2018) reported shortest plants and less number of leaves in unweeded control because of weed interference in crop till its maturity.

In general, the number of leaves increased from 30 DAS to 90 DAS. However, it was non-significant between treatments at 30 DAS (Table 6 and Fig. 4). Highest number of leaves was observed in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and lowest number of leaves in unweeded control. Baraiya *et al.* (2017) also reported greater leaf abscission in unweeded control, this may be due to the adverse effect of crop-weed competition.

The leaf area in okra was influenced greatly by the application of oxyfluorfen. At all the three intervals of observation, the leaf area was highest in herbicide treated (in both herbigation and conventional spraying) plots. Among them, herbigation @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS recorded highest leaf area and it was on par with hand weeded control. The lowest leaf area was recorded in unweeded control (Table 7 and Fig. 5). Severe infestation of weeds might have reduced the vegetative growth of plants. These results were in line and agreement with the findings by Konyeha *et al*. (2013) in okra.

Early flowering was observed in all herbicide treated plots (35 DAS) when compared to unweeded control plots (Table 8). Highest weed density and dry matter production in unweeded control throughout the crop growth period might have influenced the flowering characteristics. The node at which first flower was formed and the days to first flower opening were found non-significant among the treatments. Similar findings were reported by Olabode *et al*. (2007). According to them, the reason for more days taken by plants in unweeded control for flowering was because of higher competition from weeds.

Hand weeded control recorded highest fruit yield (13.04t ha^{-1}) (Table 9 and Fig. 7). It was on par with herbigation @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and herbigation @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. Yield increase in these treatments may be attributed to the improved growth parameters of these treatments. Lowest yield was observed in plots with conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and at 25 DAS followed by hand weeding at 50 DAS, and @ 0.20 kg ha^{-1} two days before sowing and at 25 DAS followed by hand weeding at 50 DAS. This might have resulted from phytotoxicity and the resultant shock experienced by the crop in the seedling stage. Abraham *et al*. (2010) reported phytotoxicity in rice seedlings due to spraying of oxyfluorfen but the crop recovered from it by the production of new tillers. Significantly higher fruit yield per plant was recorded in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (Table 9 and Fig. 6). Also, the fruit yield per plant and average fruit weight was highest in this treatment.

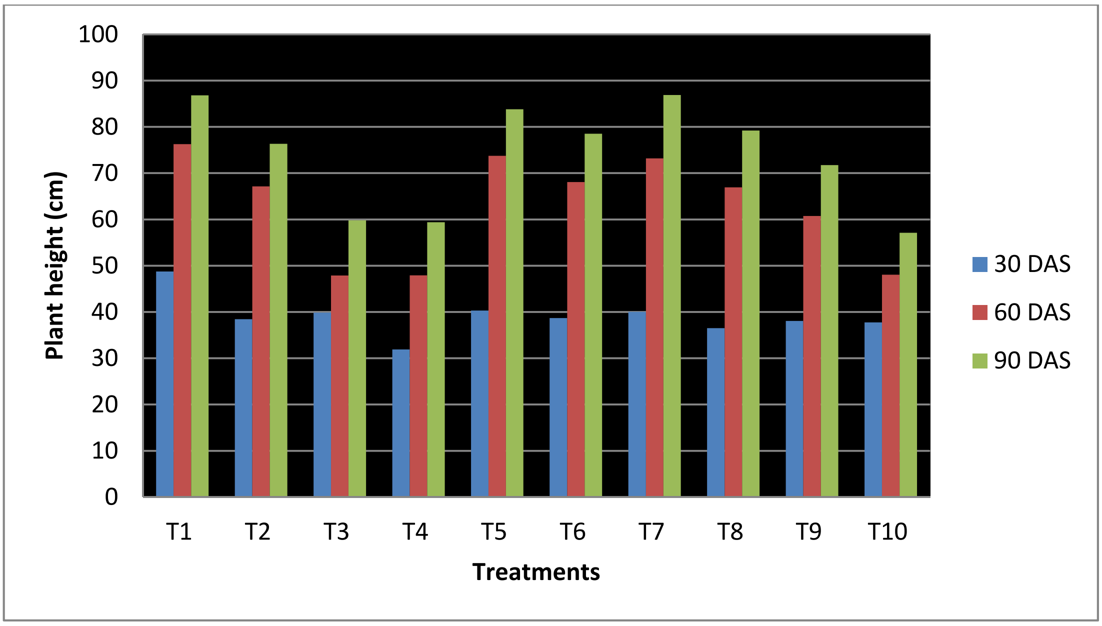

Fig 3. Effect of treatments on plant height (cm)

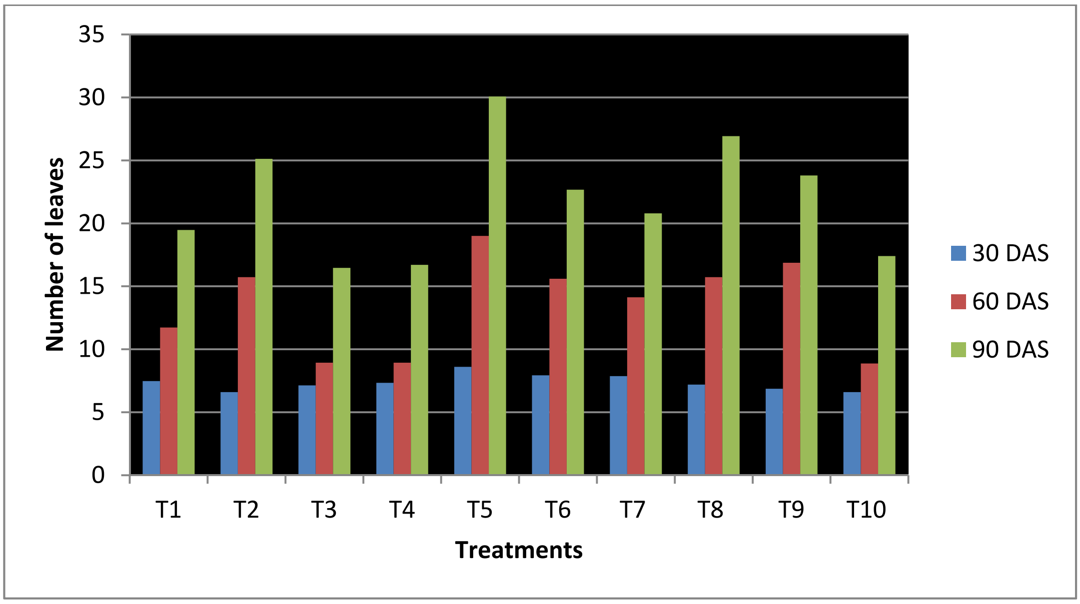

Fig 4. Effect of treatments on number of leaves

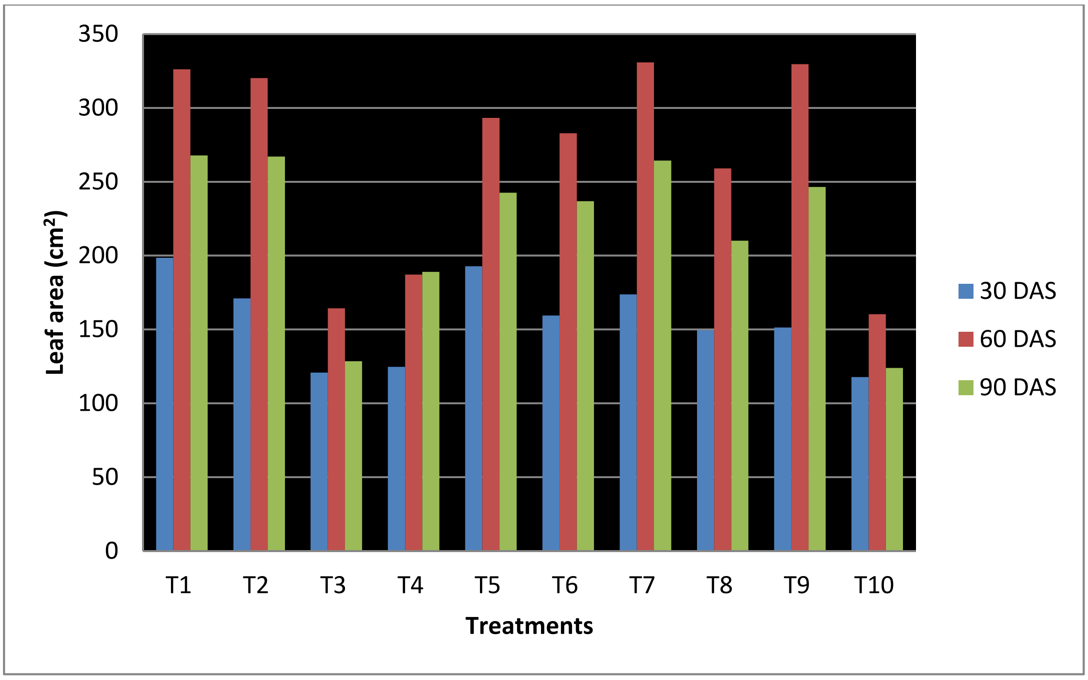

Fig. 5. Effect of treatments on leaf area (cm^2)

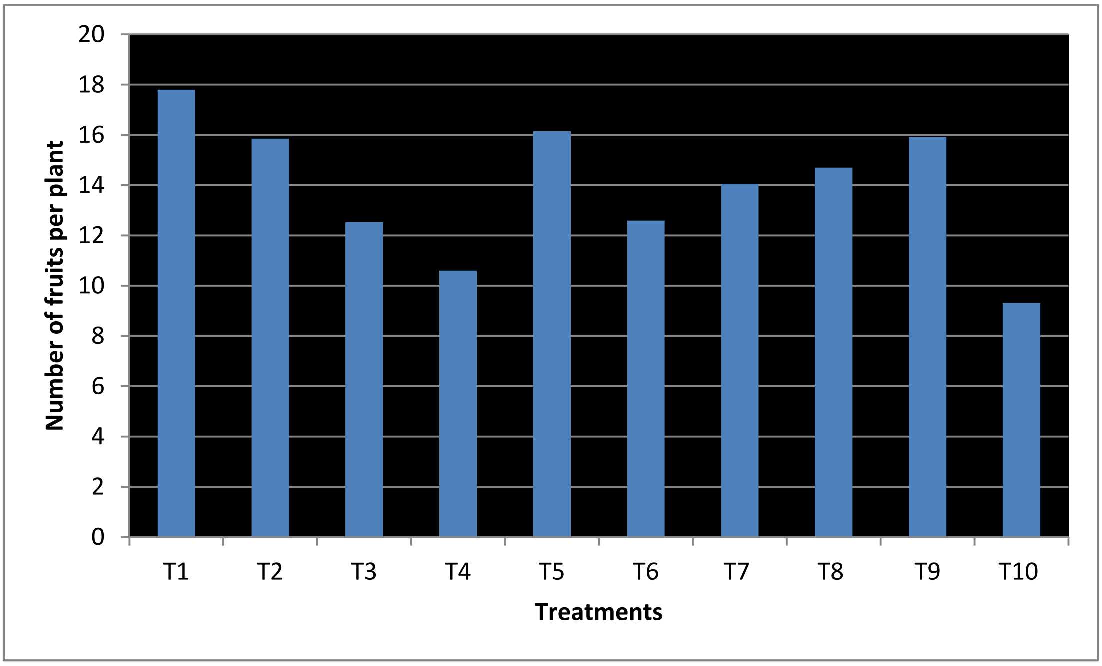

Fig. 6. Effect of treatments on number of fruits per plant

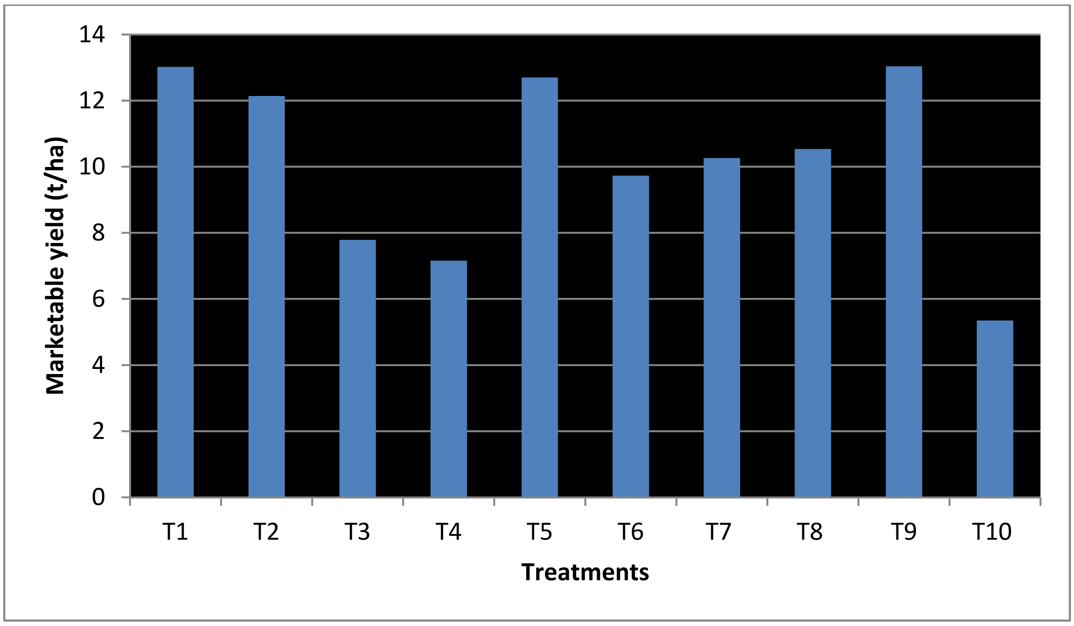

Fig. 7. Effect of treatments on fruit yield (t ha^{-1})

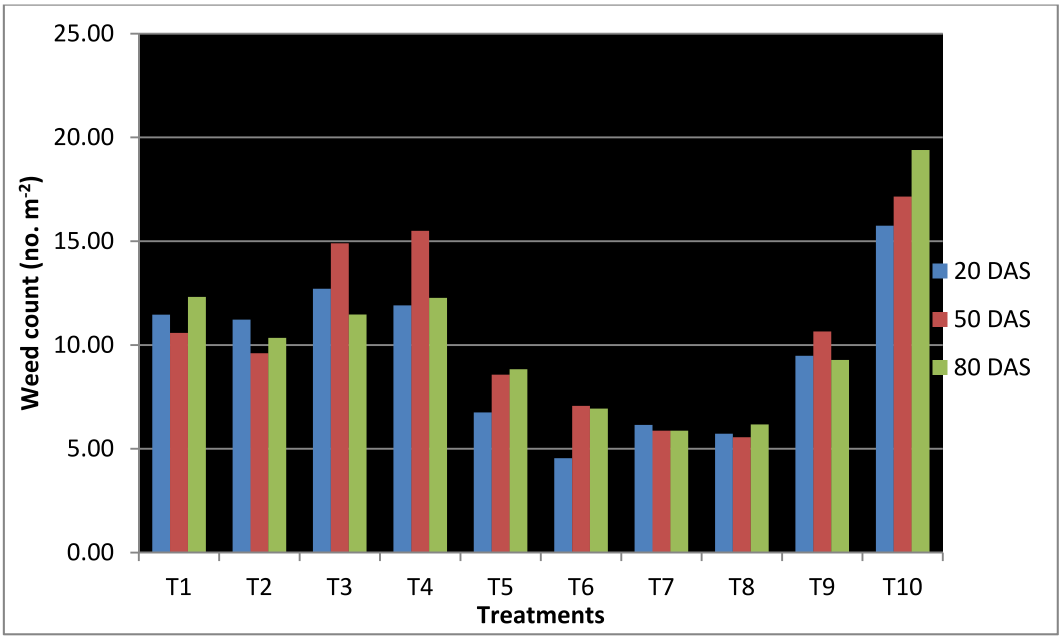

Fig.8 Effect of treatments on total weed count at 20, 50 and 80 DAS..

Herbigation had an impact on physical, chemical and biochemical changes in the soil that affected plant growth and development and often resulted in substantial yield improvement (Jagadish, 2015). Ponnuswamy (1996) reported 30.80 per cent higher yield in tapioca under herbigation when compared with unweeded control and it was on par with hand weeded control. This is due to the effective utilisation of nutrients. The lowest yield was recorded from unweeded control plots indicating nutrient deficiency due to more nutrients removed by weeds (5.35 t ha^{-1}). Higher yield in chilli had been attributed to less competition from weeds and decrease in their population helped in increasing the yield attributes which ultimately led to higher yield (Biradar *et al*., 1999).Yield improvement in crops with effective suppression of weeds either through weed free check or appropriate management practices has been reported by Kusuma (2007) in rice. Also, Rankova *et al.* (2009) reported positive effect of herbigation with pendimethalin in cherry orchard on both tree growth and yield, and soil microbial activity.

5.2 Effect of treatments on weed growth

Predominant grasses seen in the plots were *Panicum maximum, Digitaria sanguinalis, Stenotaphrum secundatum, Pennisettum pedicillatum, Brachiaria miliformis, Digitaria bicornis* and *Axonopus compressus.* Predominant broad leaved weeds were *Mimosa pudica, Ageratum conyzoides, Euphorbia hirta, Mollugo disticha, Cleome burmanii, Trianthema portulacastrum, Alternanthera bettzickiana, Ludwigia parviflora, Cleome viscosa* and *Synedrella nodiflora.*The sedges present were *Cyperus sp.,* and *Bulbostylis barbata.* Similar spectrum of weed flora was reported by Barla and Upasani(2019) in okra.

Among different weed control methods, at 20 DAS, conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS gave the lowest weed count (21.33) and weed dry weight (0.81g) as shown in Tables 11 and 14 and Figs. 8 and 12. This might have been due to the effect of diphenyl ethers of oxyfluorfen on cell membranes, which led to disruption of the cells and ionic balance, and ultimately to death of weeds. Similar results were recorded by Kanimozhi *et al.* (2019). However, the weed count and dry matter production were statistically on par in all conventional spraying treatments and hand weeded control. At 50 DAS, weed count was higher in treatments which included second application of herbicide at 25 DAS instead of hand weeding at 30 DAS. It implied that the hand weeding given at 30 days resulted in complete removal of weeds from the plots whereas the second dose of herbicide application at 25 DAS only controlled the emergence of new weeds. The already germinated weeds were not affected and this thus resulted in higher weed count as well as weed dry matter production. Also, lowest weed count and dry matter production was noticed in conventional sprayed plots and hand weeded plots. At 80 DAS, the weed count was decreased in treatments which received a hand weeding at 50 DAS. In other treatments there was not much increase in weed count due to less amount of sunlight reaching the plots due to canopy development of plants.

Baraiya *et al.* (2017) reported that use of integrated weed control treatment (pre-emergence herbicide + hand weeding at 30 DAS) resulted in very low weed population at different stages of crop growth because there was no chance for emergence of weed seedlings. Similar results were obtained by Khalid *et al.* (2005), Singh *et al.* (2010) and Sheela *et al*. (2007). All the plots which received herbicide either through herbigation or by conventional spraying recorded lower weed count and weed dry weight compared to unweeded control.

Conventional spraying with oxyfluorfen resulted in lowest weed population as compared to herbigation treatments throughout the crop period. During herbigation, herbicide is applied through drip only to the crop root zone, and in the interspaces, those weeds which could germinate even in water stress conditions would grow. However in conventional spraying, the entire cropped area came in contact with the herbicide, resulting in complete control of weeds. Ponnuswamy (1998) had also reported that herbigation was found good, but in early stages, the weed population was more in the areas where the herbicide had not come in contact with the soil surface. Subsequently, as crop growth advanced, weed population was reduced. Mustafee (1990) also found that pendimethalin applied through irrigation water reduced weeds effectively.

The reduction in weed growth under herbigation done once when compared to unweeded control is evident from reduced dry matter accumulation by weeds. It also enhanced the yield of okra. Eberlen *et al.* (2000) reported excellent weed control with site specific recommendation of metolachlor under herbigation. Higher weed count and weed dry matter production were observed in unweeded control, which was due to absence of suitable weed management practices. These results were in conformity to the findings of Raman *et al.* (2005).

The density of grasses, sedges and broad leaved weeds varied significantly with the treatments (Figs. 9 to 11). In case of grasses, conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS resulted in maximum reduction in weed count of grasses (92 % and 85 %) at 20 DAS and 80 DAS respectively. At 50 DAS, conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing and at 25 DAS followed by hand weeding at 50 DAS recorded maximum reduction (77 %) in weed count of grasses. At all stages, conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} recorded least number of sedges and broad leaved weeds when compared with other herbicide treatments. Sathyapriya *et al.* (2012) found that pre-emergence application of oxyfluorfen at 0.2 kg ha^{-1} reduced the density of broad leaved weeds (70 to 90%) in onion compared with non-treated plots. Also, oxyfluorfen @ 0.4 kg ha^{-1} resulted in higher weed control but the herbicide inhibited the crop growth in groundnut (Sathyapriya *et al.*, 2017b).

Weed control efficiency (WCE) at 20 DAS was highest in the plots with conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (91.31 %) (Table 15 and Fig. 10). Singh *et al.* (2005) also suggested that increased rate of herbicide application increased the WCE. Conventional sprayed plots gave consistently higher WCE till 80 DAS. The uniform application of herbicides all over the plots resulted in less growth of weeds. Similar favourable effect of pre emergence application of oxyfluorfen + intercultivation in reducing the weed dry matter accumulation and increasing the WCE was noticed in maize (Madhavi *et al*., 2013).Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS resulted in WCE of 86.90 per cent at 50 DAS and 85.15 per cent at 80 DAS. Similarly, Abhishek *et al*., (2017) reported higher WCE of 84.09 per cent in aerobic rice due to pre-emergent herbigation of pretilachlor + bensulfuron methyl 6.6 GR @ 10 kg ha^{-1} + one hand weeding + one intercultivation. This was due to better control of weeds during crop growth period.

The data in Table 16 indicated that the weed index varied from 0.15 to 58.97 per cent due to treatments. The treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS recorded minimum weed index. All weed control treatments performed better than unweeded control which showed the inhibitory effect of oxyfluorfen on weeds. These findings were in close proximity with that reported by Yadav *et al.* (2002) and Chandawat *et al.* (2004) in sesame. The better control of weeds might had provided comparatively stress free environment to crop.

5.3 Effect of treatments on nutrient removal by weeds

During initial stages, conventional spraying treatments recorded lowest removal of nutrients by weeds (Figs. 15 to 16). Treatments with conventional spraying recorded lowest nutrient removal by weeds and it was on par with hand weeded control. Conventionally sprayed plots resulted in minimum removal of nutrients because of comparatively less weed density. At all stages, unweeded control registered highest nutrient removal by the weeds. Similar increase in nutrient uptake due to increase in weed competition was also reported by Sunil *et al.* (2011) and Gopinath *et al.* (2012).

5.4 Effect of treatments on soil chemical properties

An increase in pH was observed on herbigation @ 0.15 kg ha^{-1}two days before sowing followed by hand weeding at 30 DAS and in unweeded control after the cropping period (Table 20).The initial status was 6.08 and post experimental soil pH ranged from 5.81 to 6.49. Among herbigation treatments, herbigation @ 0.15 kg ha^{-1}two days before sowing followed by hand weeding at 30 DAS and in conventional spraying treatments, conventional spraying @ 0.15 kg ha^{-1} two days before sowing and at 25 DAS followed by hand weeding at 50 DAS recorded highest soil pH.

The influence of herbigation treatments on soil organic carbon is seen in Table 19 and Fig. 19. The initial carbon content recorded was 1.52 per cent. The organic carbon content after the experiment was in the range of 0.68 – 1.72 per cent. Unweeded control recorded highest organic carbon content and this could be due to the extensive dry matter production by weeds.

Soil test values recorded prior to the experiment showed that the nutrient content in the experiment plots were not changed much due to the applied treatments (Table 21 and Fig.20). Higher soil N availability was recorded by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, P availability in herbigation with oxyfluorfen @ 0.15 kg ha^{-1}two days before sowing followed by hand weeding at 30 DAS and K availability in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS.

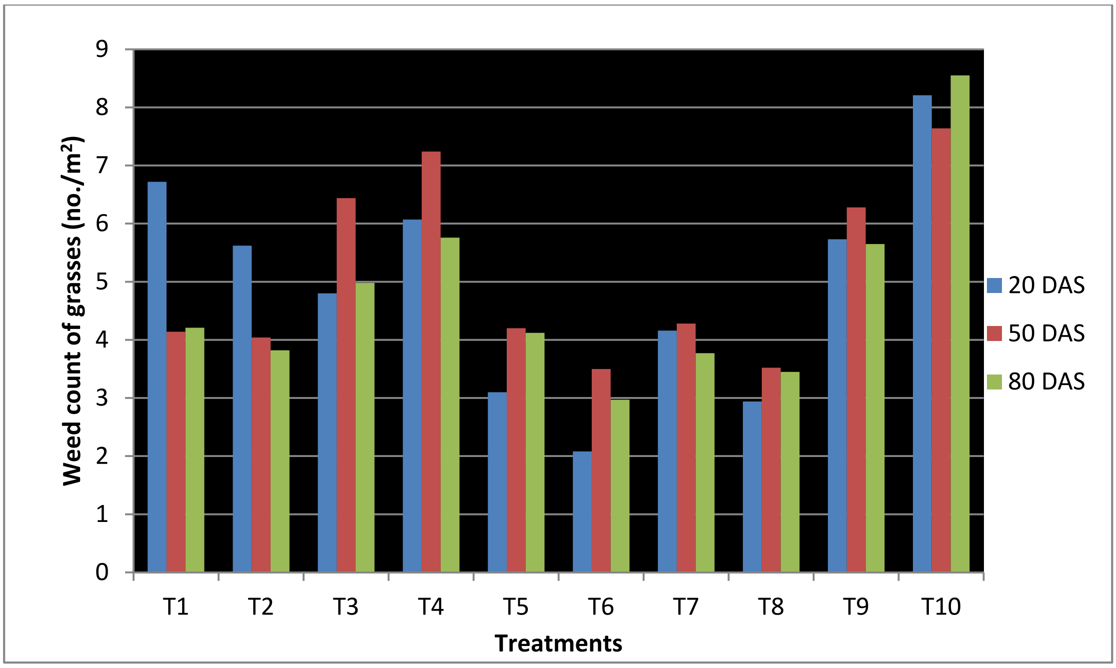

Fig. 9. Effect of treatments on density of grasses at 20 DAS, 50 DAS and 80 DAS

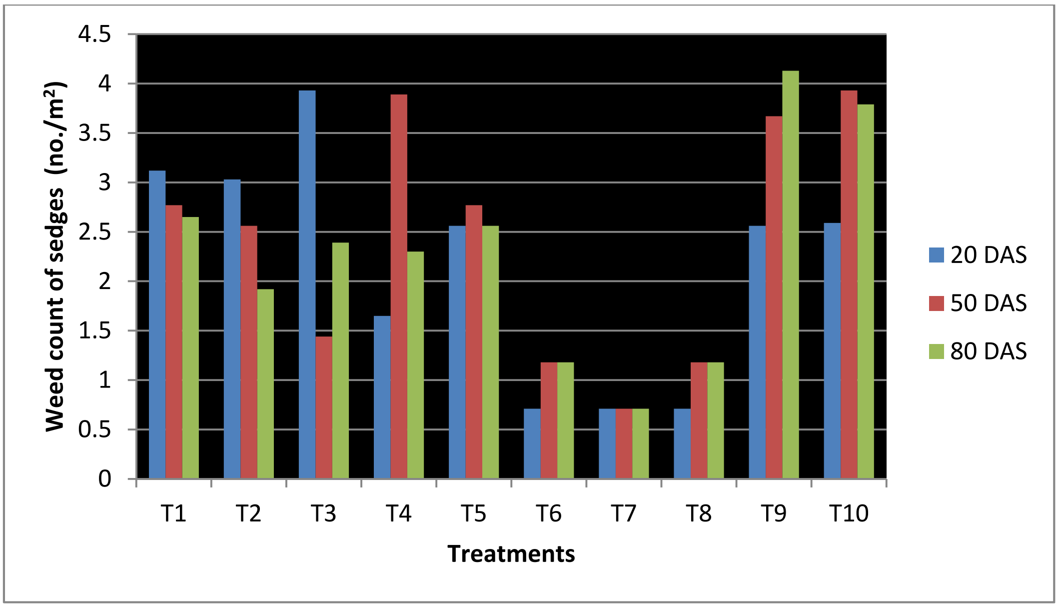

Fig. 10. Effect of treatments on density of sedges at 20 DAS, 50 DAS and 80 DAS

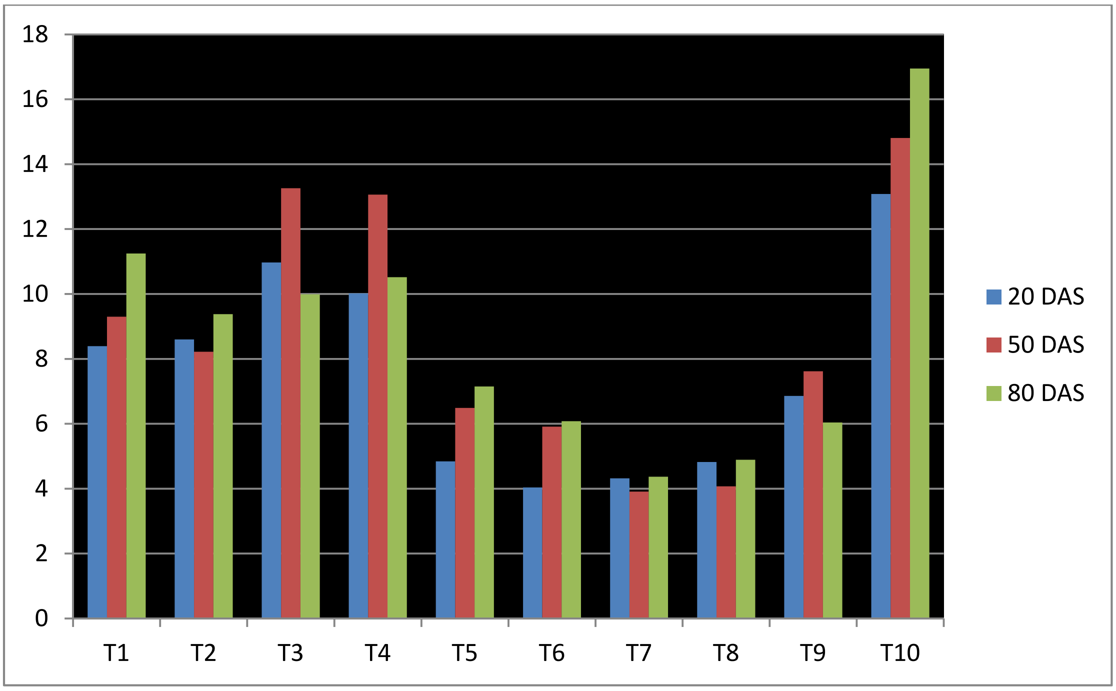

Fig. 11. Effect of treatments on density of broad leaved weeds at 20 DAS, 50 DAS and 80 DAS

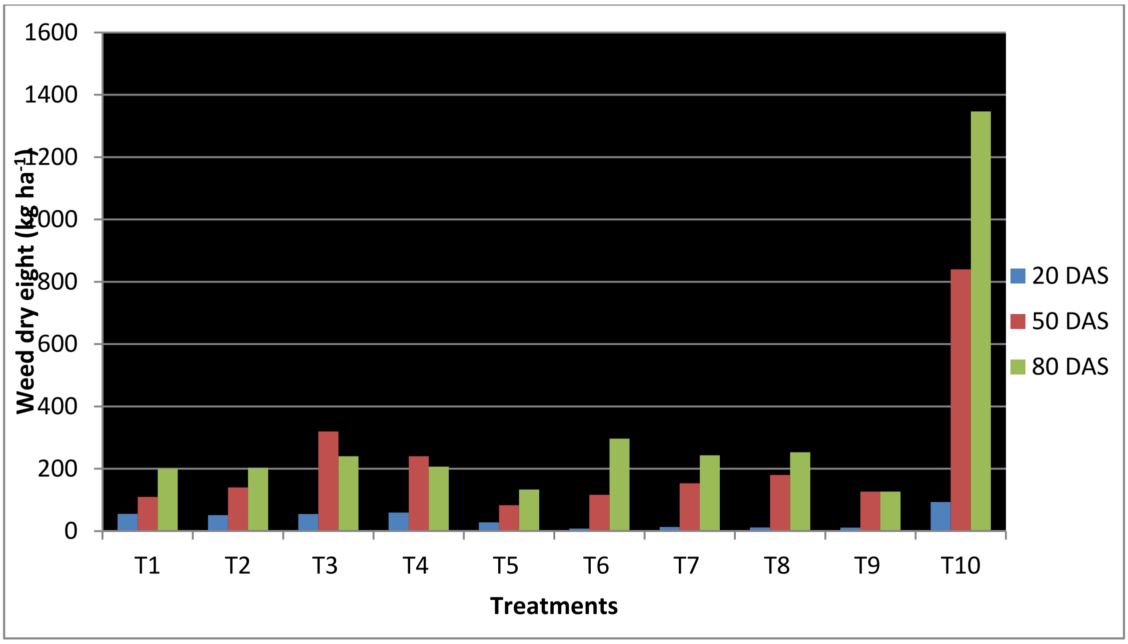

Fig.12. Effect of treatments on weed dry weight at 20, 50 and 80 DAS

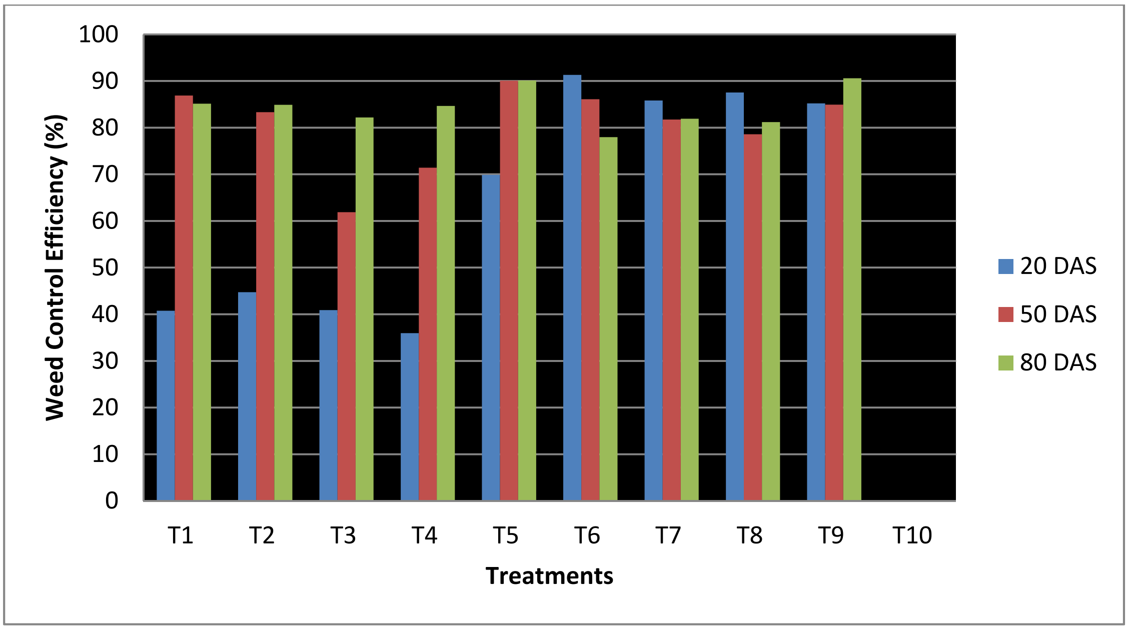

Fig.13. Effect of treatments on Weed Control Efficiency at 20, 50 and 80 DAS

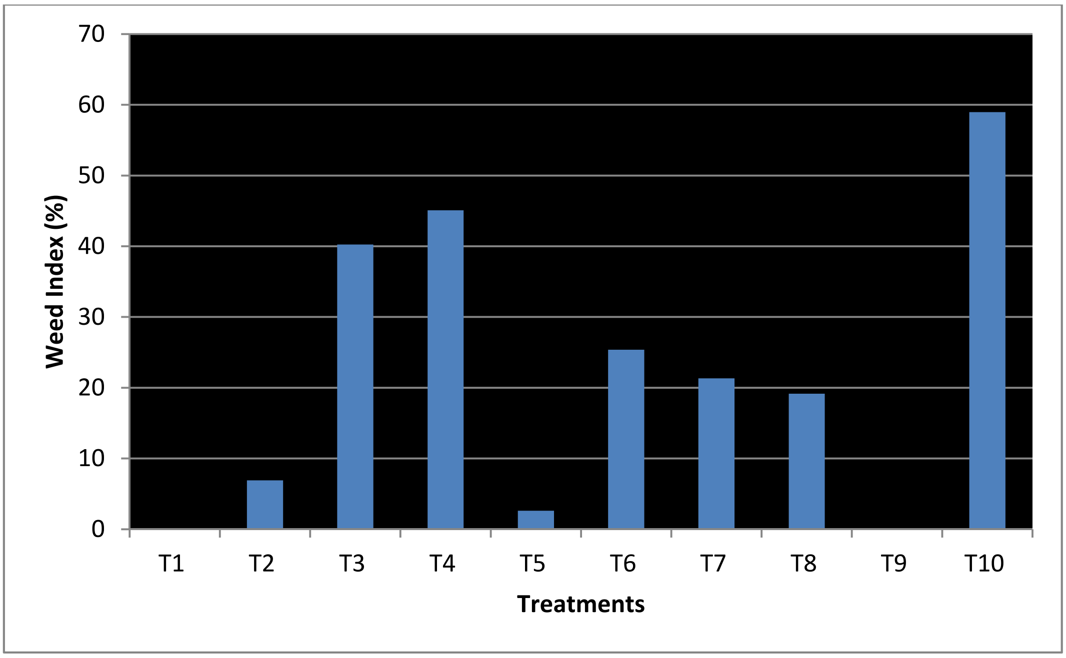

Fig.14. Effect of treatments on Weed Index

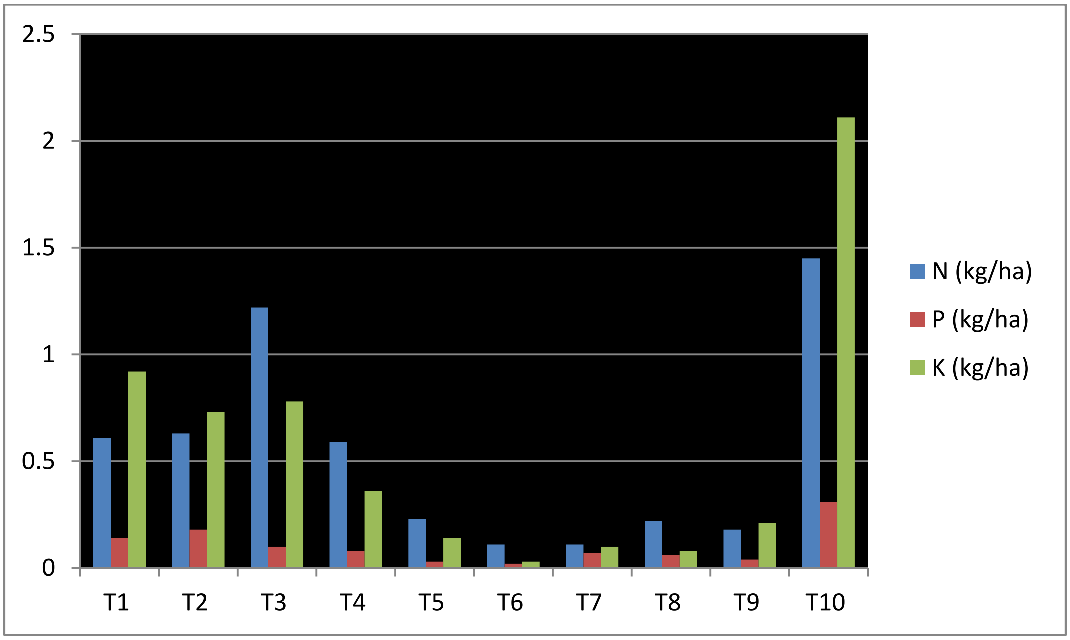

Fig. 15. Effect of treatments on N, P and K removal by weeds at 20 DAS

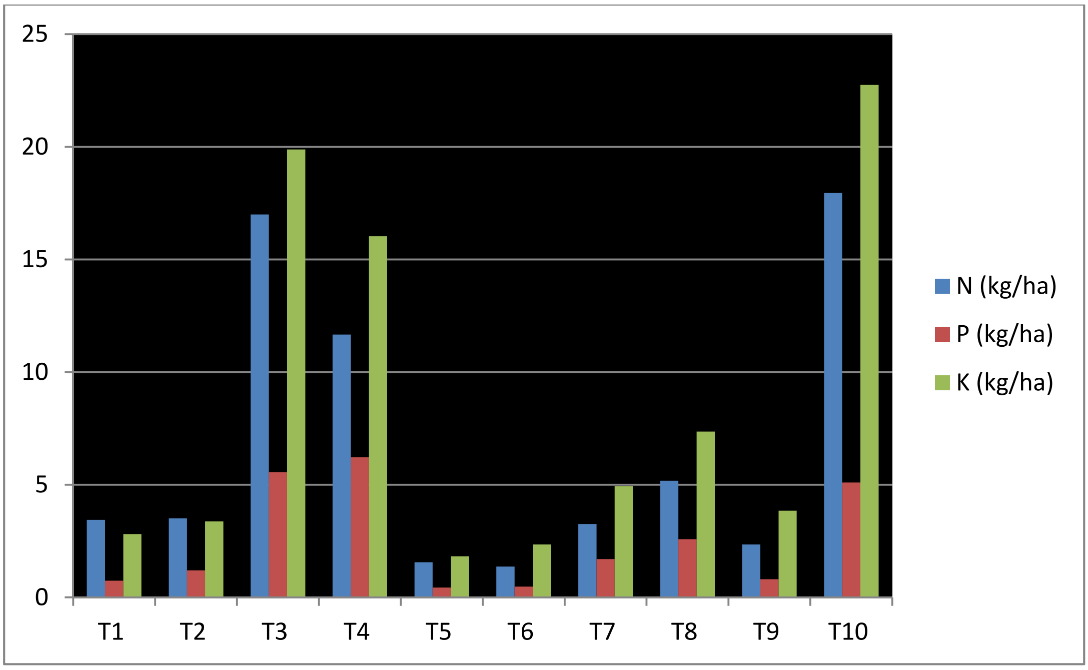

Fig. 16. Effect of treatments on N, P and K removal by weeds at 50 DAS

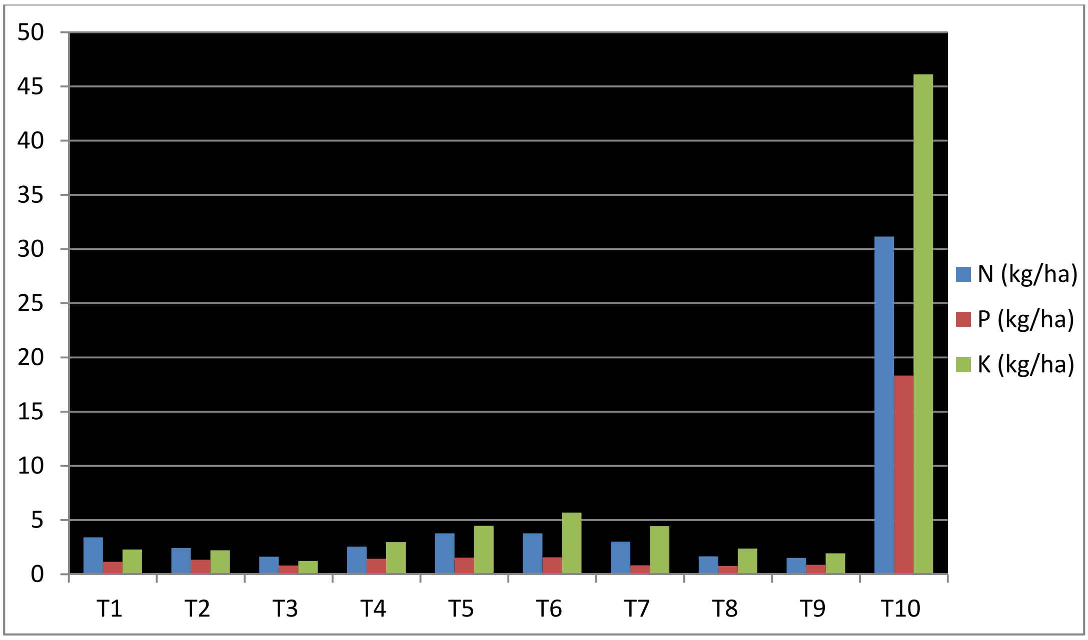

Fig. 17. Effect of treatments on N, P and K removal by weeds at 80 DAS

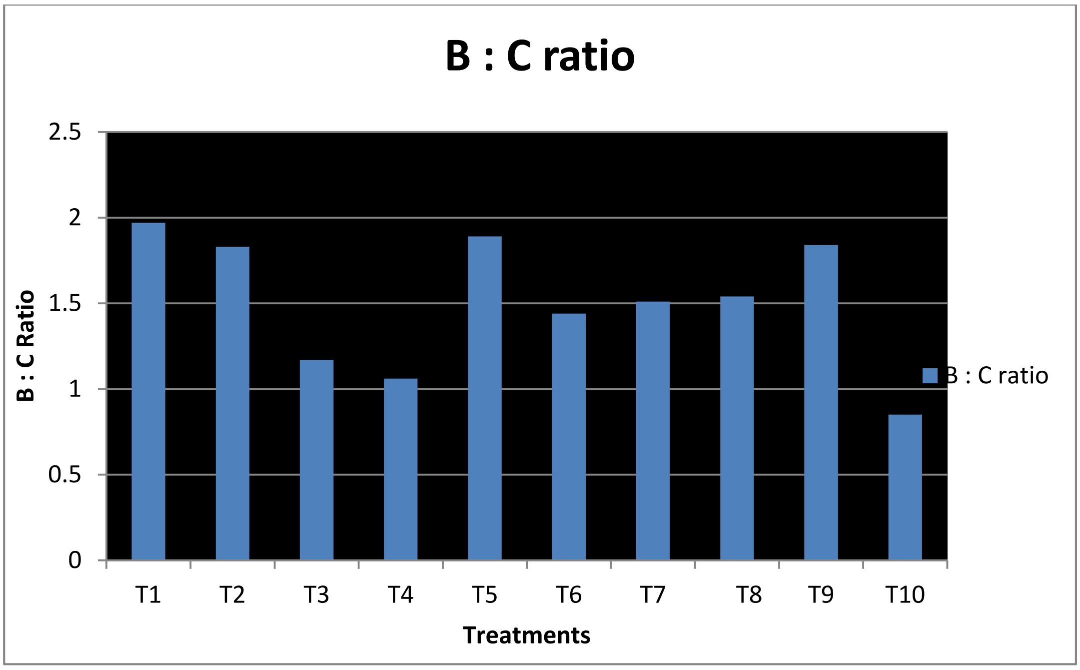

Fig 18. Economics of various treatments

5.5 Economics of herbigation

The highest B: C ratio of 1.97 was obtained in the treatment herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (Table 22). This was followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (1.89). Even though the yield was higher in hand weeded control, it recorded a lower B: C ratio of 1.84. This may be because of the higher labour requirement. Dineshwar (2017) revealed that sequential application of diclosulam and imazethapyr through drip had higher B:C ratio of 1.72 when compared with that of hand weeded control.

The study revealed that farmers could adopt either herbigation or conventional spraying of oxyfluorfen according to their convenience because both treatments performed equally well. Herbigation could be implemented in fields in which fertigation was already being carried out as it would not involve any additional cost. In addition to this, it would help in reducing the labour requirement for spraying and also the hazards associated with it.

6. Summary

6. SUMMARY

A field experiment on 'Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)' was conducted with the objective to study the effect of herbigation through drip irrigation system in okra and also to evaluate the economic feasibility of the system. The experiment was carried out at Water Management Research Unit, Vellanikkara from December 2019 to April 2020. The treatments comprised of herbigation and conventional spraying with oxyfluorfen applied at two doses (0.15 kg ha^{-1} & 0.20 kg ha^{-1}) at two stages of crop growth, hand weeded control and unweeded control. The salient findings from the experiment are summarised below.

- Predominant grasses seen in the plots were *Panicum maximum, Digitaria sanguinalis, Stenotaphrum secundatum, Pennisettum pedicillatum, Brachiaria miliformis, Digitaria bicornis* and *Axonopus compressus.* Predominant broad leaved weeds were *Mimosa pudica, Ageratum conyzoides, Euphorbia hirta, Mollugo disticha, Cleome burmanii, Trianthema portulacastrum, Alternanthera bettzickiana, Ludwigia parviflora, Cleome viscosa* and *Synedrella nodiflora.* The sedges present were *Cyperus sp.* and *Bulbostylis barbata.*
- At 20 DAS, lowest dry weight of weeds was observed in the treatment conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS; at 50 DAS in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS; and at 80 DAS in hand weeded control. Dry weight of weeds was found to be highest in unweeded control at all stages.
- Maximum weed control efficiency (WCE) was observed in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS with 91.31 per cent, conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS with 90.08 per cent at 50 DAS and hand weeded control with 90.59 per cent at 80 DAS.

- Herbigation treatments resulted in significant reduction in weed dry matter production (84 %), and higher WCE at later stages of crop growth as compared to unweeded control.
- Herbigation with oxyfluorfen @ 0.15 kg ha^{-1}two days before sowing followed by hand weeding at 30 DAS recorded higher WCE at 50 DAS and recorded lower weed index (WI) (0.15). The next best treatment was conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS.
- Herbigation when given twice (two days before sowing and 25 DAS followed by a hand weeding at 50 DAS) resulted in lower WCE when compared with herbigation given once two days before sowing followed by hand weeding at 30 DAS.
- Weed competition resulted in 58.97 per cent yield reduction in okra.
- Hand weeded control recorded significantly higher fruit yield and was on par with herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS.
- Higher soil N availability was recorded in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, P availability in herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and K availability in conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing and 25 DAS followed by hand weeding at 50 DAS. Unweeded control recorded highest organic carbon content.
- Hand weeded control recorded maximum fruit yield. It was on par with herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS, herbigation with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS.
- Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS resulted in higher gross return, net return and B:C

ratio which was closely followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS.

- The result of the study revealed that the farmers could adopt either herbigation or conventional spraying of oxyfluorfen according to their convenience because both treatments performed equally well in terms of yield.

References

REFERENCES

Abbasi, R., Alizedeh, H.M., Khanghah, H. Z., and Jahroni, K. 2008. Integration of mechanical methods and herbicides in controlling of weeds of soybean. 15th Australian Weed Conf. 5:25-63.

Abdel-Aziz, A. A. 2006. The use of chemigation technique for weed control and minimizing environmental pollution with herbicides in newly cultivated lands. *Misr. J. Eng.* 23(3):571-592.

Abhishek, G. M., Thimmegowda, M. N., Ramachandran, B. K., Nagaraju and Murukannappa. 2017. Efficiency of herbigation based weed management practices in aerobic rice. *Int. J. Sci. Nature.* 8(3):447-452.

Abraham, C. T., Prameela, P. and Lakshmi, M.P. 2010. Efficacy of oxyfluorfen for weed control in transplanted rice. *J. Crop Weed*. 6(2):67-71.

Ajeyalemi, R. D. 2007. Crop – weed competition in maize intercropped with okra in humid tropical environment. M.Sc. (Ag) thesis, Federal University of Technology, Nigeria, 155 p.

Amin, O. and Limbani, N. V. 2007. Effect of intercropping on growth and yield of cucumber and okra. Int. J. Agric. Biol. 9(4):594-597.

Anuradha, N., Gonge, V. S., Warde, A. D., Mohariya, A., and Jagdale, Y. L. 2006. Influence of integrated weed management on growth and yield of cabbage. *Int. J. Agric. Sci.* 2(1):93-94.

Baraiya, M., Yadav, K. S., Kumar, S., Lal, N., and Shiurkar, G. 2017. Effect of integrated weed management on growth and development of okra. *The Pharma Innovation J*. 6(7):1024-1028.

Barla, S. and Upasani, R. R. 2019. Economic feasibility of weed management in okra (*Abelmoschus esculentus* (L.) Moench). *Int. J. Chem. Studies.* 6:333-335.

Basha, K. G. 2000. Integrated weed management in summer irrigated okra (*Abelmoschus esculentus* (L.) Moench) cv. Arka Anamika. M.Sc. (Ag) thesis, Achargya N.G. Ranga Agricultural University, Hyderabad, 145 p.

Biradar, S. A., Agasimani, C. A., and Yenagi, B. S. 1999. Integrated weed management in chilly (*Capsicum annum* L.) under northern transition tract of Karnataka. *World Weeds* 6(1):53-59.

Borah, N., Deka, N. C., Deka, J., Barua, I. C., and Rajkhowa, D. J. 2008. Nutrient removal by weeds at different growth stages of boro rice under different weed management practices. *Proceedings of biennial conference of Indian Society of Weed Science*. 27 – 28 February 2008, Bihar. Bihar Veterinary College, Patna, p 179.

Bray, R. H. and Kurtz, L. T. 1945. Determination of total organic and available forms of phosphorus in soils. *Soil Sci.* 59:39-45.

Chandawat, M. S., Singh, I., and Rathore, M. S. 2004. Herbicidal management of weeds in sesame (*Sesamum indicum* L.). *J. Oilseeds Res*. 21(1):95-97.

Chander, N., Kumar, S., Ramesh., and Rana, S. S. 2013. Nutrient removal by weeds and crops as affected by herbicide combinations in soybean – wheat cropping system. *Indian J. Weed Sci.* 45(2):99-105.

Charlotte, V. E., Bradley, A. K., and Mary, J. G. 2000. Evaluating an automated irrigation control system for site-specific herbigation. *Weed Tech.* 14(1):182-187.

Dilip, N. 2013. Influence of herbicides on yield of okra (*Abelmoschus esculentus* (L.) Moench) in the US Virgin Islands. Basic Res. J. Agric. Sci. Rev. 2(10):191-194.

Dineshwar. 2017. Effect of herbigation on weed control in soybean under raised bed condition. MSc. (Ag) thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, 102p.

Eberlen, C. V., King, B. A. and Guttier, M. J. 2000. Evaluating an automated irrigation control system for site specific herbigation. *Weed Technol.* 14(1):182-187.

Elamin, S.M., Osman, M. A. M., Elamin, S. E., and Mahgoub, B. M. 2019. Critical period for weed control in okra (*Abelmoschus esculentus* (L.) Moench) in Dongola, Northern State, Sudan. Nile J. Agric. Sci. 4(1):15-23.

El-Gindy, A. M. 1988. Modern chemigation techniques for vegetable crops under Egyptian conditions. Mist J. Agric. Eng. 5(1):99-111.

Elsayed, S., Abdel-Aziz, A., El-bagoury, K. and Moustafa, M. 2019. Herbigation managements for maximizing green beans crop productivity under drip irrigation system. *Arab Univ. J. Agric. Sci.* 27(1):135-146.

Fourie, J.C. 1992. Herbigation in a vineyard: persistence of four major herbicides in a sandy loam soil. *S. Afr. J. Enol. Vitic.* 13(2):64-70.

Gaikwad, C. B., Kolse, R. H., Yadav, S. T. and Jadhav, J. D. 2010. Nutrient uptake and phytotoxicity study of herbicides as influenced by different treatments in onion seed crop. Int. J. Agric. Sci. 6(1):333-336.

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

Gilreath, J. P. and Santos, B. M. 2005. Weed management with oxyfluorfen and napropamide in mulched strawberry. *Weed Technol.* 19(2):65-68.

Gogoi, S., Gogoi, P. H., Mazumder, A., and Sailua, T. P. 1996. Integrated method of weed control in a seed crop of okra (*Abelmoschus esculentus* (L.) Moench). Ann. Agric. Res. 18:432-436.

Gogoi, S., Shadeque, A., and Hatibarua, P. 1997. Efficiency of integrated weed control methods in okra under the rainfed condition of Assam. Haryana J. Hortic. Sci. 26(3-4):297-300.

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

Gopinath, K. A., Mina, B. L., Singh, K. P. and Nataraja, K. C. 2012. Integrated weed management in direct-seeded rainfed rice. *Indian J. Agron*. 57(3):245-249.

Gruzdev, G. S., Lapshin, L. V., and Kushkhav, K. M. 1990. The effectiveness of herbigation. *Zashchito Rasthanii.* 3:25-26.

Hakoomat, A., Arooj, M., Sarwar, N., Areeb, A., Shahzad, A. N., and Hussain, C. S. 2017. Application of pre and post emergence herbicide under improved field irrigation system proved a sustainable weed management strategy in cotton crop. Planta Daninha. Doi: 10.1590/S0100-83582017350100052.

Hariharasudhan, V., Chinnusamy, C., and Muraliarthanari, P. 2017. Recent weed management techniques in micro irrigation system: review. *J. Pharmacogn. Phytochem*. 6(6): 324-326.

Iremiren, G. O. 1988. Frequency of weeding in okra (*Abelmoschus esculentus* (L.) Moench) for optimum growth and yield. *Exp. Agric.* 24:247-252.

Iyagba, A. G., Onuegbu, B. A., and Ibe, A. E. 2012. Growth and yield response of okra (*Abelmoschus esculentus* (L.) Moench) varieties to weed interference in south-eastern Nigeria. Glob. J. Sci. Frontier Res. Agric. Vet. Sci. 12:23-31.

Jackson, M. L. 1958. Soil Chemical Analysis (Indian Reprint, 1967). Prentice Hall of India, New Delhi, 498p.

Jagadish. 2015. Studies on weed management approaches for trickle irrigated aerobic rice. M.Sc. (Ag) thesis, University of Agricultural Sciences, Bangalore, 145 p.

Jain, P. C. and Tomar, S. S. 2005. Effect of different weed management practices on seed yield of okra (*Abelmoschus esculentus* (L.) Moench). National Biennial Conference, Indian Society of Weed Science, pp 254-255.

Jalendhar, G. 2012. Integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench) Cv. Arka Anamika. M.Sc.(Ag) thesis, Dr. Y. S. R. Horticultural University, Hyderabad,140p.

John, S. A. and Mini, C. 2005. Development of okra based cropping system. *Indian J. Hortic.* 62(1):49-51.

Kanimozhi, G., Sathyamoorthy, N., K., Babu, R., and Prabhakaran, J. 2019. Effect of herbigation through microsprinkler on weeds flora, weed dry weight and weed control efficiency. *Int. J. Chem. Studies.* 7(3):3528-3531.

KAU [Kerala Agricultural University]. 2016. Package of Practices Recommendations-Crops (15^{th} ED.). Directorate of Extension, Kerala Agricultural University, Thrissur, 360p.

Kesthkar, G., Alizodeh, H., Abbasi, F., and Zorch, A. 2010. The effectiveness of applying eradicane through irrigation on grain yield and yield attributes of corn. *Proc. of 3^{rd} Iranian Weed Sci. Cong.* 2:55-59.

Khalid, U., Ahmad, E., Khan, M. U., Ahmad, A., Imdad, A. and Javed, I. 2005. Integrated weed management in okra. *Pakistan J. Weed Sci. Res.* 11(1&2):55-60.

Khurana, S. C., Thakaral, K. K., and Pandita, M. L. 1986. Chemical weed control in okra [Abstract]. In: *Abstracts, Annual Weed Science Conference*; 3-4 March, 1985, Jaipur. Indian Society of Weed Science, Jaipur, p117.

Kohansal, A., Majab, M., Kuhnavarda, F., and Hasseini, M. 2010. Evaluating the efficiency of metribuzin and atrazine for controlling corn (*Zea mays* L.) weeds on the herbigation application. *Proc. Of 3^{rd} Iranian Weed Sci. Cong.* 2:17-18.

Kolhe, S. S. 2001. Integrated weed management in onion (*Allium cepa* L.). Indian J. Weed Sci. 33(1-2):26-29.

Kolse, R. H., Gaikwad, C. B., Jadhav, J. D. and Yadav, S. T. 2010. Efficiency of chemical weed control methods in onion seed production for controlling weeds and its effect on yield. *Int. J. Plant Prot.* 3(1):55-59.

Konyeha, S. and Alatise, M. O. 2013. Evapotranspiration and leaf area index of irrigated okra (*Abelmoschus esculentus* (L.) Moench) in Akure, south-western city of Nigeria. *Int. J. Eng. Sci. Res. Technol.* 2(9):2880-2888.

Kumar, A. and Choudhary, B. M. 2004. Weed management of okra (Abelmoschus esculentus (L.) Moench). *Orissa J. Hortic*. 32(1):73-74.

Kumar, J. C. and Singh, C. 1986. Evaluation of recommended herbicides at the farmer's field in okra (*Abelmoschus esculentus* (L.) Moench). *J. res.* 23(1):44-48.

Kumar, S., Angiras, N. N., Sharma, P., and Rana, S. S. 2011. Integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench) under mid-hill condition of Himachal Pradesh. *Himachal J. Agric. Res.* 37(1):10-16.

Kusuma, V. 2007. Studies on weed management in aerobic rice (*Oryza sativa* L.). MSc. (Ag) Thesis, University of Agricultural Sciences, Bangalore, 155 p.

Leela, D. 1993. Weedicides for Vegetables in Indian Horticulture, pp.38.

Madhavi, M., Ramprakash, T., Srinivas, A. and Yakadri, M. 2013. Integrated weed management in maize (*Zea mays* L.*)* for supporting food security in Andhra Pradesh. In: Srinivas, A. (ed.), Proceedings of the 24th Asian-Pacific Weed Science Society Conference, 22-25 October 2013, Bandung, Indonesia. pp. 310-312

Mani, V.S., Malla, M.L., Goutam, K.C. and Bhagvandas.1973. Weed killing chemicals in potato cultivation. *Indian Farming*, 23: 7-13.

Mustafee, T. P. 1990. Use of herbicides in close spaced crops. *Pestology.*14: 8-12.

Nalayini, P., Sankaranarayanan, K., and Velmourougane, K. 2013. Herbigation in cotton (*Gossypium* spp): Effects on weed control, soil micro flora and succeeding green gram (*Vigna radiata*). *Indian J. Agric. Sci.* 83(11):1144-1148.

Narayanan, S., Malik, A., Magray, M. M., Shameem, S. A., Hussain, K., Mufti, S. and Khan, F. A. 2020. Effect of weed management practices on growth, yield and quality of okra (*Abelmoschus esculentus* (L.) Moench) under temperate conditions of Kashmir valley. *Int. J. Chem. Studies.* 8(5):2485-2487.

Nisha, C. N. K. 2007. Production of weed free mother bulb of onion (*Allium cepa*) through integration of herbicides and weeding. *Indian J. Agron*. 52(1):80-82.

Olabode, O. S., Ogunyemi, S. and Awodoyin, R. O. 2006. Response of okra (*Abelmoschus esculentus* (L.) Moench) to weed control by mulching. *J. Food Agric. Environ.* 5(3-4):324-326.

Pandey, V. K. and Mishra, A. C. 2013. Weed management technology in okra. National symposium on abiotic and biotic stress management in vegetable crops, North America, March 2013.

Parameswari, Y. S. and Srinivas, A. 2014. Influence of weed management practices on nutrient uptake and productivity of rice under different methods of crop establishment. J. Rice Res. 7(1&2):77-86.

Patel, R. B., Patel, B. D., Meisuriya, M. J., and Patel, V. J. 2004. Effect of methods of herbicide application on weeds and okra (Abelmoschus esculentus (L.) Moench). *Indian J. Weed Sci.* 36(3):304-305.

Patel, R. B., Patel, B. D., Meisuriya, M. J., and Patel, V. J. 2009. Effect of methods of herbicide application on weeds of okra. *Indian J. Weed Sci.* 36(3-4):304-305.

Piper, C. S. 1942. Soil and Plant Analysis. (Asian Reprint, 1996). Hans publishers, Bombay, 368p.

Ponnuswamy, K. 1996. Influence of drip irrigation and weed control practices on productivity and quality of cassava (*Manihot esculenta* Crantz). PhD Thesis. Tamil Nadu Agricultural University, Coimbatore, 183 p.

Porwal, M. K. and Singh, M. M. 1993. Efficiency of herbicides for weed control in cauliflower (*Brassica oleracea* L.). *Indian J. Weed Sci.* 25(1&2):55-60.

Prakash, V., Pandey, P. K., Singh, R. D., and Gupta, H. S. 2001. Integrated weed management practices in okra (*Abelmoschus esculentus* (L.) Moench) under mid hill conditions of North West Himalayas. *Indian J. Weed Sci.* 33(1-2):49-51.

Qasem, J. R. 1996. Chemical weed control in garlic (*Allium sativum* L.*)* in Jordan. *Crop Prot.* 15(1):21-26.

Rajashree, V., Sathyamoorthy, V. A., Shanmugasundaram, T. and Arumugam, T. 2017. Integrated weed management on growth, yield and economics in okra (*Abelmoschus esculentus* (L.) Moench) under kharif. *Madras Agric. J.* 104(1-3):81-84.

Raj kumara, S., Palled, Y. B., Hebsur, N. S., Koti, R. V., Basavaraja, N. and Khot, A. B. 2010. Nitrogen uptake and economics of rainfed drill sown onion (*Allium cepa* L.) + chilly (*Capsicum annuum* L.) + cotton (*Gossypium herbaceum* L.) intercropping system under different weed free periods. Karnataka J. Agric. Sci. 23(4):590-594.

Ramamoorthy, K. and Jayapal, P. 1990. Influence of herbicidal treatments on yield and seed quality in bhendi (*Abelmoschus esculentus* (L.) Moench). *Prog. Hortic*. 22(1-4):51-54.

Raman, R., Kuppuswamy, G., and Krishnamoorthy, R. 2005. Response of weed management practices on the growth and yield of urd bean (*Vigna mungo* H.). *Legume Res*. 28(2): 122-124.

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

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.

Rankova, Z., Koumanov, K. S., Kolev, K., and Shilev, S. 2009. Herbigation in a cherry orchard – translocation and persistence of pendimethalin in the soil. *Acta Hort.* 825:305-312.

Rasheed, O., Awodoyin, O. and Sunday, O. 2009. On field assessment of critical period of weed interference in okra (*Abelmoschus esculentus* (L.) Moench) field in Ibadan, a rainforest savanna transition eco zone of Nigeria. *Asian J. Food Ag-Ind*. 14:288-296.

Reddy, C. N., Reddy, M. D., and Devi, M. P. 1998. Soil solarization for weed control in vegetable nurseries. *Indian J. Weed Sci.* 30(1/2):88-89.

Rupareliya, V. V., Chovatia, P. K., Vekariya, S. J. and Javiya, P. P. 2017. Effects of different pre and post emergence herbicides on growth, yield attributes, yield and quality of chickpea (*Cicer arietinum* L.). Int. J. Sci. Environ. Technol. 6(4):2587-2593.

Sah, D., Heisnam, P., and Pandey, A. K. 2018. Weed management in okra under foot hill conditions of north eastern Himalayas. *J. Crop Weed.* 14(1):201-204.

Sahhar, E.A. and El-Bagoury, K.F. 2006. Relative advantage of weed control methods applied in sprinkler and drip irrigated systems for tomato cultivation in Egypt's newly reclaimed lands. *Arab Univ. J. Agric. Sci.* 14(2): 575-589.

Saimbhai, M. S., Sandhu, K. S., Singh, D., Kooner, K. S., and Dhillon, N. P. S. 1994. Chemical weed control studies on okra (*Abelmoschus esculentus* (L.) Moench). *J. Research.* 31(1):38-41.

Sainudheen, K. 2000. Integrated weed management in okra (Abelmoschus esculentus (L.) Moench). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 145p.

Saito, S. Y. and Santos, H. N. G. 1980. Herbigation – a new method of applying herbicides. *Resumos Congresso.* 2:111-113.

Sathyapriya, R., Chinnusamy, C., Muraliarthanari, P. and Janaki, P. 2017a. Pre emergence herbicide of oxyfluorfen on weed control in transplanted rice. *Int. J. Chem. Studies.* 5(5):271-275.

Sathyapriya, R., Chinnusamy, C., Muraliarthanari, P., Janaki, P. and Babu, C. 2017b. Evaluation of oxyfluorfen (23.5 % EC) herbicide on weed control, economics and profitability of groundnut in the western zone of Tamil Nadu. Chem. Sci. Rev. Lett. 6(21):88-93.

Sathyapriya, R., Manickasundaram, P., Chinnusamy, C., and Babu, C. 2012. Influence of oxyfluorfen on weed control and yield of onion and its residual effect on succeeding sunflower and pearl millet. *Madras Agric. J.* 99(10-12):782-785.

Shaik, A. R., Lokhande, O. G., and Bhosle, R. H. 2002. Integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench). *Indian J. Agron*. 47(3):460-463.

Sharma, S. and Patel, B. D. 2011. Weed management in okra grown in kharif season under middle Gujarat conditions. *Indian J. Weed Sci*. 43(3&4)226-227.

Sharma, S. P., Buttar, G. S., Singh, S. and Khurana, D. S. 2009. Comparative efficacy of pendimethalin and oxyfluorfen for controlling weeds in onion nursery. *Indian J. Weed Sci.* 41(1&2):76-79.

Sheela, K. R., Nandakumar, C. and Pushpakumari, R. 2007. Integrated weed management in bhendi. *Acta hortic*. 7:549-551.

Sheikh, A. R. 2005. Integrated weed management in Rabi chilly (Capsicum annum). *Indian J. Weed Sci.* 37 (3&4):285-286.

Shinde, P. P., Vankar, R. R. and Bal, A. S. 2006. Role of micro irrigation and polythene mulch on growth, yield and economics of okra var. Arka Anamika. *J. Maharashtra Agric. Univ.* 31(3):278-280.

Shylaja, P. V. and Thomas, C. G. 2004. Efficacy of pre emergence herbicides for weed control in cocoa seedling nursery. J. Plant. Crops. 32(2):57-60.

Singh, G. and Tripati, S.S. 1990. Effect of herbicides on okra (*Abelmoschus esculentus* (L.) Moench) and associated weeds. Biennial conference, ISWS, JNKVV, Jabalpur, March 4-5,1990. p 127.

Singh, M., Prabhukumar, S., and Sairam, C. V. 2010. Integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench). *An. Plant Prot. Sci*. 18(2):481-483.

Singh, T., Singh, S. and Bhattia, R. K. 2005.Integrated weed management in okra. National Biennial Conference, Indian Society of Weed Science. pp. 253-254

Sivanappan. 1994. Prospects of micro irrigation in India.. *Irrig. Drain. Syst*. 8(1); 49-58.

Smith, M. A. K. 2009. Influence of pendimethalin based weed management system on weed for a composition in Indian spinach and okra in humid tropical environment. *J. Anim. Plant Sci.* 4(2):357-362.

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

Sujith, G. M. 1997. Effect of irrigation schedule and methods of herbicide application on growth and yield of groundnut. M.Sc. (Ag) thesis, University of Agricultural Sciences, Bangalore, 156 p.

Sujith, G. M., Chandrakumar, M. M., and Reddy, S. S. 2003. Herbigation : Anew vision for weed management – A review. *Crop Res.* 26(2):189-197.

Sunil, C. M., Shekara, B. G., Anilkumar, S. N., Kalyanamurthy, K. N., and Vijay, M. 2011. Economics and uptake of nutrient by crops and weeds as influenced by weed control practices in aerobic rice. *Adv. Res. J. Crop Improv.* 1(2):183-186.

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(1&2):109-111.

Trivedi, G. C., Patel, B. D., Patel, R. B., and Meisuriya, M. I. 2001. Integrated weed management practices in okra [abstract].In; Abstracts, First biennial conference in the new millennium on ecofriendly weed management option for suitable agriculture lead paper. Indian Society of Weed Science, Banglore, p 114.

Velayatham, A., Mohammad, A., Veerabhadran, V., and Senbagavalli, S. 2001. Impact of herbicides and their application techniques on yield and residues in cotton based intercropping systems. *Acta Agron. Hungarica*. 49(3):283-292.

Verma, S. K., Singh, S. B., Meena, R. N., Prasad, S. K., Meena, R. S., and Gourav. 2015. A review of weed management in India: The need of new directions for sustainable agriculture. *The Bioscan*. 10(1):253-263.

Vethamani, P. I. 1988. Studies on the effect of herbicide, nitrogen and mulching on growth and yield of bhendi (*Abelmoschus esculentus* (L.) Moench.) cv MDU. *S. Indian Hortic.* 36(4):215-219.

Vidya, R. and Singh, V. 1990. Studies on weed control in okra. *Veg. Sci.* 17(1):73-76.

Walkley, A. and Black, C. A. 1934. Estimation of organic carbon by chromic acid titration method. *Soil Sci.* 37:29-38.

Warde, A. D., Gonge, V. S., Jogdande, N. D., Ingole, P. G., and Karunakar, A. P. 2007. Integrated weed management in onion. *The Asian J. Hortic.* 2(2):205-208.

Watanabe, P. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphate in water and NH_4CO_3 extracts from soil. *Soil Sci. Soc. Am. J.* 29:677-678.

Widaryanto, E. and Roviyanti, F. 2017. Efficacy of oxyfluorfen herbicide for weed control in broccoli (*Brassica oleracea* L. var. *italica*). *Asian J. Crop Sci.* 9(2):28-34.

Yadav, M. R., Punia, S. S., and Chauhan, B. 2002. Studies on the effect of dinitroaniline herbicides on the control of weeds, growth and yield of sesame. *An. Agric. Biores.* 7(2):157-160.

Abstract

Herbigation in Okra (*Abelmoschus esculentus* (L.) Moench)

By

MINU MARIYA ISSAC

(2018-11-061)

Abstract of the Thesis

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Agronomy

COLLEGE OFAGRICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

Abstract

Herbigation is the method of application of herbicides through irrigation water. Conventional method of herbicide application takes considerable time and expensive due to the increasing cost of manual labour. Also, heavy wind at the time of spraying and improper application causes more herbicide loss, environmental pollution and drift injury to the nearby fields especially on sensitive crops. Herbigation ensures no additional costs of application. Okra is one of the important vegetable crop of Kerala. Weed competition during early stage of crop growth significantly lowers crop yields. Heavy weed infestation in okra is mainly due to wider spacing, slower crop growth during early stages, high fertilizer use and frequent irrigation. Therefore, the present study was undertaken with a view to study the effect of herbigation through drip irrigation system in okra and also to evaluate the economic feasibility of the system.

The experiment was conducted at Water Management Research Unit, Vellanikkara from December 2019 to April 2020. The experiment was laid out in RBD with ten treatments and three replications. Treatments comprised of herbigation and conventional spraying of oxyfluorfen applied in two doses (0.15 kg ha^{-1} & 0.20 kg ha^{-1}) at two different time of application , a hand weeded control and an unweeded control. The okra variety used was Arka Anamika.

Predominant grasses seen in the plots were *Panicum maximum, Digitaria sanguinalis, Brachiaria miliformis, Digitaria bicornis* and *Axonopus compressus.* Predominant broad leaved weeds were *Ageratum conyzoides, Euphorbia hirta, Mollugo disticha, Cleome burmanii, Trianthema portulacastrum, Alternanthera bettzickiana,* and *Synedrella nodiflora.* The sedges present were *Cyperus spp.,* and *Bulbostylis barbata* in the experimental field. Observations on weed count showed that application of oxyfluorfen was effective in controlling both grass and broad leaved weeds.

Maximum weed control efficiency was observed in conventional spraying with oxyfluorfen @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS with 91.31 per cent at 20 DAS; conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS with 90.08 per cent at 50 DAS and hand weeded control recorded 90.59 per cent at 80 DAS.

Lowest weed index was recorded from herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS followed by the treatment conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. Even though, conventional spraying recorded lesser weed count and weed dry weight, the yield was less due to the scorching of crop foliage. During herbigation, herbicide is applied through drip to the crop root zone, due to which weeds in the interspaces that can germinate in water stress conditions will grow. While in conventional spraying, the entire cropped area come in contact with herbicide and results in complete control of weeds. The nutrient removal by weeds was maximum in unweeded control.

Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS was on par with hand weeded control in terms of plant height, number of leaves and leaf area. It also recorded highest number of fruits per plant (17.8), average fruit weight (13.73 g), fruit yield per plant (243.90 g) and fruit yield (13.02 t ha^{-1}). It was on par with hand weeded control (13.04 t ha^{-1}), conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS and herbigation @ 0.20 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS. Weed competition resulted in 58.97 per cent yield reduction in okra. Unweeded control recorded significantly lower fruit yield (5.35 t ha^{-1}).

Both conventional spraying and herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS were equally effective in controlling weeds. Herbigation with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS resulted in higher gross return, net return and B: C ratio (1.97) which was closely followed by conventional spraying with oxyfluorfen @ 0.15 kg ha^{-1} two days before sowing followed by hand weeding at 30 DAS (1.89). The result of the study revealed that the farmers can adopt either herbigation or conventional spraying of oxyfluorfen according to their convenience because both treatments performed equally well. Herbigation can be implemented in fields in which already fertigation is carried out because it doesn’t involve any additional costs.

Appendix

APPENDIX – 1

Month	Minimum temperature (ºC)	Maximum temperature (ºC)	Relative Humidity (%)
December	22.5	33	63
January	20.4	32.9	55
February	23.4	35.3	59
March	24.8	36.7	65
April	24.6	35.8	64