MICROSITE VARIATIONS OF OKRA [*Abelmoschus esculentus* (L.) Moench.] UNDER DIFFERENT WEED MANAGEMENT PRACTICES

By

SHAMLA K.
(2015-11-016)

THESIS
Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture
(Agronomy)

Faculty of Agriculture
Kerala Agricultural University, Thrissur

Department of Agronomy
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680656
KERALA, INDIA
2017

DECLARATION

I, Shamla K. (2015-11-016) hereby declare that the thesis entitled **"Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other university or society.

Vellanikkara
Date: 23.9.2017

Shamla K.
(2015-11-016)

CERTIFICATE

Certified that the thesis entitled **"Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices"** is a bonafide record of research work done independently by **Mrs. Shamla K.** (2015-11-016) under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, associate ship or fellowship to her.

Vellanikkara

Date: 23.09.2017

Dr. P. V. Sindhu

Chairperson

Advisory Committee

CERTIFICATE

We the undersigned members of the advisory committee of **Mrs. Shamla K.** (2015-11-016) a candidate for the degree of **Master of Science in Agriculture,** with major field in **Agronomy,** agree that this thesis entitled **"Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices"** may be submitted by **Mrs. Shamla K.** (2015- 11- 016) in partial fulfillment of the requirement for the degree.

Dr. P.V. Sindhu 18/09/17
Assistant Professor (Agronomy)
AICRP on MAP & B
COH, Vellanikkara
(Chairperson)

18/9/17
Dr. C. George Thomas
Professor and Head
Department of Agronomy
COH, Vellanikkara
(Member, Advisory Committee)

18-09-17
Dr. Meera V. Menon
Professor (Agronomy)
AICRP on Weed Management
COH, Vellanikkara
(Member, Advisory Committee)

Dr. K. Surendra Gopal 18/9/17
Professor (Microbiology)
Department of Agricultural Microbiology
COH, Vellanikkara
(Member, Advisory Committee)

EXTERNAL EXAMINER
(Name and Address)

P. SUBRAMANIAN
Principal Scientist
ICAR - CPCRI
Kasaragod - 671124

Acknowlwdgement

First and foremost I bow my head before the **Almighty God** for enlightening and making me confident and optimistic throughout my life and enabled me to successfully complete the thesis work in time.

It is with immense pleasure and great respect, I avail this opportunity to express my deep sense of whole hearted and indebtedness to my major advisor **Dr. P. V. Sindhu**, Assistant Professor, AICRP on MAP & B for her expert advice, unrelenting and inspiring guidance, untiring help, constant support, constructive criticism, valuable suggestions, unfailing patience and gracious approach throughout the course of study and the period of the investigation and preparation of the thesis. I consider myself being fortunate in having the privilege of being guided by her.

I express my heartiest gratitude to **Dr. C. George Thomas,** Professor and Head, Department of Agronomy and member of my advisory committee for his valuable suggestions, critical assessments and cooperation throughout the research programme and critical scrutiny of the manuscript.

No words can truly express my profound sense of gratitude to **Dr. Meera V. Menon**, Professor (Agronomy), AICRP on Weed management and member of my advisory committee for the generous and timely help, valuable suggestions and critical comments always accorded to me during the course of this study.

I gratefully express my sincere gratiude to **Dr. K. Surendra Gopal,** Professor (Microbiology), Department of Agricultural Microbiology and member of my advisory committee for his unfailing support, Valuable guidance and relevant suggestions during my entire study which helped in successful completion this work. I thank him for all the help and cooperation he has extended to me.

My sincere thanks to **Dr. P. Prameela**, Professor (Agronomy) for her valuable help and advice during the course of my study.

Let me express my heartiest gratitude to my beloved teachers, **Dr. K. P. Prameela, Dr. J. S. Bindhu, Dr. P. Sreedevi, Dr. P. S. John, Dr. P. A. Joseph, Dr. K. E. Savithri, Dr. E. K. Lalitha Bhai (late), Dr. K. E. Usha, Dr. A. Latha and Dr. K. T. Bridgit** for their encouragement, valuable suggestions and help rendered during the course of study.

I wish to express my sincere gratitude to **Mr. Franklin, Mr. Sijith, Mrs. Deepika** (Farm Managers, Dept. of Agronomy), **Mrs. Sreela, Mrs. Shyamala and Ms. Saritha** for the sincere help, timely suggestions, encouragement and support extended during the conduct of research work.

I am grateful to all the staff of the Department of Soil Science and Agricultural Chemistry and the Department of Agricultural Microbiology for the help rendered by them during the period of work.

I am extremely thankful to the field labourers, Department of Agronomy, for their sincere help and cooperation during the conduct of field experiments.

I duly acknowledge the encouragement, moral support, precious suggestions and timely advice given by my respected seniors **Dr. Shyama S. Menon, Dr. Savitha Antony, Mrs. Indulekha, Ms. Reshma, Ms. Archana, Ms. Ancy, Ms. Atheena, Ms. Yansingh, Mrs. Rameeza, Mrs. Sreelakshmi, Mr. Rajanand, Ms. Vandana G. Pai, Mrs. Kavitha, Mrs. Shobha Rani, Mr. Saravana Kumar and Ms. Chijina.** I express my sincere thanks to my juniors **Ms. Annitroza, Ms. Nayana, Ms. Sreedhu, Ms. Jeen, Ms. Santiya and Ms. Akshatha** of Dept. of Agronomy for their affection and kind help offered during the course of study.

The encouragement rendered by my beloved friends at various stages of this investigations was invaluable and I thank to **Ms. Aparna K. K, Ms. Dhanalakshmi V. N, Ms.**

Anjana Devaraj, Mr. Akhil T. Thomas, MS. Nishidha C. T, Ms. Athira K. A, Mr. Abid, Mr. Nisak Mohammed and Mr. Syam kumar for their moral support, love and care towards me.

Words fall short as I place on record my heartfelt thanks to my beloved pals **Ms. Marjan P.S, Ms. Lekshmi sekhar, Mrs. Nadiya Rehman, and Mrs. Aishamol P. B.** who stood by me during all the times and also for their love, care and affection towards me during these years.

I thankfully remember the services rendered by all the staff members of Student's Computer Club, Library, Office of COH, and Central Library, KAU.

I am thankful to Kerala Agricultural University for technical and financial assistance for carrying out my study and research work.

Above all, I am forever beholden to my loving parents and family members for their constant prayers, boundless love, warm blessings, mental support and incessant inspiration throughout the period of my studies. Words can't really express the sincere support, selfless sacrifice, boundless patience and unflagging interest that I relished from my betterhalf throughout the period of my work.

Shamla K.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

1. INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench) is a warm season vegetable crop, which belongs to the family Malvaceae. It is widely cultivated all over the world mainly for its immature fruits. The tender fruits are used for culinary purposes. Okra has numerous health and nutritional benefits. It has high antioxidant potential, is good for digestion, stabilize blood sugar and improves eye sight and heart health. This vegetable is low in saturated fat (0.2 g/100g) and sodium (7 mg/100g), cholesterol is absent (0 mg/100g) and also a good source of protein (1.9 g/ 100g). The fruits are also rich in dietary fibre (12.8 %), vitamins A (14.3 %), C (38.3 %), K (39.1 %), B_6 (10.8 %), thiamin (13.3 %), folate (15 %), calcium (8.2 %), magnesium (14.3 %) and manganese (50 %). In addition to the tender pods, okra leaves are sometimes used for cooking purpose and in salads. Occassionally roasted powder of okra seeds are used as a caffeine-free substitute for coffee. The greenish yellow oil extracted from okra seeds is high in unsaturated fats, and is suitable for using as a biofuel. Stem yield bast fibre which has industrial value.

Weed infestation is a major constraint in vegetable cultivation and a yield loss to the tune of 70 to 80 percent was reported by Rana *et al.* (2011). Heavy infestation of weeds is a major constraint in cultivation of okra due to its wide spacing and slow growth rate during initial stages of growth. A yield loss of about 54.1 to 90.6 percent has been reported in okra due to weed competition (Singh *et al.*, 1982; Jalendhar *et al.*, 2016). Weeds are generally controlled by physical and cultural methods. Hand weeding is the most efficient method of weed control. However, these methods are tedious, time consuming and laborious. The easiest way to control weeds is through herbicides, which is less time consuming and less costly as compared to other methods. Considering the side effects of continued use of chemicals, relying only on chemicals for weed management is not ideal. Mulching is a proven alternative. It is a non chemical cultural method of covering the land surface with organic or inorganic materials, often for managing weeds. Most mulches reduce the germination and development of weed seeds through mechanical (DenHollander *et al.*, 2007) and allelopathic effects (Kruidhof *et al.*, 2008).

Before considering a production system which is ecologically sustainable, it is necessary to assess its possible impacts on the soil-plant-atmospheric continuum. Changes in physical, chemical and biological properties of soil because of management practices are good indicators of sustainability. Weed management can influence the productivity of both crop and soil. However, the effects of weed management practices on modifying micro environment of crops often vary depending on the method adopted, environmental conditions, and other management practices. The present experiment was planned to study the effects of certain weed management practices on microsite variations and their consequent effects on growth and yield of okra.

The experiment was planned with the following objectives:

1. To study the effect of weed management practices on microsite variations
2. To assess the consequent effects of weed management practices on growth and yield of okra

Review of literature

2. REVIEW OF LITERATURE

Vegetables are important in human nutrition as they are considered as protective foods. Growing vegetables is economical because they will produce more biomass per unit area and fetch more returns per unit produce. A review on weed management in vegetables is attempted in this chapter.

2.1 Problems due to weeds in vegetable crops

Weeds are the hidden stealers of plant nutrients, soil moisture and solar energy. They also invade the space which would otherwise be available to the main crop. They also shelter insect pests and disease causing organisms, impel adverse allelopathic effects, decrease quality of farm produce and increase cost of production (Ghosh and Kumar, 2014).

Weeds exhaust the soil resource base and boost expense of cultivation. In India, on an average, weeds reduce crop yields by 36.5% during rainy season and 22.7% during winter (Das *et al.,* 2012). They reduce quality of farm and animal products such as food, fibre, oil, forage/fodder, meat and milk and also cause problems to health in humans and animals.

Losses due to weeds are higher than those from insects and diseases. According to Rao (2000), weeds cause more yield loss than insects and diseases, and crop losses due to insects, weeds, diseases and other pests were 30%, 45%, 20% and 5% respectively. In addition to this, about 30 - 40 kg N, 10 - 15 kg P_2O_5 and 20 - 40 kg K_2O were removed by weeds per hectare (Das *et al.,* 2012). The nature of weed flora, their potency and duration of weed competition and soil and climatic factors determines the extent of yield loss.

Research studies demonstrated yield losses of up to 66% in spring cabbage, 51% in cauliflower, 70% in pea, 40% in okra, 60% in tomato, 62 - 82% in potato, 95% in beetroot, 28 - 78% in carrot, 2 - 41% in root and 86% in radish seed yield, 42% in onion, 60% in garlic and 15 - 75% in groundnut (Leela, 1987;

Ahuja *et al.*,1999; Singh and Bhan, 1999; Kumar *et al.*, 2001; Sandhu *et al.*, 2002; Jat *et al.*, 2011, Kaur *et al.*, 2015).

2.2 Weed flora in vegetables

Weeds in vegetable and flower fields are in different sizes, forms and behaviors. They belong to various families and differ in physiology, morphology and habits of growth. Mostly the weeds are seasonal in nature, because their life cycle is short.

Weed flora associated with vegetable crops in India during Rabi season include *Chenopodium album, Melilotus indica, Melilotus alba, Lathyrus aphaca, Vicia sativa, Convolvulus arvensis, Cynodon dactylon, Cyperus rotundus, Orobanche* spp. and *Euphorbia hirta* and in Kharif season, *Trianthema portulacastrum, Echinochloa colona, Cyperus rotundus, Digeria arvensis, Amaranthus viridis, Physalis minima, Phyllanthus niruri, Commelina benghalensis, Eleusine indica, Ageratum conyzoides, Cynodon dactylon* and *Celosia argentea* (Kumar *et al.*, 2012a). Bhullar *et al.* (2015) reported that *Setaria verticillata*, *Dactyloctenium aegyptium*, *Eleucine indica*, *Digitaria sanguinalis*, *Echinochloa colona*, *Trianthema portulacastrum*, *Cucumis callosus*, *Amaranthus viridis*, *Digera arvensis*, *Euphorbia microphylla*, *Phyllanthus niruri*, *Portulaca oleracea*, *Commelina benghalensis* and *Cannabis sativa* are the common weeds present in vegetable fields of India.

Smith *et al.* (2009) reported the weed flora associated with okra are mostly 14 species of annual weeds which included *Amaranthus spinosus, Celosia trigyna, Celosia argentea, Corchorus corchorifolia, Aspilia africana, Synedrella nodiflora* etc. Iyagba *et al.* (2013) enlisted the cumulative weed flora composition in an okra field in Nigeria which included *Amaranthus spinosus, Celosia loxa, Ageratum conyzoides, Aspilia africana, Chromoleana odorata, Tridax procumbens, Commelina benghalensis, Commelina diffusa, Cyperus rotundus, Cyperus tuberosus, Euphorbia heterophylla, Phyllantus amarus, Mimosa pudica, Sida acuta, Boerhaavia diffusa, Axonopus compressus, Cynodon dactylon, Eleusine* *indica, Eragrostis atrovirens, Paspalum conjugatum, Panicum maximum, Sporobalus pyramadalis, Talinum triangulare, Diodia scandiens, Mitracarpus villosus, Physalis angulate* and *Laportea aestuans.*

Kaukovirta (1988) reported *Chenopodium album, Stellaria media, Viola* spp., *Poa annua* and *Elymus repens* as the most abundant weed species in vegetable fields in Finland. Santos *et al.* (2017) identified and reported the weed flora associated with okra under organic cropping system in Brazil. They identified 44 weed species of 17 different families, in which 38.46% were monocot weeds and 61.54% were dicot weeds. Important species were *Commelina benghalensis*, *Cynodon dactylon*, *Eleusine indica*, *Phyllanthus niruri* and *Alternanthera tenella.* The total yield loss due to these weeds was around 51%.

Weeds like *Cyperus rotundus*, *Cynodon dactylon* and *Echinochloa crusgalli* contributed to 75 % of weed flora in okra in Kerala (Rattan *et al.*, 1981; Sainudheen, 2000). It is reported that in Kerala, the major weeds of okra and chilli in fields were *Cynodon dactylon, Cyperus rotundus, Digitaria ciliaris, Brachiaria distachya, Eleusine indica, Ludwigia parviflora, Cleome viscosa* and *Ageratum conyzoides* (KAU, 1992). Sainudheen (2000) reported that the major perennial weeds in okra as *Cynodon dactylon* and *Cyperus rotundus* and annual weeds as *Cyperus iria, Digitaria ciliaris, Dactyloctenium aegyptium, Eleusine indica* and *Ludwigia parviflora*. Syriac and Geetha (2007) reported *Eleusine indica, Digitaria sanguinalis*, *Paspalum* sp. and *Eragrostis* sp. as major grassy weeds infesting vegetable crops and *Ageratum conyzoides*, *Leucas aspera, Ludwigia perennis, Commelina benghalensis, Cleome viscosa, Phyllanthus niruri, Vernonia cineria* as major broad leaved weeds. According to them, major sedges included *Cyperus rotundus*, *C. iria* and *Kyllinga monocephala*.

According to Norman *et al*. (2011), most prevalent weeds in the okra field are *Cyperus rotundus, Talinum triangulare, Paspalum conjugatum, Digitaria horizontalis, Mollugo nudiculis, Euphorbia heterophylla, Dactyloctenium* *aegyptium* and *Cleome viscosa.* Amare *et al.* (2015) reported that in tomato, 83.3% of the weeds were broad leaved weeds and about 8.33% sedges and 8.33% grassy weeds. The main weed species infesting the field were *Amaranthus hybridus, Bidens pilosa, Commelina benghalensis, Cyperus esculentus, Datura stramonium, Digitaria abyssinica, Raphanus raphanistrum* and *Ipomea ariocarpa.*

2.3 Critical period of crop weed competition

Critical period of crop weed competition is defined as the interval in the lifecycle of the crop when it must be kept weed free to prevent yield loss. Crops are very sensitive to weed competition particularly horticultural crops and it is needed to keep crops free from weeds until the end of their critical period of weed competition.

Importance of maintaining the fields free from weeds at critical stages for getting maximum yield in okra was reported by Singh *et al.* (1982). Critical period of crop-weed competition of some important crops includes beet (2-4 weeks after emergence), cabbage (3 weeks after planting), carrot (3-6 weeks after emergence), cucumber (4 weeks after seeding), lettuce (3 weeks after planting), onion (whole season), potato (15-45 days after planting), chilli (30-45 days after transplanting), pea (30-60 days after planting), turmeric (60-150 days after planting), groundnut (30 days after planting) (Jat *et al.,* 2011; Bhullar *et al.,* 2015). Generally, in direct seeded crops, the critical period of weed competition is longer than in transplanted crops. For most of the row crops including vegetables, the period from emergence to four weeks is considered as critical period of crop weed competition (Bhullar *et al.,* 2015).

2.4 Nutrient uptake by weeds

Weeds are more competitive in removing nutrients from the soil than crops. Negative correlation between nutrient uptake by weeds and crops was reported by Shetty and Hosmani (1977). In groundnut field, weeds removed as much as twice more N, 24% more K and twice more Ca than groundnut plants, thereby, inhibiting the crop from optimum nutrient uptake and increasing the total nutrient requirement of groundnut crop. Chaudari *et al.* (2007) observed maximum nutrient removal by weeds from unweeded control plot in groundnut (16.45, 3.09 and 3.97 kg N, P and K ha^{-1} respectively), with minimum crop uptake (45.81, 17.40 and 9.94 kg N, P and K ha^{-1} respectively). Weeds which competed with crop for different growth factors expended greater amounts of nutrients and thus suppressed the crop.

On an average weeds removed 52.3, 13.0 and 72.2 kg of N, P and K ha^{-1} from groundnut field under rainfed situation at Junagadh (Jat *et al.,* 2011). Kumar *et al.* (2012b) reported that weeds reduced wheat grain yield by 78.8% and removed about 28.7 kg of N, 13.4 kg P_2O_5 and 21.5 kg of K_2O ha^{-1} as compared to weed free conditions. Maximum removal of N, P and K by weeds was recorded in weedy check plot due to higher dry matter of weeds which enabled them to absorb more nutrients. Controlling weeds reduced the uptake of nutrients by them and made them available to crops and reduced the cost on additional nutrients application. Integrated weed management with combination of chemical, mechanical and hand weeding resulted in efficient weed control, and higher yields (Gowda *et al.,* 2012).

Mean nutrient depletion by weeds under soybean - wheat cropping system was reported by Chander *et al.* (2013). According to them weeds in unweeded check removed 71.5 kg N, 6.9 kg P and 97.4 kg K, thus suppressing crop growth and yield.

2.5 Weed management in vegetables

Weed control in vegetable crops is essential early in the season, as the weed competition reduced the vigour, uniformity and overall yield of the crop. Several methods are in vogue to control weeds. The methods used to control weeds are broadly classified into chemical methods and non chemical methods and reviewed here.

2.5.1 Chemical methods

Compared to other countries, pesticide consumption in India is very small. Wheat, rice, soybean and sugarcane are the major crops using herbicides with approximate shares of 28, 20, 9, and 7 % respectively. With the increase in labour shortage, usage of herbicides has also increased (Yaduraju, 2012). Herbicides are profitable where labour is scarce or expensive. Early season weed competition results in the greatest yield reduction, and there fore, pre emergence herbicides are used for early control of weeds. However, a major disadvantage of herbicides is persistence of some of them in the environment causing environmental pollution. Herbicides are grouped into two based on the time of application, pre emergence herbicides and post emergence herbicides.

Pre emergence herbicides

Most of the pre emergence herbicides are soil active compounds and are effective against weeds emerging from the seeds. Atrazine, alachlor, diuron and simazine are some of the examples of pre emergence herbicides used in agriculture (Gupta, 2010).

In Irish potato (*Solanum tuberosum* L.), excellent control of weeds was obtained by the application of metribuzin + metolachlor (0.56 and 2.24 kg ha^{-1} respectively) as pre emergence followed by sethoxydim + crop oil (0.22 kg ha^{-1} and 2.34 L ha^{-1} respectively) as post emergence application (Hoyt and Monks, 1996).

As per reports of Nandal *et al.* (2005), application of oxadiazon at 1.0 kg ha^{-1} one day prior to transplanting of cabbage (*Brassica oleracea* var. *capitata* L.) recorded the lowest weed intensity, dry weight of weeds and maximum yield. The increase in yield was 219% over the weedy check treatment.

Pre emergence application of alachlor (2.0 and 2.5 kg ha^{-1}) recorded excellent weed control and dry matter production of weeds was lowered comparable to weed free check at 30 and 60 DAT in brinjal (Syriac and Geetha, 2007). According to Sheela *et al.* (2007) pre emergence application of fluchloralin @ 0.4 kg a.i. ha^{-1} reduced the weed population and improved the fruit yield over control treatment in okra. About 87.9 per cent weed control efficiency was found with the treatment pendimethalin (1.0 kg ha^{-1}) followed by two hand weedings in brinjal (Sultana *et al.*, 2008).

Panotra *et al.* (2012) reported that application of fluchloralin @1.0 kg a.i. ha^{-1} and pendimethalin @ 1.0 kg a.i. ha^{-1} as preplanting and pre emergence spray in french bean significantly decreased the population of *Anagallis arvensis, Melilotus alba, Melilotus indica* and *Phalaris minor* than other treatments and significantly improved the growth and yield parameters viz. plant height, number of branches, dry matter production, number of pods per plant and seeds per pod, seed and straw yield. Nandwani (2013) reported that application of trifluralin (2 oz. /10 sq. ft., granular) and Pelargonic acid (5% v/v) a day before transplanting of okra plants into the field controlled emergence of weeds with in the first two to three weeks after application.

Pendimethalin application at the rate of 0.33 kg ha^{-1} prior to planting performed best in terms of okra growth, and controlling weeds, and showed no phytotoxic symptoms to okra seedlings as compared to other higher doses of pendimethalin treatments (Adijoro and Olopha, 2013).

Arivukkarasu and Kathiresan (2014) suggested that integration of atrazine @ 1 kg ha^{-1} followed by hand weeding at 30 DAS can be recommended for controlling invasive weed *Trianthema portulacastrum* and other weed species found in hybrid maize. The method has recorded the highest benefit-cost ratio of 3.08 showing that it is economically viable leads to higher productivity and profitability. According to Muhammed *et al.* (2015) application of pendimethalin @ 1.0 kg ha^{-1} as a pre emergence spray gave the lowest weed count (34 no. m^{-2}) and weed dry weight (2.33 g m^{-2}) as compared to the other treatments including hand weeding and mulching in okra.

Post emergence herbicides

Post emergence application of the herbicide metoxuron @ 3.0 kg a.i. ha^{-1} at 15 and 30 DAS as band application or inter row brushing in carrot resulted in 88 and 92 % reduction in weed density respectively (Baumann and Slembrouck, 1994). Eizenberg *et al.* (2003) reported that the root parasitic weed *Orobanche* spp. in tomato can be effectively controlled by application of Rimsulfuron at 100-200 g a.i. ha^{-1}, and sulfosulfuron at 50- 100 g a.i. ha^{-1} at 14 DAP followed by irrigation of 300 m^3 ha^{-1} and further emergence can be controlled by application of chlorsulfuron 3 g a.i. ha^{-1} along with irrigation water at 28, 42 and 56 DAP.

Jat *et al.* (2011) reported that application of Fluazifop-p-butyl (Fusillade) @ 0.25 kg a.i. ha^{-1} as post emergence spray at 15-20 DAS proved beneficial on controlling weeds in groundnut at Akola, Jalgaon and Khargaon. In plasticulture vegetable production systems, tank mixed application of carfentrazone with flumioxazin or *S*-metolachlor resulted in reduction of total weed density to 70 - 90% as compared to the untreated control in tomato (Boyd, 2016).

According to Singh *et al.* (2016), post emergence application of imazethapyr + imazamox @ 40 g ha^{-1} applied at 3-4 leaf stage (around 20 DAS) in cluster bean (*Cyamopsis tetragonoloba* L.) recorded minimum weed density and dry weight for both grassy and broad leaved weeds and obtained maximum weed control efficiency (around 88.1%).

2.5.2 Non chemical methods

Interest in non-chemical weed control methods has been growing in recent years with the increased acceptance of organic farming and environmental concerns over negative effects of herbicides. Potential problems associated with herbicides use are injury to non target vegetation, crop injury, residues in soil and water, i.e., reduction of soil and water quality, toxicity to other non target organisms, concerns for human health and safety, and herbicide-resistant weed populations. Excessive dependence on a single herbicide could result in reduction of potential of the herbicide in selecting weeds and result in shift in weed flora (Abouziena *et al.,* 2008). Prominent non-chemical methods related to the present study are reviewed here.

Hand weeding

Hand weeding is a conventional method of weed management which helps to keep weed population below economic threshold level throughout the crop period, however, it is time consuming, tedious and uneconomical in most of the situations (Dhananivetha *et al.,* 2017).

Rahman *et al.* (2011) reported that the highest bulb yield of onion (12.25 tons ha^{-1}) was recorded in plots with hand weeding throughout the crop period, which controlled all the weeds but was an uneconomical and tedious method. Hand weeding at 20 and 40 DAS resulted in the least weed density, weed index, higher weed control efficiency and yield in okra as reported by Jalendhar *et al.* (2016).

Hand weeding at 20 and 40 DAS in okra recorded a seed yield of 16.18 q ha^{-1}, which was statistically similar to seed yields obtained from pre emergence application of the herbicides alachlor and metolachlor (1 kg a.i. ha^{-1}) integrated with hand weeding at 40 DAS (Sharma and Sharma, 2000). Hand weeded plots recorded lower weed index (23.10 %) and higher yield (12.02 t ha^{-1}) than other treatments including organic mulches and pre emergence application of herbicide in okra as reported by Muhammed *et al.* (2015).

Hand weeding twice at 20 and 40 DAS recorded lowest weed density and dry matter production, resulting in higher weed control efficiency (84.29%) and significant improvement in the yield in soybean (Paudel *et al.,* 2017).

Mulching

The word 'mulch' is derived from the German word "*molsch*", meaning soft to decay, apparently referring to the use of straw and leaves by gardeners as a spread over the ground as mulch (Jacks *et al.,* 1955).

Mulches modify the micro environment of surrounding crops differently depending on mulch properties, environmental conditions, and management practices; however, in general, organic mulches result in cooler and moist soil compared with bare ground (Munn, 1992). Use of different types of soil covers or mulches like straw, leaves, husk, crop residues and black plastics have been found to conserve moisture, control weeds, moderate soil temperature and produce increase in yield of different vegetables (Tiwari *et al.,* 1998). Mulching has smothering effect on weed population by acting as a physical barrier to photosynthetic activity of weeds and hinders the growth. Competition occuring between the main crop and weeds can be reduced through mulching creating favorable conditions for crop growth (Sharma and Kathiravan, 2009). Mulching affected soil physical properties. Application of mulches reduced bulk density and soil temperature significantly and increased porosity and moisture content compared with the control (Adekiya *et al.,* 2017).

Mulches are used to cover soil surface around the plants to create suitable condition for the growth. This includes temperature moderation, control of weeds and also constitutes positive effects on crop like earliness, yield and quality. Mulches are either organic or inorganic. Organic mulches are those derived from plant and animal materials. The mulches which do not decompose are known as inorganic mulches, therefore, it must be removed from the soil after usage (Monks and Bass, 1999). The most frequently used organic mulches include plant residues such as straw, hay, peanut hulls, leaf mold and compost, wood products such as sawdust, wood chips and shavings and animal manures (Kumar and Lal, 2012).

Applications of mulches enhanced the soil hydrothermal regime and thereby improved the vegetative and flowering properties of the plant and as a result increased the fruit yield of tomato over unmulched plot (Agele *et al.,* 2000). Waterer (2000) reported that mulching produced higher soil temperature and positively affected yield of melons to about 73% as compared to the control plot. This practice also reduced cost of production of melon as compared to nonmulched treatments.

Usman *et al.* (2005) reported that in okra, mulching improved plant height, number of leaves, pod length and pod diameter and reduced weed density, and also was found helpful in conserving soil moisture and produced higher yield. Goswami and Saha (2006) reported that mulching improved the yield of elephant foot yam by about 7.1- 28.8 % than unmulched plot and also conserved soil moisture to about 26.3 - 29.7 % in the soil. According to Kumar *et al.* (2014) the contents of organic carbon, available nitrogen, phosphorus and potassium, and the bacterial and fungal population increased significantly by mulching as compared to unmulched plots and it also improved soil biological activities.

According to Govindappa *et al.* (2015), mulching was highly desirable in crop production. It reduced soil moisture transpiration, controlled weed, maintained optimum soil temperature and enhanced soil microbial activity and soil organic carbon. It is also proved that mulching increased soil moisture content and decreased soil erosion, improved soil structure and reduced the weed growth.

Organic mulching

Organic mulches are derived from plant and animal materials such as straw, hay, peanut hulls, leaf mold, compost, sawdust, wood chips, shavings and animal manures, grass clippings, leaves, newspapers (shredded or in layers), and straw (Bhardwaj, 2013). Organic mulches are effective in reduction of nitrate leaching, improvement of soil physical properties, checked erosion, provided organic matter, adjusted temperature and water retention, improved nitrogen balance, took part in nutrient cycle as well as increased the biological activity.

Jodaugiene *et al.* (2006) reported that all organic mulches (straw, peat, wood chips) reduced weed germination and it had very favorable effect particularly during intensive weed emergence. It was also important to ensure that mulches were not contaminated with weed seeds before application.

Thankamani *et al.* (2016) reported that mulching with paddy straw significantly reduced the dry weight of weeds. Similar effect was found in treatments with coconut leaves along with green leaf mulches in ginger. By using organic mulches better weed management could be achieved, as it would nourish the crop rhizosphere and improve the yield (Muhammed *et al.,* 2015).

Organic mulches supplemented plant nutrients to soil when they decomposed and thereby saved the labour cost, which was an additional benefit of organic mulches over the plastic mulches. Plastic materials for mulching were expensive and might not be easily accessible, on the other hand, organic materials for mulching were almost available everywhere and could be easily collected by farmers (Kader *et al.,* 2017).

Sathiyamurthy *et al.* (2017) reported that in chilli, organic mulches showed superior performance in plant height, number of fruits per plant, fruit length and weight, and yield than control treatment showing that organic mulches had favourable effect on the growth and development of the plants.

Paper mulching

Paper mulches have been considered for use in fruit and vegetable production since the early 20th century. Asphalt-impregnated paper mulches were successfully used in pineapple (*Ananas comosus*) production in the 1920s in Hawaii for increasing yield and quality (Smith, 1931).

Paper mulches could be made from recycled fibres and it would improve organic matter content of the soil since they were bio degradable. The major problem associated with paper mulching was tearing and wind blowing. Correct laying and fast crop establishment could reduce this problem. Several types of papers were used as mulches like brown paper, black paper, newspaper and crimped paper. Newspaper might acidify the soil during its degradation. Newspaper, with eight pages thick lasted for a growing season and degraded slowly (Grundy and Bond, 2007).

Sanchez *et al.* (2008) reported that mulching with shredded newspaper recorded the lowest weed population than other treatments and the degradation rate of mulches was the highest for treatments with newspaper, followed by shredded newspaper and straw. Shredded newspaper treatments were best in suppressing weeds than straw mulching and non mulching treatments and gave higher yield than other treatments (Munn, 1992).

Newspaper mulching recorded the higher germination percentage of teak (50.38 %) than other mulching materials including different polythene mulches and straw mulch in teak nursery, Kerala (Sudhakara, 2013).

Splawski *et al.* (2016) reported that newspaper mulch decreased total weed biomass, to greater than 90%, and newspaper + grass mulch decreased total weed biomass to 78% compared with control treatment. Newspaper mulching retained higher soil moisture content than black plastic and control and also resulted in higher total numbers of marketable pumpkins. They suggested that shredded newspaper or newspaper + grass mulches could be useful for organic or small scale urban crop producers as an effective alternative to black plastic mulch.

Straw mulching

Ghosh *et al.* (2006) observed that mulching with straw (either wheat or paddy) had a favourable effect on soil water and temperature which resulted in early seed emergence, more number of flowers and mature pods and less weeds in groundnut. Straw mulching produced more pod and haulm yields, 17 - 24% and 16% respectively, than other treatments which included polythene mulch (black or transparent) and no mulch.

Straw mulching was the better method to reduce weed germination as it was not infected with the weed seeds itself and it reduced impact on weed emergence by about 3.5 to 14.1 times than the plots without mulching (Jodaugiene *et al.,* 2006). The biomass, kernel yield and nitrogen use efficiency of maize increased due to straw mulching. Mulching had insignificant effects on the distribution of dry matter and harvest index of maize (Feng *et al.*, 2009).

Li *et al.* (2013) reported that mulching with wheat straw significantly reduced water loss - a fallow plot mulched with wheat straw conserved 106.9 mm water in the 0 - 200 cm soil layer and had a fallow efficiency of 35% compared with nonmulch plots having a low fallow efficiency of 10 - 15%. Mupangwa *et al.* (2013) observed increase in soil organic carbon and decrease in soil bulk density due to straw mulching.

The presence of straw on the soil surface reduced the maximum temperature, and increased the minimum diurnal soil temperature. It also increased concentration of nitrate N and available P in the upper soil layer significantly and improved water use efficiency in alfalfa (Jun *et al.*, 2014). Straw mulch applied at 10 t ha^{-1} significantly increased the yield of baby corn by 68.98% as compared to weedy check. Maximum favourable effect on population of non-symbiotic N-fixing and phosphate solubilizing bacteria was found under straw mulch treatments (Dutta *et al.,* 2016).

Mulching treatments influenced soil microbial parameters. Comparing wheat straw and plastic mulch, soil microbial biomass (C_{mic}) content was slightly higher in soil under straw mulch (160 mg kg^{-1}) than soil under plastic mulching (140 mg kg^{-1}). Straw enhanced soil microbial populations, and soil bacteria and fungi population were significantly higher in straw as compared to plastic mulching. The number of soil bacteria was 1.2 times higher in straw than in plastic mulching treatment while numbers of fungal CFU under straw mulching were up to 6.6 times higher than in soils under plastic film (Munoz *et al.,* 2017).

Mulching with coir geo textiles

Coir geo textiles are made from coir fibre or yarn which is obtained from coconut husk either by natural retting or by mechanical process. These are permeable fabrics and able to control soil erosion, promote vegetation and protect the earth by retaining the top soil. They can be used as mulching material to control weeds (Coir Board, 2016).

Mulching with rubberized coir improved crop growth parameters like plant height, leaf number and lateral spread in okra. It also facilitated early flowering and increased fruit yield. Coir materials as mulch resulted in yield increase from about 67 to 196%. In pineapple, rubberized coir mulch enhanced the fruit yield. It also reduced soil temperature and improved soil moisture. Coir materials were biodegradable and eco-friendly, and could be recommend as good mulch material for okra and pineapple with reduced weed problem (Beena and Anil, 2011).

Vishnudas *et al.* (2012) reported that the highest moisture retention capacity was found in slopy areas treated with geotextile and crops, followed by plots with geotextiles alone, and the control plot had the lowest moisture retention capacity. As this method was economically viable for income generation, food security, along with slope stabilization, it was suitable to poor and marginal farmers in the highland region of Kerala.

Zribi *et al.* (2015) reported that mulching with geotextile reduced the soil evaporation rates as compared to bare soil, and therefore, geo textiles could be recommended for soil evaporation control over pine bark only if the mulching material was not in contact with the wetted soil.

Plastic mulching

Plastic mulching was the most widely used mulch for weed control in organic and conventional systems. It could be used in a wide variety of crops like vegetables and orchards. Plastic mulching could also be used for short periods to disrupt early weed emergence in freshly prepared beds or for several months over established vegetables (Grundy and Bond, 2007). It accounted for the greatest volume of mulch used in commercial crop production. The plastic materials used as mulch are poly vinyl chloride or polyethylene films. Owing to its greater permeability to long wave radiation it could increase temperature around the plants during night in winter. Hence, polyethylene film mulch was preferred as mulching material for production of horticultural crops (Bhardwaj, 2013).

Mulching the soil with black polyethylene sheeting, on the day of planting of tomato and eggplant seedlings eliminated *Orobanche* and also controlled a large number of other annual weeds (Vouzounis and Americanos, 1998). Singh *et al.* (2009) reported that use of black polythene mulch along with drip irrigation increased the fruit yield of tomato to 57.87 t ha^{-1} as compared to control plot (29.43 t ha^{-1}). It also improved other growth parameters like plant height, LAI, dry matter production, fruit weight and yield.

The use of dark colored plastic mulches increased total yield of okra compared with bare soil and also increased soil and air temperatures (Gordon *et al.,* 2010). Lalitha *et al.* (2010) reported that plastic mulching improved soil properties like soil temperature, moisture content, bulk density, aggregate stability and nutrient availability. Due to the improved microclimate, plant growth and yield were also increased under plastic mulching.

Aniekwe (2015) observed 100% weed suppression under black plastic mulched plots than other mulching methods and unmulched plots. Besides, black plastic mulch modulated the daily soil temperature and promoted early germination and flowering and significantly improved the yield in okra. According to Parmar *et al.* (2013) black polyethylene mulch improved all the plant growth, yield and quality characters significantly over unmulch (control), which resulted in better growth and yield in water melon and also gave high B:C ratio.

Singh *et al.* (2014) reported that mulching with black polythene extended the harvesting of summer squash to 10 days, while in tomato and capsicum it extended to 2 weeks and also increased yield to 31.6 % in tomato and 46.6 % in summer squash. The treatments under plastic mulch had higher moisture content, soil temperature, relative leaf water content (RLWC), and water use efficiency than organic mulch and other treatments without mulch. It also increased the plant characters like plant height, branching, fruit diameter, root parameters (length, volume and dry weight) and yield of brinjal (Kaur, 2015). In chilli, the lowest weed density of 13.23 m^{-2} was recorded for polythene mulch followed by organic mulch, which recorded 18.33 m^{-2} at 75 days after planting and also recorded highest B:C ratio (Sathiyamurthy *et al.,* 2017).

2.6 Effect of mulching on soil microflora

The soil microorganisms act as sink and source of nutrients as these are organic decomposers and hence provide more nutrients to plants. Soil microorganisms are also capable of promoting plant growth through different mechanisms, such as biological nitrogen fixation (BNF), phytohormone production, phosphate solubilization and siderophore production. They are also known to participate in many important ecosystem processes such as the biological control of plant pathogens, nutrient cycling, and/ or seedling growth (Zahir *et al.,* 2004).

Mulching had a stimulating effect on soil microbes and through this on soil fertility (Csaba *et al.,* 2007). According to Yadav *et al.* (2008), mulches provided different kinds of ecological niches in the subsystem of crop environment. They encouraged multiplication of micro arthropods, earthworms and other beneficial microorganisms in the rhizosphere which brought about changes in the status of soil fertility.

Mulching increased the soil microbial activity, population of bacteria, fungi and actinomycetes on comparing with the plot which received chemical weed management. Among the different organic mulches such as mango leaves, coconut leaves, newspaper, paddy straw and polythene, microbial population was higher in paddy straw mulched plot than others (Muhammed *et al.,* 2015).

Mulched soil contained more microbial population than unmulched soil. Mulching increased organic carbon in the soil, which was the major constituent of the food supply for microorganisms, and led to increased microbial population in the mulched plot. Mulching and N fertilization increased the rhizospheric microbial population which indirectly resulted in more decomposition of nutrients into inorganic forms, therefore availability of major nutrients to the plants increased which had a positive effect on plant growth and yield (Bhagat *et al.,* 2016).

2.7 Effect of weed management methods on soil microclimate

Soil temperature

Mulching influenced the microclimate largely and it was by way of regulating soil temperature, moisture content, humidity, concentration of carbon dioxide and wind speed. Several studies on the influence of soil temperature have been reported. Ham *et al.* (1993) studied the optical properties of plastic mulch and reported that the highest mid day soil temperature beneath the mulches was due to high short wave transmittance (transparent) along with long wave transmittance. The increase in temperature due to sun's energy which passed through the mulch and heated the air and soil beneath the mulch directly and then the heat was trapped by the phenomenon of "greenhouse effect" (Hu *et al.*, 1995).

Mulching with wheat straw increased the minimum temperature of soil to about 2 - 3^0C which was recorded at 8.00 hours during the emergence and early growth period of groundnut crop, while it reduced the maximum soil temperature to 2 - 4°C recorded at 14.00 hours during pod development stage of the crop. At the same time black polythene mulch increased the soil temperature to 4 - 5 °C during the whole crop season (Ghosh *et al.,* 2006).

Sharma and Kathiravan (2009) observed the order of soil temperature during morning hours under different mulches as follows: transparent polythene > black polythene > bicoloured polythene > available field grasses > pine needle > no mulch treatments. The maximum rise in soil temperature by 2.9^0C was observed in mulched soil as compared to unmulched soil with respect to air temperature.

As per Eruola *et al.,* (2012) mulching significantly improved soil temperature and also the emergence and development of yam setts and increased tuber yield as compared to unmulched plots. Rate of chemical reactions, water content, and nutrient transport in soil were influenced by soil temperature, besides it also affected physiological aspects of plants like ion uptake, root growth, and also the composition and function of soil microbial communities. Soil temperature extremes influenced the germination of seeds, functional activity of root system and development of crop. The soil temperature was found to be higher by about 1 to 10ºC in mulched plot as compared to no mulched plot inside and outside the poly house (Abhivyakti *et al.,* 2016).

Bahar and Singh (2013) reported that in maize, soil temperature at 5 cm depth was lower in hand weeded and herbicide (atrazine @ 1 kg a.i. ha^{-1}) applied plots than plots mulched with polythene sheet and straw, but soil temperature in these plots were higher than unweeded control plots.

Soil moisture

Mulching has been promoted as an effective means for conserving soil moisture. Ghosh *et al.* (2006) reported that wheat straw and black polythene mulch retained higher amount of soil moisture at a depth of 0 - 15 cm than unmulched plot all over the growing period of groundnut. Among the mulched plots wheat straw mulch conserved 10 - 20% more soil moisture than black polythene mulch, particularly in the months of April and May.

Sharma and Kathiravan (2009) reported that treatments with mulches maintained correspondingly higher soil moisture contents over unmulched control treatment. It acted as an insulating barrier and prevented evaporation from soil surface (Kumar and Lal, 2012). Under rainfed cultivation conservation of soil moisture is essential for favorable crop production. *Insitu* moisture conservation was more in upper 0-7.5 cm layer.

In China, plots mulched with wheat straw maintained 106.9 mm water in the upper 200 cm soil depth with an efficiency of 35.1% while those plots mulched with plastic sheets conserved 140.9 mm water with 46.1% efficiency (Li *et al.,* 2013). The conservation of soil moisture through mulching is due to modification of favourable microclimatic conditions in soil. Organic mulches helped to prevent weed growth, reduced evaporation and increased infiltration of rain water during crop period. Besides this, plastic mulch helped in exuding excess water away from the crop root zone during periods of heavy rain fall. This could reduce irrigation frequency and amount of water used (Bharadwaj, 2013).

Saikia *et al.* (2014) reported that in mustard, the treatment with straw mulching stored more soil moisture than unmulched treatment. Plastic mulch treatments had higher moisture content at depths 0-15 cm and 15-30 cm than organic mulch and treatments without mulch (Kaur, 2015). Alliaume *et al.* (2017) reported that combination of mulching and reduced tillage improved water capture to about 9.5% and reduced runoff by 37%, resulting in reduced risk of erosion and improved availability of water to the plants over four years of trial.

Malviya *et al.* (2012) reported lower soil moisture in hand weeded and herbicide treated plots than treatments with different mulches. Similar findings were also given by Muhammed (2015).

2.8 Effect of weed management methods on yield

Ghosh *et al.* (2006) after a seven year study and concluded that organic mulch was superior to inorganic mulch and no mulch treatments. In okra, higher fruit yield was from the plots with application of a pre emergence herbicide fluchloralin @ 0.4 kg a.i. ha^{-1} followed by one inter cultivation at 40 DAS and mulching with green leaves with one inter cultivation at 40 DAS, but these were on par with the farmer's practice with three to four inter cultivation (Sheela *et al.*, 2007).

Hand weeding twice at 25 and 45 DAS and pre emergence application of fluchloralin @ 1 kg a.i. ha^{-1} and pendimethalin @ 1 kg a.i. ha^{-1} integrated with hand weeding at 35 DAS recorded superior yields of soybean and better control of weeds (Peer *et al.,* 2013).

Organic mulching produced 17 - 24% higher yield and an additional profit of Rs. 3935 ha^{-1} than no mulch treatments. Mulching improved the yield in both fruit crops and vegetable crops. The percentage yield increase in fruit crops ranged from 12.61 to 64.24 % and in vegetable crops it was from 17.39 to 60.74 % (Govindappa *et al.,* 2015). Muhammed *et al.* (2015) reported that polythene mulching gave higher yield of okra (15.63 t ha^{-1}) followed by hand weeding (12.02 t ha^{-1}). According to them, pre emergence application of pendimethalin @ 1 kg a.i. ha^{-1} also improved the yield of okra.

Abhivyakti *et al.* (2016) recorded maximum fruit yield (37.3 t ha^{-1}) for the treatment with black polythene mulch which was significantly higher over the no mulch treatment (28.6 t ha^{-1}) in tomato under open condition. Hand weeding in maize at 20 and 45 DAS gave higher grain yield (8.64 t ha^{-1}) than straw (5.98 t ha^{-1}) and polythene (4.25 t ha^{-1}) mulching as reported by Abdullahi *et al.* (2016). Pre emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + one hand weeding at 30 DAS resulted in significantly taller plants, high leaf area index, high pod yield per plant (127.16 g) and higher total pod yield (13279 kg ha^{-1}) in okra (Jalendhar *et al.,* 2016)

Mulching with grasses in okra produced 49% and 158% higher pod yield compared with legume mulching and the control treatments during 2015 (dry season). During 2016 (wet season) mulching with legume material increased the pod yield of okra by about 56% and 122% compared with grass mulch and the control treatment respectively. Therefore grass materials could be used as mulch in the dry season and the legume materials could be used as mulch during the wet season which would maximise yield (Adekiya *et al.,* 2017).

2.9 Economics of weed management

Goswami and Saha (2006) reported higher benefit:cost (B:C) ratio of 3.12 - 3.38 in mulching with organic materials than that of inorganic or synthetic mulches (1.88-2.09). According to Ghosh *et al.* (2006), combined use of wheat straw and black polythene mulch recorded significantly higher returns than other mulch treatments. Wheat straw mulch recorded highest net return (Rs. 21,030) which was statistically similar to net returns with wheat straw and black polythene together (Rs. 19,180). The lowest net return was recorded for transparent polythene mulch (Rs. 11,515).

Application of paddy straw as mulch showed the highest net returns per hectare (US$ 8615.1) followed by application of coconut leaves along with green leaf mulch (US$ 7843.9) and the lowest net return was recorded under the control treatment. Maximum benefit cost ratio (B:C) was observed for application of coconut leaves alone and application of paddy straw. Lowest B:C ratio (0.86) was noticed for mulching with black polythene and control (Thankamani *et al.,* 2016).

Black polythene mulch promoted growth and development of okra and recorded a B:C ratio of 2.77 as compared to 0.30 in the control plot (Muhammed, 2015). Maheswari *et al.* (2015) obtained the highest gross returns (Rs. 89,597 ha^{-1}) were with the treatment orthosulfamuron @ 120 g ha^{-1} as pre emergence at 3-5 DAT followed by orthosulfamuron @120 g ha^{-1} as post emergence at 25-30 DAT and recorded the highest B:C ratio (1.91). Pre emergence application of pendimethalin 1 kg ha^{-1} + 1 HW at 40 DAS recorded significantly higher yields and net returns of Rs.17550 ha^{-1} in summer black gram than treatment with hand weeding at 20 and 40 DAS (Khot *et al.,* 2015).

Pendimethalin at 1.0 kg ha^{-1} as pre emergence followed by quizalofop-p-ethyl at 50 g ha^{-1} at 20 DAS in soybean was highly efficient for *Sorghum halepense* and produced comparable seed and stalk yield with the highest net returns (\$711.22 ha^{-1}) and B:C ratio of 1.51 than all other treatments including hand weeding and mechanical measures (Paudel *et al.*, 2017).

Materials & Methods

3. MATERIALS AND METHODS

The present study entitled "Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices" was carried out at the Agronomy farm, Department of Agronomy, College of Horticulture, Vellanikkara from March to June 2016. The materials used and methodology adopted for the study are described in this chapter.

3.1 General details

Location

The experiment was conducted at the Agronomy farm, Department of Agronomy, College of Horticulture, Vellanikkara, Thrissur, Kerala. The field is situated geographically at 13° 32'N latitude and 76° 26'E longitude, at an altitude of 40 m above mean sea level.

Climate and weather conditions

The area enjoys a typical tropical humid climate. The mean weekly averages of important meteorological parameters observed during the experimental period are presented in Appendix 1.

Soil

The soil was sandy clay loam in texture and acidic in reaction with a pH of 5.08. The physico - chemical properties of soil at the experimental site are presented in Table 1.

Season

The experiment was conducted during the summer season (March- June) of 2016.

Table 1. Physico - chemical properties of soil

Particulars	Value	Method used
1.Physical properties **Particle size composition**		
Coarse sand (%)	31.90	Robinson international pipette method (Piper, 1942)
Fine sand (%)	27.30	
Silt (%)	18.64	
Clay (%)	22.16	
2.Chemical properties		
1. pH	5.08	1:2.5 soil water ratio (Jackson, 1958)
2. Organic carbon (%)	1.06	Walkley and Black method (Jackson, 1973)
3. Available N (kg ha^{-1})	165.23	Alkaline permanganate method (Subbaiah and Asija, 1956)
4. Available P (kg ha^{-1})	12.58	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
5. Available K (kg ha^{-1})	136.80	Neutral normal ammonium acetate extractant using flame photometry (Jackson, 1958)

Crop and variety

Okra variety 'Arka Anamika' which is resistant against yellow vein mosaic virus with a yield potential of 20 t ha^{-1}, was used for the experiment. Plants of Arka Anamika are tall and well branched. The stem is green with purple shade. A purple pigmentation can be seen on both sides of the petal base. Fruits are long and green in colour.

Cropping history of the experimental site

The experimental area had been under cultivation with the fodder grass Hybrid Napier during the previous year.

3.2 Experimental details

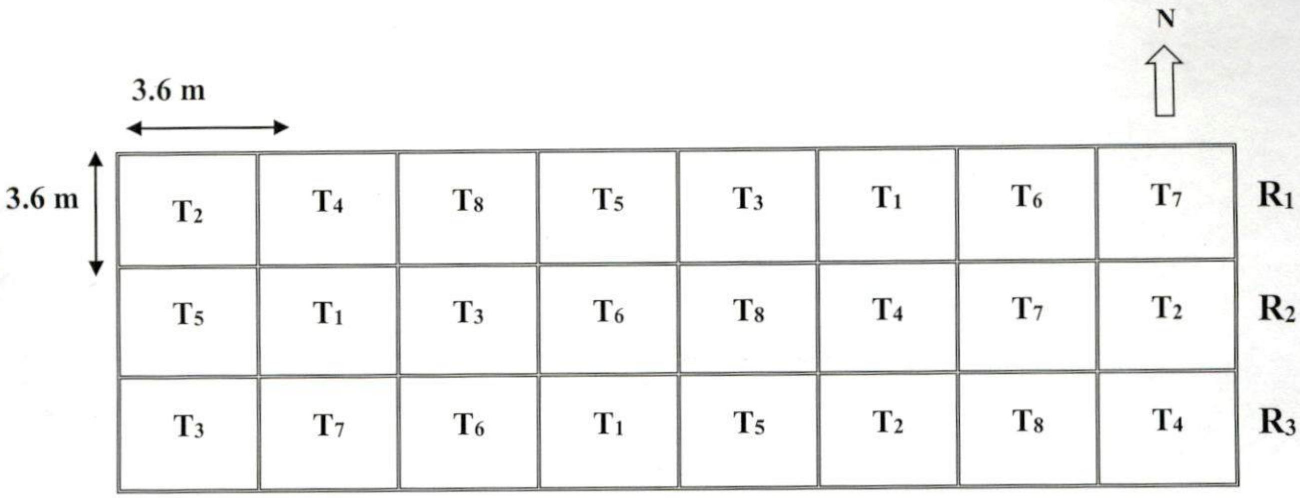
The study was conducted during the summer months (March to June) of 2016. The experiment was laid out in Randomized Block Design (RBD) with 8 treatments and 3 replications. The plot size was 3.6 m x 3.6 m with spacing of 60 cm x 30 cm. The treatment details are given in Table 2.

Table 2. Details of the treatments in the experiment

Treatments	
T_1	Mulching with mango leaves @ 5 t ha^{-1} followed by hand weeding at 45 DAS
T_2	Mulching with paddy straw @ 5t ha^{-1} followed by hand weeding at 45 DAS
T_3	Mulching with newspaper (two layers) followed by hand weeding at 45 DAS
T_4	Mulching with coir fibre mat (1000 GSM)
T_5	Mulching with polythene sheet (30 micron silver top black bottom polythene)
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS
T_7	Pendimethalin 1.0 kg ha^{-1} (pre emergence), followed by hand weeding at 45 DAS
T_8	Unweeded control

Layout

Fig.1. Layout of the experimental field



Land preparation and sowing

The experimental field was ploughed thoroughly with a disc plough and worked with a cultivator to produce fine tilth. The gross plot size was 12.96 m^2 and net plot size was 9 m^2. Ridges and furrows were formed at a spacing of 60 cm. Mulch materials were spread uniformly in individual plots as per treatments. Sowing was done on 19^{th} March, 2016. The seeds were pre soaked and dibbled at a spacing of 60 cm x 30 cm at the rate of 2 seeds/hole. Planting in black polythene sheet and newspaper mulched plots were done by making circular holes of 5 cm diameter at a spacing of 30 cm. The seed rate was 8.5 kg ha^{-1}. Seeds of 'Arka Anamika' was obtained from the Department of Olericulture, College of Horticulture, Vellanikkara.

Manures and fertilizers

Manures and fertilizers were applied as per the Package of Practices Recommendations of KAU (2011). FYM @ 12 t ha^{-1} was applied as basally during land preparation. $N:P_2O_5:K_2O$ were applied @ 55:35:70 kg ha^{-1} at the time of sowing. An additional dose of 55 kg N ha^{-1} was given in one month after sowing.

Irrigation

Hose irrigation was done at 10 mm depth once in 3 days.

Plant protection

Incidence of termites was noticed in the plots mulched with coir fibre mat. Soil drenching with chlorpyriphos (3%) was done against termites at 10 DAS. Dimethoate 30% EC was sprayed against aphids at 22 DAS. Incidence of fruit borers and leaf rollers were noticed in the crop. Collection and destruction was the method adopted against these pests.

Weed management

Weed management was done as per treatments. Three hand weedings were done at 20 DAS, 45 DAS and 60 DAS in the plots with hand weeding treatment. Hand weeding at 45 DAS was done in all the treatments with mulching except for the treatment with coir fibre mat and black polythene sheet. In the treatment including herbicide application with hand weeding, pre emergence herbicide pendimethalin (Stomp 30 EC) @1.0 kg ha^{-1} was sprayed on the third day after sowing and hand weeding was done at 45 DAS.

Harvesting

For harvesting the fruits, hand picking was adopted. The first harvest was done at 40 DAS and fruits were harvested at 3 days interval.

3.3 Observations recorded

3.3.1 Soil analysis

The pH and content of major nutrients were estimated before and after the experiment. Soil samples were collected, air dried, powdered and passed through

0.5 mm sieve, and then used for analyzing the organic carbon content. Soil samples passed through 2 mm sieve were used for analyzing major nutrients viz., available N, available P and available K using standard procedures detailed in Table 1. The soil pH was analyzed in soil: water suspension of 1:2.5.

3.3.2 Microclimate studies

Relative humidity

Relative humidity at canopy level was recorded at 8.30 LMT (local mean time) at weekly intervals using relative humidity meter (+ type K/J Humidity/Temperature meter model: HT-3006 HA) and the mean was worked out.

Soil temperature

Soil temperature at 10 cm depth was recorded at 8.30 LMT at weekly intervals using a soil thermometer (EMCON soil thermometer) and the mean was worked out.

Soil moisture content

Soil moisture content at 0 - 15 cm and 15 - 30 cm depths was determined at fortnightly intervals by thermo gravimetric method before irrigation using the formulae

$$Pw = \frac{Wm - Wd \times 100}{Wd}$$

Pw = Percentage of soil moisture by weight Wm = Weight of moist sample

Wd = Weight of oven dry sample

3.3.3 Soil microflora

Total population of bacteria, fungi and actinomycetes, nitrogen fixers, P-solubilizers, fluorescent pseudomonads, *Trichoderma* sp. and microbial biomass of the soil were analysed at sowing, flowering and final harvest. Total population of microflora was enumerated by serial dilution and plate count technique (Wollum, 1982). Microbial biomass carbon was analysed by fumigation and extraction method (Jenkinson and Powlson, 1976). The soil samples were collected from the root zone of the crop and the details of media used for the enumeration are presented in Table 3.

Table 3. Media used for enumeration of microorganisms in soil

Sl No.	Microbes	Medium	Reference
1	Bacteria	Nutrient agar	Agarwal and Hasija, 1986
2	Actinomycetes	Kenknight's agar	
3	Fungi and *Trichoderma*	Martin's Rose Bengal agar	
4	Nitrogen fixers	Jenson's N- free agar	Jensen, 1955
5	Phosphorus solubilizers	Pikovskaya's agar	Pikovskaya, 1948
6	Fluorescent pseudomonads	King's medium B agar	Gould *et al.,* 1985

3.3.4 Biometric observations

1. Plant height at 30, 60 and 90 DAS
2. No. of branches at 30, 60 and 90 DAS
3. Days to first flowering
4. Days to first harvest
5. No. of fruits per plant
6. No. of harvests
7. Yield/ ha
8. Duration of crop
9. Incidence of pest and diseases

From each plot, five plants were selected randomly as the sampling unit for biometric observations. The harvested fruits from each plot were weighed separately and the total yield (t ha^{-1}) was worked out. Incidence of pest and diseases was observed and recorded.

3.3.5 Plant analysis

Content of major nutrients, viz., N, P and K at 30 and 60 DAS were analyzed by standard procedures. The uptake of N, P and K were calculated as the product of the content of these nutrients and plant dry weight and expressed in kg ha^{-1}.

Nitrogen content

Nitrogen content was determined by distillation and titration method (Jackson, 1958).

Phosphorus content

Plant samples were digested with diacid and the P content was determined by the method vanadomolybdo phosphoric yellow colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965).

Potassium content

K content in diacid digest was estimated using flame photometer (Jackson, 1958).

Relative chlorophyll content (SPAD)

The chlorophyll content in the leaves was estimated at 30 DAS and at 60 DAS using LEAF + Chlorophyll meter. The first fully opened leaf from the top was selected for observation. Observations were taken from five leaves from a plot and mean was worked out.

3.3.6 Observation on weeds

Weed count

Species wise weed count was recorded using a 50 cm x 50 cm (0.25 m^2) quadrat from the sampling strip. The quadrat was placed at random in each plot and observations were taken at 20, 45 and 90 DAS. The count was expressed in number/ m^2.

Dry matter production of weeds

Weeds collected from the quadrat were uprooted, cleaned, air dried and oven dried at $80 \pm 5°C$ and dry weight was recorded in g/m^2.

Weed control efficiency

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

$$WCE = \frac{\text{Weed dry weight in unweeded plot - Weed dry weight in treated plot x100}}{\text{Weed dry weight in unweeded plot}}$$

Weed index

Weed index was worked out using the formulae suggested by Gill and Vijaykumar (1969).

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

X = Yield from treatment with least weeds

Y = Yield from treated plot

3.3.7 Economics

The prevailing labour charge in the locality, cost of inputs and extra treatment costs were considered and gross expenditure was computed and expressed in rupees per hectare. The price of okra at current local market price was used for computing gross return and expressed in rupees per hectare.

The Benefit: Cost ratio was worked out according to the formulae given below

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

3.3.8 Statistical analysis

The data were subjected to analysis of variance using the statistical package 'WASP 2' (Statistical package, ICAR Goa). The data on weed count and weed biomass and microbial count which showed wide variation were subjected to square root ($\sqrt{x}$ +0.5) and logarithmic transformation respectively to make the analysis of variance valid (Gomez and Gomez, 1984).

Plate 1. General field view

Mulching with mango leaves (T_1)

Mulching with paddy straw (T_2)

Mulching with newspaper (T_3)

Mulching with coir fibre mat (T_4)

Mulching with black polythene (T_5)

Plate 2. Application of mulches in the field

Mulching with paddy straw

Mulching with newspaper

Pre emergence application of pendimethalin

Mulching with black polythene

Unweeded control

Mulching with coir fibre mat

Plate 3. Field view at 45 DAS

Results

4. RESULTS

The results of the study on "Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices" conducted in the Department of Agronomy, College of Horticulture, Vellanikkara during the year 2016 are presented below.

4.1. Biometric observations

4.1.1. Plant height

Data on plant height of okra at different stages are presented in Table 4. At 30 DAS, the greatest plant height (47.07 cm) was recorded in mulching with black polythene sheet. The next better treatment was paddy straw mulch (T_2) with a plant height of 43.13 cm, which was statically on par with mulching with mango leaves (T_1). At this stage, lower plant heights were recorded in plots treated with pre emergence herbicide (T_7) and plots with newspaper mulching.

At 60 DAS, mulching with black polythene sheet still recorded enhanced plant height of 110.23 cm. However, it was on par with the treatments newspaper mulching (T_3), hand weeding (T_6) and pre emergence application of pendimethalin (T_7). Lower plant height was recorded for unweeded control (T_8) and mulching with coir fibre mat (T_4).

At 90 DAS also, greater plant height (123.87 cm) was recorded for black polythene sheet (T_5) and was on par with newspaper mulch and hand weeding (120.8 cm and 119.87 cm respectively). Plots with coir fibre mat mulching (T_4) and unweeded control plots (T_8) recorded lower heights of 102.03 cm and 100.87 cm respectively during final stage of observation.

4.1.2. Number of branches

The data on number of branches are given in Table 5. Black polythene sheet mulching (T_5) showed the highest number of branches (3 branches/plant) at

30 DAS. All other treatments except unweeded control were statistically on par, unweeded control treatment recorded lowest number of branches (1 branch/plant).

At 60 DAS also, the same trend was observed for number of branches. Higher number of branches were observed for mulching with black polythene sheet (T_5) with 4 branches/plant. It was on par with newspaper mulching (T_3) where 3 branches/plant was observed. Paddy straw (T_2), mango leaves (T_1) and pendimethalin (T_7) treatments were statistically on par. Lowest number of branches was recorded for unweeded control treatment (T_8) with one branch/ plant.

Black polythene sheet mulch continued its dominance in maintaining higher number of branches till 90 DAS (4.33 branches/plant). Lower number of branches were recorded for unweeded control treatment throughout the crop period. The plots mulched with coir fibre mat (T_4) also recorded lower number of branches (1.66 branches/plant).

4.1.3. Days to first flowering

The data on days to first flowering are presented in Table 6. On an average, the crop took 37 days for first flowering. From the table, it is clear that all the treatments except mulching with coir fibre mat and unweeded control showed almost similar trend for days to first flowering. The number of days to first flowering under unweeded condition was 43.66 days, and it was 38.33 days for crops under coir fibre mat mulching.

4.1.4. Days to first harvest

The data pertaining to days to first harvest are given in Table 7. Number of days taken for the first harvest ranged from 41 days to 48 days. Almost all the treatments were on par except for coir fibre mat mulching (T_4) and unweeded control (T_8). Unweeded control treatment took more number of days for the first harvest (48 days).

4.1.5. Number of fruits per plant

The data on total number of fruits per plant are given in Table 8. The highest number of fruits/plant (12.26) was recorded for mulching with black polythene sheet (T_5). The next better treatments were mulching with newspaper (T_3) and hand weeding (T_6) which produced 10.60 and 10.46 fruits/plant respectively, which were statistically on par with mulching with paddy straw (10.20 fruits/plant). The plots mulched with coir fibre mat (T_4) recorded 7.60 fruits/plant. The lowest number of fruits (5.26) recorded for unweeded control (T_8).

4.1.6. Total fruit yield

The data on total fruit yield are depicted in Table 9. The treatments significantly affected on fruit yield. The highest fruit yield of 14.58 t ha^{-1} was recorded in black polythene sheet mulching (T_5). The next better treatments were mulching with paddy straw (T_2), newspaper (T_3), and hand weeding (T_6) with a yield of 11.16, 11.01 and 10.69 t ha^{-1} respectively which were statistically on par. Treatment with the application of pre emergence herbicide (T_7) recorded a yield of 10.06 t ha^{-1} which was on par with hand weeding treatment. The lowest yield (1.12 t ha^{-1}) recorded for unweeded control (T_8), followed by mulching with coir fibre mat (5.30 t ha^{-1}).

4.1.7. Number of harvests

Number of harvests for each treatment is presented in Table 10. The number of harvests ranged from 4.33 to 10.33. Black polythene sheet mulching (T_5) recorded the highest number of harvests. Unweeded control recorded less number of harvests (4.33) which was on par with coir fibre mat mulching (4.66). Number of harvests for all other treatments was statistically on par.

Table 4. Effect of treatments on plant height of okra at different stages of growth

Treatments		Plant height (cm)		
		30 DAS*	60 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	40.13^{bc}	101.73^{bc}	107.37^{de}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	43.13^{b}	102.20^{bc}	112.13^{cd}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	34.53^{de}	106.77^{ab}	120.80^{ab}
T_4	Mulching with coir fibre mat	38.00^{cd}	99.07^{c}	102.03^{ef}
T_5	Mulching with polythene sheet	47.07^{a}	110.23^{a}	123.87^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	38.80^{c}	106.17^{ab}	119.87^{ab}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	33.27^{e}	105.10^{abc}	115.70^{bc}
T_8	Unweeded control	37.32^{cd}	99.67^{c}	100.87^{f}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

*DAS- days after sowing.

Table 5. Effect of treatments on number of branches of okra at different stages of growth

Treatments		Number of branches/plant		
		30 DAS	60 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	1.33^{bc}	2.00^{bcd}	2.33^{cd}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	2.00^{b}	2.66^{bc}	3.00^{bc}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	2.00^{b}	3.00^{ab}	3.66^{ab}
T_4	Mulching with coir fibre mat	1.33^{bc}	1.66^{cd}	1.66^{de}
T_5	Mulching with polythene sheet	3.00^{a}	4.00^{a}	4.33^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	1.33^{bc}	2.00^{bcd}	2.33^{cd}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	2.00^{b}	2.66^{bc}	2.66^{bcd}
T_8	Unweeded control	1.00^{c}	1.00^{d}	1.00^{e}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 6. Effect of treatments on number of days to first flowering in okra

Treatments		Days to first flowering
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	36.66^c
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	36.66^c
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	36.33^c
T_4	Mulching with coir fibre mat	38.33^b
T_5	Mulching with polythene sheet	36.00^c
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	36.33^c
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	35.66^c
T_8	Unweeded control	43.66^a

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 7. Effect of treatments on number of days to first harvest in okra

Treatments		Days to first harvest
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	42.00^{bc}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	42.00^{bc}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	41.66^{bc}
T_4	Mulching with coir fibre mat	43.00^{b}
T_5	Mulching with polythene sheet	41.00^{c}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	41.33^{c}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	40.66^{c}
T_8	Unweeded control	48.00^{a}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 8. Effect of treatments on number of fruits per plant of okra

Treatments		No. of fruits per plant
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	9.46^{c}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	10.20^{bc}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	10.60^{b}
T_4	Mulching with coir fibre mat	7.60^{d}
T_5	Mulching with polythene sheet	12.26^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	10.46^{b}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	9.60^{c}
T_8	Unweeded control	5.26^{e}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 9. Effect of treatments on fruit yield of okra

	Treatments	Yield ($t\ ha^{-1}$)
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	9.03^{d}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	11.16^{b}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	11.01^{b}
T_4	Mulching with coir fibre mat	5.30^{e}
T_5	Mulching with polythene sheet	14.58^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	10.69^{bc}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	10.07^{c}
T_8	Unweeded control	1.12^{f}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 10. Effect of treatments on number of harvests of okra

Treatments		No. of harvests
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	9.00^b
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	9.00^b
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	9.00^b
T_4	Mulching with coir fibre mat	4.66^c
T_5	Mulching with polythene sheet	10.33^a
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	9.00^b
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	9.00^b
T_8	Unweeded control	4.33^c

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

4.1.8. Duration of crop

The data on duration of the crop are given in Table 11. The treatments were significantly different with respect to duration of crop. Crop duration varied from 90 - 95 days. Unweeded control (T_8) and mulching with coir fibre mat (T_4) recorded lower duration (90 days). All other treatments recorded the same duration of 95 days.

4.1.9. Incidence of pests and diseases

The data on the incidence of pests and diseases are given in Table 12. During the initial stages of the crop, aphid infestation was noticed in all the plots irrespective of treatments. Shoot and fruit borer incidence was noticed in all the plots. The plants were infested with yellow vein mosaic disease during the final stages of crop growth. With respect to incidence of pest and diseases, treatment difference were absent.

4.2. Plant analysis

4.2.1. Uptake of N, P and K by the crop

The data regarding the uptake of N, P and K by the crop at 30 and 60 DAS are given in Tables 13 and 14. The highest uptake of N, P and K was in the treatment with black polythene sheet mulching and the lowest was in unweeded control treatment during both stages of observation. At 30 DAS, the highest uptake of N (23.29 kg ha^{-1}) was observed in black polythene sheet mulching (T_5). Hand weeding (T_6), newspaper mulching (T_3), paddy straw mulching (T_2) and pendimethalin application (T_7) were statistically on par with N uptake of 11.94, 11.35, 11.09 and 10.49 kg ha^{-1} respectively. Mulching with mango leaves recorded N uptake of 8.74 kg ha^{-1} which was intermediate among the treatments. Mulching with coir fibre mat (T_4) and unweeded control (T_8) recorded lower uptake values of N (4.70 and 3.85 kg ha^{-1} respectively).

Table 11. Effect of treatments on duration of the okra crop

Treatments		Duration (days)
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	95.33[a]
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	95.33[a]
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	95.00[a]
T_4	Mulching with coir fibre mat	90.00[b]
T_5	Mulching with polythene sheet	95.66[a]
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	95.00[a]
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	95.33[a]
T_8	Unweeded control	90.00[b]

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 12. Effect of treatments on incidence of pests and diseases in okra

Treatments		Pests observed		Disease observed
		Shoot and fruit borer (*Earias vitella*)	Aphid (*Aphis gossypii*)	Yellow vein mosaic virus
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	✓	✓	✓
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	✓	✓	✓
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	✓	✓	✓
T_4	Mulching with coir fibre mat	✓	✓	✓
T_5	Mulching with polythene sheet	✓	✓	✓
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	✓	✓	✓
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	✓	✓	✓
T_8	Unweeded control	✓	✓	✓

The uptake of P at 30 DAS was the highest for black polythene sheet mulched plots (4.17 kg ha^{-1}). Mulching with newspaper and paddy straw were the next best treatments with P uptake of 3.21 and 3.13 kg ha^{-1}. Unweeded control and coir fibre mat mulching recorded lower P uptake (1.62 and 1.80 kg ha^{-1}). Regarding uptake of K at 30 DAS, black polythene sheet mulch recorded the highest value of 16.97 kg ha^{-1}. Paddy straw mulch resulted in K uptake of 11.67 kg ha^{-1} which was statistically on par with newspaper mulching (10.85 kg ha^{-1}). Unweeded control recorded the lowest uptake of K (5.27 kg ha^{-1}) followed by coir fibre mat mulching (6.88 kg ha^{-1}).

At 60 DAS also, the same trend was observed for uptake of N, P and K with highest uptake values in black polythene sheet mulch. Mulching with black polythene sheet recorded N, P and K uptake values of 31.48, 5.74 and 34.75 kg ha^{-1} respectively. The treatments hand weeding, paddy straw mulching and newspaper mulching were on par with N uptake of 24.65, 24.11 and 23.96 kg ha^{-1} respectively. The lowest uptake of N was observed for unweeded control (7.50 kg ha^{-1}). The uptake of P at 60 DAS in treatments with hand weeding and mulching with paddy straw were at par (4.77 kg ha^{-1} and 4.41 kg ha^{-1}). The lowest uptake of P was recorded for unweeded control (1.23 kg ha^{-1}). Uptake of K was lesser for unweeded control (10.81 kg ha^{-1}) and coir fibre mat mulching (12.57 kg ha^{-1}). Uptake of K in plots with pre emergence application of pendimethalin, paddy straw mulching and mango leaf mulching were statistically on par (26.78, 25.37 and 24.53 kg ha^{-1} respectively).

4.2.2. Relative chlorophyll content

The data on the content of relative chlorophyll are given in Table 15. Mulching with black polythene sheet (T_5), newspaper (T_3), paddy straw (T_2), and pre emergence application of pendimethalin (T_7) recorded significantly superior SPAD (Soil Plant Analysis Development) units of 54.01, 53.65, 53.04, and 52.57 respectively at 30 DAS. Mulching with mango leaves (T_1) and hand weeding (T_6)

Table 13.Effect of treatments on uptake of N, P and K at 30 DAS

Treatments		Nutrient uptake at 30 DAS (kg ha^{-1})		
		N	P	K
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	8.74^{d}	2.32^{e}	8.44^{e}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	11.09^{b}	3.13^{b}	11.67^{b}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	11.35^{b}	3.21^{b}	10.85^{bc}
T_4	Mulching with coir fibre mat	4.70^{d}	1.80^{f}	6.88^{f}
T_5	Mulching with polythene sheet	23.29^{a}	4.17^{a}	16.97^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	11.94^{b}	2.86^{c}	9.76^{d}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	10.49^{b}	2.59^{d}	10.37^{cd}
T_8	Unweeded control	3.85^{d}	1.62^{f}	5.27^{g}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 14.Effect of treatments on uptake of N, P and K at 60 DAS

Treatments		Nutrient uptake at 60 DAS ($kg\ ha^{-1}$)		
		N	P	K
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	19.23^{d}	3.23^{d}	24.53^{c}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	24.11^{b}	4.41^{bc}	25.37^{c}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	23.96^{b}	4.32^{c}	27.79^{bc}
T_4	Mulching with coir fibre mat	11.93^{e}	1.69^{e}	12.57^{d}
T_5	Mulching with polythene sheet	31.48^{a}	5.74^{a}	34.75^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	24.65^{b}	4.77^{bc}	29.99^{b}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	21.63^{c}	3.93^{c}	26.78^{c}
T_8	Unweeded control	7.50^{f}	1.23^{f}	10.81^{d}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 15. Effect of treatments on relative chlorophyll content (SPAD units)

Treatments		SPAD Meter reading	
		30 DAS	60 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	52.14^{ab}	43.05^{d}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	53.04^{a}	48.54^{b}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	53.65^{a}	50.76^{a}
T_4	Mulching with coir fibre mat	50.21^{bc}	41.31^{d}
T_5	Mulching with polythene sheet	54.01^{a}	51.45^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	52.70^{ab}	51.71^{a}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	52.57^{a}	45.36^{c}
T_8	Unweeded control	48.83^{c}	38.70^{e}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

were statistically on par with the above treatments. Lowest SPAD reading (48.83) was recorded for unweeded control treatment (T_8).

At 60 DAS, black polythene sheet mulching, hand weeding and newspaper mulching recorded higher SPAD units of 51.45, 51.75 and 50.76 respectively followed by mulching with paddy straw (48.54). Mulching with mango leaves and coir fibre mat (T_4) recorded lower SPAD meter readings. Unweeded control treatment recorded the lowest SPAD value (38.70).

4.3 Observation on weeds

4.3.1. Weed count

Data on observations on weed count are given in Table 16. The lowest weed count at 20 DAS was noticed under black polythene sheet mulching (1.67 no./m^2) followed by pendimethalin (18.33 no./m^2). At this stage, higher weed counts were observed in unweeded control plots (530.33 no./m^2) and hand weeding (452 no./m^2). Total number of weeds in plots with coir fibre mat mulching was 260.33 no./m^2. Mulching with mango leaves (T_1), paddy straw (T_2) and newspaper (T_3) recorded total weed counts of 168.67, 126.67, and 45.33 no./m^2 respectively.

At 45 DAS, higher weed count was noticed in unweeded control plots (355 no./m^2) and mulching with coir fibre mat (291.33 no./m^2). Mulching with mango leaves and paddy straw recorded weed count of 162.67 and 94 no./m^2 respectively. Pendimethalin and hand weeding treatments recorded lower weed counts of 44 and 41 no./m^2 respectively. These were statistically on par with newspaper mulching (66.67 no./m^2). At this stage also black polythene sheet mulch recorded the lowest weed count (2.67 no./m^2).

At 90 DAS also black polythene sheet mulch continued its superiority in preventing germination and establishment of weeds and recorded the lowest weed count of 12.00 no./m^2. Newspaper mulching was the next best option for controlling weeds with a total weed count of 53.33 no./m^2. Mulching with mango leaves, paddy straw and pendimethalin were statistically on par, recording weed counts of 110.67, 95, 102.67 no./m^2 respectively. The highest weed count was recorded for unweeded control (277.33 no./m^2) treatment.

4.3.2. Weed dry weight

The data on weed dry weight at different stages of plant growth are presented in Table 17. Unweeded control (T_8), hand weeding (T_6) and mulching with coir fibre mat (T_4) recorded higher weed dry weight of 30.73, 29.65, and 27.18 g/m^2 respectively at 20 DAS. The lowest weed dry weight was (3.09 g/m^2) recorded for black polythene sheet mulching (T_5) followed by mulching with newspaper (7.64 g/m^2) and pre emergence application of pendimethalin (8 g/m^2). With straw mulching (T_2), dry weight of weeds at 20 DAS was 12.75 g/m^2. Mango leaf mulching (T_1) recorded a dry weight of 14.69 g/m^2.

At 45 DAS, the highest dry weight was observed for unweeded control (485.79 g/m^2) followed by mulching with coir fibre mat (366.67 g/m^2). Mulching with black polythene sheet, newspaper and hand weeding recorded lower weed dry weights of 9.10, 16.87, and 22.43 g/m^2 respectively. Pre emergence application of pendimethalin and mulching with paddy straw recorded weed dry weights of 72.47 and 78.10 g/m^2 respectively.

At 90 DAS, mulching with black polythene sheet recorded the lowest weed dry weight of 29.48 g/m^2 followed by newspaper mulching, paddy straw mulching, hand weeding and pre emergence application of pendimethalin, with weed dry weights of 58.55, 72, 74.97, and 77.67 g/m^2 respectively. Unweeded control plot recorded higher weed dry weight of 531 g/m^2 and was on par with weed dry weight in coir fibre mat mulch (453.25 g/m^2).

Table 16. Effect of treatments on weed count at 20, 45 and 90 DAS

Treatments		Weed count (No. m^{-2})		
		20 DAS	45 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	12.99^{c}** (168.67)	12.71^{b} (162.67)	10.15^{c} (110.67)
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	11.25^{c} (126.67)	9.68^{c} (94.00)	9.74^{cd} (95.00)
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	6.75^{d} (45.33)	7.81^{cd} (66.67)	7.29^{e} (53.33)
T_4	Mulching with coir fibre mat	16.05^{b} (260.33)	17.05^{a} (291.33)	13.81^{b} (192.00)
T_5	Mulching with polythene sheet	1.39^{f} (1.67)	1.61^{e} (2.67)	3.43^{f} (12.00)
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	21.25^{a} (452.00)	6.35^{d} (41.00)	9.06^{d} (82.67)
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	4.27^{e} (18.33)	6.56^{d} (44.00)	10.07^{cd} (102.67)
T_8	Unweeded control	23.01^{a} (533.33)	18.74^{a} (355.00)	16.64^{a} (277.33)

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesis

Table 17. Effect of treatments on weed dry weight at 20, 45 and 90 DAS

Treatments		Weed dry weight (g m^{-2})		
		20 DAS	45 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	3.87^{b}** (14.69)	13.85^{c} (192.00)	10.70^{b} (116.67)
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	3.63^{bc} (12.75)	8.70^{d} (78.10)	8.44^{bc} (72.00)
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	2.83^{c} (7.64)	4.02^{e} (16.87)	7.62^{cd} (58.55)
T_4	Mulching with coir fibre mat	5.26^{a} (27.18)	19.07^{b} (366.67)	21.25^{a} (453.25)
T_5	Mulching with polythene sheet	1.74^{d} (3.09)	3.01^{e} (9.10)	5.40^{d} (29.48)
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	5.46^{a} (29.65)	4.65^{e} (22.43)	8.63^{bc} (74.93)
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	2.85^{c} (8.00)	8.49^{d} (72.47)	8.73^{bc} (77.66)
T_8	Unweeded control	5.59^{a} (30.73)	21.93^{a} (485.79)	23.02^{a} (531.07)

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

** $\sqrt{x+0.5}$ transformed values, original values are given in parenthesis

4.3.3. Weed control efficiency

The data on weed control efficiency at 20, 45 and 90 DAS are given in Table 18. At 20 DAS, higher weed control efficiency of 95.67% was recorded for black polythene sheet mulch (T_5). Pre emergence application of pendimethalin (T_7) and newspaper mulching were the next better treatments with weed control efficiencies of 85.20 and 79.34% respectively. Weed control efficiency of mulching with coir fibre mat was lower (13.60%) compared to other mulching treatments.

At 45 DAS, weed control efficiency of mulching with black polythene sheet, newspaper, hand weeding and pre emergence application of pendimethalin were statistically on par (98.06, 98.01, 95.09 and 85.15% respectively). Among organic mulches mulching with mango leaves and paddy straw gave weed control efficiency of 54.75% and 40.84% which were on par. Coir fibre mat mulching recorded the lower weed control efficiency (10.68%).

At 90 DAS, the highest weed control efficiency was recorded for black polythene sheet mulch (93.14%) followed by hand weeding three times at 20, 45 and 60 DAS (85.60 %). Pre emergence application of pendimethalin followed by hand weeding at 45 DAS and newspaper mulch followed by hand weeding at 45 DAS were on par with weed control efficiencies of 79.91 and 79.75% respectively. The lowest weed control efficiency recorded for coir fibre mat mulching (13.11%).

4.3.4. Weed index

The data on weed index are presented in Table 19. Next to black polythene sheet (T_5), mulching with paddy straw (T_2) and newspaper (T_3) recorded lower values for weed index (23.42 and 24.47% respectively) followed by hand weeding (26.59%) and pre emergence application of pendimethalin (30.89%). The treatment mulching with mango leaves recorded a weed index of 37.98%. The highest weed index was recorded for unweeded control (92.35%) followed by coir fibre mat mulch (63.61%).

Table 18. Effect of treatments on weed control efficiency (%)

Treatments		Weed control efficiency (%)		
		20 DAS	45 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	25.49^{de}	54.75^{b}	55.31^{d}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	34.90^{d}	40.84^{b}	66.63^{c}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	79.34^{b}	98.01^{a}	79.75^{b}
T_4	Mulching with coir fibre mat	13.60^{e}	10.68^{c}	13.11^{e}
T_5	Mulching with polythene sheet	95.67^{a}	98.06^{a}	93.14^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	17.24^{e}	95.09^{a}	85.60^{ab}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	85.20^{b}	85.15^{a}	79.91^{b}
T_8	Unweeded control	0.00	0.00	0.00

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 19. Effect of treatments on weed index (%)

Treatments		Weed index (%)
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	37.98^{c}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	23.42^{e}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	24.47^{e}
T_4	Mulching with coir fibre mat	63.61^{b}
T_5	Mulching with polythene sheet	0.00
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	26.59^{de}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	30.89^{d}
T_8	Unweeded control	92.35^{a}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

4.4. Micro climate studies

4.4.1. Relative humidity

The data pertaining to relative humidity are presented in Table 20. Mulching with mango leaves and paddy straw resulted in higher relative humidity during the initial stages of crop growth, i.e at 21 and 28 DAS. At 21 DAS, mango leaves recorded a relative humidity of 79.36% and paddy straw mulching recorded 79.13% which were statistically on par. During these periods, black polythene sheet mulch showed lower relative humidity of 76.06% and 73.16% respectively.

At 42 DAS, paddy straw mulching, newspaper mulching and unweeded control recorded higher relative humidity (78.60%, 77.66%, and 77.96% respectively) than other treatments. The treatments hand weeding and pre emergence application of pendimethalin were statistically on par and recorded 77.30% and 77.36% relative humidity respectively. At 63 DAS, unweeded control recorded higher relative humidity followed by mulching with coir fibre mat and pre emergence application of pendimethalin (77.80%, 77.30% and 76.50% respectively). Hand weeding, mulching with paddy straw and newspaper mulching recorded lower relative humidity.

At 70 DAS, lowest relative humidity at canopy level was recorded for black polythene sheet mulching followed by newspaper mulching and mango leaf mulching. All other treatments were statistically on par. During 90 DAS, coir fibre mat mulching showed lower relative humidity of 81.73%, all other treatments recorded almost similar relative humidity and were statistically on par.

4.4.2. Soil temperature

The data on weekly soil temperature are presented in Table 21. Black polythene sheet mulched plots (T_5) maintained higher soil temperature throughout the crop period. During the initial stages of crop growth (7, 14, 21 and 28 DAS) the plots mulched with mango leaves (T_1) recorded lower soil temperature than other treatments. During 35 DAS, the lowest soil temperature was recorded for the unweeded control plots (T_8) followed by mulching with mango leaves. At 42 DAS, black polythene sheet mulched plots recorded higher soil temperature (35.26°C) and all other treatments were statistically on par. During 56 and 63 DAS, unweeded control plot recorded lower soil temperature of 31.4°C and 30.3°C respectively while black polythene sheet mulch recorded higher soil temperature of 35.7°C and 33.3°C respectively. Almost all other treatments were statistically on par during these periods. During the end of the crop period (77, 84 and 90 DAS), soil temperature in all the plots were statistically on par except for black polythene sheet mulching which recorded a higher temperature of 31.60, 31.43 and 31.73°C respectively.

4.4.3. Soil moisture content

The data regarding the moisture content at 15 and 30 cm depths are presented in Tables 22 and 23. In general, all the plots with mulching recorded higher moisture content than plots with no mulching. Among different mulches, black polythene sheet mulching (T_5) conserved higher soil moisture content both at 15 cm and 30 cm depths. Plots with hand weeding (T_6), herbicide application (T_7) and unweeded control (T_8) recorded lower soil moisture contents.

Soil moisture content at 15 cm depth taken after 14 DAS, was higher in all the mulched treatments compared to unmulched plots. The plots mulched with coir fibre mat (T_4) and mango leaves (T_1) recorded higher soil moisture content at 15 cm depth (14.62 and 13.78%) which was statistically on par with mulching with black polythene sheet (T_5), paddy straw (T_2) and newspaper (T_3) where the moisture contents were 13.69, 13.51, and 12.52% respectively. Lower soil moisture content was recorded for hand weeding and pendimethalin followed by unweeded control treatment (10.58, 10.61 and 10.95% respectively). Moisture content at 90 DAS was statistically on par in all the plots except for unweeded control and mulching with coir fibre mat.

Table 20. Effect of treatments on relative humidity at canopy level of okra

	Treatments	Relative humidity (%) at canopy level												
		7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t/ha *f.b.* hand weeding at 45 DAS	71.46^{a}	71.73^{a}	79.36^{a}	77.13^{a}	78.68^{a}	75.73^{c}	75.46^{a}	77.16^{a}	75.80^{bc}	80.46^{bcd}	82.10^{a}	82.70^{a}	82.23^{ab}
T_2	Mulching with paddy straw @ 5t/ha *f.b.* hand weeding at 45 DAS	71.50^{a}	71.85^{a}	79.13^{a}	76.53^{ab}	77.30^{a}	78.60^{a}	77.16^{a}	77.93^{a}	75.40^{c}	81.46^{abc}	82.70^{a}	82.13^{a}	82.16^{ab}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	71.36^{a}	71.73^{a}	78.00^{b}	76.20^{ab}	77.53^{a}	77.66^{a}	77.10^{a}	76.43^{a}	74.93^{c}	80.33^{cd}	82.56^{a}	82.40^{a}	82.33^{ab}
T_4	Mulching with coir fibre mat	71.05^{a}	72.73^{a}	77.80^{b}	72.56^{d}	77.60^{a}	75.76^{c}	75.50^{a}	78.00^{a}	77.30^{ab}	81.80^{a}	81.20^{a}	81.96^{a}	81.73^{b}
T_5	Mulching with polythene sheet	70.43^{a}	71.50^{a}	76.06^{d}	73.16^{d}	78.33^{a}	76.12^{bc}	77.06^{a}	77.06^{a}	75.93^{bc}	80.06^{d}	82.33^{a}	82.80^{a}	82.30^{ab}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	72.33^{a}	71.91^{a}	77.10^{bc}	75.80^{bc}	76.00^{a}	77.30^{ab}	76.33^{a}	77.53^{a}	75.53^{c}	81.96^{a}	82.60^{a}	82.53^{a}	82.86^{a}
T_7	Pendimethalin 1.0 kg /ha *f.b.* hand weeding at 45 DAS	71.09^{a}	71.60^{a}	76.43^{cd}	74.76^{c}	77.03^{a}	77.36^{ab}	76.76^{a}	76.63^{a}	76.50^{abc}	81.66^{ab}	82.10^{a}	82.50^{a}	82.83^{a}
T_8	Unweeded control	71.21^{a}	71.78^{a}	77.66^{b}	75.43^{bc}	75.63^{a}	77.96^{a}	76.76^{a}	78.36^{a}	77.80^{a}	81.76^{ab}	82.90^{a}	82.73^{a}	82.90^{a}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 21. Effect of treatments on soil temperature in okra plots

Treatments		Soil temperature at 10 cm depth (°C)												
		7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	63 DAS	70 DAS	77 DAS	84 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t/ha *f.b.* hand weeding at 45 DAS	31.46^{e}	31.13^{d}	31.60^{e}	32.03^{d}	31.30^{cd}	31.00^{b}	31.93^{bc}	31.86^{bc}	30.83^{bc}	30.13^{bc}	29.83^{b}	29.03^{b}	29.03^{b}
T_2	Mulching with paddy straw @ 5t/ha *f.b.* hand weeding at 45 DAS	32.23^{cd}	31.80^{c}	32.73^{bc}	32.86^{bc}	31.96^{b}	31.40^{b}	32.30^{b}	32.26^{b}	31.10^{b}	30.50^{b}	29.60^{b}	29.30^{b}	29.40^{b}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	32.00^{d}	31.86^{c}	32.36^{bcd}	32.73^{bc}	31.83^{bc}	31.06^{b}	32.46^{b}	32.26^{b}	30.63^{bc}	29.60^{c}	29.60^{b}	29.46^{b}	29.23^{b}
T_4	Mulching with coir fibre mat	32.73^{bc}	32.73^{b}	32.93^{b}	33.16^{b}	32.16^{b}	31.43^{b}	32.36^{b}	32.20^{b}	30.80^{bc}	29.96^{bc}	29.66^{b}	29.56^{b}	29.03^{b}
T_5	Mulching with polythene sheet	34.20^{a}	34.93^{a}	35.67^{a}	35.80^{a}	35.73^{a}	35.26^{a}	35.83^{a}	35.70^{a}	33.30^{a}	32.16^{a}	31.60^{a}	31.43^{a}	31.73^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	33.00^{b}	31.70^{cd}	32.23^{cd}	32.36^{cd}	31.33^{cd}	30.96^{b}	31.90^{bc}	31.70^{cd}	30.70^{bc}	29.83^{bc}	29.73^{b}	29.20^{b}	29.33^{b}
T_7	Pendimethalin 1.0 kg /ha *f.b.* hand weeding at 45 DAS	32.30^{cd}	31.93^{c}	32.76^{bc}	32.70^{bc}	31.60^{bcd}	31.16^{b}	32.20^{b}	32.00^{bc}	30.66^{bc}	29.90^{bc}	29.70^{b}	29.36^{b}	29.40^{b}
T_8	Unweeded control	32.36^{cd}	31.86^{c}	32.13^{de}	32.53^{cd}	31.16^{d}	30.63^{b}	31.53^{d}	31.40^{d}	30.300^{c}	29.60^{c}	29.60^{b}	29.40^{b}	28.96^{b}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT

At 30 cm depth also, mulching with black polythene sheet and coir fibre mat showed higher moisture contents than other treatments. Hand weeding, unweeded control plots and pendimethalin applied plots recorded lower moisture content than mulched plots. At 14 DAS, soils of plots mulched with mango leaves showed higher moisture content (15.64%) followed by paddy straw and coir fibre mat mulching (14.52 and 14.61%). Lower moisture contents were recorded for hand weeding, unweeded control and newspaper mulching (11.59, 12.24 and 12.14% respectively). At 56 DAS, higher moisture content was recorded for black polythene sheet mulching and coir fibre mat mulching (12.79 and 11.96%) and lower moisture content in unweeded control plot (7.58%). Moisture content at 90 DAS was statistically on par in all the plots except for unweeded control and mulching with coir fibre mat.

4.5. Soil analysis

4.5.1. Soil pH

The data on soil pH is given in Table 24. Generally the soil was acidic in nature. After the experiment there was a decreasing trend in soil pH as compared to pre experimental soil. The initial soil pH was 5.08. The differences in soil pH among the treatments were found non significant. The soil pH after the experiment ranged from 4.88 to 4.70.

4.5.2. Organic carbon

The data pertaining to the effect of treatments on soil organic carbon are given in Table 25. As compared to the pre experimental soil, the organic carbon content increased in all the treatments. Higher percentage of organic carbon was observed for mulching with paddy straw (1.42%) and mango leaves (1.37%) which were statistically on par. Mulching with black polythene was next best treatment with an organic carbon content of 1.35%. The lower organic carbon content was recorded for plots with hand weeding and pre emergence application of pendimethalin (1.11 and 1.15%). Mulching with newspaper was intermediate (1.26%) with respect to soil organic carbon content after the experiment.

Table 22. Effect of treatments on soil moisture content (15 cm)

Treatments		Soil moisture content (%)					
		14 DAS	28 DAS	42 DAS	56 DAS	76 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	13.78^{a}	12.80^{a}	11.05^{b}	11.28^{b}	13.34^{a}	14.38^{a}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	13.51^{ab}	12.95^{a}	11.44^{b}	11.26^{b}	13.63^{a}	14.38^{a}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	12.52^{abc}	11.93^{ab}	11.28^{b}	9.61^{c}	13.65^{a}	13.95^{a}
T_4	Mulching with coir fibre mat	14.62^{a}	12.74^{a}	11.62^{b}	11.84^{ab}	13.27^{a}	11.89^{b}
T_5	Mulching with polythene sheet	13.69^{ab}	13.79^{a}	13.75^{a}	13.06^{a}	14.12^{a}	14.34^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	10.58^{c}	10.62^{bc}	10.43^{bc}	9.06^{c}	13.89^{a}	14.21^{a}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	10.61^{c}	9.82^{c}	10.22^{bc}	8.62^{cd}	13.35^{a}	13.81^{a}
T_8	Unweeded control	10.95^{bc}	9.38^{c}	8.91^{c}	7.53^{d}	13.45^{a}	11.94^{b}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 23. Effect of treatments on soil moisture content (30 cm)

Treatments		Soil moisture content (%)					
		14 DAS	28 DAS	42 DAS	56 DAS	76 DAS	90 DAS
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	15.64^{a}	12.95^{ab}	12.68^{a}	11.25^{ab}	15.82^{a}	14.09^{a}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	14.52^{ab}	13.34^{a}	11.90^{a}	10.01^{bc}	14.91^{ab}	14.00^{a}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	12.14^{d}	11.79^{bc}	11.12^{a}	9.83^{bc}	13.76^{c}	13.20^{a}
T_4	Mulching with coir fibre mat	14.61^{ab}	13.73^{a}	12.10^{a}	11.96^{a}	13.75^{c}	13.33^{a}
T_5	Mulching with polythene sheet	13.78^{bc}	13.88^{a}	12.65^{a}	12.79^{a}	13.68^{c}	13.34^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	11.59^{d}	10.14^{d}	8.33^{b}	10.04^{bc}	14.13^{bc}	12.82^{a}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	12.60^{cd}	11.19^{cd}	9.23^{b}	8.34^{cd}	14.41^{bc}	12.54^{ab}
T_8	Unweeded control	12.24^{d}	8.35^{e}	7.78^{b}	7.85^{d}	12.29^{d}	10.88^{b}

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 24. Effect of treatments on soil pH

Treatments		Soil pH
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	4.74[a]
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	4.87[a]
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	4.87[a]
T_4	Mulching with coir fibre mat	4.78[a]
T_5	Mulching with polythene sheet	4.80[a]
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	4.78[a]
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	4.88[a]
T_8	Unweeded control	4.86[a]
Pre experiment		5.08

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

Table 25. Effect of treatments on soil organic carbon

Treatments		Soil organic carbon (%)
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	1.37^{a}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	1.43^{a}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	1.26^{bc}
T_4	Mulching with coir fibre mat	1.20^{cd}
T_5	Mulching with polythene sheet	1.35^{ab}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	1.11^{d}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	1.15^{d}
T_8	Unweeded control	1.20^{cd}
Pre experiment		1.06

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

4.5.3. Available N, P and K

The data on the effect of treatments on the available status of major nutrients in soil are presented in Table 26. The content of available nitrogen was higher in plots with black polythene mulching (144.47 kg ha^{-1}), paddy straw mulching (143.90 kg ha^{-1}) and newspaper mulching (141.07 kg ha^{-1}) which were on par. Mulching with mango leaves (T_1), hand weeding (T_6) and herbicide applied plots (T_7) recorded available nitrogen contents of 138.62, 135.71 and 132.61 kg ha^{-1} respectively. Lower available nitrogen content was noticed for unweeded control (120.37 kg ha^{-1}) followed by mulching with coir fibre mat (125.09 kg ha^{-1}).

Higher available phosphorus content was observed for mulching with black polythene sheet (16.61 kg ha^{-1}). Lower phosphorus content was noticed in unweeded control plot and coir fibre mat mulching (7.24 and 7.70 kg ha^{-1}). All other treatments were statistically on par.

Black polythene mulch treatments showed higher available potassium content (245.63 kg ha^{-1}). Mulching with mango leaves, paddy straw and newspaper were the next best treatments, recording 207.46, 208.13 and 208.03 kg ha^{-1} available K respectively and were statistically on par. Lower available K content was recorded for unweeded control plot and mulching with coir fibre mat (119.43 and 129.13 kg ha^{-1}).

4.6. Soil microflora

4.6.1. Total population of bacteria, fungi and actinomycetes

The population of soil microflora including bacteria, fungi and actinomycetes are presented in Table 27. Compared to initial population of bacteria, fungi and actinomycetes, the counts increased from sowing to harvest with peak population at the time of flowering. The initial population of bacteria, fungi and actinomycetes were 5.33 $x10^6$, 2.33 x 10^4 and 2.67 x 10^4 cfu/g respectively. In general, plots with mulching recorded higher counts of microbes during all stages of observation.

Table 26. Effect of treatments on available nutrients in soil

Treatments		Available nutrients (kg ha^{-1})		
		N	P	K
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	138.62[ab]	13.39[b]	207.47[b]
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	143.91[a]	13.62[b]	208.13[b]
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	141.08[a]	13.35[b]	208.03[b]
T_4	Mulching with coir fibre mat	125.09[bc]	7.71[c]	129.13[d]
T_5	Mulching with polythene sheet	144.47[a]	16.61[a]	245.63[a]
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	135.76[abc]	11.09[b]	166.13[c]
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	132.61[abc]	11.41[b]	169.67[c]
T_8	Unweeded control	120.37[c]	7.25[c]	119.43[d]

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

At flowering, highest population of bacteria were observed in plots with paddy straw mulching (T_2), mulching with black polythene sheet (T_5), mulching with coir fibre mat (T_4) and unweeded control (T_8) which were on par. As compared to pre experimental soil, increment in the population of bacteria was negligible in plots which received pre emergence application of herbicide (T_7). The bacterial population in these plots was 5.67 x 10^6 cfu/g as compared to 16.33 x 10^6 cfu/g in plots with paddy straw mulching. The plots with hand weeding and mulched with mango leaves recorded lower counts of 10 x 10^6 and 7.00 x 10^6 cfu/g. The same trend was observed during harvesting stage also, with higher bacterial population in plots with paddy straw (10 x 10^6 cfu/g) and plots with black polythene sheet mulching (9.33 x 10^6 cfu/g). The lowest population of bacteria at this stage was recorded in plots with pre emergence application of pendimethalin followed by hand weeding at 45 DAS (5.67 x 10^6 cfu/g).

During flowering, higher population of fungi was noticed in coir fibre mat and paddy straw mulching (23.67 x 10^4 and 22.00 x 10^4 cfu/g respectively). Plots with hand weeding and pendimethalin application recorded lower population of fungi (6.0 x 10^4 and 9.67 x 10^4 cfu/g) than other treatments. In all the treatments, except hand weeding, the fungi population decreased from flowering to harvesting. However, the plots with paddy straw mulching maintained almost uniform population. At harvesting stage, higher population of fungi was recorded in paddy straw (21.00 x 10^4 cfu/g) mulch and unweeded control plot (16.00 x 10^4 cfu/g) which was followed by hand weeding (11.33 x 10^4 cfu/g) and mango leaf mulching (10.67 x 10^4 cfu/g).

Population of actinomycetes was the highest in black polythene sheet mulched plots during flowering as well as at harvesting. The population of actinomycetes at flowering in black polythene sheet mulched plot was 109.33 x 10^4 cfu/g followed by hand weeding (90 x 10^4 cfu/g) and paddy straw mulching (85.67 x 10^4 cfu/g). Mulching with newspaper and pre emergence spray of pendimethalin recorded lower count of acinomycetes during flowering (60.33 x 10^4 and 64 x 10^4 cfu/g). During harvesting black polythene sheet mulch recorded higher count of actinomycetes (79.67 x 10^4 cfu/g) followed by unweeded control treatment (77.67x 10^4 cfu/g). Newspaper mulching recorded lower number of actinomycetes (42.67x 10^4 cfu/g) during harvesting which was followed by mulching with paddy straw (52 x 10^4 cfu/g).

4.6.2. Total population of nitrogen fixers, P- solubilizers and antagonists (Fluorescent pseudomonads and *Trichoderma*)

Significant improvement in the population of nitrogen fixers, P-solubilzers and antagonists (Fluorescent pseudomonads and *Trichoderma*) were observed in the soil with different crop management measures (Table 28). The population of these microbes was the highest during flowering stage. From the pre experiment soil, fluorescent pseudomonads could not be enumerated. However, the population reached to a maximum count of 11 x 10^4 cfu/g at flowering and 7.33 x 10^4 cfu/g during harvesting. During flowering paddy straw mulching recorded the highest number of pseudomonads (11 x 10^4 cfu/g). Plots mulched with newspaper recorded the lowest count of fluorescent pseudomonads at flowering stage of crop (3.00 x 10^4 cfu/g). During harvesting stage, mulching with black polythene sheet and newspaper mulching recorded higher count of pseudomonads (7.33 x 10^4cfu/g). Unweeded control recorded lower count of pseudomonads during harvesting (1.33 x 10^4 cfu/g) followed by mulching with paddy straw (3.00 x 10^4 cfu/g). Mulching with coir fibre mat and hand weeding were statistically on par with respect to pseudomonads count during harvesting (4.33 x 10^4 and 3.33 x 10^4 cfu/g).

Population of *Trichoderma* was higher in mulching with coir fibre mat, unweeded control, paddy straw mulching and newspaper mulching (13 x 10^4, 13 x 10^4, 12.67 x 10^4 and 10.67 x 10^4 cfu/g respectively) which were on par. Mulching with mango leaves, black polythene sheet, hand weeding and pre emergence application of pendimethalin were statistically on par and recorded 5.33 x 10^4, 5.33 x 10^4, 3.67 x 10^4 and 3.33 x 10^4 cfu/g respectively. At harvest, mulching with paddy straw was superior among treatments and recorded *Trichoderma* count of

2.67×10^4 cfu/g which was followed by mulching with mango leaves and unweeded control with count of 2×10^4 cfu/g *Trichoderma* in soil. Mulching with coir fibre mat, black polythene sheet and hand weeding were statistically on par and recorded 1.33×10^4 cfu/g *Trichoderma* in soil. Newspaper mulching recorded lower count of *Trichoderma* (1×10^4 cfu/g).

At flowering stage, higher population of P - solubilisers were recorded in plots with paddy straw mulching and newspaper mulching, which were statistically on par and recorded a population of 17.33×10^4 and 17.00×10^4 cfu/g soil. Lower count of P- solubilisers was observed in black polythene sheet mulching (2.66×10^4 cfu/g) followed by coir fibre mat (8.00×10^4 cfu/g). The population was statistically on par in plots with pre emergence application of pendimethalin, hand weeding, mango leaf mulching, and unweeded control (12.33×10^4, 11×10^4, 10×10^4, 9×10^4 cfu/g respectively). During harvesting, all the treatments were on par with respect to the count of P - solubilisers.

Higher number of nitrogen fixers during flowering stage was found in plots with paddy straw mulching and coir fibre mat mulching with a population of 115.33×10^4 and 114.67×10^4 cfu/g. Plots with pre emergence application of pendimethalin recorded lowest number of nitrogen fixers during flowering (52.67×10^4 cfu/g). Treatments hand weeding, mulching with mango leaves, newspaper, black polythene sheet and unweeded control were statistically on par and recorded population of 83.67×10^4, 82×10^4, 81.67×10^4, 74×10^4 and 73×10^4 cfu/g respectively. During harvesting, plots with hand weeding and black polythene sheet mulch recorded higher populations of nitrogen fixers (39×10^4 and 38.33×10^4 cfu/ g) and unweeded control treatment recorded lowest population (8.33×10^4 cfu/g). Pre emergence application of pendimethalin, mulching with mango leaves, paddy straw and newspaper mulching were statistically on par and recorded 26.67×10^4, 26.67×10^4, 21×10^4, 20×10^4 cfu/g respectively.

4.6.3. Soil microbial biomass

The data pertaining to microbial biomass carbon during flowering and harvesting are presented in Table 29. As compared to pre experimental soil, microbial biomass carbon (MBC) increased after the cultivation of crop. Before cultivation of the crop, MBC in the soil was 40.68 $\mu g\ g^{-1}$. MBC increased during flowering and then showed lower values at harvesting stage. Mulching with black polythene sheet and paddy straw recorded higher MBC during flowering (137.13 and 136.13 $\mu g\ g^{-1}$). Lowest MBC was recorded from plots with pre emergence application of pendimethalin (101.33 $\mu g\ g^{-1}$ soil). The MBC in hand weeded plots was only 104.92 $\mu g\ g^{-1}$ soil. Unweeded control treatment and coir fibre mat mulching also recorded lower MBC of 107.9 and 105.96 $\mu g\ g^{-1}$.

At harvest, the highest MBC was recorded for black polythene sheet mulching (107.84 $\mu g\ g^{-1}$) followed by mulching with paddy straw (103.00 $\mu g\ g^{-1}$). Mango leaf mulching and coir fibre mat were statistically on par and recorded MBC of 95.94 and 94.91 $\mu g\ g^{-1}$ soil. Plots with pre emergence application of pendimethalin recorded lower MBC of 83.44 $\mu g\ g^{-1}$ followed by hand weeding, which recorded 83.97 $\mu g\ g^{-1}$.

4.7. Cost benefit analysis

The data regarding B:C ratio are given in Table 30. The highest cost of cultivation (Rs. 414299 ha^{-1}) was for mulching with coir fibre mulching. A higher B:C ratio of 3.02 was obtained from mulching with black polythene sheet (T_5). Mulching with newspaper gave a B:C ratio of 2.49. Mulching with paddy straw, pre mergence application of pendimethalin followed by one hand weeding at 45 days and hand weeding thrice at 20, 45 and 60 DAS recorded B:C ratios of 2.22, 2.46 and 2.26 respectively. Unweeded control and coir fibre mat mulching recorded lower B:C ratios of 0.31 and 0.38 respectively.

Table 27. Effect of treatments on total population of bacteria, fungi and actinomycetes in the rhizosphere of okra

	Treatments	Population (cfu/g)					
		Bacteria ($x10^6$)		Fungi ($x10^4$)		Actinomycetes ($x10^4$)	
		Flowering	Harvesting	Flowering	Harvesting	Flowering	Harvesting
	Initial count	5.33		2.33		2.67	
T_1	Mulching with mango leaves @ 5 t/ha *f.b.* hand weeding at 45 DAS	0.99^{b} (10.00)	0.90^{abc} (8.00)	1.25^{ab} (18.33)	1.00^{ab} (10.67)	1.87^{bcd} (75.00)	1.73^{cde} (55.00)
T_2	Mulching with paddy straw @ 5t/ha *f.b.* hand weeding at 45 DAS	1.21^{a} (16.33)	0.99^{a} (10.00)	1.32^{a} (22.00)	1.31^{a} (21.00)	1.93^{abc} (85.67)	1.70^{de} (52.00)
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	1.16^{a} (14.67)	0.85^{bc} (7.33)	1.04^{bc} (11.00)	0.65^{c} (4.67)	1.77^{d} (60.33)	1.62^{e} (42.67)
T_4	Mulching with coir fibre mat	1.20^{a} (16.00)	0.93^{ab} (8.67)	1.36^{a} (23.67)	0.86^{bc} (8.00)	1.91^{bc} (81.67)	1.85^{abc} (71.33)
T_5	Mulching with polythene sheet	1.20^{a} (16.00)	0.96^{a} (9.33)	1.08^{bc} (12.33)	0.73^{bc} (6.67)	2.03^{a} (109.33)	1.90^{a} (79.67)
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	0.83^{c} (7.00)	0.82^{cd} (6.67)	0.76^{d} (6.00)	1.04^{ab} (11.33)	1.94^{ab} (90.00)	1.75^{bcde} (57.33)
T_7	Pendimethalin 1.0 kg /ha *f.b.* hand weeding at 45 DAS	0.75^{c} (5.67)	0.75^{d} (5.67)	0.94^{cd} (9.67)	0.83^{bc} (7.00)	1.80^{d} (64.00)	1.83^{abcd} (69.67)
T_8	Unweeded control	1.13^{a} (13.50)	0.93^{ab} (8.67)	1.05^{bc} (11.67)	1.20^{a} (16.00)	1.83^{cd} (69.67)	1.88^{ab} (77.67)

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

** Original values, logarithmic transformed values in parenthesis

Table 28. Effect of treatments on total population of nitrogen fixers, P- solubilizers and antagonists (fluorescent Pseudomonads and *Trichoderma*)

	Treatments	Population (cfu/g)							
		Pseudomonads (x10^4)		*Trichoderma* (x10^4)		P- solubilisers (x10^4)		Nitrogen fixers (x10^4)	
		Flowering	Harvesting	Flowering	Harvesting	Flowering	Harvesting	Flowering	Harvesting
	Initial count	-		1.00		2.00		9.00	
T_1	Mulching with mango leaves @ 5 t/ha *f.b.* hand weeding at 45 DAS	0.67^{cd}** (5.67)	0.66^{bc} (4.67)	2.29^{b} (5.33)	0.30^{ab} (2.00)	0.99^{ab} (10.00)	0.53^{a} (3.67)	1.91^{b} (82.00)	5.07^{b} (26.67)
T_2	Mulching with paddy straw @ 5t/ha *f.b.* hand weeding at 45 DAS	1.04^{a} (11.00)	0.46^{d} (3.00)	3.56^{a} (12.67)	0.42^{a} (2.67)	1.23^{a} (17.33)	0.75^{a} (6.33)	2.06^{a} (115.33)	4.57^{b} (21.00)
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	0.46^{d} (3.00)	0.85^{ab} (7.33)	3.26^{a} (10.67)	0.00^{c} (1.00)	1.21^{a} (17.00)	0.85^{a} (7.33)	1.91^{b} (81.67)	4.44^{b} (20.00)
T_4	Mulching with coir fibre mat	0.99^{ab} (10.00)	0.63^{cd} (4.33)	3.57^{a} (13.00)	0.10^{bc} (1.33)	0.88^{b} (8.00)	0.66^{a} (5.00)	2.05^{a} (114.67)	4.08^{c} (16.67)
T_5	Mulching with polythene sheet	0.77^{abc} (6.00)	0.86^{a} (7.33)	2.28^{b} (5.33)	0.10^{bc} (1.33)	0.36^{c} (2.66)	0.92^{a} (9.00)	1.86^{b} (74.00)	6.19^{a} (38.33)
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	0.74^{bc} (5.67)	0.52^{cd} (3.33)	1.88^{b} (3.67)	0.10^{bc} (1.33)	1.01^{ab} (11.00)	0.76^{a} (6.00)	1.91^{b} (83.67)	6.24^{a} (39.00)
T_7	Pendimethalin 1.0 kg /ha *f.b.* hand weeding at 45 DAS	0.69^{cd} (5.00)	0.69^{abc} (5.00)	1.73^{b} (3.33)	0.20^{abc} (1.67)	1.08^{ab} (12.33)	0.82^{a} (6.67)	1.72^{c} (52.67)	5.15^{b} (26.67)
T_8	Unweeded control	0.89^{abc} (8.00)	0.10^{e} (1.33)	3.60^{a} (13.00)	0.30^{ab} (2.00)	0.94^{ab} (9.00)	0.78^{a} (6.33)	1.85^{b} (73.00)	2.84^{d} (8.33)

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT.

** Original values, logarithmic transformed values in parenthesis

Table 29. Effect of treatments on soil microbial biomass

Treatments		Microbial biomass carbon ($\mu g\ g^{-1}$)	
		Flowering	Harvesting
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	114.91^{b}	95.94^{c}
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	136.13^{a}	103.00^{b}
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	108.97^{c}	85.97^{d}
T_4	Mulching with coir fibre mat	105.96^{d}	94.91^{c}
T_5	Mulching with polythene sheet	137.13^{a}	107.84^{a}
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	104.92^{e}	83.97^{ef}
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	101.33^{f}	83.44^{f}
T_8	Unweeded control	107.90^{d}	85.85^{de}
Presowing		40.68	

*In a column, means followed by common letters do not differ significantly at 5% level in DMRT

95

Table 30. Effect of treatments on Benefit:Cost ratio

Treatments		Cost of cultivation (Rs/ha)	Income (Rs/ha)	B:C ratio
T_1	Mulching with mango leaves @ 5 t ha^{-1} *f.b.* hand weeding at 45 DAS	134659	270900	2.01
T_2	Mulching with paddy straw @ 5t ha^{-1} *f.b.* hand weeding at 45 DAS	150951	334800	2.22
T_3	Mulching with newspaper *f.b.* hand weeding at 45 DAS	132651	330300	2.49
T_4	Mulching with coir fibre mat	414299	159000	0.38
T_5	Mulching with polythene sheet	144799	437400	3.02
T_6	Hand weeding at 20 DAS, 45 DAS and 60 DAS	141817	320700	2.26
T_7	Pendimethalin 1.0 kg ha^{-1} *f.b.* hand weeding at 45 DAS	122644	302100	2.46
T_8	Unweeded control	107224	33600	0.31

* Labour charges (Men – Rs. 449/day and Women- Rs. 349/ day)

*Cost of black polythene sheet – Rs. 6.10/ m^2 (100 % coverage of field)

*Cost of Coir fibre mat – Rs. 30/m^2

*Cost of pendimethalin – Rs.470/L

*Sale price of okra – Rs. 30/kg

Discussion

5. DISCUSSION

The experiment entitled "Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices" was conducted in the Department of Agronomy, College of Horticulture, Vellanikkara during 2016. The results obtained from the experiment which were presented in the previous chapter are discussed below.

5.1 Effect of treatments on plant growth and yield

The plant height of okra ranged from 33.27 cm to 47.07 cm, 99.67 cm to 110.23 cm and 100.87 cm to 123.87 cm at 30, 60 and 90 DAS respectively (Table 4 and Fig. 2). Mulching with black polythene sheet recorded the highest plant height throughout the crop period. Improvement in height of plants grown under polythene mulches was reported by Kaur (2015). According to her application of plastic mulch significantly improved the plant height over organic mulch and no mulch treatments in brinjal. Plant height in newspaper mulching and hand weeding treatments were more or less the same. Among organic mulches, newspaper and paddy straw recorded highest plant height, whereas coir fibre mat mulching recorded lowest plant height. Unweeded control plot recorded the lowest plant height throughout the crop period. As suggested by Usman *et al.* (2005), it is obvious that reduction in plant height is due to severe crop-weed competition.

In general, the number of branches increased from 30 DAS to 90 DAS (Table 5 and Fig. 3). Higher number of branches were observed in black polythene sheet during the entire crop period. Muhammed (2015) also reported higher number of branches in okra plants under black polythene mulching. Among organic mulches, newspaper mulching recorded higher number of branches followed by paddy straw. Number of branches in hand weeding and mango leaf mulched plots were more or less similar. The lowest number of branches was in unweeded control plot, the reason could be severe infestation of weeds in this treatment.

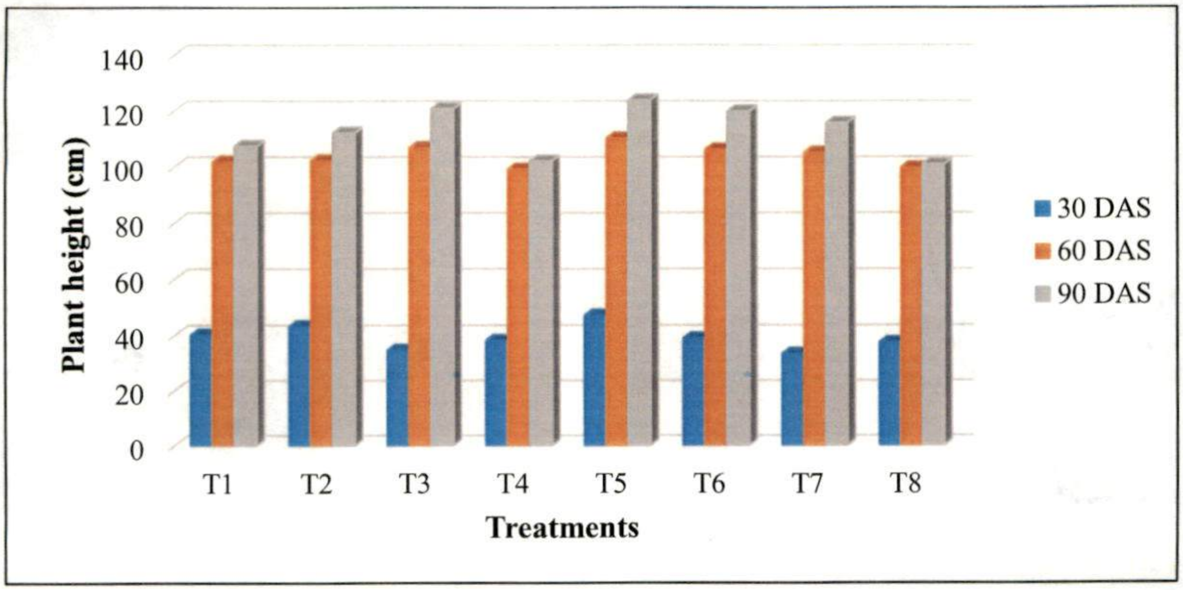


Fig.2. Effect of treatments on plant height (cm)

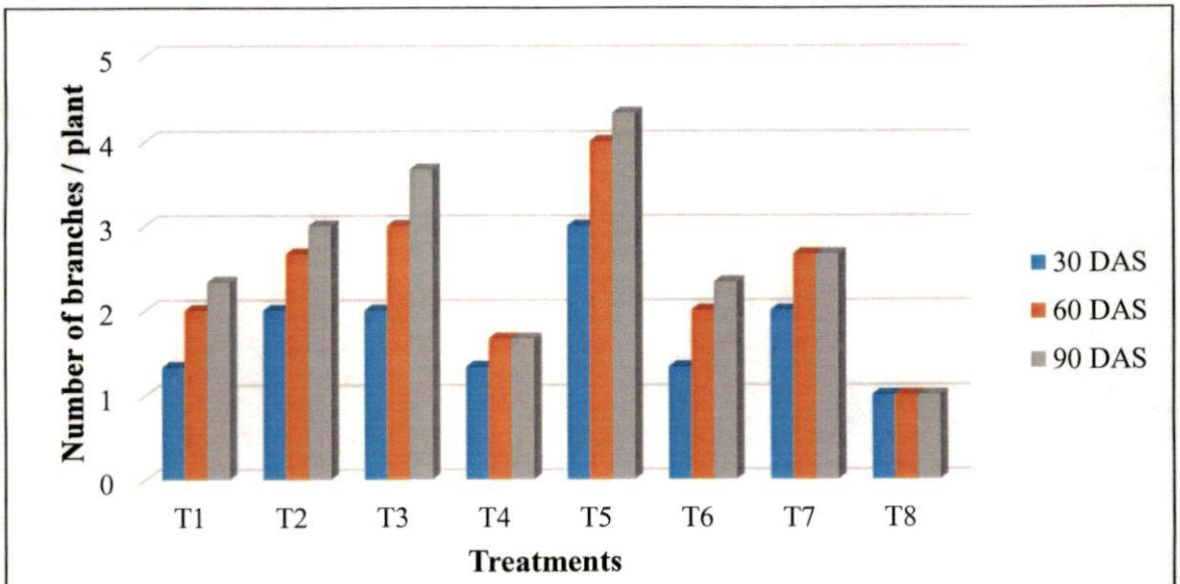


Fig.3. Effect of treatments on number of branches/plant

All the treatments except unweeded control and mulching with coir fibre mat started to flower by 36th day after sowing. Unweeded control treatment took more number of days for first flowering (43 DAS) and harvesting (48 DAS) as depicted in Tables 6 and 7. The plants under coir fibre mat took 38.33 days for the first flowering and 43 days for the first harvest. In these treatments weed count and weed dry matter production were very high throughout the crop growth period (Tables 16 and 17). Similar findings were reported earlier by Olabode *et al.* (2007). According to them, weedy check took more number of days for flowering because of higher competition from weeds. Black polythene sheet, hand weeding and pre emergence spraying of pendimethalin were good treatments considering number of days to harvest.

Number of fruits produced per plant was significantly higher in black polythene sheet (12.26 nos.) than other treatments (Table 8 and Fig. 4). The number of fruits per plant ranged from 7.60 to 12.26. Mulching with newspaper, paddy straw and hand weeding were the next bèst alternatives in case of number of fruits per plant. Unweeded control plots gave the lowest number of fruits (5.26). Similarly plants under black polythene sheet and plants with heavy weed infestation (unweeded control) gave the highest and lowest number of harvests (Table 10). Except for mulching with coir fibre mat all other treatments with mulching were similar while considering number of harvests. As reported by Arin and Ankara (2001), polyethylene mulches are useful for encouraging crop development during initial stages of plant resulting in early harvest and high total yield.

Weed management practices significantly influenced the yield of okra as presented in Table 9 and Fig. 5. Black polythene sheet mulching gave the highest yield (14.58 t ha^{-1}). Significant influence of polythene mulching on increasing yield of okra was reported by Aniekwe (2015). Among organic mulches, mulching with paddy straw (11.16 t ha^{-1}) and newspaper (11.01 t ha^{-1}) were better treatments for yield. Positive influence of paddy straw mulching and paper mulching on yield of okra was reported by many workers (Muhammed, 2015;

Dutta *et al.,* 2016). Yield with coir fibre mat was very low compared to other weeded treatments (5.30 t ha^{-1}). Higher weed growth noticed in coir fibre mat might have influenced crop growth adversely and finally yield. The fruit yield from hand weeded plots and plots with pre emergence application of herbicide were statistically at par (10.69 and 10.07 t ha^{-1}). The unweeded control plot recorded the lowest fruit yield of 1.12 t ha^{-1} which was 13.46 tons per hectare less than the best yielding treatment. Compared to traditional hand weeding and pre emergence application of pendimethalin, weed management by black polythene sheet mulching gave 3.88 and 4.51 tons more yield per hectare respectively. Yield from plots with paddy straw and newspaper mulching followed by one hand weeding at 45 DAS were at par with hand weeding three times at 20, 45 and 60 DAS, indicating the possibility of reducing number of hand weedings from three to one by the application of organic mulches.

Analysis of the data on nutrient uptake (Table 13) revealed that different weed management methods significantly influenced nutrient uptake by the plant. In general, black polythene sheet mulch and unweeded control recorded the highest and lowest uptake of nutrients at 30 and 60 DAS, may be due to absence or presence of weeds respectively. In addition, increased uptake of nutrients by plants grown with plastic mulching can be linked to increased mineralization of nutrients. Hankin *et al.* (1982) suggested that the temperature differential in soil under mulches may be sufficient to affect the growth of microorganisms, the amount of extracellular enzymes released to the soil, and ultimately the rate of degradation of organic materials and release of nutrients to the plants. Among the treatments with mulching, except for coir fibre mat, all other treatments had higher uptake of nutrients. Consequent to increased uptake of N by the plants with less weed competition, these plants showed higher relative chlorophyll contents (SPAD units). Mulching with black polythene sheet, paddy straw, newspaper and pre emergence application of pendimethalin recorded significantly higher relative chlorophyll content at 30 DAS.

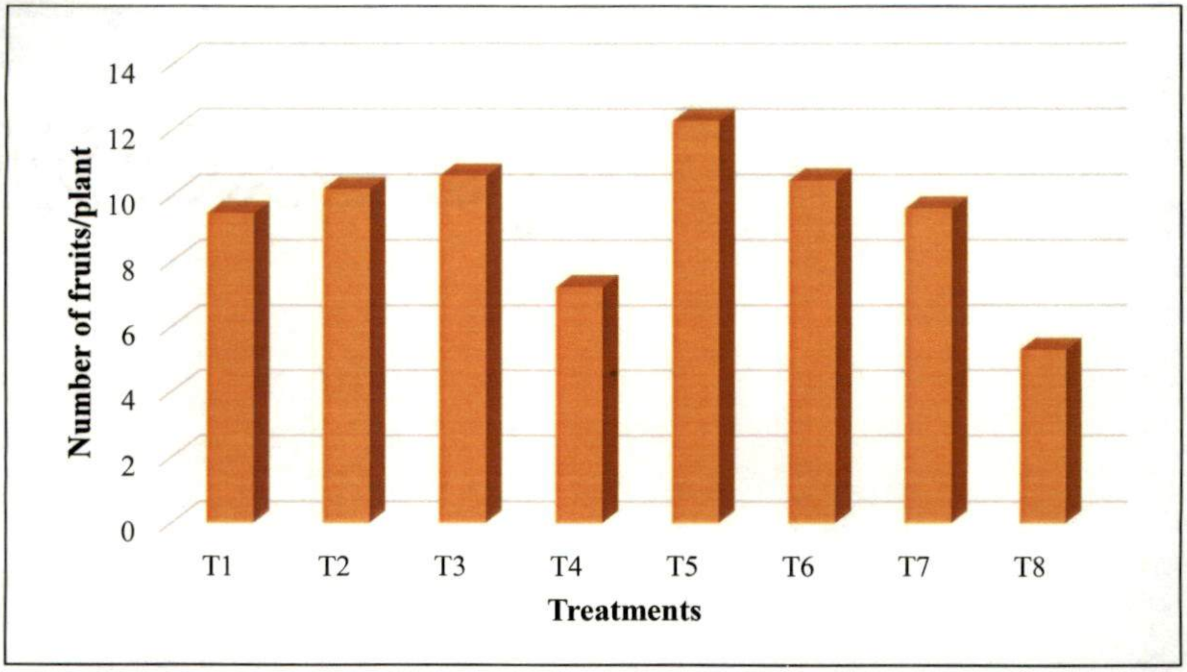


Fig. 4. Effect of treatments on number of fruits per plant

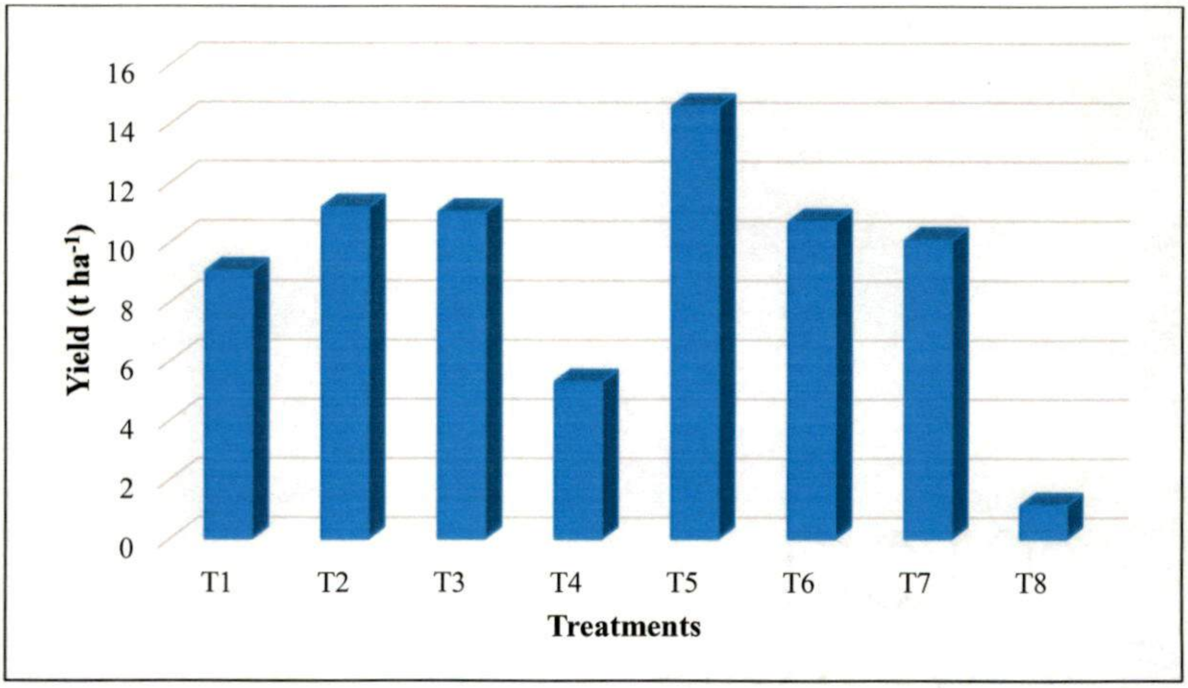


Fig. 5. Effect of treatments on total fruit yield (t ha^{-1})

Black polythene sheet mulching, newspaper mulching and hand weeding recorded higher chlorophyll content at 60 DAS too. Unweeded control treatment showed the lowest chlorophyll content during both at 30 and 60 DAS.

5.2. Effect of treatments on weed growth

Weeds found in the experimental field were typical upland weeds. The main grass weeds observed in the field were *Digitaria ciliaris* and *Panicum maximum*. The broad leaf weeds were *Cleome burmanii, Euphorbia geniculata, Borreria hispida, Phyllanthus amara, Sida acuta,* and *Alternanthera bettzickiana.* No sedges were noticed during the crop period.

At 20 DAS, the lowest weed count and dry weight was observed in mulching with black polythene sheet (Tables 16, 17 and Figs. 5, 6). Pre emergence application of pendimethalin @ 1.0 kg ha^{-1} was the next better treatment considering weed count and dry weight. Among different organic mulches, newspaper mulching was superior in controlling weeds, and recorded lowest weed count and dry weight, followed by mulching with paddy straw and mango leaves. Munn (1992) reported that mulching with newspaper resulted in better control of weeds than straw mulch and bare soil. Mulching with coir fibre mat recorded a higher weed count and dry weight due to emergence of weeds through the holes of coir fibre mat. Hand weeded plots recorded higher weed count and dry weight because hand weeding was done on 20^{th} day.

Black polythene sheet mulch continued its superiority in controlling weeds throughout the growing period as compared to other treatments. Sainudheen (2000) reported the superiority of black polythene sheet mulching in controlling weeds of okra, and according to him no weed growth was observed under polythene mulching except a few, which germinated through the holes made for sowing the seeds. The superiority of black polythene sheet in suppression of weed growth was also reported by Aniekwe (2015). The weed count and dry weight of pendimethalin sprayed plots increased from 20 DAS to 90 DAS showing that its efficiency was only up to initial growth stages of crop. Similar finding was reported by Muhammed (2015). At 45 DAS, lower weed density and dry weight was observed in polythene sheet mulched plots and hand weeded plots followed by newspaper mulched plots and pre emergence application of pendimethalin. Mulching with paddy straw and mango leaves also reduced weed density and dry weight. Significant reduction of weed dry weight in paddy straw mulching was reported by Thankamani *et al.* (2016). Among organic mulched plots, mulching with coir fibre mat showed higher weed count and dry weight. In all other plots with mulching, comparatively lower weed density and dry weight were observed.

Black polythene sheet mulching showed higher weed control efficiency (WCE), more than 90 % throughout the growth period (Table 18 and Fig. 7). Among organic mulches, newspaper mulching gave higher WCE during the entire growth period. At 20 DAS, WCE was the highest in black polythene sheet mulched plots followed by pre emergence application of pendimethalin. At 45 and 90 DAS, black polythene sheet mulching, hand weeding, pendimethalin spray and newspaper mulching gave higher WCE than other treatments. About 87 % WCE was reported for pre emergence application of pendimethalin followed by two hand weedings (Sultana *et al.,* 2008). Mulching with mango leaves and paddy straw gave comparatively better WCE during the growth period.

Mulching with black polythene sheet showed lower weed index. Among organic mulches, mulching with newspaper, paddy straw and mango leaves recorded lower weed index (Table 19 and Fig. 8). As reported by Muhammed *et al.* (2015), better weed management in okra can be achieved by organic mulching and thereby crop yield could be increased. Hand weeding and pre emergence application of pendimethalin also recorded lower weed index showing the effectiveness of the treatments in reducing crop weed competition, resulting in better yield.

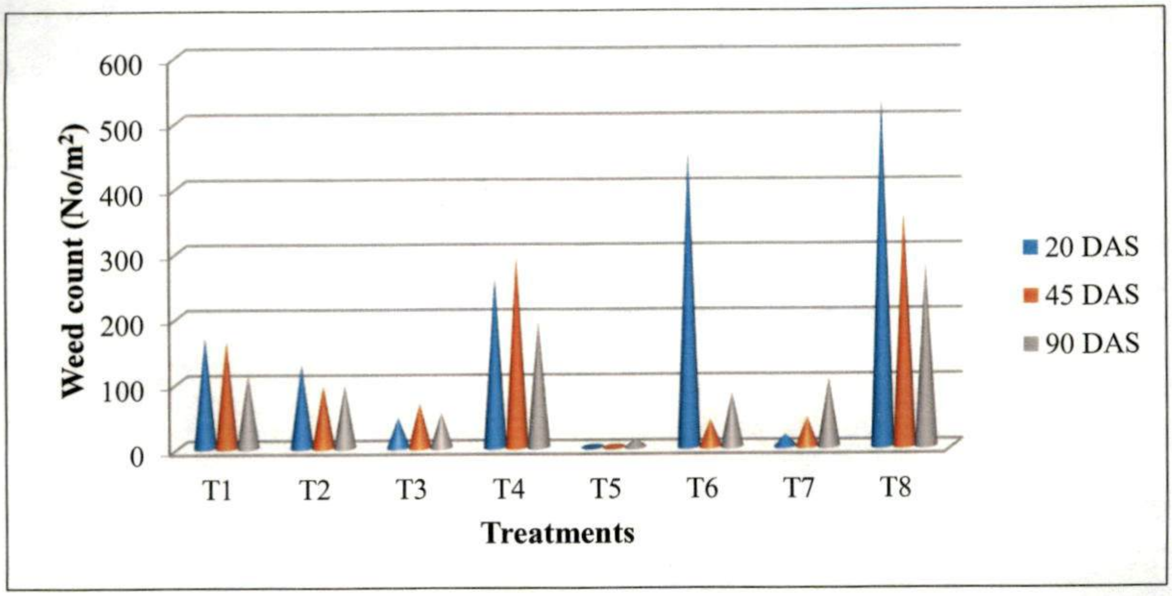


Fig. 6. Effect of treatments on weed count at 20, 45 and 90 DAS

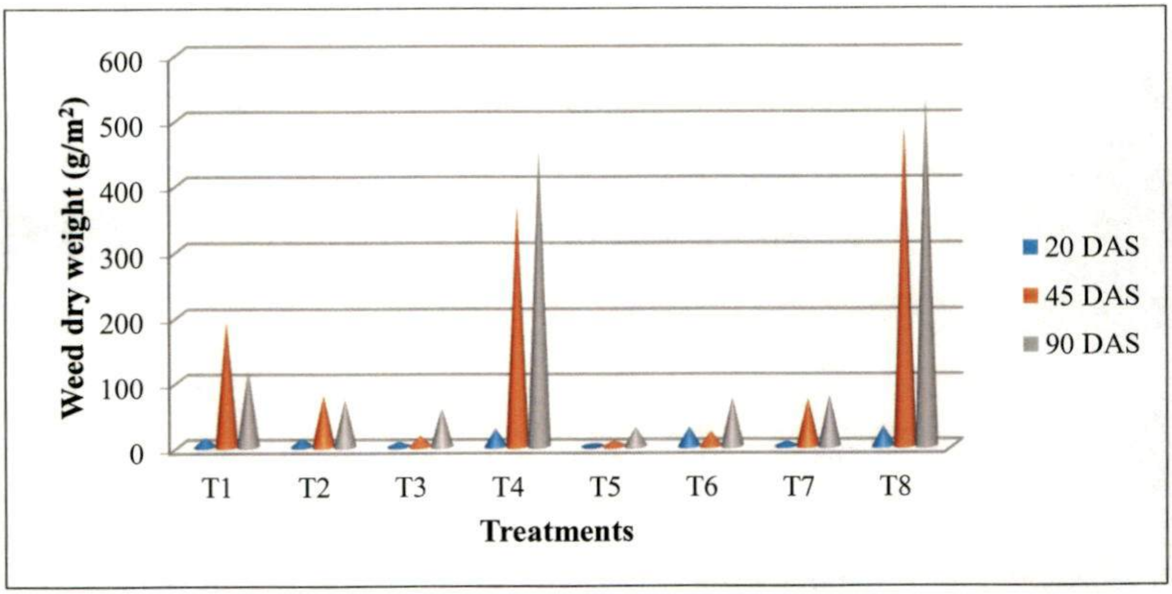


Fig. 7. Effect of treatments on weed dry weight at 20, 45 and 90 DAS

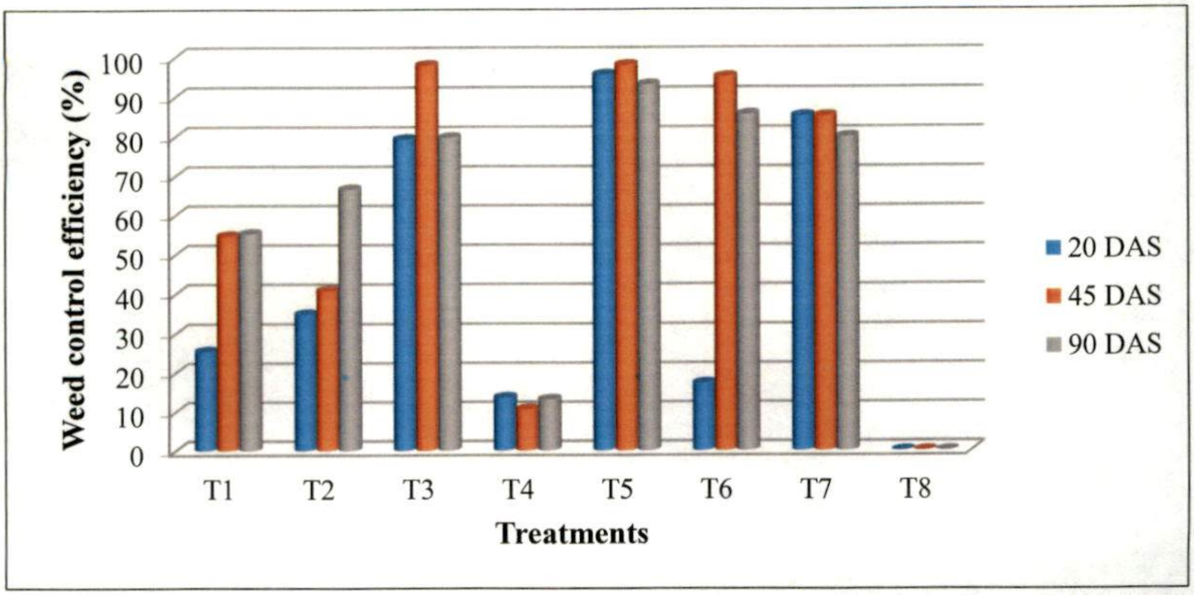


Fig. 8. Effect of treatments on weed control efficiency at 20, 45 and 90 DAS

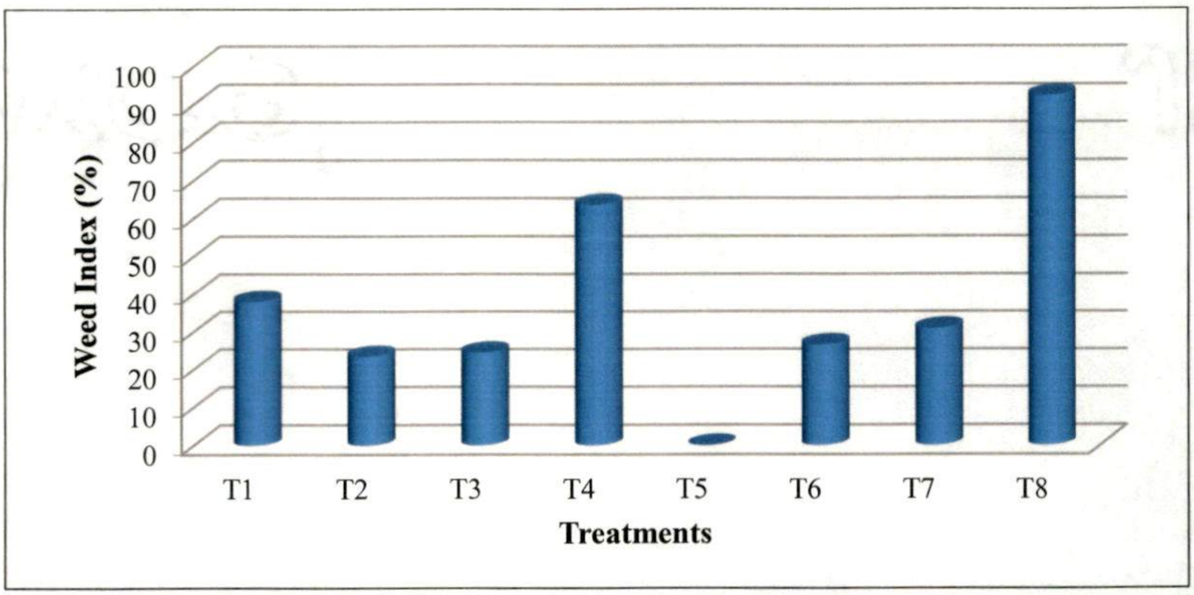


Fig. 9. Effect of treatments on weed index (%)

5.3. Effect of treatments on microclimate

Relative humidity at canopy level of mulched plots was higher during the initial period of the crop than treatments without mulching. Mulching with mango leaves and paddy straw showed higher relative humidity compared to other mulches. During the end of the crop period, most of the treatments recorded almost similar values for relative humidity. Yu-zhu *et al.* (2011), reported that mulching improved the canopy level relative humidity and provided more favourable micro environment for the growth and yield of rice.

During the entire growth period, mulching with black polythene sheet recorded higher soil temperature than other treatments. Black polythene sheet mulched plots increased soil temperature by about 1.66 to 3.65°C at different growth stages of the crop. Ghosh *et al.* (2006) reported that black polythene mulch increased soil temperature to 4-5°C during the crop period. The rise in soil temperature may be due to solar energy trapped inside the mulch material through green house effect (Hu *et al.*, 1995). During the initial stages of the crop soil temperature in the organic mulched plots were lower than unmulched plots. Organic mulches reduced soil temperature and maintained higher soil moisture levels than other treatment as reported by Schonbeck and Evanylo (1998). Among organic mulches, mulching with coir fibre mat recorded higher soil temperature than other treatments.

Weed management methods significantly influenced the soil moisture content at different depths at different growth stages of the crop. In general, all the treatments with mulching recorded higher moisture content at both depths than treatments without mulching. Higher soil moisture content in the mulched plots than unmulched plots was reported by Sharma and Kathiravan (2009). Among organic mulching treatments, mulching with newspaper recorded lower moisture content than other treatments. At 15 cm depth, mulching with black polythene sheet recorded significantly higher moisture content throughout the growth period. Hand weeded, pendimethalin sprayed and unweeded control recorded lower soil moisture. At 30 cm depth also, almost similar trend was observed. Black polythene sheet mulch recorded higher moisture content during most of the crop period. Higher moisture content under polythene mulching may be due to reduced evaporation rate as reported by Lalitha *et al.* (2010). According to Liakatas *et al.* (1986) plastic mulches directly affect the microclimate around the plant by modifying the radiation budget of the surface and decreasing the soil water loss. High moisture content in all the treatments towards the final stage of crop was due to higher rainfall received during the season (Appendix 1).

5.4. Effect of treatments on soil chemical properties

In general, a decrease in soil pH after the experiment was observed. The pH was 5.08 and after the experiment, pH ranged from 4.74 - 4.86. Soil pH in different plots were not significantly different after experiment. Considerable influence of mulches on soil organic carbon was observed. Organic carbon in the soil before the experiment was 1.06 percent and after the experiment, organic carbon increased, ranging from 1.11 to 1.42 percent. Mulching with paddy straw and mango leaves recorded higher organic carbon content and were on par (1.42 and 1.37 percent respectively). Lower organic carbon content was observed in plots without mulching. Increased soil organic carbon content in mulched plots as compared to unmulched plots was reported by Bajoriene *et al.* (2013). Breakdown of organic mulches may have added organic matter to the soil.

Nutritional status of the soil was significantly influenced by different treatments. Available N and K were higher in mulched plots than unmulched plots. Khan *et al.* (2002) reported that straw mulching application increased available N, P, and K status in soil. Improved nutrient availability under mulched plots than unmulched plots was reported by Agele *et al.* (2000). Available P content was more or less similar in mulched and unmulched plots. Compared to organic mulches, mulching with black polythene sheet recorded higher contents of available nutrients. Reduced nutrient loss by less weed population and enhanced mineralization of nutrients under polythene mulches may be the reasons.

According to Lalitha *et al.* (2010), the mineral N content (NO_3^- and NH_4^+) in soil under polythene mulching is higher due to high mineralization of organic N. Breakdown of organic materials releases soluble nutrients like NO_3^- , NH_4^+, Ca^{2+}, Mg^{2+}, K^+ and fulvic acid to the soil which in turn increases soil nutrient availability. Unweeded control plot recorded low available nutrients; presumably because of higher nutrient removal by weeds.

5.5. Effect of treatments on soil microflora

In general, total population of microbes in pre experimental soil was very low (Tables 27 and 28). The microbial activity was enhanced by cultivation practices. The total population of soil microbes were higher during flowering stage of the crop and later decreased. All the treatments with mulching recorded higher population of soil microflora as compared to unmulched plots. Stimulatory effect of mulches on soil microbial population was reported by Csaba *et al.* (2007), according to him it might be due to higher organic carbon content in the soil under mulching which is considered as one of the major portions of the food source for microbes. Among organic mulches, paddy straw exhibited stimulatory influence on soil bacteria, fungi and actinomyctes. Positive influence of straw mulching on the population of bacteria, fungi and actinomycetes was observed by Muhammed *et al.* (2015) which is in agreement with the present study.

Although the population of all the microbes under the study during flowering stage was lower in plots with pre emergence application of pendimethalin, the population turned out to be on par with that in unmulched soil towards later stages. According to Majumdar *et al.* (2010) the microbial activity in herbicide applied plots started to recover at 15 days after application and the activity in those plots synchronized with plots without herbicide towards the final stage of the crop due to the acclimitization of the microorganisms to consume the herbicide as a source of carbon, resulted in improved population of microbes. The same trend could be observed in the present study also.

5.5.1 Total population of bacteria, fungi and actinomycetes

Total population of bacteria were higher in mulched plots than in unmulched plots (Table 27 and Fig. 10). The population of bacteria was lower in herbicide sprayed plots during both flowering and harvesting. Among mulched treatments, paddy straw mulch recorded higher population of bacteria which was statistically on par with mulching black polythene sheet mulch. Bhagat *et al.* (2016) reported that straw mulch increased bacteria, fungi and plant growth promoting rhizobacteria in soil and the increase in microbial population might be due to increased organic carbon content of the soil under mulches. Increased organic matter content in soil due to high temperature under plastic mulches enhanced the microbial activity was reported by Kader *et al.* (2017).

Total population of fungi (Table 27 and Fig. 11) were higher under paddy straw mulch during both flowering and harvesting. Bare soils (hand weeded and pendimethalin sprayed) recorded lower fungal population. Increased activity of rhizobacteria in the rhizosphere, rhizoplane and root interior of vegetables grown in mulched soils compared with bare soil was reported by Khan *et al.* (1998). Among different mulching treatments, newspaper mulching showed lower population of fungi than other treatments.

Population of actinomycetes (Table 27 and Fig. 12) was significantly higher in black polythene sheet mulched plots during both flowering and harvesting stages. Which might be due to tolerance to high temperature. Haines (1932) reported that optimum temperature for the growth of actinomycetes is around 37 - 40°C. Compared to bacteria and fungus, reduction in the population of actinomycetes from flowering stage to harvesting stage was not radical. Hand weeding was the next best treatment at flowering which was followed by paddy straw mulch. Lower population was found in pendimethalin sprayed plots and newspaper mulched plots. Balasubramanian and Sankaran (2001) also reported suppression of soil microflora during the initial stages of crop in herbicide applied soils and recovered later. This might be due to the toxic effects of herbicides immediately after the application.

5.5.2 Total population of nitrogen fixers, P - solubilizers and antagonists (Fluorescent pseudomonads (FP) and *Trichoderma*)

Total population of FP was significantly higher in paddy straw mulch during flowering period followed by coir fibre mat mulching (Table 28 and Fig. 13). Black polythene sheet and unweeded control treatments were statistically on par considering FP population. Newspaper mulch recorded the lowest count of FP. At harvesting black polythene sheet mulch and unweeded control treatments recorded highest and lowest population of FP respectively. Casale *et al.* (1995) found that application of mulches favouring healthy growth of plants also favour the growth of *P. fluorescens* in the rhizosphere.

Trichoderma population was significantly influenced by different treatments. Population was high at flowering and decreased towards harvest (Table 28 and fig. 14). Mulching with coir fibre mat, paddy straw and newspaper, and unweeded control were statistically on par and recorded higher population of *Trichoderma* at flowering. At harvest, paddy straw mulch recorded highest population than other treatments. Which might be due to high carbon availability in these plots (Zhang *et al.,* 2014). Newspaper mulch recorded lowest population of *Trichoderma* at the time of harvest. Total population of P - solubilisers was significant during flowering. At flowering, paddy straw and newspaper mulches recorded significantly higher population of P - solubiliser than other treatments (Fig. 15). Mulching with black polythene sheet recorded lowest population of P - solubilisers followed by coir fibre mat mulching. Mulching with mango leaves, hand weeding, pendimethalin spray and unweeded control were statistically on par. At harvest, the treatments did not differ significantly. According to Wardle *et al.* (1993), all weed management strategies which influence soil temperature and moisture contents were likely to induce significant responses by the beneficial soil microflora.

Total population of nitrogen fixers were significantly higher in plots mulched with paddy straw and coir fibre mat (Fig. 16). Dutta *et al.* (2016) observed a higher population of non symbiotic N-fixing and phosphate solubilizing microbes under straw mulched treatments. Conservation of soil moisture and increased availability of nutrients might have enhanced the population of these microbes under straw mulching. Treatments with pre emergence application of pendimethalin recorded the lowest population of nitrogen fixers during flowering. Inhibition of nitrite oxidizer population during initial stages of crop growth by herbicide application was reported by Saini *et al.* (2009). Mulching with mango leaves, newspaper, black polythene, hand weeding and unweeded control treatment were statistically on par during flowering. During harvesting, black polythene sheet mulching and hand weeding recorded higher population of nitrogen fixers. Although at flowering, the population of N fixers was lower in plots treated with pre emergence application of pendimethalin, at harvest, the population was on par with mulching with mango leaves, paddy straw and newspaper. At harvest unweeded control recorded lower population of nitrogen fixers which was followed by mulching with coir fibre mat. Dutta *et al.* (2016) reported lower population of microbes under weedy check, which might be due to the detrimental effect of root exudates released by weed flora in rhizosphere soil.

In general, all the plots with mulching favoured the population of soil micro flora. Among mulches, paddy straw mulching improved population of most of the microbes in soil than all other treatments.

5.5.3 Soil microbial biomass

Soil microbial biomass carbon increased after the cultivation of the crop. Higher MBC values were recorded at flowering stage than at harvest. This might be due to increased rhizobial effect during flowering stage of the crop. Increased microbial activity during panicle initiation stage of rice which lead to faster multiplication of microflora was also reported by Aparna (2000). At flowering, paddy straw and black polythene sheet recorded higher MBC than other treatments (Table 29 and Fig. 17). Since, MBC is one of the general indices of soil microbial activities, improved MBC in these treatments can be correlated with increased population of soil microbes. Lalfakzuala *et al.* (2006) reported a linear relationship between soil microbial population and MBC. Plots without mulches (pre emergence application of pendimethalin and hand weeding) recorded lower MBC during flowering. Mulching with mango leaves was the next best treatment after paddy straw and black polythene sheet. This might due to higher organic carbon in the mulched plots due to high temperature which might have increased the MBC in soil. Great influence of soil organic carbon on soil microbial carbon were reported by Srinivasarao *et al.* (2007). At harvest, black polythene sheet mulch recorded higher MBC followed by paddy straw mulching. High temperature and high moisture under polythene sheet mulches might have increased MBC in the polythene mulched plots. Piao *et al.* (2001) observed positive correlation with temperature and MBC. According to Kader *et al.* (2017), soil moisture plays an important role in the level of soil microbial biomass carbon. They reported a strong correlation between the soil moisture and soil microbial biomass carbon. In the present studies, it was found that mulching with black polythene sheet and paddy straw were the best treatments to increase the microbial biomass

5.6. Economics of mulching

The highest B:C ratio was obtained for mulching with black polythene sheet which recorded a B:C ratio of 3.02 (Table 30 and Fig. 18). Mulching with newspaper showed a B:C ratio of 2.49. The B:C ratio for herbicidal weed management was 2.46 whereas the B:C ratio for hand weeding was 2.26; indicating the possibility of substituting herbicide and hand weeding methods with organic mulches like newspaper. Weed management by application of straw as mulch also gave better B:C ratio of 2.22.

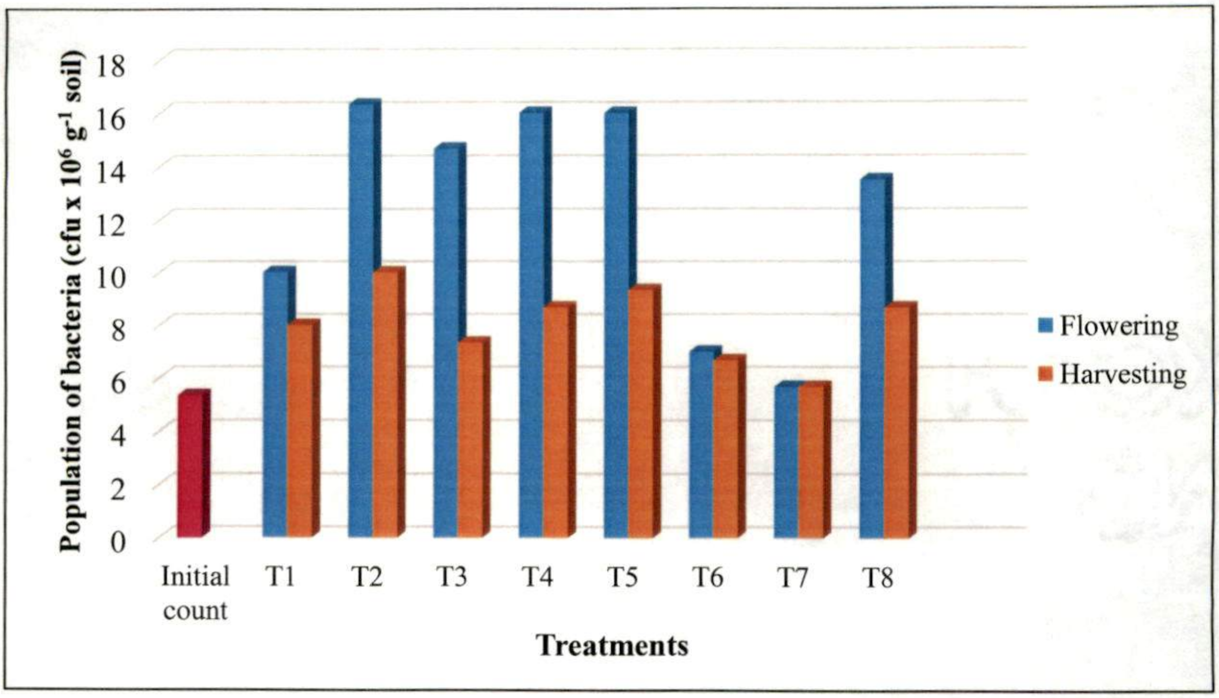


Fig. 10. Effect of treatments on total population of bacteria in rhizosphere of okra

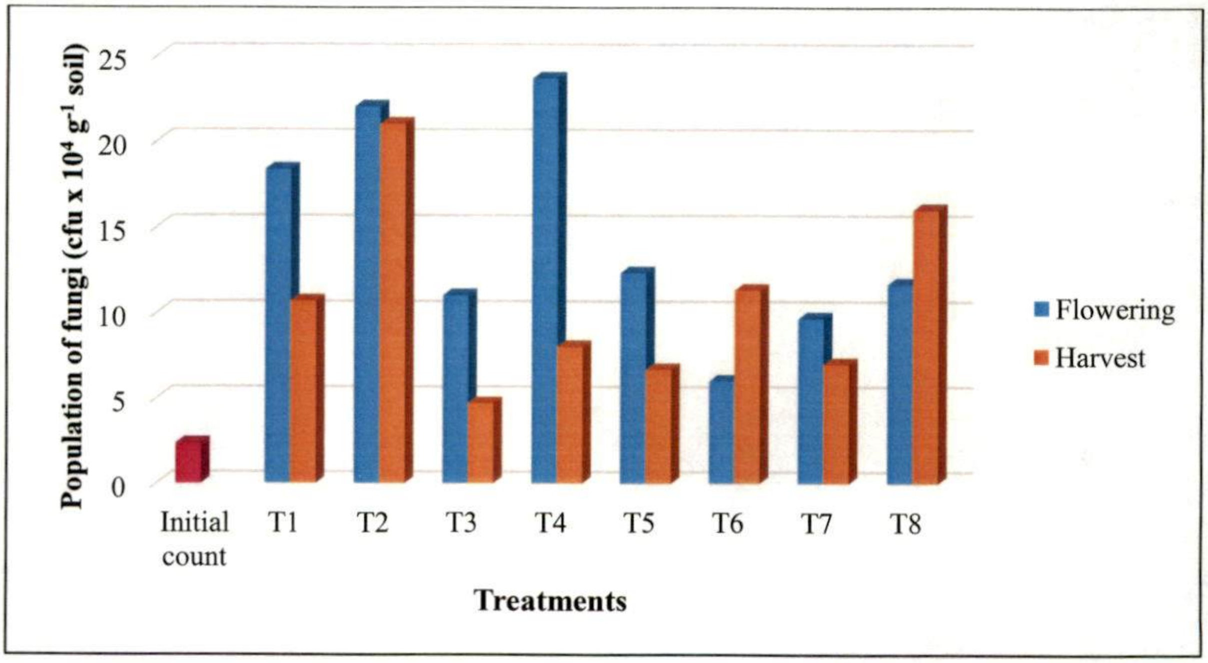


Fig. 11. Effect of treatments on total population of fungi in rhizosphere of okra

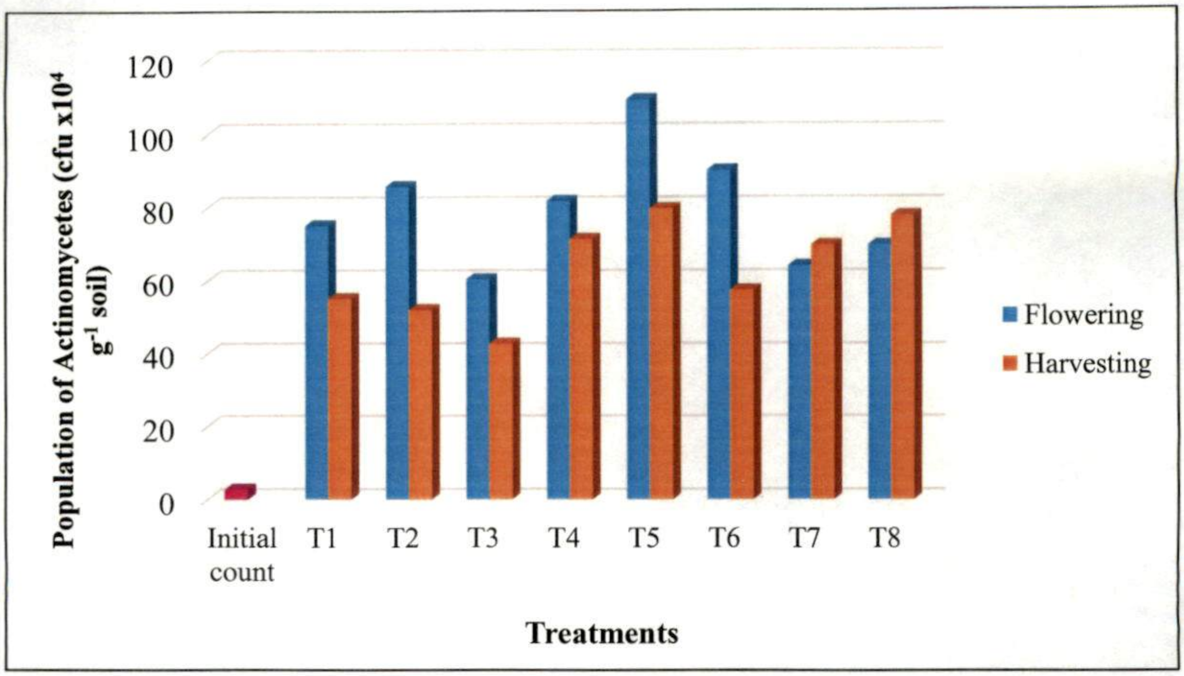


Fig. 12. Effect of treatments on total population of actinomycetes in rhizosphere of okra

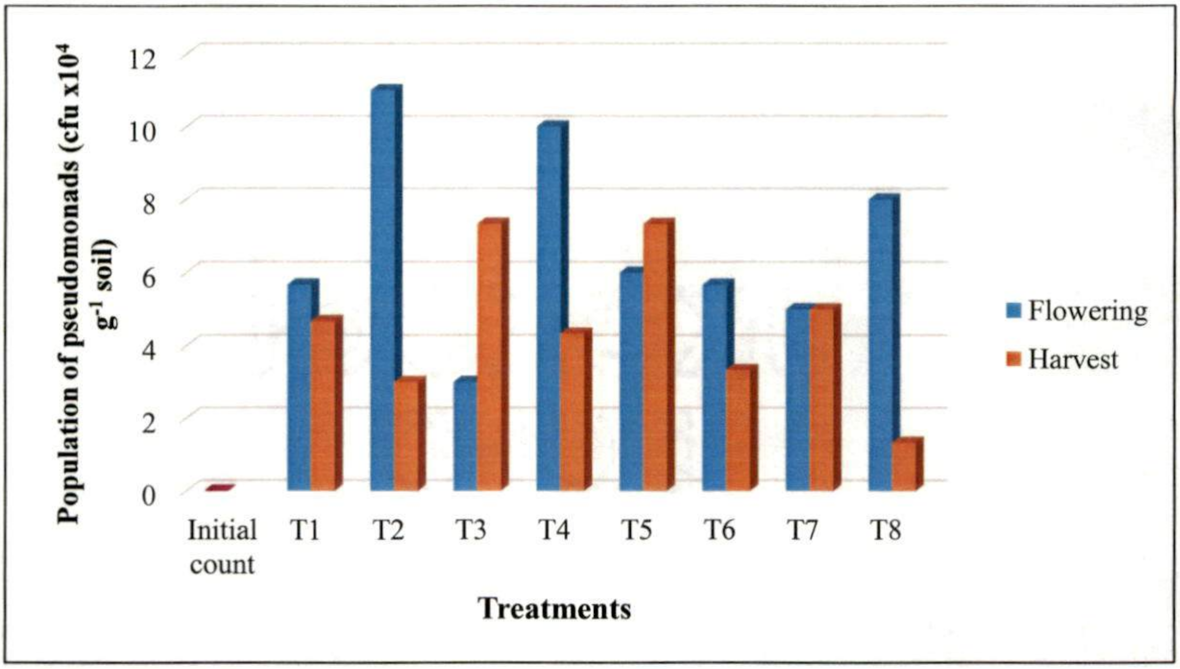


Fig. 13. Effect of treatments on total population of pseudomonads in rhizosphere of okra

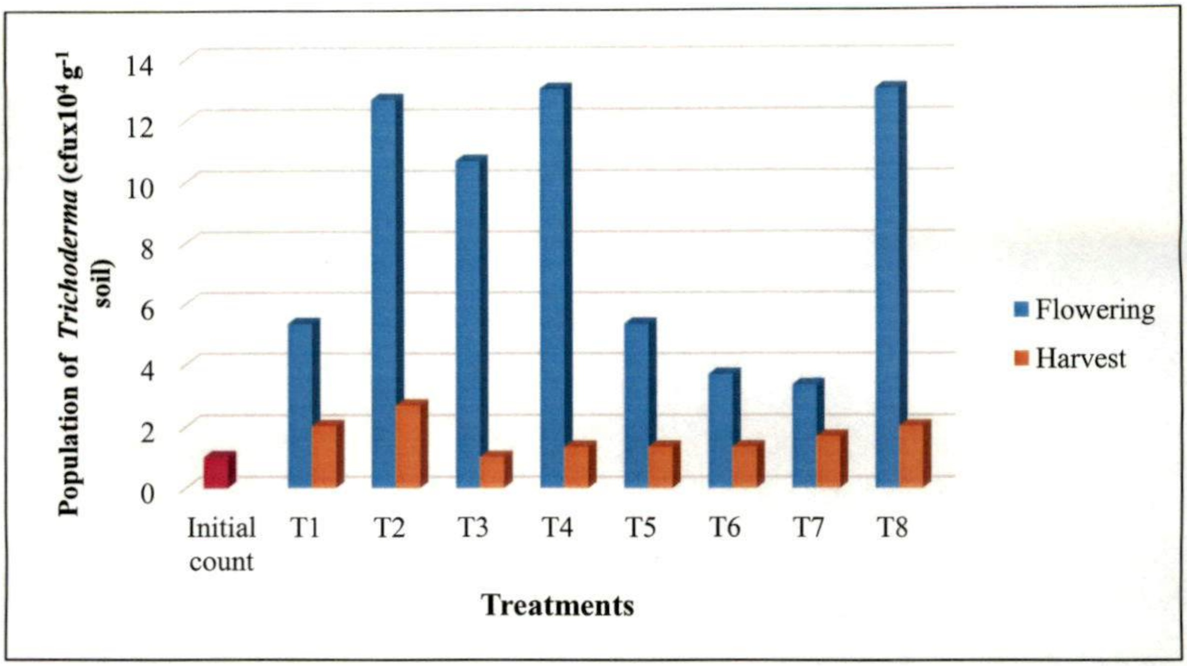


Fig. 14. Effect of treatments on total population of *Trichoderma* in rhizosphere of okra

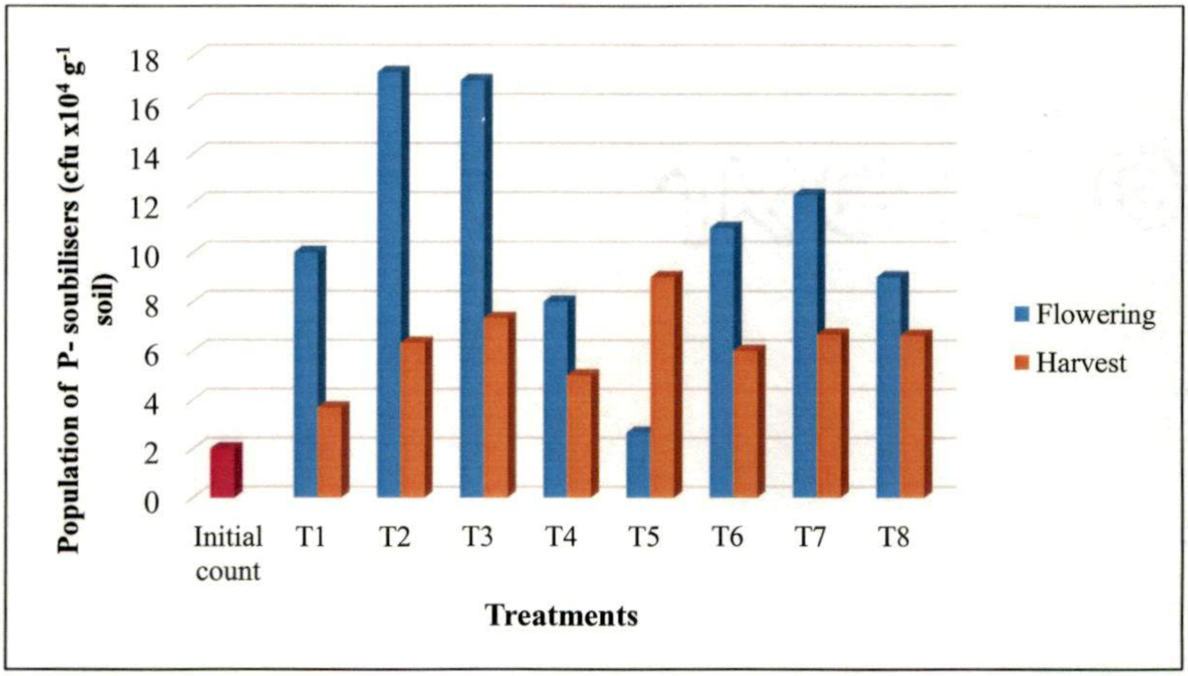


Fig. 15. Effect of treatments on total population of P- solubilisers in rhizosphere of okra

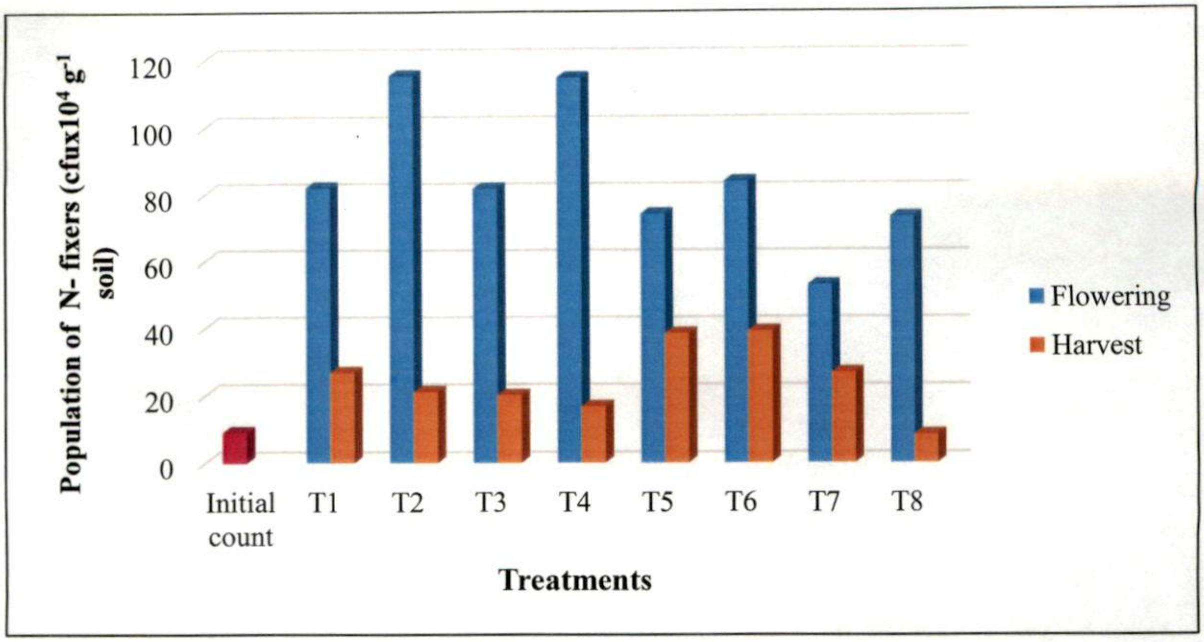


Fig. 16. Effect of treatments on total population of N- fixers in rhizosphere of okra

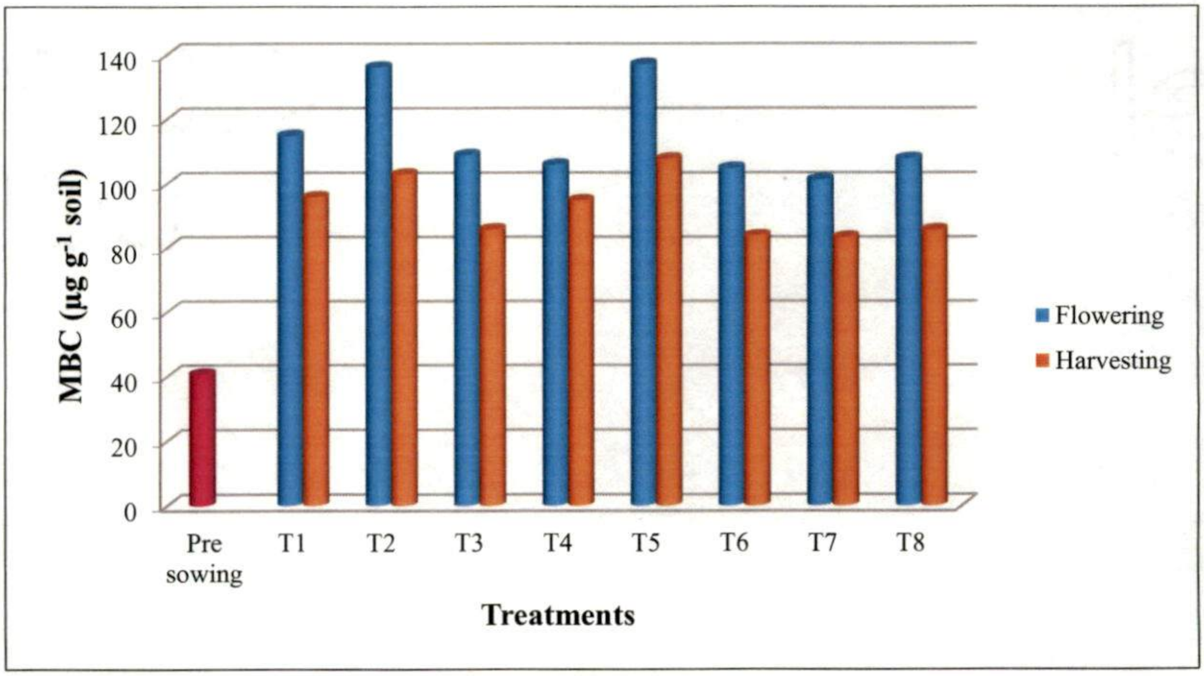


Fig. 17. Effect of treatments on microbial biomass carbon (µg g^{-1})

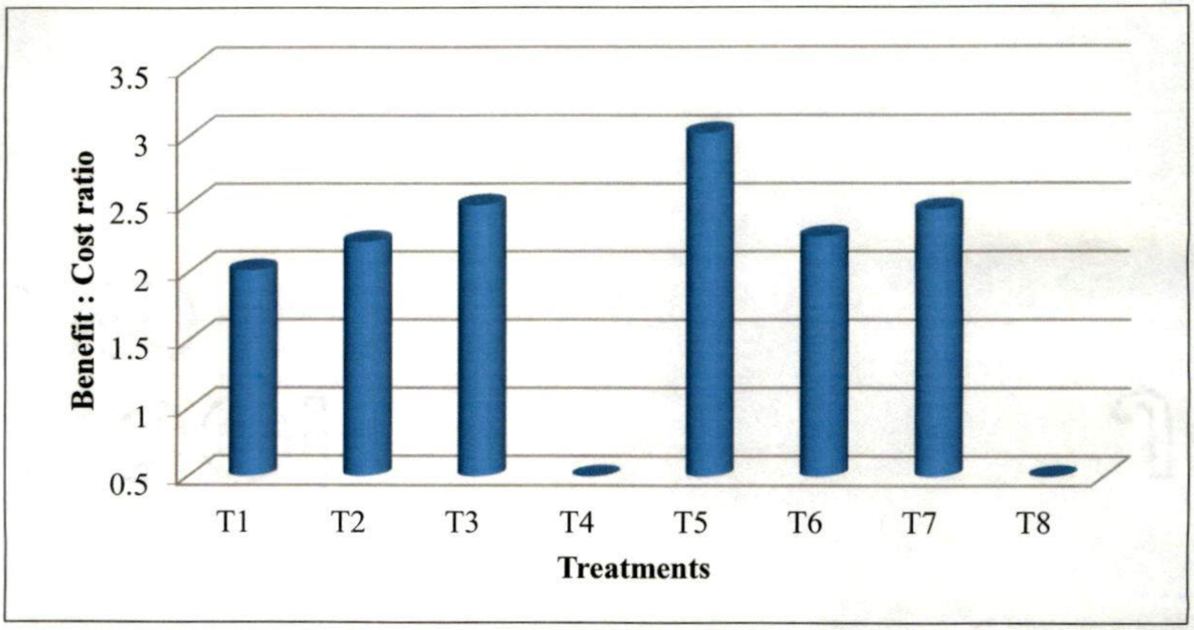


Fig. 18. Effect of treatments on Benefit:Cost ratio

Summary

6. SUMMARY

Weed competition is one of the major production constraints which lead to low productivity of agricultural crops. Hence weed management is an important practice to improve production potential of a crop. Different weed management practices will modify the micro environment of the crop differently depending on the method adopted, environmental conditions, and other management practices. Therefore to assess the effect of different weed management practices on the microsite variations and its consequent effect on growth and yield of okra, a study entitled "Microsite variations of okra [*Abelmoschus esculentus* (L.) Moench.] under different weed management practices" was conducted at the Department of Agronomy, College of Horticulture, Vellanikkara during the period from March to June 2016. The experiment was laid out in randomized block design with three replications. The treatments comprised of four different organic mulches (mango leaves, paddy straw, newspaper and coir fibre mat), mulching with black polythene sheet, hand weeding, weed management by herbicide and an unweeded control treatment.

Yield and yield attributes of okra showed significant variation due to different weed management methods. Black polythene sheet mulching greatly influenced the plant height. Similar trend was observed for number of branches too. With respect to days to first flowering and harvesting weed management practices showed its influence. Almost all the treatments except for unweeded control and coir fibre mat mulching took almost similar number of days for first flowering. Black polythene sheet, hand weeding and herbicide treatment were better treatments in case of reducing number of days to first harvest.

Number of fruits per plant was higher in black polythene sheet mulched plots. Newspaper and paddy straw mulches also improved number of fruits per plant. Higher number of harvests and high yield was obtained in black polythene sheet mulch. Black polythene sheet mulching recorded a fruit yield of 14.58 t ha^{-1} followed by paddy straw mulching, newspaper mulching (11.16 and 11.01 t ha^{-1}). Mulching with paddy straw and newspaper recorded more yield than hand weeding and pre emergence application of pendimethalin. Higher uptake was noticed under black polythene sheet and lower uptake was in unweeded control plot. Similarly except for coir fibre mat mulching, all other treatments with mulching recorded higher uptake of nutrients and as a consequence, these plants showed higher relative chlorophyll content (SPAD units).

Improvement in soil organic carbon content was noticed after the experiment. Mulching favoured the soil organic carbon content. Mulching also improved the soil nutritional status as compared to bare soils of hand weeded, herbicide treated and weedy check plots. Available N and K were higher in mulched plots. Whereas available P content was more or less similar in all the plots. A decrease in soil pH after the experiment was noticed. However, there was no significant difference in pH due to treatments.

Considerable effect of mulches on relative humidity at canopy level was noticed. The relative humidity of mulched plots were higher than plots without mulching. Black polythene sheet recorded higher soil temperature than other treatments during the entire crop period. Soil temperature in the plots with organic mulches was lower than the plots without mulching. Weed management methods significantly influenced the soil moisture content at different depths at different growth stages of the crop. In general, all the treatments with mulching recorded higher moisture content at both depths than treatments without mulching.

Different weed management practices significantly affected the soil microflora. The microbial population improved after the experiment. The population of soil microbes was higher during flowering stage of the crop and later decreased. All the plots with mulching recorded higher population of soil microflora as compared to unmulched plots. Paddy straw mulching improved the soil bacteria and fungi both at flowering and harvesting. Population of actinomycetes was found higher under black polythene sheet mulch during flowering and harvesting. Almost similar trend was found in the total population of P - solubilisers, nitrogen fixers and antagonists. Population of pseudomonads was higher in paddy straw mulching during flowering. However, at harvesting, higher population of pseudomonads was found in black polythene sheet mulching. Lowest count of nitrogen fixer was found in herbicide treated plot during flowering. Total population of P - solubilsers and *Trichoderma* were found higher under mulching with paddy straw both during flowering and harvesting.

Soil microbial biomass carbon was also influenced by different treatments. Higher MBC was recorded for paddy straw mulch during flowering and lower in plots with pre emergence application of pendimethalin. During harvesting higher MBC was found in black polythene sheet mulched plots followed by paddy straw.

All the treatments managed the weeds effectively. Black polythene sheet mulching was the best treatment considering weed control. Pre emergence application of pendimethalin resulted in lower weed population and dry weight during initial period of the crop and there after population and dry weights increased. Among different organic mulching, newspaper mulching recorded higher weed control followed by paddy straw mulching. Mulching coir fibre mat failed to reduce weed growth throughout the crop period. Higher weed control efficiency (more than 90 %) was found in black polythene sheet throughout the crop period. Mulching with paddy straw and newspaper recorded lower weed index than hand weeding and pre emergence application of pendimethalin.

Higher benefit cost ratio of 3.02 was recorded for black polythene sheet mulching. Newspaper mulching and pre emergence spray of pendimethalin were the next best treatmentswith respect to B:C ratio.

From the experiment, it can be concluded that different weed management practices influenced the micro environment of the crop greatly and resultant micro site variation influenced the yield and yield parameters of crop and also soil quality parameters. The results also suggest the possibility of using mulches either organic (newspaper or paddy straw) or inorganic (polythene) as a better alternative to manual weeding and herbicidal application for weed management and for better B:C ratio in okra.

References

References

Abhivyakti, Kumari, P., Ojha, R. K. and Job, M. 2016. Effect of plastic mulches on soil temperature and tomato yield inside and outside the polyhouse. *Agric. Sci. Digest* 36(4): 333-336.

Abouziena, H. F., Hafez, O. M., El-Metwall, I. M., Sharma, S. D. and Singh, M. 2008. Comparison of weed suppression and mandarin fruit yield and quality obtained with organic mulches, synthetic mulches, cultivation and glyphosate. *Hort sci.* 43(3): 795–799.

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M. and O. Dunsin. 2017. Response of okra (*Abelmoschus esculentus* (L.) Moench.) and soil properties to different mulch materials in different cropping seasons. *Sci. Hortic.* 217: 209–216.

Adijoro, S. A. and Olopha, P. K. 2103. Weed control in Okra (*Abelmoschu s esculentus* (L). Moench.) with pendimethalin and its residual effects on soil physical chemical properties. *J. Sustain. Technol.* 4(2): 58- 65.

Agarwal, G. P. and Hasija, S. K. 1986. *Microorganisms in Laboratory.* Print House India Ltd., Lucknow, 155p.

Agele, S. O., Iremiren, G. O. and Ojeniyi, S. O. 2000. Effects of tillage and mulching on the growth, development and yield of late-season tomato (*Lycopersicon esculentum* L.) in the humid south of Nigeria. *J. Agric. Sci.*134(1): 55-59.

Ahuja, K. N., Yaduraju, N. T., Singh, R. and Singh, D. K. 1999. Chemical weed control in potato (*Solanum tuberosum* L.). *Indian J. Weed Sci.* 31: 8–12.

Alliaume, F., Rossing, W. A. H., Tittonell, P. and Dogliotti, S. 2017. Modelling soil tillage and mulching effects on soil water dynamics in raised-bed vegetable rotations. *Eur. J. Agron.* 82: 268–281.

Amare, T., Sileshi, F. and Hamza, I. 2015. Effect of weed interference period on yield of transplanted tomato (*Lycopersicon esculentum* M.) in Guder West Shewa- Oromia, Ethiopia. *J. Food Agric. Sci.* 5(3): 14-20.

Aniekwe, N. L. 2015. Comparative effects of organic and plastic mulches on the environment, growth and yield of okra in a derived savanna zone of Nigeria. *Int. J. Sci. Res.* 4(1): 1860- 1864.

Aparna, B. 2000. Distribution, characterization and dynamics of soil enzymes in selected soils of Kerala. PhD Thesis, Kerala Agricultural University. 365 p.

Arin, L. and Ankara, S. 2001. Effect of low-tunnel, mulch and pruning on the yield and earliness of tomato in unheated glasshouse. *J. Appl. Hortic*. 3(1): 23-27.

Arivukkarasu, K. and Kathiresan, R. M. 2014. Effect of weed management practices on *Trianthema portulacastrum* in hybrid maize. *Int. J. Adv. Res. Biol. Sci.* 1(4): 120-122.

Bahar, F. A. and Singh, K. N. 2013. Modification of crop ecology in maize (*Zea mays*) through fertility levels and weed control measures under temperate conditions of Kashmir. *Indian J. Agron.*58 (3): 349-353.

Bajoriene, K., Jodaugiene, D., Pupaliene, R. and Sinkeviciene, A. 2013. Effect of organic mulches on the content of organic carbon in the soil. *Estonian J. Ecol.* 62(2): 100-106.

Balasubramanian, K. and S. Sankaran. 2001. Effect of pendimethalin on soil micro-organisms. *Ind. Agric*. 45: 93-98.

Baumann, D. T. and Slembrouck, I. 1994. Mechanical and integrated weed control systems in row crops. *Acta Hortic.* 372: 245-252.

Beena, K. S. and Anil, K. R. 2011. Effectiveness of coir geotextiles in soil moisture conservation. *Int. J. Eng. Technol.* 3(3): 200-207.

Bhagat, P., Gosal, S. K. and Singh, C. B. 2016. Effect of mulching on soil environment, microbial flora and growth of potato under field conditions. *Indian J. Agric. Res*. 50(6): 542-548.

Bhardwaj, R. L. 2013. Effect of mulching on crop production under rainfed condition - a review. *Agric. Rev*. 34 (3): 188-197.

Bhullar, M. S., Kaur, T., Kaur, S. and Yadav, R. 2015. Weed management in vegetable and flower crop-based systems. *Indian J. Weed Sci.* 47(3): 277–287.

Boyd, N. S. 2016. Pre - and post emergence herbicides for row middle weed control in vegetable plasticulture production systems. *Weed Technol.* 30 (4): 949-957.

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

Casale, W. L., Minassian, V., Menge, J. A., Lovatt, C. J., Pond, E., Johnson, E. and Guillemet, F. 1995. Urban and agricultural wastes for use as mulches on avocado and citrus and for delivery of microbial biocontrol agents. *J. Hortic. Sci*. 70: 315–332.

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.

Chaudhari, A. P., Gaikwad, C. B., Tiwari, T. K., Nikam, A. S., Bhende, S. N. and Bagwan, I. R. 2007. Effect of weed control on nutrient uptake, weed weight and yield of groundnut. *Int. J. Agric. Sci*. 3(1): 193-195.

Coir Board. 2016. *Coir Bhoovasthra - an eco friendly, bio degradable material for soil conservation and rural road.* Print ExPress, Cochin, pp.115-116.

Csaba, V., Fekete, I., Piskolczi, M., Dorka, D. and Helmeczi. 2007. The effect of different mulching materials on quantitative changes of microbes in the soil of an integrated apple plantation. In: *Seventh International Multidisciplinary Conference*; 17-18 May, Baia Mare, Romania, pp.725-30.

Das, T. K., Tuti, M. D., Rajvir, S., Paul, T. and Ram, M. P. 2012. Weed management research in India: an overview. *Indian J. Agron.* 57(3): 148-156.

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

Dhananivetha, M., Amnullah, M. M., Arthanari, M. P. and Mariappan, S. 2017. Weed management in onion: a review. *Agric. Rev.* 38(1): 76-80.

Dutta, D., Thentu, T. L. and Duttamudi, D. 2016. Effect of weed-management practices on weed flora, soil micro-flora and yield of baby corn (*Zea mays*). *Indian J. Agron.* 61(2): 210- 216.

Eizenberg, H., Hershenhorn, J., Graph, S., and Manor, H. 2003. *Orobanche aegyptiaca* control in tomato with sulfonylurea herbicides. *Acta Hortic.* 613: 205- 208.

Eruola, A. O., Bello, N. J., Ufoegbune, G. C. and Makinde, A. A. 2012. Effect of mulching on soil temperature and moisture regime on emergence, growth and yield of white yam in a tropical wet and dry climate. *Int. J. Agric. For.* 2(1): 93-100.

Feng, Z. X., Bin, Z. J., Yang, W. C., Li, X. X., Jun, G. Y. and Xiu, L. S. 2009. Effects of different mulching methods on growth and nutrients absorption of maize. *Agric. Res. Arid Areas* 27(2): 80-98.

Ghosh, P. and Kumar, A. D. 2014. Soil solarization, an eco-physiological method of weed control. *Glob. J. Sci. Frontier Res.* 14(4): 42- 44.

Ghosh, P. K., Dayal, D., Bandyopadhyay, K. K. and Mohanty. M. 2006. Evaluation of straw and polythene mulch for enhancing productivity of irrigated summer groundnut. *Field Crops Res.* 99: 76–86.

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

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

Gordon, G. G., Foshee, W. G., Reed, S. T., Brown, J. E. and Vinson, E. L. 2010. The effects of colored plastic mulches and row covers on the growth and yield of okra. *Hort Technol.* 20(1): 224- 233.

Goswami, S. B. and Saha, S. 2006. Effect of organic and inorganic mulches on soil-moisture conservation, weed suppression and yield of elephant-foot yam (*Amorphophallus paeoniifolius*). *Indian J. Agron*. 51(2): 154 – 156.

Gould, W. D., Hagedorn, C., Bardinelli, T. R. and Zablotowics, R. M. 1985. New selective media for enumeration and recovery of fluorescent pseudomonads from various habitats. *Appl. Environ. Microbiol*. 49: 28–32.

Govindappa, M., Pallavi. and Seenappa, C. 2015. Importance of mulching as a soil and water conservative practice in fruit and vegetable production-review. *Int. J. Agric. Innovations Res*. 3(4): 1014- 1017.

Gowda, S. G. K., Naveen, D. V., Bhagyalakshmi, T. and Gowda, R. C. 2012. Weed management practices on nutrient removal by weeds and its relation to yield of finger millet in eastern dry zone of Karnataka. *Int. J. Agric. Sci.* 8(2): 385-389.

Grundy, A. C. and Bond, B. 2007. Use of Non-living Mulches for Weed Control. In: Upadhyaya, M. K. and Blackshaw, R. E. (eds.). *Non-chemical Weed Management.* CAB International. pp. 135- 153.

Gupta. O. P. 2010. *Weed Management Principles and Practices* (3rd Ed.). Agrobios, Jodhpur, pp.85- 87.

Haines, R. B. 1932. The influence of temperature on the rate of growth of saprophytic actinomycets. *J. Exp. Biol.* 9: 45-60.

Ham, J. M., Kluitenberg, G. J. and Lamont, W. J. 1993. Optical properties of plastic mulches affect the field temperature regime. *J. Am. Soc. Hortic. Sci.* 118: 188-193.

Hankin, L., Hill, D. E. and Stephens, G. R.1982. Effect of mulches on bacterial populations and enzyme activity in soil and vegetable yields. *Plant Soil* 64: 193-201.

Hoyt, G. D. and Monks, D. W. 1996. Weed management in strip-tilled Irish potato and sweet potato systems. *Hortic. Technol.* 6(3): 238-240.

Hu, W., Duan, S. and Sui, Q. 1995. High yield technology for groundnut. *Int. Arachis Newsletter* 15: 1-22.

Iyagba, A. G., Onuegbu, B. A. and Ibe, A. E. 2013. Growth and yield response of okra (*Abelmoschus esulentus* (L.) Moench.) to NPK fertilizer rates and weed interference in South-eastern Nigeria. *Int. Res. J. Agric. Sci. Soil Sci.* 3(9): 328-335.

Jacks, C. V., Brind, W. D. and Smith, R. 1955. Mulching Technology Comm, No. 49, Common Wealth. *Bulletin of Soil Science,* 118p.

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

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

Jalendhar, G., Reddy, C. S. K., Srinivas, A. and Rao, M. A. 2016. Effect of integrated weed management practices on growth, yield and it's attributes in okra (*Abelmoschus esculentus* (L.) moench.) cv. Arka anamika. *Int. J. Sci. Nature* 7(1): 165-167.

Jat, R. S., Meena, H. N., Singh, A. L., Surya, J. N. and Misra, J. B. 2011. Weed management in groundnut (*Arachis hypogaea* L.) in India - a review . *Agric. Rev.* 32(3): 155 – 171.

Jenkinson, D. S. and Powlson, D. S. 1976. The effects of biocidal treatments on metabolism in soil-V. A method for measuring soil biomass. *Soil Biol. Biochem.* 8: 209-213.

Jensen, H. L. 1955. Non-symbiotic nitrogen fixation In: Barthdlomew, W. V. and Clark, F. E. (eds.) *Soil nitrogen.* American Society of Agronomy, Madison, 10: 436-480.

Jodaugiene, D., Pupaliene, R., Urboniene, M., Pranckietis, V. and Pranckietiene, I. 2006. The impact of different types organic mulches on weed emergence. *Agron. Res.* 4: 197- 201.

Jun, F., Yu, G., Jiu, W. Q., Malhi, S. S. and Yang, L. Y. 2014. Mulching effects on water storage in soil and its depletion by alfalfa in the Loess Plateau of northwestern China. *Agric. Water Manag.* 138: 10-16.

Kader, M. A., Senge, M., Mojid, M. A. and Ito, K. 2017. Recent advances in mulching materials and methods for modifying soil environment. *Soil Tillage Res.* 168: 155–166.

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

KAU [Kerala Agricultural University]. 2011. *Package of Practices Recommendations – Crops* (14^{th} Ed.). Directorate of Extension, Kerala Agricultural University, Thrissur, 360p.

Kaukovirta. E. 1988. Composition of weed flora in vegetables with and without chemical control in Finland. In: Cavalloro, R. and El Titi, A. (eds.). *Weed*

Control in Vegetable Production: Proceedings of a meeting of the EC Experts' Group, Stuttgart. Commission of Europian Communities, pp. 49-57.

Kaur, K. P. 2015. Effect of FYM levels and mulch sources on growth, productivity and water use of brinjal (*Solanum melongena*) at varying irrigation depth. M. Sc. (Ag) thesis, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 80p.

Kaur, N., Bhullar, M. S. and Gill, G. 2015. Weed management options for sugarcane-vegetable intercropping systems in North Western India. *Crop Prot.* 74: 18-23.

Khan, A. R., Singh, S. S., Nanda, P., Chandra, D. and Anand, P. S. B. 2002. Effect of organic mulching on physico-chemical properties of soil. *United Nations Educational Scientific and Cultural Organization and International Atomic Energy Agency*. 5p.

Khan, V. A., Stevens, C., Lu, J. Y., Mafolo, T., Rhoden, E. G., Wilson, M. A., Brown, J. E. and Collins, D. J. 1998. Evidence of soil microflora change associated with increased growth response of vegetables grown on agrimulch systems. In: Ben, Y. S (ed.), *14th International congress on plastics in agriculture*, March 1997. Tel Aviv, Israel, pp. 207-215.

Khot, D. B., Pagar, R. D. and Munde, S. D. 2015. Effect of different weed management practices on yield and economics of summer black gram (*Vigna mungo* L.). *Agric. Sustain. Dev*. 3(1): 21-22.

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

Kumar, P., Tewatia, A. S., Khurana, S. C., Duhan, D. V. and Lajpat. 2001. Effect of cultural practices and herbicides on the growth and development of carrot. *Haryana J. Hortic. Sci.* 30(1&2): 97-99.

Kumar, R., Sood, S., Sharma, S., Kasanab, R. C., Pathani, V. L., Singh, B. and Singh, R. D. 2014. Effect of plant spacing and organic mulch on growth, yield and quality of natural sweetener plant stevia and soil fertility in western Himalayas. *Int. J. Plant Prod.* 8(3): 311- 334.

Kumar, D., Kumar, M., Kumar, R., Thakur, K. S., Vikram, A. and Kumar, S. 2012a. Weed management in vegetable crops. In: Bhardwaj, M. L., Sharma, H. D., Kumar, M., Kumar, R., Kansal, S., Thakur, K., Singh, S. P., Kumar, D., Kumari, S., Gupta, M. and Sharma, V. (eds), *Vegetable Production Under Changing Climate Scenario.* Department of Vegetable Science. Directorate of Extension Education. Dr YS Parmar University of Horticulture & Forestry. Himachal Pradesh. pp. 209 – 217.

Kumar, S. D. and Lal, B. R. 2012b. Effect of mulching on crop production under rainfed condition: a review. *Int. J. Res. Chem. Environ.* 2(2):8-20.

Kumar, S., Singh, R., Shyam, R. and Singh, V. K. 2012. Weed dynamics, nutrient removal and yield of wheat as influenced by weed management practices under valley conditions of Uttarakhand. *Indian J. Weed Sci.* 44(2): 110–114.

Lalfakzuala, R., Kayang, H. and Dkhar, M. S. 2006. Effect of fertilizers on soil microbial biomass under leguminous cultivation. *Asian J. Microbiol. Biotechnol. Env. Sci*. 8(3): 623-631.

Lalitha, M., Thilagam, V. K., Balakrishnan, N. and Mansour, M. 2010. Effect of plastic mulch on soil properties and crop growth - a review. *Agric. Rev.* 31 (2): 145 – 149.

Leela, D. 1987. Weed control by herbicides in knoll khol and radish. *Trop. Pest Manag.* 33(3): 214-219.

Li, S. X., Wang, Z. H., Li, S. Q., Gao, Y. J. and Tian, X. H. 2013. Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dry land areas of China. *Agric. Water Manag.* 116: 39–49.

Liakatas, A. J., Clark, A. and Monteita, J. L. 1986. Measurements of the heat balance under plastic mulches. Part 1. Radiation balance and soil heat flux. *Agric. Meteorol.* 36: 227-239.

Maheswari, M. D., Rao, A. S., Rani, P. P. and Venkateswarlu, B. 2015. Effect of weed management practices on growth and economics of transplanted rice. *Int. J. Pure Appl. Biosci.* 3(3): 113-116.

Majumdar, B., Saha, A. R., Sarkar, S., Maji, B. and Mahapatra, B. S. 2010. Effect of herbicides and fungicides application on fibre yield and nutrient uptake by jute (*Corchorus olitorius*), residual nutrient status and soil quality. *Indian J. Agric. Sci.* 80(10): 878-883.

Malviya, A., Malviya, N., Singh, B. and Singh, A. K. 2012. Integrated Weed Management in Maize (*Zea mays*) under Rainfed Conditions. *Indian J. Dryland Agric. Res. Dev.* 27(1): 70- 73.

Mani, V. S., Mala, M. L., Goutam, K. C. and Bhagavandas. 1973. Losses in crop yield in India due to weed growth. *Pans (C)* 14: 142-158.

Monks, D. W. and Bass, L. 1999. *Weed Control in Vegetable Gardens*. Horticulture Information Leaflet, Series No. 8101, Department of Horticultural Science, North Carolina Cooperative Extension Service, North Carolina, 4p.

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

Muhammed, F. B. U. P., Sindhu, P. V., Gopal, K. S. and Thomas, C. G. 2015. Influence of mulches on rhizosphere microflora, yield and weed competition in okra [*Abelmoschus esculentus* (L.) Moench.]. *J. Tropical Agric.* 53(1): 70-74.

Munn, D. A. 1992. Comparison of shredded news paper and wheat straw as crop mulches. *Hort Technol.* 2(3): 361-366.

Munoz, K., Buchmann, C., Meyer, M., Schmidt-Heydt, M., Steinmetz, Z., Diehl, D., Thiele-Bruhn, S. and Schaumann, G. E. 2017. Physicochemical and microbial soil quality indicators as affected by the agricultural management system in strawberry cultivation using straw or black polyethylene mulching. *Appl. Soil Ecol.* 113: 36–44.

Mupangwa, W., Twomlow, S. and Walker, S. 2013. Cumulative effects of reduced tillage and mulching on soil properties under semi-arid conditions. *J. Arid Environ*. 91: 45-52.

Nandal, T. R., Dhiman, N. K. and Sharma, R. 2005. Integrated weed management in cabbage (*Brassica oleracea* var. *capitata* L.). *Indian J. Weed Sci*. 37(3 & 4): 240-243.

Nandwani, D. 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. Available: http://www.basicresearchjournals.org, Basic Research Journal [07 March 2017].

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

Olabode, O. S., Ogunyemi, S. and Adesina, G. O. 2007. Response of okra (*Abelmoschus esculentus* (L.) Moench.) to weed control by mulching. *J. Food Agric. Environ*. 5(3-4): 324-326.

Panotra, N., Singh, O. P. and Kumar, A. 2012. Effect of chemical and mechanical weed management on yield of french bean–sorghum cropping system. *Indian J. Weed Sci*. 44(3): 163–166.

Parmar, H. N., Polara, N. D. and Viradiya, R. R. 2013. Effect of mulching material on growth, yield and quality of watermelon (*Citrullus lanatus* Thunb.) Cv. Kiran. *Universal J. Agric. Res.* 1(2): 30-37.

Paudel, P., Singh, R. S., Pandey, I. B. and Prasad, S. S. 2017. Effect of different weed management practices on weed dynamic, yield and economics of soybean production. *Azarian J. Agric*. 4(2): 54-59.

Peer, F. A., Hassan, B., Lone, B. A., Qayoom, S., Ahmad, L., Khanday, B. A., Singh, P. and Singh, G. 2013. Effect of weed control methods on yield and yield attributes of soybean. *Afr. J. Agric. Res.* 8(48): 6135-614.

Piao, H. C., Liu, G. S., Wu, Y. Y. and Xu, W. B. 2001. Relationships of soil microbial biomass carbon and organic carbon with environmental parameters in mountainous soils of southwest China. *Biol. Fert. Soils* 33(4): 347–350.

Pikovskaya, R. I. 1948. Mobilization of phosphorous in soil in connection with vital activity of some microbial species. *Microbiologiya* 17: 362-70.

Piper, C. S. 1942. *Soil and plant analysis.* (Asian Reprint, 1996). Hans publishers, Bombay, 368p.

Rahman, H., Ullah, K., Sadiq, M., Zubair, M., Javaria, S., Khan, M. A. and Khattak, A. M. 2011. Relative efficacy of different weed control methods in onion (*Allium cepa* L.) crop. *Pak. J. Weed Sci. Res.* 17(4): 343-350.

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

Rao, V. S. 2000. Principles of weed science (2nd Ed.). Mohan Primlani for Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, pp. 1.

Rattan, R. S., Hundal, I. S., Saini, S. S. and Singh, A. K. 1981. Effect of herbicides on weeds and some horticultural traits in okra [*Abelmoschus esculentus* (L.) Moench.]. *Veg. Sci.* 3(2): 87-91.

Saikia, U. S., Kumar, A., Das, S., Pradhan, R., Goswami, B., Wungleng, V. C., Rajkhowa, D. J. and Ngachan, S. V. 2014. Effect of mulching on microclimate, growth and yield of mustard (*Brassica juncea*) under mid-hill condition of Meghalaya. *J. Agrometeorol.* 16(1): 144-145.

Saini, B., Suneja, S. and Kukreja, K. 2009. Impact of long term use of clodinafop in wheat on soil microbes. *Indian J. Weed Sci.* 41 (1 & 2): 50-53.

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

Sanchez, E., Lamont, Jr. W. J. and Orzolek, M. D. 2008. Newspaper mulches for suppressing weeds for organic high-tunnel cucumber production. *Hort Technol.* 18(1): 154.

Sandhu, K. S., Singh. D., Sandhu, M. S., Gill, B. S. and Singh, J. 2002. Weed management in seed crop of radish. *PAU J. Res.* 39(4): 504-507.

Santos, R. N. V., Rodrigues, A. A. C., Silva, M. R. M., Correa, M. J. P., and Mesquita, M. L. R. 2017. Phytosociology and weed interference in okra under organic cropping system. *Afr. J. Agric. Res.* 12(4): 251-259.

Sathiyamurthy, V. A., Rajashree, V., Shanmugasundaram, T. and Arumugam, T. 2017. Effect of different mulching on weed intensity, yield and economics in chilli (*Capsicum annuum* L.). *Int. J. Curr. Microbiol. Appl. Sci.* 6(3): 609-617.

Schonbeck, M. W. and Evanylo, G. K. 1998. Effects of mulches on soil properties and tomato production I. soil temperature, soil moisture and marketable yield. *J. Sustain. Agric.* 13(1): 55-81.

Sharma, J. C. and Kathiravan, G. 2009. Effect of mulches on soil hydrothermal regimes and growth of plum in mid hill region of Himachal Pradesh. *Indian J. Hortic.* 66(4): 465- 471.

Sharma, K. C. and Sharma, J. J.2000. Weed management in okra under mid-hill conditions of North Western Himalayas. *Indian J. Hill Farming* 13 (1/2): 47-51.

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

Shetty, T. K. P. and Hosmani, M. M. 1977. Crop weed competition in groundnut (*Arachis hypogaea* L.). *Curr. Res*. 6(12): 210-212.

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

Singh, R., Kumar, S., Nangare, D. D. and Meena, M. S. 2009. Drip irrigation and black polyethylene mulch influence on growth, yield and water-use efficiency of tomato. *Afr. J. Agric. Res*. 4(12): 1427-1430.

Singh, S. P., Yadav, R. S. and Sharma, V. 2016. Weed control in cluster bean through post-emergence herbicides. *Indian J. Weed Sci.* 48(2): 202–205

Singh, V. P. and Bhan, V. M. 1999. Herbicidal control of weeds in potato (*Solanum tuberosum* L.) in Vertisol. *Indian J. Weed Sci*. 31: 214-217

Singh, V. P., Lalit, B. and Netrapal, M. 2014. Impact of plastic mulching technology on production economics of off-season vegetables in Uttarakhand hills. *J. Community Mobilization Sustain. Dev.* 9(2): 155-158.

Smith, A. 1931. Effect of paper mulches on soil temperature, soil moisture, and yields of crops. *Hilgardia* 6: 159–201.

Smith, M. A. K., Dabo, S. and Oloyede, K. O. 2009. Influence of pendimethalin-based weed management systems on weed flora composition in Indian spinach (*Basella alba* L.) and okra (*Abelmoschus esculentus* (L.) Moench.) in a humid tropical environment. *J. Anim. Plant Sci.* 4(2): 357 - 362.

Splawski, C. E., Regnier, E. E., Harrison, S. K., Bennett, M. A. and Metzger, J. D. 2016. Weed suppression in pumpkin by mulches composed of organic municipal waste materials. *Hort Sci.* 51(6): 720-726.

Srinivasarao, C. H., Wani, S. P., Venkateswarlu, B., Vittal, K. P. R., Vijayasankarbabu, M., Reddy, T. Y. and Kundu, S. 2007. Organic carbon forms in alfisol profile after twenty years of cropping, fertilization, groundnut shells and farm yard manure addition under arid conditions. Conference paper. Available: http://oar.icrisat.org/id/eprint/3894. [2 July 2017].

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

Sudhakara, K. 2013. Comparison of different mulching materials in teak nursery bed. *Indian For.* 139(11): 1012-1016.

Sultana, R., Pathania, N. K., Angiras, N. N. and Sood, M. 2008. Integrated weed management in brinjal (*Solanum melongena* L.). *Himachal J. Agric. Res.* 34(2): 35- 39.

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.

Thankamani, C. K., Kandiannan, K., Hamza, S. and Saji, K. V. 2016. Effect of mulches on weed suppression and yield of ginger (*Zingiber officinale* Roscoe.). *Sci. Hortic.* 207: 125–130.

Tiwari, K. N., Mal, P. K., Singh, R. M. and Chattopadhyay, A. 1998. Response of okra (*Abelmoschus esculentus* (L.) Moench.) to drip irrigation under mulch and non-mulch conditions. *Agric. Water Manag.* 38: 91-102.

Usman, K., Ahmad, E., Khan, M. U., Ahmad, A., Imdad, A. and Iqbal, J. 2005. Integrated weed management in okra. *Pak. J. Weed Sci. Res.* 11(1-2): 55-60.

Vishnudas, S., Savenije, H. H. G., Van der Zaag, P. and Anil, K. R. 2012. Coir geotextile for slope stabilization and cultivation – A case study in a highland region of Kerala, South India. *Phys. Chem. Earth* 47- 48: 135-138.

Vouzounis, N. A. and Americanos, P. G. 1998. *Control of Orobanche (broomrape) in tomato and eggplant.* Agricultural Research Institute Ministry of Agriculture, Natural Resources and the Environment, Series No. 169, J. G. Cassoulides & Son Ltd, Nicosia, 7p.

Wardle, D. A., Yeates, G. W., Watson, R. N. and Nicholson, K. S. 1993. Response of soil microbial biomass and plant litter decomposition to weed management strategies in maize and asparagus cropping systems. *Soil Biol. Biochem.* 25(7): 857-868.

Watanabe, P. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphate in water and NH_4HCO_3 extracts from soil. *Proc. Soil. Sci. Am.* 29: 677-678.

Waterer, D. R. 2000. Effect of soil mulches and herbicides on production economics of warm season vegetable crops in a cool climate. *Hort Technol.* 10: 154-159.

Wollum, A. G. 1982. *Methods of Soil Analysis.* Madison, Wisconsin, USA, pp.781-801.

Yadav, R. L., Yadav, D. V. and Duttamajumder, S. K. 2008. Rhizospheric environment and crop productivity: a review. *Indian J. Agron.* 53(1): 1-17.

Yaduraju, N. T. 2012. Weed management perspectives for India in the changing agriculture scenario in the country. *Pak. J. Weed Sci. Res.* 18: 703-71.

Yu-zhu, Z., Yang, L., Xiang, Z., Kai-lin, C., Ze-hui, H. and Hong-ke, X. 2011. Effects of mulching mode on canopy physiological, ecological characteristics and yield of upland rice. *Rice Sci.* 18(3): 217–223.

Zahir, Z. A., Arshad, M. and Frankenberger, W. T. 2004. Plant growth promoting rhizobacteria: applications and perspectives in agriculture. *Adv. Agron.* 81: 97-168.

Zhang, P., Wei, T., Jia, Z., Han, Q., Ren, X. and Li, Y. 2014. Effects of straw incorporation on soil organic matter and soil water-stable aggregates content in semiarid regions of Northwest China. *Plos One.* 9(3): 1- 11.

Zribi, W., Aragues, R., Medina, E. and Faci, J. M. 2015. Efficiency of inorganic and organic mulching materials for soil evaporation control. *Soil Tillage Res.* 148: 40 - 45.

Appendices

Appendix 1. Weekly weather data during experimental period

Std. Week No.	Date	Max. temp. (°C)	Min. temp. (°C)	Relative humidity (%)			Wind speed (Km/hr)	Mean Sun shine hours	Rain fall (mm)	Rainy days (No.)	Mean evap. (mm)	Soil temp. (°C) (10 cm depth)
				Morning	Evening	Mean						
12	19/3 – 25/3	35.8	27.3	92	56	74	2.0	7.4	000.0	0	4.3	32.0
13	26/3 – 01/4	36.8	25.5	88	51	70	2.1	8.5	000.0	0	4.5	31.8
14	02/4 – 08/4	36.4	25.8	87	52	69	2.1	8.9	000.0	0	4.8	32.9
15	09/4 – 15/4	35.0	26.3	88	59	74	1.8	7.0	023.6	2	4.0	31.1
16	16/4 – 22/4	35.9	26.4	85	57	71	2.0	6.7	002.2	0	4.6	32.6
17	23/4 – 29/4	36.0	26.6	84	56	70	2.5	8.8	000.0	0	5.1	33.8
18	30/4 – 06/5	36.2	25.9	82	56	69	2.3	9.3	000.0	0	5.3	34.4
19	07/5 – 13/5	36.0	23.9	89	58	74	2.5	7.4	047.2	1	5.0	31.9
20	14/5 – 20/5	32.1	23.5	95	74	84	1.4	2.8	157.9	4	2.4	28.3
21	21/5 – 27/5	33.0	24.6	91	68	79	1.6	5.3	035.9	1	3.2	28.0
22	28/5 – 03/6	31.3	22.6	93	79	86	1.4	3.3	148.4	5	2.4	27.6
23	04/6 – 10/6	29.8	22.9	96	89	93	0.9	1.5	220.6	6	2.2	27.4
24	11/6 – 17/6	30.8	22.0	95	79	87	1.4	2.2	094.6	5	2.4	27.5
25	18/6 – 24/6	29.8	20.7	93	81	87	1.5	2.4	072.7	4	2.1	27.1
26	25/6 – 1/07	28.7	20.9	97	83	90	1.1	0.3	147.4	5	1.8	26.2

MICROSITE VARIATIONS OF OKRA [*Abelmoschus esculentus* (L.) Moench.] UNDER DIFFERENT WEED MANAGEMENT PRACTICES

By

SHAMLA K.

(2015-11-016)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

(Agronomy)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

Department of Agronomy

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2017

141

ABSTRACT

Okra [*Abelmoschus esculentus* (L.) Moench.] is a warm season vegetable crop cultivated mainly for its immature fruits. Weed control is an expensive management practice in okra production which can influence productivity of both crop and soil. Weed management practices can modify the micro environment of crops, the extent depending on the method adopted, environmental conditions, and other management practices. The present study was taken up in the Department of Agronomy, College of Horticulture, Vellanikkara during March to June, 2016 to assess the effect of weed management practices on microsite variations and their consequent effect on growth and yield of okra. The treatments comprised of four different organic mulches (mango leaves, paddy straw, newspaper and coir fibre mat), mulching with black polythene sheet, hand weeding, application of pre emergence herbicide and an unweeded control treatment.

Black polythene mulching positively influenced the yield and yield attributes of okra and resulted in greatest plant height and number of branches. Mulching with black polythene, hand weeding and herbicide treatment reduced the number of days to harvest. Higher number of harvests and number of fruits per plant were obtained with black polythene mulching. This treatment recorded a fruit yield of 14.58 t ha^{-1}, followed by the treatments paddy straw mulching and newspaper mulching (11.16 and 11.01 t ha^{-1}).

Crop uptake of nutrients was higher under black polythene mulch and was lowest in unweeded control. Similarly, except for coir fibre mat mulching, all other treatments with mulching showed higher uptake of nutrients, and consequently, these plants showed higher relative chlorophyll content (SPAD units). Mulching also improved the soil nutrient status as compared to hand weeded, herbicide treated and weedy check plots. Available N and K were higher in mulched plots while available P content was more or less similar in all the plots.

Considerable effect of weed management practices on soil microclimate was noticed. Black polythene sheet recorded higher soil temperature during the entire crop period. Soil temperature in the plots with organic mulches was lower than the plots without mulching. In general, the soil moisture content at different growth stages of the crop was higher in all the treatments with mulching as compared to treatments without mulching.

Higher population of soil microflora was observed with mulching as compared to unmulched plots. Paddy straw improved soil bacterial and fungal populations both at flowering and harvesting, whereas, actinomycetes were higher under black polythene mulch. At flowering, total population of P - solubilsers, nitrogen fixers and antagonists were higher under mulching with paddy straw. At harvest higher microbial biomass carbon was found in black polythene mulched plots, followed by paddy straw.

Higher weed control efficiency (more than 90 %) was observed with black polythene mulching throughout the crop period. Among different organic mulches, newspaper mulch recorded higher weed control efficiency followed by paddy straw mulch. Mulching with coir fibre mat failed to reduce weed growth. Mulching with paddy straw and newspaper recorded lower weed indices than hand weeding and pre emergence application of pendimethalin.

The highest benefit:cost ratio of 3.02 was recorded for black polythene mulching. Newspaper mulching and pre emergence spray of pendimethalin were next with respect to B:C ratio.

Different weed management practices significantly influenced the micro environment of the crop, and influenced the yield and yield parameters of okra as well as the soil quality. Use of either organic (newspaper or paddy straw) or inorganic (polythene) mulches is a better alternative to manual weeding or herbicidal application for effective weed management and for better B:C ratio in okra.