NON-CHEMICAL WEED MANAGEMENT IN CHILLI (*Capsicum annuum* L.)

By

Fasna P.

(2019-11-103)

Department of Agronomy

COLLEGE OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

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COLLEGE OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA

2021

DECLARATION

I hereby declare that this thesis entitled **"Non-chemical weed management in chilli (*Capsicum annuum* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 05-10-2021

FASNA P.

(2019-11-103)

CERTIFICATE

Certified that this thesis entitled **"Non-chemical weed management in chilli (*Capsicum annuum* L.)"** is a bonafide record of research work done independently by **Ms. Fasna P. (2019-11-103)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

5-10-2021

Vellanikkara

Date: 5-10-2021

Dr. Meera V. Menon

(Chairperson, Advisory Committee)

Professor (Agronomy)

Cashew Research Station

Madakkathara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Fasna P. (2019-11-103),** a candidate for the degree of Master of Science in Agriculture with major field in Agronomy, agree that this thesis entitled "**Non-chemical weed management in chilli (*Capsicum annuum* L.)**" may be submitted by **Ms. Fasna P.** in partial fulfillment of the requirement for the degree.

5-10-21

Dr. Meera V. Menon
(Chairperson, Advisory Committee)
Professor (Agronomy)
Cashew Research Station
Madakkathara

5/10/21

Dr. P. Prameela
Professor and Head (Agronomy)
Department of Agronomy
College of Agriculture, Vellanikkara

05.10.21

Dr. P.V. Sindhu
Assistant Professor (Agronomy)
AICRP (MAP & B)
College of Agriculture, Vellanikara

5/10/2021

Dr. P. Anitha
Associate Professor & P.I.
AICRP (Vegetables)
College of Agriculture, Vellanikara

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Fasna

Fasna P.

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Introduction

1. INTRODUCTION

Weeds are a major problem in any crop production system, reducing both the yield and quality of produce. The use of herbicides, in spite of effective and sustained weed control, is not a preferred option at present because of environmental concerns as well as the probability of herbicide residues in the produce. This is particularly true in the case of vegetables, some of which are consumed either partially cooked or raw. Vegetable crops are characterized by a slow initial growth and canopy development which render them susceptible to competition from weeds. Weed control measures should therefore be adopted from sowing or transplanting itself.

Complete removal of weeds is not an objective in organic farming. The major non-chemical weed management methods in such systems include hand weeding, physical and mechanical measures, crop rotation, stale seed beds and the use of plastic and degradable mulches. Non-chemical methods of weed management are of particular relevance in a state like Kerala which promotes organic farming. In the organic production of vegetables, non-chemical weed control could also achieve ecologically sustainable weed management.

Chilli (*Capsicum annuum* L.) is an important solanaceous vegetable crop. In India, it is one of the most valued commercial crops. More than 400 different varieties of chilli are found all over the world. India ranks first in production, consumption and export of chilli in the world. The major chilli growing states in India are Andhra Pradesh, Karnataka, Maharashtra, Odisha, Tamil Nadu, Bihar, Uttar Pradesh and Rajasthan. These states account for nearly 80 per cent area under chilli cultivation in India. Chilli is a popular vegetable among the farmers of Kerala and in view of the growing health consciousness, there is a need for the development of organic cultivation practices for the crop.

Presence of weeds in chilli is one of the reasons for yield reduction. Weeds are highly problematic and they compete with the crop for light, space, water, nutrients and also act as alternate hosts for pests and disease causing pathogens. Weed infestation reduces economic yield in chilli by 60 to 70 per cent (Patel *et al.*, 2004). The critical crop-weed competition period in chilli is 30 to 60 days after transplanting

(Frank *et al.*, 1998) and the presence of weeds during the critical stages of crop-weed competition could reduce the fruit number and fruit weight substantially. So it is very important to control weeds at this time to get profitable yield.

The use of mulches, both organic and inorganic, has been reported to enhance the growth and fruit yield of chilli. In addition to weed control, mulching increases the soil moisture content and effectively controls problems like evaporation loss, nutrient loss, and soil erosion. When organic mulches are decomposed by microbes, they also add nutrients to soil, helping in carbon sequestration. They also improve the physical properties of soil. Identification of an easily available, environment friendly and cost effective mulching material for weed control in chilli is essential to improve the productivity and profitability of the crop. Polythene mulching has achieved great success in improving the yield and quality of several crops including chilli. It is also an option for safe weed control.

Stale seed bed is a good crop husbandry practice in which one to two flushes of weeds are allowed to germinate and are removed before planting of any crop and maintains a weed-free environment in which the crop germinates. Integrating hand weeding with stale seed bed could further enhance the efficiency of the technique.

The experiment entitled "Non-chemical weed management in chilli (*Capsicum annuum* L.)" was performed with the objective of evaluation of non-chemical methods of weed management in chilli.

Review of Literature

2. REVIEW OF LITERATURE

Literature on the diversity of weeds occurring in chilli, critical period of crop-weed competition, effects of weeds on growth and yield and different non-chemical weed control methods like stale seed bed, mulching with organic and inorganic materials *etc* are reviewed in this chapter.

2.1. Dominant weeds in chilli

A wide array of weeds are reported to occur along with the chilli crop. In Kerala, the major weeds in chilli field were *Cynodon dactylon, Cleome viscosa, Cyperus rotundus, Ageratum conyzoides, Eleusine indica, Digitaria ciliaris, Brachiaria distachya* and *Ludwigia parviflora* (KAU, 1992).

According to Hajebi *et al*. (2016), the dominant weeds in chilli field at IARI, New Delhi were *Arachne racemosa, Cyperus rotundus, Dactyloctenium aegyptium, Commelina benghalensis, Digitaria sanguinalis, Echinochloa colona, Trianthema portulacastrum, Digera arvensis, Phyllanthus niruri, Convolvulus arvensis* and *Parthenium hysterophorus.*

Chopra and Chopra (2004) observed that *Cyperus rotundus, Cenchrus ciliaris, Eleusine indica, Trianthema monogyna, Echinochloa colona, Tribulus terrestris, Parthenium hysterophorus* and *Euphorbia hirta* were the major weeds in chilli fields in Haryana.

Aguilar-acosta (1975) claimed that the prominent weeds in chilli varieties of Zacatecas region of Mexico were *Amaranthus palmeri*, *Galinsoga parviflora, Bidens odorata*, *Helianthus petiolaris, Simsia amplexicaulis, Eragrostis diffusa, Chenopodium album* and other minor weeds. He also added that *Bidens odorata* was the major weed species there, affecting 36-40 per cent of fields.

Daramola *et al.* (2021) reported that *Boerhavia diffusa, Commelina benghalensis, Euphorbia heterophylla*, *Gomphrena celosioides, Spigelia anthelmia, Tridax procumbens*, *Chromolaena odorata, Talinum triangulare, Digitaria* *horizontalis, Panicum maximum, Axonopus compressus, Eleusine indica, Rottboellia cochinchinensis, Cynodon dactylon, Cyperus rotundus* and *Cyperus esculentus* were the prominent weeds in chilli in Abeokuta region of Nigeria.

Mari *et al.* (2020) stated that in Spain, the dominant weeds in chilli were *Portulaca oleracea, Amaranthus retroflexus, Echinochloa colona, Setaria verticillata, Cyperus rotundus, Capsella bursapastoris* and *Malva sylvestris.*

Bottenberg *et al*. (1997) observed that *Amaranthus retroflexus* and *Portulaca oleracea* were the dominant weeds in vegetable production farms of mid-western United States. Chandran and Nelson (2018) stated that *Cyperus esculentus, Mollugo verticillata, Solanum ptycanthum, Abutilon theophrasti, Trifolium repens, Acalypha virginica, Amaranthus hybridus, Echinochloa crus-galli, Portulaca oleracea, Panicum dichotomiflorum* and *Chenopodium album* were the important weeds in chilli fields of Morgantown region in U.S.A.

2.2. Critical period of weed competition

The critical period of weed competition was defined by Zimdahl (1993) as the time period after crop emergence when weed competition cause yield reduction and economic loss. Therefore it is very important to control weed infestation during this period. According to Ghosheh *et al.* (1996), the critical stage for weed control was formulated by the intersection of two components: the maximum weed-infested period and minimum weed-free period. Knezevic *et al.* (2002) defined critical period of weed competition as a period during which weeds must be managed to prevent unacceptable yield losses in the crop.

Swanton and Weise (1991) claimed that the critical period of weed competition was very much important for the formation of alternative weed control techniques and integrated weed management programs.

For each crop, the critical stage for weed competition is different. Frank *et al.* (1988) stated that in chilli, 30-60 days after transplanting was the critical period in which weed competition cause yield reduction. The mean weed infestation period needed for a 10 per cent reduction in fruit weight and fruit number in bell pepper, was

38.5 days (Frank *et al*., 1992).

Woolley *et al*. (1993) stated that, the critical period of weed competition might differ depending upon weed pressure levels and crop cultivars. According to Ghosheh *et al*. (1996), more competitive weeds had long critical periods.

2.3. Effects of weeds on growth and yield of crop

Weeds are highly problematic and they compete with the crop for light, space, water and nutrients. The yield and growth of crops are affected by weed infestation. Mennan *et al.* (2020) concluded that, the yield of vegetables might be reduced by 45-95 per cent due to weed competition.

Frank *et al*. (1992) reported that the presence of weeds during the critical stages of crop-weed competition could reduce the fruit weight and fruit number in bell pepper. Weed infestation reduced economic yield in chilli by 60 to 70 per cent (Patel *et al.*, 2004).

Amador-Ramirez *et al*. (2007) stated that, weed infestation caused reduction in the plant height, internode length and stem diameter of chilli whereas these were higher under weed-free conditions. Hajebi *et al*. (2016) reported that the chilli yield and fruit length were significantly reduced due to the presence of weeds whereas the weed-free plots had the highest yield and fruit length. As per Mari *et al.* (2020), the yield of chilli was too low when weed infestation was high.

Adigun (2018) concluded that, in chilli, the weed infestation resulted in 81-90 percent yield reduction. Prakash *et al.* (2003) claimed that weed infestation in chilli resulted in reduction in the yield up to 78 per cent. Presence of weeds in chilli caused reduction in plant dry weight and plant height (Hajebi *et al.*, 2016).

Weed interference in chilli caused significant reduction in growth and yield parameters. Morales-Payan *et al*. (1997) stated that, the fruit yield was reduced up to 44 percent in chilli by the presence of weeds such as purple nutsedge (*Cyperus rotundus* L.). Khokhar *et al*. (2006) observed that the chilli fruit yield reduction was 30.1 and 46.4 per cent due to weed-crop competition. Daramola *et al*. (2021) reported that the number of branches, leaves, fruits and fruit yield in chilli were significantly reduced due to crop- weed competition.

Norsworthy *et al.* (2007) reported that, the weed palmer amaranth (*Amaranthus palmeri*) infestation caused reduction in fruit number of chilli by 94 per cent.

According to Amador-Ramirez (2002), five per cent yield loss was observed in chilli when weed interference occurred between 0.7 and 3.2 weeks after transplanting (WAT). They also added that the yield loss in chilli increased from 2.5 to 10 percent when the field was infested with weeds during the critical period of weed competition. They suggested that, a weed-free period of 12.2 weeks was needed in order to avoid a yield loss of more than 5 per cent in chilli.

Due to weed interference, the yield and leaf area index of legumes like soya bean and Bengal gram was found to be reduced significantly (Chokar and Balyan, 1999; Mohammadi *et al.*, 2004). Stagnari and Pisante (2011) reported that in French bean (*Phaseolus vulgaris*), the leaf area index (LAI) was found sensitive to interference by weeds and decreased with prolonged delays in weed removal.

There are several factors that affect the per cent of yield reduction in vegetables like: the densities of weeds and plants, the competitiveness of the crop with the weeds and time of weed establishment and the duration of competition (Weiner, 1982). Mennan *et al.* (2020) claimed that due to weed-vegetable competition, the yield of vegetables might be decreased by 45-95 per cent.

2.4. Non-chemical weed control methods

The non-chemical methods for controlling weeds are gaining popularity among farmers now a days. This is mainly due to the problems created by chemical herbicides such as environmental pollution, herbicide residue and development of herbicide resistant weeds. Kropff and Walter (2000) reported that the overuse of chemical herbicides resulted in environmental issues because herbicides had negative effects on non-target organisms, could cause pollution to food and ground water with their residues, and result in mammalian toxicity.

Increasing interest in farmers towards organic farming is another reason. Organic products are gaining more acceptance among consumers and hence farmers could increase their profitability by cultivating crops organically. Mennan *et al*. (2020) reported that for the organic production of vegetables, non-chemical weed control was very important and it could also achieve ecologically sustainable weed management.

Melander *et al.* (2005) stated that the use of non-chemical weed control methods in minor crops were important because of the scarce availability of chemicals. Mennan *et al.* (2020) reported that non-chemical weed control was desired in vegetables because there were several chances of contamination of vegetables by herbicide residue compared to cereals or pulse crops.

Senthilkumar *et al.* (2019) listed the reasons for the growing need for non-chemical weed management tools, as: developing consumer concern about herbicide and other pesticide residues, herbicide resistance in weeds, reduction in number of herbicides due to their withdrawal by regulators and growth of organic agriculture which excluded the use of chemicals as inputs into farming systems.

According to Bond *et al.* (2003), non-chemical weed control methods could be classified as direct weed control and indirect weed control methods. The direct weed control methods included physical methods (mechanical weed control with hand tools, harrows, tractor hoes, brush weeders, mowers, cutters and strimmers), pneumatic weed control, thermal weed control (flame weeding, infrared radiation, freezing, steaming, direct heat, electrocution, microwaves, electrostatic fields, irradiation, lasers, ultraviolet light, and solarization), and mulching (living mulches, particle mulches and sheeted mulches)] and biological weed control (classical biological control, inundative biological control, conservative biological control, broad-spectrum biological control, allelopathy and biodynamics). The indirect weed control included the cultural methods of weed control such as tillage, stale seed bed, inter cropping, cover cropping, fallowing etc.

Cover crops can be used effectively to control weeds. Living mulch, catch crops, smother crops and green manures are the synonyms of cover crops.

Competition and allelopathy were the mechanisms by which cover crops reduced weed infestation (Creamer *et al.*, 1995). Samarajeewa *et al.* (2006) stated that in order to control weeds in crops, cover crops could act as an alternative to tillage practices.

Intercropping is an effective cultural practice to reduce weed growth. Weerarathne *et al.* (2016) claimed that when spatial and temporal compatibility of intercrop combinations were achieved, intercropping could be adopted to manage weeds.

Caldwell and Mohler (2001) observed that in vegetable cropping systems, stale seed bed practice might improve weed control and could reduce herbicide use in integrated weed management programs.

The practice of mulching reduced weed seed germination, weed growth and resulted in overall reduction in weed infestation (Zaag *et al*., 1986). Depending upon the environmental conditions, mulch properties and management practices, mulches could modify the micro climate surrounding the crop (Munn, 1992). Both organic and inorganic mulches could be used effectively for weed control in various crops.

Basavaraja and Nanjappa (1999) claimed that the weed population in chilli-maize cropping system was reduced by practicing soil solarization. Reddy *et al*. (1998) stated that broad leaved weeds could be effectively controlled by soil solarization.

Review of literature on the non- chemical methods stale seed bed and mulching, which are pertinent to the present study, is as follows:

2.4.1. Stale seed bed

Heatherly *et al.* (1992) defined stale seed bed as a seed bed prepared several days, weeks or months before sowing or planting a crop. Saikia *et al*. (2013) reported that stale seed bed was a good crop husbandry practice in which one to two flushes of weeds were allowed to germinate and destroyed before planting any crop. The newly emerged weed seedlings were removed either by hoeing or by applying a non-selective, non-residual herbicide on the prepared seed bed. The weed-free environment in which the crop germinated was the advantage of stale seed bed (Saikia *et al*., 2013).

Caldwell and Mohler (2001) stated that stale seed bed followed by flaming or glyphosate applicaton significantly reduced the density and biomass of weeds such as common purslane (*Portulaca oleracea*) and common chickweed (*Stellaria media*). They also concluded that in vegetable cropping systems, stale seed bed practice might improve weed control and could reduce herbicide use in integrated weed management programs. Melander *et al.* (2005) and Rasmussen *et al.* (2011) stated that, an earlier seed bed preparation combined with irrigation stimulated the germination of certain weed species in the top 40-60 mm soil layer. The emerged weeds could be removed by slight hoeing or flaming.

Standifer *et al.* (1984) reported that the viability of weeds like *Digitaria sanguinalis* and *Cypreus* spp were reduced in the upper 2 cm of soil in lima bean field, and the count of viable *Poa annua* in the upper 2 cm and *Eleusine indica* in uppermost 1 cm soil were significantly reduced due to the adoption of stale seed bed technique. A field experiment was carried out by Gopinath *et al*. (2009) in garden pea to evaluate the effect of stale seed bed, hand weeding, hoeing and mulching and they concluded that stale seed bed coupled with hand weeding, and hand weeding at 30 and 60 DAS, were the best for controlling weeds. Saikia *et al.* (2013) claimed that in black gram, techniques like stale seed bed could be practiced to reduce the cost of cultivation and for organic production of the crop.

In organic cultivation of carrot (Peruzzi *et al*., 2005, Tei *et al*., 2002) and chilli (Pannacci *et al*., 2015), stale seed bed was found effective. Krishna *et al.* (2017) studied the impact of various weed management practices in okra and concluded that stale seed bed technique with 25 per cent reduced spacing was good in controlling broad spectrum weeds and recorded highest yield and economic returns.

Venkatakrishnan (1997) stated that in sesame cultivation, stale seed bed which was prepared a month before sowing significantly reduced the broad leaved weeds, grasses and sedges compared to conventional preparation of seed bed. Arora and Tomar (2012) reported that in ground nut, the highest 100-kernel weight, number of branches per plant and pods per plant and were recorded in stale seed bed, which was followed by soil solarisation. They also added that the highest pod and haulm yields were recorded in stale seed bed, which was followed by soil solarisation.

Stale seed bed technique was found successful when majority of the non-dormant weed seeds were in the top six cm of the soil (Sanbagavalli, 2001). Because of the low seed dormancy and inability to germinate from a depth greater than one cm, weeds like *Cyperus iria, Cyperus difformis, Fimbristylis miliacea, Leptochloa chinensis,* and *Eclipta prostrata* were relatively more susceptible to the stale seed bed technique (Chauhan and Johnson, 2009).

Senthilkumar *et al.* (2019) reported that in order to reduce labour and cost of weed management, stale seed bed could be opted.

Leblanc and Cloutier (1996) reported that in maize cultivation, stale seed bed was effective in decreasing the density of annual weeds.

2.4.2. Mulching

Solaiappan *et al.* (1999) defined mulching as covering the soil surface with plastics, organic and non-organic materials in order to decrease water loss and to reduce fluctuations in soil temperature. In states like Kerala, mulching is a very important activity in vegetable cultivation. Chalker-Scott (2007) defined mulches as materials that were applied to soil surface and that were incorporated into the soil profile. Mulching materials covered the soil surface, increased water infiltration into the soil, reduced the effect of soil erosion and retarded surface runoff (Adekalu *et al.*, 2007).

According to Chandran and Nelson (2018), a mulch is any protective material such as crop residue, straw, leaves, paper, plastic film, gravel or dry soil which when placed on the soil surface controlled weed growth by preventing light penetration.

The practice of mulching reduced weed seed germination, weed growth and resulted in overall reduction in weed infestation (Zaag *et al*., 1986). Problems like evaporation loss, nutrient loss, soil erosion and weed infestation could be effectively controlled by using mulches (Derwerken and Wilcox, 1988). Depending upon the environmental conditions, mulch properties and management practices, mulches could modify the microclimate surrounding the crop (Munn, 1992). According to DenHollander *et al.* (2007), the development and germination of weeds could be lowered by mulches through mechanical effects. Both organic and inorganic mulches had effects on micro climates, agronomic productivity and yield of crops (Atreya *et al.*, 2008).

Depending on the characteristics of mulching materials, they could suppress weeds, diseases, insects and pests (Moore *et al.*, 1994). The physical barrier of mulch reduced the germination and nourishment of many species of weeds. Weed growth was more likely in organic mulches than inorganic mulches (Relf and Appleton, 2009).

Ashrafuzzaman *et al.* (2011) studied the effects of plastic mulch on growth and yield of chilli (*Capsicum annuum*), and found that black plastic mulch was good in controlling weeds in chilli. Das *et al.* (2017) claimed that the yield of chilli and French bean was high when geotextile jute mulch was used. Vibhute and Singh (2019) reported that the use of organic and inorganic mulch was effective in improving growth and yield of chilli (*Capsicum annuum* L.).

According to Kader (2016) the mulching materials were broadly classified into three main categories: organic materials [straw (rice, wheat, maize), dry clips (grass, weeds, wood, bark), chopped leaves, cassava bagasse, geo-textile materials, husks (rice, coconut, maize stalk), small branches of trees, paper (newspaper, kraft paper), animal wastes (cow dung, manure) and cover crops (weeds, fodder)], inorganic materials [biennial colour plastic film, black plastic film, silver plastic film, transparent plastic film, plastic film with holes, biodegradable plastic film, photodegradable plastic film and sprayable polymer film] and special type materials [gravel, concrete and tephra mulch].

2.4.3. Organic mulches

Ji and Unger (2001) reported that the most common organic mulching material was cereal straw in almost all climatic areas and it had several advantages after applying in the field and was good for soil moisture storage.

Olasantan (2000) claimed that with the application of *Glyricidia sepium* prunings as mulch, the weed dry weight in tomato and okra decreased significantly by 60-66 per cent and 70-75 per cent respectively. In order to control weeds and to increase yields in chilli and tomato, hairy vetch mulches combined with reduced mechanical weed control could be adopted (Isik *et al*., 2009, Campiglia *et al*., 2010).

Das *et al.* (2017) conducted an experiment on the effect of geotextile jute mulches in French bean-chilli cropping system and arrived at a conclusion that the available N, P, K and organic carbon pool had increased in treatments with geotextile mulching of 500 gsm. They also concluded that higher yields were obtained for both French bean and chilli in that treatment. They also recorded higher weed control efficiency (94.05 %) and zero weed index from geotextile mulching of 500 gsm.

Paddy straw mulching along with light and frequent irrigation in sandy loam soil reduced the temperature by 2 to 7°C and increased the okra and tomato yield by 400 and 100 per cent respectively (Gupta and Gupta, 1987). Straw mulch added organic matter to the soil, reduced bulk density and mechanical impedance and increased infiltration (Tindall *et al.*, 1991). Goswami and Saha (2006) claimed that organic mulches were suited for temperature regulation, soil moisture conservation and weed control.

Mulching with newspaper is a low cost alternative to paddy straw and polythene sheets. When tomato plants were grown with newspaper mulch, the yield was high on comparing with bare field (Grassbaugh *et al.*, 2004). Cirujeda *et al.* (2012) observed that biodegradable paper mulching materials were effective in controlling purple nutsedge (*Cyperus rotundus*) in chilli fields.

Vibhute and Singh (2019) reported that the use of organic and inorganic mulch was effective in enhancing growth and yield of chilli (*Capsicum annuum* L.). They also added that through mulching, weed competition, soil compaction and soil erosion could be reduced. Mulching also helped to maintain a uniform root environment and conserve soil moisture. It enhanced the microbial activity by improving the properties of soil, it reduced the requirement of nitrogen fertilizer, warmed the soil, controlled weed growth and caused increase in yield of crops.

Masiunas (1998) stated that in vegetable production, the use of pesticides and fertilizers could be reduced by using living and cover crop mulches. Living mulches were grasses, legumes or *Brassica* species that grew together with the vegetable crop. He also observed that pest populations in vegetable field could be reduced by living mulches but they were difficult to manage because of the competition with the crop. Cover crop mulches were commonly small grains or legumes which were killed prior to planting of the vegetable crop (Masiunas, 1998). Cover crop mulches reduced the weed and insect populations by releasing certain allelochemicals and they also modified the microclimate.

In case of organic mulches, thickness was an important factor in determining its effectiveness. (Teasdale and Mohler, 2000). Mulching with organic materials could improve physical, chemical and biological properties of soil (Grassbaugh *et al*., 2004; Wang *et al.*, 2009).

According to Srivastava and Singh (1992), when rape straw and sugarcane leaves were used as mulches in tomato and okra, the yields were found to be increased. Wheat and oats straw could be used as mulches in cucurbits for controlling weeds and improving the crop quality (Sherriff *et al.*, 1998). Monks and Bass (2000) stated that germination of weeds like *Chenopodium album*, *Amaranthus retroflexus*, and *Portulaca oleracea* were inhibited by rye straw mulch. Jelonkiewicz and Borowy (2005) observed 76-100 per cent weed control in vegetables when rye residue mulch was used at a thickness of 3-4 cm.

2.4.4. Polythene mulches

Ashrafuzzaman *et al.* (2011) studied the effects of plastic mulch on growth and yield of chilli (*Capsicum annuum*) and found that, transparent and blue plastic mulches encouraged weed population which were suppressed under black plastic mulch. Higher soil temperature and soil moisture were generated under different mulches. Plants on black plastic mulch had the maximum number of fruits and highest yield. Mulching significantly increased the number of fruits per plant and reduced the percentage fruit abortion compared to unmulching control (Ravinder *et al.*, 1997 and Ashrafuzzaman *et al*., 2011).

A field experiment was conducted by Narayan *et al.* (2017) to study the effect of mulching on growth and yield of chilli. Three levels of paddy straw (6.0 t/ha, 9.0 t/ha and 12.0 t/ha) and three forms of polythene mulch (30 micron) as black double coated, white double coated and black single coated were used. Observations on weeds, yield parameters of chilli and soil properties were taken. Black polythene mulch (double coated) had the highest soil moisture retention (16.74 %), lowest weed density (74.81 g/plot dry weight), highest number of fruits per plant (140/plant), maximum fruit weight (9.99 g) and total fruit yield (463.08 q/ha). Under temperate conditions, mulching with double coated black polythene recorded highest B:C ratio of 3.49 and therefore it could be used as a viable tool to increase yield in chilli.

Chandran and Nelson (2018) conducted a field experiment to evaluate certain physical methods of weed management in organically-grown chilli under irrigated conditions. Hand weeding, plastic mulch, and straw mulch were evaluated for weed control, growth attributes, and yield of chilli. They concluded that hand weeding and plastic mulching treatments provided at least 250 per cent higher chilli yields than plots that received straw mulch. In these treatments, approximately 20-fold yield increase was noted compared to untreated plots. Weed count was also lower in plots with plastic mulch or hand weeding.

Bhardwaj *et al*. (2018) reported that when chilli was grown on raised bed with 100 micron Linear Low Density Poly Ethylene plastic mulch and drip irrigation, significantly higher seedling survival at 15 and 30 DAT (95.16 % and 91.70 %), highest plant height (47.10 cm at 45 DAT and 54.60 cm at harvest), maximum number of branches per plant (14.93), maximum stem girth (2.32 cm), number of roots per plant (138.5), highest fruit set (38.47 per cent), fruit length (12.56 cm), fruit diameter (3.52 cm) and fresh fruit weight (8.42 g) were recorded.

A field experiment was carried out by Vibhute and Singh (2019) to study the effect of different mulches and drip fertigation on growth and yield of chilli. The experiment was laid out with two mulching treatments, 25 and 50 micron black plastic mulch and three fertigation levels, 75, 100 and 125 percent of recommended dose of fertilizer (RDF). Among the various treatments, black polythene mulch (25 micron) and drip fertigation with 125 % RDF recorded maximum plant height and number of primary branches (85.11 cm and 8.10 respectively). Maximum yield of chilli (465.12 q/ha) was observed in black polythene mulch (25 micron) and fertigation with 125 per cent RDF which was followed by black polythene mulch (50 micron) and fertigation with 125 per cent RDF (440.44 q/ha). Moisture conservation, high yield, maximum water and fertilizer use efficiency and higher weed control were the benefits of black plastic mulch with drip fertigation.

Albregts and Howard (1973) stated that when chilli was grown in black paper which was coated with a thin layer of polythene mulch, early growth and high yield were recorded. Wang *et al*. (1998) claimed that in chilli field, all types of polythene mulch increased the soil moisture per cent compared to control.

A study on weed control efficacy, growth and yield of potato (*Solanum tuberosum* L.) as affected by alternative weed control methods was conducted by Shehata *et al*. (2019). The treatments were blue, white and black plastic mulches, biodegradable (plastic and rice straw) mulches, infrared transmitting (IRT) plastic mulch and natural herbicides (acetic acid (AA) 20%, citric acid (CA) 10% and AA 10% + CA 5%) in comparison with hoeing, metribuzin herbicide and unweeded check. At 90 days after planting, black and biodegradable plastic mulches recorded weed control efficiency (WCE) significantly higher than hoeing treatment with values of 98.10 per cent and 93.80 per cent respectively, compared with 83.10 per cent for hoeing.

Mendonc *et al.* (2021) claimed that soil mulching materials had distinct effects on development and yield of tomato, which was dependent on the growing season.

The chlorophyll content of crops was found to be increased when straw and plastic mulches were used (Yang *et al*., 2006). According to Zribi *et al.* (2015), the water use efficiency was increased by 20 to 60 per cent by using plastic mulching.

According to Chakraborty and Sadhu (1994), plastic mulches could conserve more soil moisture than organic mulches. Pannacci *et al*. (2017) claimed that because of the effectiveness of polythene mulch in weeding, it could be widely used in horticultural crops, and polythene mulching caused an increase in soil temperature while comparing to transparent mulches.

Bond and Grundy (2001) reported that as the perennial weeds pierced plastic mulches, polythene mulches were more effective against annual weeds than perennial weeds. Dittmar *et al.* (2017) observed that weed germination was inhibited in plastic mulch by preventing light penetration into the soil surface. White plastic allowed light penetration into soil whereas black plastic mulch prevented light penetration. They also added that yellow and purple nutsedge could pierce through the plastic mulch and hence plastic mulches were not effective for these weeds.

Lament (1993) listed the advantages and disadvantages of using plastic mulches in vegetable production, the advantages were earlier and higher yield of crops, reduction in rate of evaporation, reduction in weed emergence, low fertilizer leaching, reduction in soil compaction, cleaner product, low levels of gas exchange and aids in fumigation and soil solarization. Disadvantages were removal and disposal of plastic mulches, environmental issues and high initial cost.

Materials and Methods

3. MATERIALS AND METHODS

A field experiment on "Non-chemical weed management in chilli (*Capsicum annuum* L.)" was conducted from June 2020 to September 2020 (Kharif season) at the Agronomy Farm, College of Agriculture, Vellanikkara. The materials adopted and methods followed for conducting the field experiment are described in this chapter.

3.1. Details of area under study

3.1.1. Experimental location

The field experiment was conducted at Agronomy Farm, College of Agriculture, Vellanikkara, located at 10° 31′ N latitude and 76° 13′ E longitude, at an altitude of 40.3 m above mean sea level.

3.1.2. Climate

The experimental site experiences warm humid climate and the important meteorological observations recorded during the period of experiment are shown in Appendix.

3.1.3. Soil characters

The experiment was carried out in acidic soil with sandy loam texture. The pre-experimental status of the soil is presented in Table 3.1.

3.1.4. Variety

Anugraha, a high yielding, early maturing and bacterial wilt resistant chilli variety was used for the study. It is a variety developed by the Kerala Agricultural University, suitable for cultivation in Kerala. The plants are of medium stature with long green medium pungent fruits with an average yield of 27 t/ha and average fruit weight of 3.6 g.

Table 3.1. Pre-experimental soil status of the experimental field

Particulars	Value	Method used
Chemical composition		
pH	5.20	1: 2.5 (soil: water) suspension- pH meter (Jackson, 1958)
EC	0.80	1: 2.5 (soil: water) suspension- Electrical Conductivity meter (Jackson, 1958)
Organic carbon (%)	1.36	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	189.00	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	51.23	Ascorbic acid reduced molybdo-phosphoric blue colour method (Watanabe and Olsen, 1965)
Available K (kg/ha)	437.80	Neutral Normal NH4OAC extract method using flame photometer (Jackson, 1958)

3.1.5. Season

The season of cropping was Kharif. During the month of May 2020, nurserywas raised and seedlings were transplanted in the main field during June 2020.

3.1.6. Cropping history of the experimental site

During the previous year tubers were cultivated in the experimental field.

3.2. Experimental details

3.2.1. Treatments

The field experiment was conducted at Agronomy Farm, College of Agriculture, Vellanikkara during Kharif (2020). The design of the experiment was Completely Randomized Block Design (RBD) with seven treatments and three replications. The plot size was 3.6 m x 2.25 m.

Table 3.2. Treatments

T_1	Stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by two hand weedings at 30 DAT and 60 DAT
T_2	Stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by a hand weeding at 45 DAT
T_3	Black polythene mulch (30 microns)
T_4	Straw mulch at 7.5 t/ha applied twice, at planting and one month after planting
T_5	Straw mulch at 7.5 t/ha applied twice, at planting and one month after planting, followed by one hand weeding at 60 DAT
T_6	Hand weeding at 30 and 60 DAT
T_7	Unweeded control

3.2.2. Lay out of the experiment

R_1T_2	**R_1T_7**	**R_1T_1**	**R_1T_5**	**R_1T_6**	**R_1T_3**	**R_1T_4**
R_2T_3	**R_2T_6**	**R_2T_7**	**R_2T_4**	**R_2T_1**	**R_2T_2**	**R_2T_5**
R_3T_4	**R_3T_5**	**R_3T_1**	**R_3T_2**	**R_3T_3**	**R_3T_7**	**R_3T_6**

N

3.2.3. Cultural practices

Various cultural operations practiced during the experiment are detailed below.

Land preparation

The field was cleared by removing the weeds and previous crop residues in the beginning of May 2020. Then the land was ploughed with a tractor and then leveled. The experiment was laid out and beds of 3.6 m length, 2.25 m width and 30 cm height were formed. In order to reduce the acidity of soil, lime was applied at 250 kg/ha two weeks before transplanting of seedlings. FYM was applied one week before transplanting at the rate of 20 tonnes/ha.

Stale seed bed

There were two treatments with stale seed bed technique. Here, the beds were prepared two weeks before chilli seedling transplanting, and weeds were allowed to germinate. After 14 days, all the emerged weeds were removed by shallow digging and hoeing.

Mulching

Mulching was done in three treatments, one with black polythene mulch and the other two with straw mulch. Black polythene of 30 microns thickness was used for mulching with holes of approximately 5 cm diameter at 45cm x 45 cm spacing to facilitate transplanting of chilli seedlings. Paddy straw at 7.5 t/ha was mulched in the respective treatments in two applications, half at the time of planting and half one month after planting.

Transplanting

One month old chilli seedlings were transplanted on 9th June 2020 in the main field at a spacing of 45 cm x 45 cm and the transplanted seedlings were given shade with mango twigs. Gap filling was done one week after transplanting in order to maintain the plant population.

Fertilizer application

The recommended dose of fertilizer for chilli is 75:40:25 kg N, P_2O_5 and K_2O per hectare. Urea, rajphos and muriate of potash were supplied such that half the nitrogen, the entire phosphorus and half the potash were applied basally, one fourth of nitrogen and half of potash were applied at 30 DAT and the remaining one fourth nitrogen was provided at 60 DAT.

Hand weeding

Hand weeding was done in three treatments. In T_2 the stale seed bed technique was followed by a hand weeding at 45 DAT, and in T_5, straw mulching was followed by a hand weeding at 60 DAT. Hand weeding was done twice in T_6 (hand weeding treatment) at 30 and 60 DAT, while T_7 was maintained as unweeded control.

Harvesting

Chilli fruits were harvested on attaining maturity and the plot-wise yield was noted in kg/ha. First harvest was done in August and four harvests were done from each plot. However, only three harvests could be made from the unweeded control plot.

Plate 1. Field preparation

Plate 2. Transplanting

Plate 3. Field view at 1 WAT

Plate 4. Experimental field at 30 DAT

Plate 5. Flowering stage

Plate 6. Fruiting stage

Plate 7. Harvesting

Plate 8. Chilli fruits

Plate 9. Polythene mulching

Plate 10. Straw mulching

Plate 11. Straw mulching fb a hand weeding

Plate 12. Hand weeding

Plate 13. Stale seed bed fb 2 hand weeding

Plate 14. Stale seed bed fb a hand weeding

Plate 15. Unweeded control

3.3. Observations on chilli

Growth parameters

a) Height of plant (cm)

Height of five chilli plants from each plot were measured at 30, 60 and 90 DAT. It was measured from the bottom of the plant to the tallest leaf tip, and the mean value was calculated.

b) Number of branches per plant

Total number of branches per plant of five plants from each plot were recorded at 30, 60 and 90 DAT and the mean value was calculated.

c) Leaf area index

It is the ratio of leaf area to land area. Leaf area was calculated using factor method. Total number of leaves per plant of five plants per plot was counted and the mean value was found. Ten leaves were selected from each plot and their length and breadth were measured. Leaf area was calculated as per the formula given by Kvet and Marshall (1971).

Leaf area per plant = length x breadth x factor (0.70) x total number of leaves per plant

Leaf area index = leaf area per plant/ spacing

d) Total chlorophyll content (mg/g)

Leaf samples from each treatment plot were collected and total chlorophyll content was estimated using spectrophotometry which was put forward by Arnon (1949).

Yield parameters

a) Days to first flowering

The average number of days taken to first flowering in each plot was recorded.

b) Number of fruits per plant

The chilli fruits harvested from five observational plants in each treatment plot were counted and the mean values recorded. This was done for all pickings.

c) Fruit length (cm)

Fruit length was measured from point of pedicel attachment to its apex in centimeters. Length of fruits from five plants in each plot were measured and the mean worked out.

d) Fruit girth (cm)

Fruit girth was measured at its maximum width. Fruits from five plants were selected from each treatment plot and girth was measured in centimeters. The mean value was calculated.

e) Average fruit weight (g)

The average weight of a chilli fruit was measured in each treatment by finding the mean weight of fruits from five observational plants in each plot and finally finding the average value.

f) Fruit yield (t/ha)

The yield of chilli fruits obtained at each harvest from each plot was recorded. On the basis of this, fruit yield was calculated in tonnes/ha for each treatment.

g) Number of harvests

The number of pickings of chilli fruits from each plot was recorded.

3.4. Observations on weeds

a) Species-wise weed density

A quadrat of dimensions 0.5 m x 0.5 m (0.25 m^2) was utilized. In each experimental plot, the quadrat was thrown in two random spots. Weeds which were present in the quadrat were uprooted, and classified in to grasses, broad leaved weeds and sedges, and the species were also identified and counted. The species-wise weed density and total weed density were recorded at 30, 60 and90 DAT.

b) Weed dry matter production

The weeds uprooted in each quadrat as detailed above were utilized for assessing dry matter production of weeds. Soil particles adhering to the roots were washed off and the weeds were air dried. They were then placed in brown paper covers and dried in a hot air oven at 70 ± 5˚C to constant weight. The weed dry weight was expressed in g/m².

c) Weed control efficiency (WCE)

WCE was calculated using the formula put forward by Mani and Goutham (1973).

$$\text{WCE} = \frac{\text{WDMP in unweeded control} - \text{WDMP in treatment plot}}{\text{WDMP inunweeded control}} \times 100$$

where, WDMP is the weed dry matter production at 30, 60 and 90 DAT

d) Weed index (WI)

Weed index was calculated using the formula given by Gill andVijayakumar (1969).

$$\text{WI} = \frac{\text{Yield in polythene mulching} - \text{Yield in treatment plot}}{\text{Yield in polythene mulching}} \times 100$$

3.5. Incidence of pests and diseases

The pest and disease infestation at each stage of the crop was monitored and recorded.

3.6. Soil analysis

Representative soil samples were taken from the field before transplanting, at 60 DAT and after final harvest. Five soil samples were collected from each experimental plot at a depth of 15 cm by digging a V shaped hole. The collected soil was mixed well and all the clods were broken. By successive quartering the sample size was reduced to one kg. The soil samples were dried under shade and bagged in clean poly bags and used in the laboratory for further analysis. The procedures followed for analysis are detailed in Table 3.1.

3.7. Economics of cultivation and B:C ratio

The economics of cultivation was assessed for each treatment by analyzing the B:C ratio. The benefit:cost ratio was worked out from the total cost of cultivation and gross returns. Gross returns were estimated from the prevailing market price of chilli during the season.

3.8. Data analysis

The statistical analysis of data was done using the online statistical software WASP 2.0.

Results

4. RESULTS

A field experiment entitled "Non-chemical weed management in chilli (*Capsicum annuum* L.)" was carried out in 2020 (Kharif season) at Agronomy Farm, College of Agriculture, Vellanikkara. The results of the experiment are presented in this chapter.

4.1. Observation on weeds

4.1.1. Predominant weed species observed in the field

Different weed species were found at the experimental field and they were classified into grasses, broad leaved weeds and sedges.

a) Grass weeds

Grass weed species found in the field were *Eleusine indica, Panicum maximum, Echinochloa colona, Eragrostis tenella, Digitaria ciliaris* and *Pennisetum pedicellatum.*

b) Broad leaved weeds

Major broad-leaf weeds found in the field were *Borreria hispida, Cleome burmanii, Cleome monophylla, Lindernia crustacea* and *Scoparia dulcis*. Other minor weeds were *Alternanthera bettzickiana, Ludwigia perennis, Ageratum conyzoides, Phyllanthus amara, Sida acuta, Mollugo disticha* and *Catharanthus pusillus.*

c) Sedges

Cyperus rotundus and *Kyllinga monocephala* were the sedges observed in the experimental field.

4.1.2. Weed density

The weed density (nos./m^2) was observed at three stages, at 30, 60 and 90 days after transplanting (DAT) of chilli seedlings (Tables 4.1, 4.2 and 4.3). At 30 DAT, the broad leaved weeds were *Borreria hispida, Cleome burmanii, Mollugo disticha,* *Phyllanthus amara, Sida acuta, Alternanthera bettzickiana, Ageratum conyzoides, Ludwigia perennis* and *Catharanthus pusillus.* The main grasses present were *Panicum maximum, Eleusine indica, Echinochloa colona, Eragrostis tenella* and *Digitaria ciliaris*. The predominant sedge was *Cyperus rotundus*. The density of broad leaved weeds was significantly lower (2.67 nos./m²) when black polythene sheet was applied as mulch. This was followed by straw mulching, both when done alone (34.00 nos./m²) and when followed by one hand weeding at 60 DAT (36.67 nos./m²). The treatment stale seed bed followed by both two hand weedings and one hand weeding recorded values significantly lower than straw mulching when done without or with subsequent hand weeding (95.33 and 108.00 nos./m² respectively), but were on par with each other. Hand weeding treatment and unweeded control, at par with each other, were not effective in controlling weeds and the weed density values recorded were significantly higher. The trend in effect of treatment on density of grasses and sedges was similar to that in broad leaved weeds. However, straw mulching was as good as polythene mulching in controlling sedges and values recorded were on par in these treatments.

When the density of total weeds at 30 DAT was considered, the effect could be summarized as: unweeded control > hand weeding > stale seed bed followed by one hand weeding and two hand weedings > straw mulching without and with subsequent hand weeding > polythene mulching.

Borreria hispida, Cleome burmanii, Cleome monophylla, Lindernia crustacea and *Scoparia dulcis* constituted the major broad leaved weeds in the experimental plots at 60 DAT. Weed density was again lowest in the treatment polythene mulching (1.33 nos./m²). This was followed by stale seed bed technique followed by one hand weeding (16.67 nos./m²). Straw mulching was the next best treatment, while unweeded control registered highest broad leaved weed density (151.33 nos./m²). The major grasses in the field at this stage were *Panicum maximum, Eleusine indica* and *Digitaria ciliaris*. All the weed management practices except unweeded control were seen to be on par. A similar trend was seen in the density of sedges. Considering the total weeds, the effect of polythene mulching was the best, followed by stale seed bed technique followed by one hand weeding, and straw mulching. Stale seed bed technique followed by two hand weedings and hand weeding treatment came next, and were on par with each other. Again, unweeded control had the highest total weed density at this stage.

At 90 DAT, the weed density was lowest in the treatment polythene mulching (1.33 nos./m²) which was followed by straw mulching followed by one hand weeding at 60 DAT (16.00 nos./m²). The important broad leaved weed species found in the experimental plot were *Borreria hispida*, *Lindernia crustacea, Scoparia dulcis, Alternanthera bettzickiana, Ludwigia perennis, Ageratum conyzoides*, *Phyllanthus amara and Sida acuta. Eleusine indica* and *Panicum maximum* were the major grass weeds found. Considering the grass weeds, all the weed management practices were on par, except the unweeded control. In the case of sedges, the trend was the same as that of grass weeds.

After three months of transplanting, the weed density was lowest in black polythene mulch, which was followed by straw mulch followed by one hand weeding. Straw mulching and hand weeding at 30, 60 DAT came next, while the efficiency of stale seed bed technique in controlling weeds was found to be less. The highest number of weeds occurred in the unweeded control.

4.1.3. Weed dry matter production

The effect of different weed management practices on weed dry matter production was observed and recorded at 30, 60 and 90 DAT (Table 4.4). At 30 DAT, the lowest weed dry matter production was observed in the treatment polythene mulching (2.63 g/m²) which was followed by straw mulching (8.33 g/m²). Straw mulching followed by one hand weeding at 60 DAT (9.96 g/m²) was the next best treatment which was followed by stale seed bed followed by two hand weedings at 30 and 60 DAT (27.5 g/m²). The treatments, stale seed bed followed by one hand weeding at 45 DAT and hand weeding at 30 and 60 DAT recorded comparatively higher weed dry matter production (31.97 and 53.13 g/m² respectively). The weed dry matter production was found highest in the unweeded control (64.03 g/m²).

At 60 DAT, polythene mulching again had the least weed dry matter production (7.86 g/m²), which was followed by stale seed bed followed by a hand weeding (36.03 g/m²). The treatments straw mulching alone (144.66 g/m²) and straw mulching followed by one hand weeding at 60 DAT (146.00 g/m²) and hand weeding at 30 and 60 DAT (158.66 g/m²) were on par. Unweeded control had the highest weed dry matter production.

From the data on weed dry matter production at 90 DAT it was seen that polythene mulching was effective in controlling weeds as it had the lowest weed dry matter production (9.46 g/m²). Straw mulching followed by one hand weeding was the next best treatment followed by straw mulching alone. The weed dry matter production at 90 DAT was in the order of unweeded control > stale seed bed followed by a hand weeding > stale seed bed followed by two hand weedings > hand weeding at 30, 60 DAT > straw mulching > straw mulching followed by one hand weeding > polythene mulching.

4.1.4. Weed Control Efficiency

Data on weed control efficiency at 30, 60 and 90 DAT are given in Table 4.5. At 30 DAT, highest weed control efficiency was recorded for polythene mulching (95.89 %). The second best weed management practice with high weed control efficiency was straw mulching (86.99 %), which was followed by straw mulching followed by one hand weeding (84.44 %). Stale seed bed followed by two hand weedings (57.05 %) was the next best treatment, and was followed by stale seed bed followed by one hand weeding. Hand weeding at 30 and 60 DAT was less effective in controlling weeds and had low weed control efficiency than other treatments (17.02 %).

At 60 DAT polythene mulching had the highest weed control efficiency (99.19 %). At this stage, stale seed bed followed by one hand weeding had higher weed control efficiency than straw mulching (96.31 % and 85.20 % respectively). Straw mulching followed by one hand weeding had only slightly lower weed control efficiency than straw mulching alone. The treatments hand weeding twice, and stale seed bed followed by two hand weedings, were not effective methods of weed control.

Considering the weed control efficiency at 90 DAT, polythene mulching was found to be the best in controlling weeds. It had the highest weed control efficiency (98.93 %). It was followed by straw mulching followed by one hand weeding (88.67 %) and straw mulching alone (83.52 %). Hand weeding was the next best treatment. The stale seed bed technique followed by both one and two hand weedings recorded values significantly lower than hand weeding at 30 and 60 DAT. While considering the weed control efficiency, the effect of different treatments at 90 DAT could be summarized as polythene mulching > straw mulching followed by one hand weeding > straw mulching > hand weeding > stale seed bed followed by two hand weedings > stale seed bed followed by a hand weeding > unweeded control.

4.1.5. Weed Index

Polythene mulching was the best weed management practice among the different treatments. Straw mulching both when done alone and when followed by one hand weeding were the next best treatments after polythene mulching and had low weed indices (15.81 % and 18.08 % respectively). Hand weeding was less effective in controlling weeds and had significantly higher weed index than straw mulching (40.43 %). Stale seed bed treatments followed by both two hand weeding and one hand weeding were not effective in controlling weeds and had high weed index than hand weeding (45.07 % and 57.51 % respectively). The unweeded control had the highest weed index (93.55 %).

Treatments	Table 4.1. Species wise weed density (nos./m^2) at 30 DAT as influenced by non-chemical weed management practices									
	Borreria hispida	*Cleome* spp	Other minor BLW	Total BLW	*Panicum maximum*	*Eleusine indica*	Other minor grasses	Total grasses	Total sedges	Total weeds
T_1: SSB fb 2 HW at 30 DAT and 60 DAT	*6.36^{b} (40.67)	6.52^{b} (42.00)	3.62^{cd} (12.67)	9.76^{b} (95.33)	2.02^{bc} (4.67)	1.47^{cd} (2.00)	1.32 (2.00)	2.91^{c} (8.67)	2.16^{c} (5.33)	10.45^{c} (109.33)
T_2: SSB fb 1 HW at 45 DAT	6.48^{b} (42.00)	6.41^{b} (40.67)	5.06^{a} (25.33)	10.38^{b} (108.00)	2.44^{ab} (7.33)	1.65^{bc} (2.67)	0.71 (0.00)	3.06^{bc} (10.00)	2.75^{bc} (7.33)	11.18^{c} (125.33)
T_3: Polythene sheet	1.41^{d} (2.00)	0.99^{d} (0.67)	0.71^{f} (0.00)	1.61^{d} (2.67)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71 (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	1.61^{e} (2.67)
T_4: Straw mulch	3.15^{c} (10.00)	3.98^{c} (15.33)	3.01^{de} (8.67)	5.82^{c} (34.00)	0.99^{cd} (0.67)	0.71^{d} (0.00)	0.71 (0.00)	0.99^{d} (0.67)	0.71^{d} (0.00)	5.88^{d} (34.67)
T_5: Straw mulch fb 1 HW at 60 DAT	3.73^{c} (14.00)	4.14^{c} (16.67)	2.53^{e} (6.00)	6.05^{c} (36.67)	0.99^{cd} (0.67)	0.71^{d} (0.00)	1.65 (2.67)	1.32^{d} (2.00)	0.99^{d} (0.67)	6.27^{d} (39.33)
T_6: HW at 30 and 60 DAT	9.36^{a} (87.33)	10.05^{a} (102.00)	3.86^{bc} (14.67)	14.25^{a} (204.00)	3.11^{ab} (9.67)	2.38^{ab} (5.33)	1.47 (2.00)	4.13^{b} (17.00)	3.48^{ab} (12.00)	15.25^{b} (233.00)
T_7: UWC	9.68^{a} (94.67)	10.59^{a} (112.00)	4.45^{ab} (19.33)	14.82^{a} (220.00)	3.66^{a} (13.33)	3.23^{a} (10.00)	2.08 (4.00)	5.26^{a} (27.33)	4.11^{a} (16.67)	16.24^{a} (264.00)
C D (0.05)	**0.87 (15.00)**	**1.11 (21.16)**	**0.68 (5.61)**	**0.79 (21.21)**	**1.29 (6.25)**	**0.86 (3.09)**	–	**1.10 (6.44)**	**1.16 (6.02)**	**0.82 (21.62)**
S E (m)	**0.28 (4.87)**	**0.36 (6.87)**	**0.22 (1.82)**	**0.26 (6.88)**	**0.42 (2.03)**	**0.28 (1.00)**	–	**0.33 (2.09)**	**0.38 (1.95)**	**0.27 (7.02)**

*$\sqrt{x+0.5}$ transformed values, original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT. SSB- Stale seed bed, HW- Hand weeding, UWC- Unweeded control, BLW- Broad leaved weeds, fb – followed by

Treatments	Table 4.2. Species wise weed density (nos./m^2) at 60 DAT as influenced by non-chemical weed management practices										
	Borreria hispida	*Cleome* spp	*Lindernia crustacea*	Other minor BLW	Total BLW	*Panicum maximum*	*Eleusine indica*	Other minor grasses	Total grasses	Total sedges	Total weeds
T_1: SSB fb 2 HW at 30 DAT and 60 DAT	*3.80^{bc} (14.00)	4.29^{b} (18.00)	5.64^{a} (31.33)	3.71^{b} (13.33)	8.78^{b} (74.67)	0.71^{b} (0.00)	0.99^{b} (0.67)	0.71^{b} (0.00)	0.99^{b} (0.67)	1.17^{b} (1.33)	8.89^{b} (78.66)
T_2: SSB fb 1 HW at 45 DAT	2.41^{d} (5.33)	0.99^{c} (0.67)	2.67^{d} (6.67)	2.08^{c} (4.00)	4.14^{d} (16.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	4.13^{d} (16.67)
T_3: Polythene sheet	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{e} (0.00)	1.29^{d} (1.33)	1.29^{e} (1.33)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	1.29^{e} (1.33)
T_4: Straw mulch	3.63^{c} (12.67)	4.05^{b} (16.00)	3.80^{c} (14.00)	0.71^{d} (0.00)	6.56^{c} (42.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	6.56^{c} (42.67)
T_5: Straw mulch fb 1 HW at 60 DAT	4.05^{b} (16.00)	4.21^{b} (17.33)	3.97^{c} (15.33)	0.71^{d} (0.00)	7.01^{c} (48.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	7.01^{c} (48.67)
T_6: HW at 30 and 60 DAT	4.14^{b} (16.67)	4.22^{b} (17.33)	5.01^{b} (24.67)	3.34^{b} (10.67)	8.35^{b} (69.33)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	8.35^{b} (69.33)
T_7: UWC	8.71^{a} (75.33)	5.96^{a} (35.33)	0.71^{e} (0.00)	6.39^{a} (40.67)	12.31^{a} (151.33)	4.58^{a} (21.33)	2.90^{a} (8.00)	2.86^{a} (12.67)	6.51^{a} (42.00)	3.12^{a} (9.33)	14.24^{a} (202.67)
C D (0.05)	**0.36 (3.17)**	**0.66 (5.73)**	**0.28 (2.15)**	**0.64 (5.63)**	**0.55 (7.95)**	**0.73 (6.76)**	**0.44 (1.65)**	**1.25 (2.80)**	**0.37 (2.69)**	**0.61 (2.28)**	**0.57 (9.45)**
S E (m)	**0.11 (1.03)**	**0.21 (1.86)**	**0.09 (0.69)**	**0.21 (1.83)**	**0.18 (2.58)**	**0.24 (2.19)**	**0.14 (0.54)**	**0.41 (0.91)**	**0.12 (0.87)**	**0.19 (0.74)**	**0.18 (3.07)**

*$\sqrt{x+0.5}$ transformed values, original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT. SSB- Stale seed bed, HW- Hand weeding, UWC- Unweeded control, BLW - Broad leaved weeds, fb – followed by

Treatments	Table 4.3. Species wise weed density (nos./m^2) at 90 DAT as influenced by non-chemical weed management practices										
	Borreria hispida	*Lindernia* spp	*Scoparia dulcis*	Other minor BLW	Total BLW	*Panicum maximum*	*Eleusine indica*	Other minor grasses	Total grasses	Total sedges	Total weeds
T_1: SSB fb 2 HW at 30 DAT and 60 DAT	*2.79^{c} (7.33)	4.60^{ab} (20.67)	2.79^{c} (7.33)	2.79^{c} (7.33)	6.57^{c} (42.67)	0.99^{b} (0.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.99^{b} (0.67)	1.18^{b} (1.33)	6.91^{c} (47.33)
T_2: SSB fb 1 HW at 45 DAT	3.62^{b} (12.67)	4.88^{a} (23.33)	3.53^{b} (12.00)	3.53^{b} (12.00)	7.77^{b} (60.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	1.44^{b} (2.67)	7.95^{b} (62.67)
T_3: Polythene sheet	0.71^{e} (0.00)	1.29^{e} (1.33)	0.71^{e} (0.00)	0.71^{e} (0.00)	1.29^{f} (1.33)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	1.29^{f} (1.33)
T_4: Straw mulch	2.53^{cd} (6.00)	4.05^{c} (16.00)	2.55^{c} (6.00)	2.12^{d} (4.00)	5.75^{d} (32.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	5.75^{d} (32.67)
T_5: Straw mulch fb 1 HW at 60 DAT	1.79^{d} (3.33)	3.23^{d} (10.00)	1.47^{d} (2.00)	0.99^{e} (0.67)	4.01^{e} (16.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	4.02^{e} (16.00)
T_6: HW at 30 and 60 DAT	2.76^{c} (7.33)	4.29^{bc} (18.00)	2.67^{c} (6.67)	2.79^{c} (7.33)	6.31^{cd} (39.33)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	6.31^{cd} (39.33)
T_7: UWC	6.66^{a} (44.00)	0.71^{f} (0.00)	5.01^{a} (24.67)	5.33^{a} (28.00)	9.85^{a} (96.67)	4.37^{a} (18.67)	2.53^{a} (6.00)	3.44^{a} (11.33)	6.04^{a} (36.00)	3.89^{a} (14.67)	12.15^{a} (147.33)
C D (0.05)	**0.77 (4.32)**	**0.48 (2.88)**	**0.61 (3.23)**	**0.50 (3.37)**	**0.74 (9.20)**	**0.37 (1.67)**	**0.26 (1.34)**	**0.12 (0.76)**	**0.34 (0.77)**	**1.06 (3.67)**	**0.81 (9.86)**
S E (m)	**0.25 (1.40)**	**0.16 (0.94)**	**0.19 (1.05)**	**0.16 (1.09)**	**0.24 (2.99)**	**0.12 (0.54)**	**0.08 (0.43)**	**0.04 (0.25)**	**0.00 (0.25)**	**0.34 (1.19)**	**0.26 (3.19)**

*$\sqrt{x+0.5}$ transformed values, original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT. SSB- Stale seed bed, HW- Hand weeding, UWC- Unweeded control, fb- followed by

Table 4.4. Weed dry matter production as influenced by non-chemical weed management practices

Treatments	Weed dry matter production (g/m^2)		
	30 DAT	60 DAT	90 DAT
T_1: Stale seed bed followed by two handweedings at 30 DAT and 60 DAT	*5.24^d (27.50)	15.67^b (245.66)	13.82^c (191.00)
T_2 : Stale seed bed followed by one hand weeding at 45 DAT	5.65^c (31.97)	6.00^d (36.03)	14.71^b (216.53)
T_3: Black polythene mulch	1.62^g (2.63)	2.80^e (7.86)	3.07^g (9.46)
T_4: Straw mulch	2.88^f (8.33)	12.03^c (144.66)	12.08^e (146.00)
T_5 : Straw mulch followed by one handweeding at 60 DAT	3.15^e (9.96)	12.08^c (146.00)	10.01^f (100.33)
T_6: Hand weeding at 30 and 60DAT	7.28^b (53.13)	12.59^c (158.66)	13.28^d (176.33)
T_7: Unweeded control	8.00^a (64.03)	31.24^a (978.00)	29.77^a (886.30)
CD (0.05)	**0.18 (2.23)**	**1.23 (73.72)**	**0.33 (9.20)**
S E (m)	**0.06 (0.72)**	**0.39 (23.92)**	**0.10 (2.99)**

*$\sqrt{x+0.5}$ transformed values, original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

DAT- Days after transplanting

Table 4.5. Weed control efficiency at different stages as influenced by non-chemical weed management practices

Treatments	Weed Control Efficiency (%)		
	30 DAT	60 DAT	90 DAT
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	57.05	74.88	78.44
T_2: Stale seed bed followed by a hand weeding at 45 DAT	50.07	96.31	75.56
T_3: Black polythene mulch	95.89	99.19	98.93
T_4: Straw mulch	86.99	85.20	83.52
T_5: Straw mulch followed by one hand weeding at 60 DAT	84.44	85.07	88.67
T_6: Hand weeding at 30 and 60 DAT	17.02	83.77	80.10
T_7: Unweeded control	0.00	0.00	0.00

DAT- Days after transplanting

Table 4.6. Weed index as influenced by non-chemical weed management practices

Treatments	Weed index (%)
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	45.07
T_2: Stale seed bed followed by a hand weeding at 45 DAT	57.51
T_3: Black polythene mulch	0.00
T_4: Straw mulch	15.81
T_5: Straw mulch followed by one hand weeding at 60 DAT	18.08
T_6: Hand weeding at 30 and 60 DAT	40.43
T_7: Unweeded control	93.55

DAT- Days after transplanting

4.2. Observations on chilli

a) Growth parameters

4.2.1. Height of plant

Plant height (cm) was observed at three different growth stages i.e., 30, 60 and 90 DAT and data are given in Table 4.7. At 30 DAT, the plant height was greater in the treatment polythene mulching (20.33 cm). This was followed by straw mulching, both when followed by one hand weeding (17.57 cm) and when done alone (17.53 cm). The plant height in the treatment hand weeding at 30 and 60 DAT was 15.90 cm, which was the next best treatment. The treatments stale seed bed followed by both two hand weedings and one hand weeding had plant heights which were comparable (15.67 cm and 15.33 cm respectively). The lowest plant height was recorded in unweeded control (12.26 cm).

At 60 DAT, chilli plants with greater height were seen in the polythene mulched plots (57.80 cm). The plant height in the treatments straw mulching (50.93 cm) and straw mulch followed by one hand weeding (51.20 cm) were statistically on par. This was followed by plant height in treatments hand weeding at 30 and 60 DAT (44.06 cm) and stale seed bed followed by two hand weedings (41.83 cm) which were on par. The plant height in stale seed bed followed by one hand weeding (36.30 cm) and unweeded control (33.70 cm) were on par.

At 90 DAT, the plant height was again greater in polythene mulched plots (59.23 cm). This was followed by the treatments straw mulching (52.76 cm) and straw mulching followed by one hand weeding (53.56 cm). Plant height in the treatments hand weeding at 30 and 60 DAT (46.53 cm) and stale seed bed followed by two hand weedings (44.16 cm) were on par. The lowest plant height was recorded in unweeded control (34.73 cm) which was on par with the plant height in the treatment stale seed bed followed by one hand weeding (38.23 cm).

4.2.2. Number of branches per plant

The number of branches per chilli plant was recorded at 30, 60 and 90 DAT and the data are presented in Table 4.8. At 30 DAT, the number of branches was highest in the treatment polythene mulching (4) which was followed by straw mulching when done alone (3) and when followed by one hand weeding (3). The number of branches in the treatment stale seed bed followed by both two hand weedings (2) and one hand weeding (2) and hand weeding at 30 and 60 DAT (2) were on par. No number of branches was recorded in unweeded control.

At 60 DAT, the number of branches in the treatment polythene mulching (5), hand weeding at 30 and 60 DAT (5) and stale seed bed followed by two hand weedings (5) were statistically on par. This was followed by the number of branches in straw mulch when done alone (4) and when followed by one hand weeding (4). The number of branches in the treatment stale seed bed followed by one hand weeding was 3, and the least number of branches per plant was observed in the unweeded control (1).

The number of branches per plant of chilli in polythene mulched plots (5), stale seed bed followed by two hand weedings (5), hand weeding at 30 and 60 DAT (5) was more than the number of branches of chilli in other treatments at 90 DAT. This was followed by the number of branches in straw mulching (4) and straw mulching followed by one hand weeding (4). The number of branches in the treatment stale seed bed followed by one hand weeding was 3, and the unweeded control recorded the least number of branches (1) at 90 DAT.

4.2.3. Leaf Area Index

The leaf area index of chilli was assessed at different stages, i.e., 30, 60 and 90 DAT. At all the three observational stages, the leaf area index of chilli plants in all the treatments were statistically on par except for the unweeded control, which was significantly lower than the other treatments (Table 4.9).

Table 4.7. Plant height of chilli as influenced by non-chemical weed management practices

Treatments	Plant height (cm)		
	30 DAT	60 DAT	90 DAT
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*15.67[c]	41.83[c]	44.16[c]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	15.33[c]	36.30[d]	38.23[d]
T_3: Black polythene mulch	20.33[a]	57.80[a]	59.23[a]
T_4: Straw mulch	17.53[b]	50.93[b]	52.76[b]
T_5: Straw mulch followed by one hand weeding at 60 DAT	17.57[b]	51.20[b]	53.56[b]
T_6: Hand weeding at 30 and 60 DAT	15.90[bc]	44.06[c]	46.53[c]
T_7: Unweeded control	12.26[d]	33.70[d]	34.73[d]
C D (0.05)	**1.73**	**4.79**	**4.48**
S E (m)	**0.56**	**1.55**	**1.45**

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

DAT-Days after transplanting

Table 4.8. Number of branches per plant as influenced by non-chemical weed management practices

Treatments	Number of branches		
	30 DAT	60 DAT	90 DAT
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*2^{b}	5^{a}	5^{ab}
T_2: Stale seed bed followed by a hand weeding at 45 DAT	2^{b}	3^{b}	3^{b}
T_3: Black polythene mulch	4^{a}	5^{a}	5^{a}
T_4: Straw mulch	3^{ab}	4^{ab}	4^{ab}
T_5: Straw mulch followed by one hand weeding at 60 DAT	3^{ab}	4^{ab}	4^{ab}
T_6: Hand weeding at 30 and 60 DAT	2^{b}	5^{a}	5^{ab}
T_7: Unweeded control	--	1^{c}	1^{c}
C D (0.05)	**1.14**	**1.27**	**1.19**
S E (m)	**0.36**	**0.41**	**0.38**

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

DAT-Days after transplanting

Table 4.9. Leaf area index at different stages as influenced by non-chemical weed management practices

Treatments	Leaf Area Index		
	30 DAT	60 DAT	90 DAT
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*0.123[a]	0.706[a]	1.487[a]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	0.122[a]	0.707[a]	1.485[a]
T_3: Black polythene mulch	0.124[a]	0.707[a]	1.485[a]
T_4: Straw mulch	0.124[a]	0.707[a]	1.485[a]
T_5: Straw mulch followed by one hand weeding at 60 DAT	0.124[a]	0.706[a]	1.484[a]
T_6: Hand weeding at 30 and 60 DAT	0.124[a]	0.707[a]	1.483[a]
T_7: Unweeded control	0.109[b]	0.496[b]	0.867[b]
C D (0.05)	**0.004**	**0.006**	**0.056**
S E (m)	**0.001**	**0.001**	**0.018**

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

DAT-Days after transplanting

4.2.4. Total chlorophyll content

The total chlorophyll content (mg/g) in chilli was estimated at 90 DAT. It was noticed that the chlorophyll content in the treatment stale seed bed followed by two hand weedings (1.466 mg/g), stale seed bed followed by one hand weeding (1.467 mg/g), polythene mulching (1.467 mg/g), straw mulching (1.467 mg/g), straw mulching followed by one hand weeding (1.467 mg/g) and hand weeding (1.467 mg/g) were on par, whereas the total chlorophyll content in unweeded control (1.420 mg/g) was lowest (Table 4.10).

b) Yield parameters

4.2.5. Days to first flowering

The number of days for first flower to emerge was recorded and data are given in Table 4.12. It was found that in the treatments polythene mulching and straw mulching, when done alone and when followed by one hand weeding, the number of days to first flowering was the same (39 days). In the treatments hand weeding at 30 and 60 DAT, and stale seed bed followed by both two hand weedings and one hand weeding, 40 days were required for first flower emergence, while for the treatment unweeded control, it took 44 days. Hence, all the weed management practices were on par except for the unweeded control.

4.2.6. Number of fruits per plant

The total number of chilli fruits per plant in each treatment was recorded and tabulated (Table 4.13). The highest number of fruits per plant were observed in the treatment polythene mulching (218) which was followed by straw mulching when done alone and when followed by one hand weeding (182 and 177 respectively). The next best treatments were hand weeding at 30 and 60 DAT (120) and stale seed bed followed by two hand weedings (117), both of which were statistically on par. The number of fruits per plant in stale seed bed followed by one hand weeding was 92, and the unweeded control had the lowest number of fruits (14).

Table 4.10. Total chlorophyll content at 90 DAT as influenced by non-chemical weed management practices

Treatments	Total chlorophyll content (mg/g)
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*1.466[a]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	1.467[a]
T_3: Black polythene mulch	1.467[a]
T_4: Straw mulch	1.467[a]
T_5: Straw mulch followed by one hand weeding at 60 DAT	1.467[a]
T_6: Hand weeding at 30 and 60 DAT	1.467[a]
T_7: Unweeded control	1.420[b]
C D (0.05)	**0.002**
S E (m)	_

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

DAT-Days after transplanting

4.2.7. Fruit length

Data on the length of fruit (cm) as affected by different treatments are presented in Table 4.11. The fruit length in the treatments stale seed bed followed by both two hand weedings (6.00 cm) and one hand weeding (5.96 cm), polythene mulching (6.16 cm), straw mulching alone (6.03 cm) and when followed by a hand weeding (6.16 cm) and hand weeding at 30 and 60 DAT (6.00 cm) was on par. The unweeded control had the lowest fruit length (4.20 cm).

4.2.8. Fruit girth

The fruit girth was measured and the values are given in Table 4.11. It was noticed that the fruit girth values of all the weed management practices were on par except in the unweeded control. The fruit girth in the treatments polythene mulching, stale seed bed followed by two hand weedings and straw mulching when done alone and when followed by one hand weeding was 2.70 cm, and in straw mulch followed by a hand weeding was 2.76 cm. The unweeded control had a fruit girth of 2.13 cm.

4.2.9. Average fruit weight

The average weight of fruit in the treatments stale seed bed followed by two hand weedings (3.20 g) and followed by one hand weeding (3.13 g), polythene mulching (3.30 g), straw mulching alone (3.30 g) and when followed by a hand weedings (3.20 g) and hand weeding at 30 and 60 DAT (3.26 g) was on par. The average fruit weight was low in unweeded control (2.70 g).

4.2.10. Fruit yield

Data on the yield of chilli are shown in Table 4.13. The fruit yield was highest in the treatment polythene mulching (22.44 t/ha), followed by straw mulching when done alone (18.89 t/ha) and when followed by one hand weeding (18.38 t/ha). The yields of the two treatments with straw mulching were on par and significantly lower than polythene mulching. The yield in the treatment hand weeding at 30 and 60 DAT was 13.37 t/ha and in stale seed bed followed by two hand weedings was 12.33 t/ha, both of which were on par. The treatment stale seed bed followed by a hand weeding

Table 4.11. Fruit weight, fruit length and fruit girth of chilli as influenced by non-chemical weed management practices

Treatments	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*3.20[a]	6.00[a]	2.70[a]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	3.13[a]	5.96[a]	2.63[a]
T_3: Black polythene mulch	3.30[a]	6.16[a]	2.70[a]
T_4: Straw mulch	3.30[a]	6.03[a]	2.70[a]
T_5: Straw mulch followed by one hand weeding at 60 DAT	3.20[a]	6.16[a]	2.76[a]
T_6: Hand weeding at 30 and 60 DAT	3.26[a]	6.00[a]	2.67[a]
T_7: Unweeded control	2.70[b]	4.20[b]	2.13[b]
C D (0.05)	**0.23**	**0.39**	**0.19**
S E (m)	**0.07**	**0.13**	**0.06**

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

DAT-Days after transplanting

(9.53 t/ha) had a lower yield than stale seed bed followed by two hand weedings. The lowest yield of chilli among all the treatments was recorded for the unweeded control (1.44 t/ha).

4.2.11. Number of harvests

The treatments were not significantly different with respect to the number of harvests. All the treatments had four harvests, but the unweeded control had only three (Table 4.12).

4.3. Pest and disease occurence

Important pests noticed in the field were chilli mite (*Polyphagotarsonemus latus*) and chilli thrips (*Scirtothrips dorsalis*). As the symptoms were identified at the initial stage itself, both the sucking pests were controlled using 2% neem oil - garlic emulsion spray. No disease was observed in chilli during the period of observation.

4.4. Soil physico-chemical properties

4.4.1. Soil pH

Data on soil pH values are given in Table 4.14. The soil was slightly acidic in nature and the initial pH before the experiment was 5.20. At 60 DAT, a higher pH was recorded in the treatment stale seed bed followed by two hand weedings (5.70). Soil pH in the treatments polythene mulching and unweeded control were on par. All the other treatments had pH values which were on par and significantly lower than the pH in polythene mulching and unweeded control.

After the final harvest also, there were significant difference in soil pH values of different treatments. Stale seed bed followed by two hand weedings and polythene mulching had significantly higher pH than all other treatments and were on par. All the remaining treatments except straw mulching followed by one hand weeding had pH values which were on par.

Table 4.12. Days to first flowering and number of harvests of chilli as influenced by non-chemical weed management practices

Treatments	Days to first flowering	No. of harvests
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*40^b	4
T_2: Stale seed bed followed by a hand weeding at 45 DAT	40^b	4
T_3: Black polythene mulch	39^b	4
T_4: Straw mulch	39^b	4
T_5: Straw mulch followed by one hand weeding at 60 DAT	39^b	4
T_6: Hand weeding at 30 and 60 DAT	40^b	4
T_7: Unweeded control	44^a	3
C D (0.05)	**1.07**	_
S E (m)	**0.34**	_

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

DAT-Days after transplanting

Table 4.13. Number of fruits/plant and fruit yield of chilli as influenced by non-chemical weed management practices

Treatments	No. of fruits/plant	Fruit yield (t/ha)
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*117[c]	12.33[c]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	92[d]	9.53[d]
T_3: Black polythene mulch	218[a]	22.44[a]
T_4: Straw mulch	182[b]	18.89[b]
T_5: Straw mulch followed by one hand weeding at 60 DAT	177[b]	18.38[b]
T_6: Hand weeding at 30 and 60 DAT	120[c]	13.37[c]
T_7: Unweeded control	14[e]	1.44[e]
C D (0.05)	**9.68**	**1.25**
S E (m)	**3.14**	**0.41**

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

DAT-Days after transplanting

4.4.2. Electrical conductivity

Data on the EC values of the soil are given in Table 4.14. Before starting the experiment the EC of soil was 0.80 dS/m. But there were significant difference in EC values at 60 DAT and after the final harvest. At 60 DAT and after the final harvest, stale seed bed followed by two hand weedings recorded the highest EC value (0.79 dS/m) and straw mulching followed by one hand weeding had the lowest (0.24 dS/m).

4.4.3. Organic carbon

Data on the percentage of organic carbon in soils of different treatments are given in Table 4.14. Before starting the experiment, the organic carbon in the soil of experimental plots was 1.36 %. Significant differences in organic carbon content were noticed in different treatments at 60 DAT and after the final harvest. In both the stages, the highest per cent of organic carbon was recorded in polythene mulching, and unweeded control recorded the lowest values.

4.4.4. Available N, P and K

Values of available N, P and K at 60 DAT and after the final harvest are given in Table 4.15. The pre-experimental N content in soil was 189.00 kg/ha. But there was significant difference in N content in different treatments at 60 DAT and after the final harvest. At 60 DAT the highest N content was recorded in the treatment polythene mulching (247.40 kg/ha) which was on par with the N content in straw mulching followed by one hand weeding (246.16 kg/ha) and the lowest N content was estimated in unweeded control (195.63 kg/ha). After the last harvest, the N content in the treatment stale seed bed followed by one hand weeding recorded the highest value (238.86 kg/ha), which was on par with the N content in the treatment polythene mulching (238.23 kg/ha). At this stage also, unweeded control recorded the lowest N content (198.30 kg/ha).

The available phosphorus in the soil before starting the experiment was 51.23 kg/ha. Considering the soil available P, the treatments were significantly different at 60 DAT and after the final harvest. The treatment straw mulching recorded the highest available P content at 60 DAT (76.51 kg/ha) and after the last harvest (79.17 kg/ha) while it was lowest in the unweeded control at both stages.

The treatment straw mulching recorded highest potassium content at 60 DAT (413.70 kg/ha) and after the final harvest (408.13 kg/ha), followed by the treatment polythene mulching at both stages. The lowest available K content was recorded in the unweeded control at both stages.

4.5. Economics of production of chilli

Data on the effect of weed management practices on economics of production of chilli are given in Table 4.16. It was seen that the treatment polythene mulching generated the highest gross returns (Rs. 22.44 lakhs/ha), net returns (Rs. 9.94 lakhs/ha) and B:C ratio (1.84), which was followed by the treatment straw mulching in gross returns (Rs. 18.89 lakh/ha), net returns (Rs. 5.59 lakh/ha) and B:C ratio (1.42). The B:C ratio in the treatment straw mulching was closely followed in straw mulching when followed by one hand weeding (1.34). All the treatments except stale seed bed followed by one hand weeding and unweeded control recorded positive values for net returns and B:C ratios more than one. Unweeded control recorded the lowest gross returns (Rs. 1.44 lakh/ha), net returns (Rs. -9.97 lakh/ha) and B:C ratio (0.12).

Table 4.14. Soil characteristics as influenced by non-chemical weed management practices

Treatments	pH		EC (dS/m)		Organic carbon(%)	
	At 60 DAT	After final harvest	At 60 DAT	After final harvest	At 60 DAT	After final harvest
T_1:Stale seed bed followed by two hand weedings at30 DAT and 60 DAT	*5.70[a]	5.73[a]	0.79[a]	0.89[a]	1.23[d]	1.16[de]
T_2:Stale seed bed followed by a handweeding at 45 DAT	5.26[c]	5.26[b]	0.69[c]	0.67[c]	1.34[b]	1.14[e]
T_3:Black polythene mulch	5.53[b]	5.63[a]	0.26[f]	0.28[d]	1.45[a]	1.49[a]
T_4: Straw mulch	5.26[c]	5.23[b]	0.34[e]	0.26[d]	1.25[c]	1.33[b]
T_5:Straw mulch followed by one hand weeding at 60 DAT	5.23[c]	4.96[c]	0.24[f]	0.25[d]	1.15[f]	1.24[c]
T_6: Hand weeding at 30 and 60 DAT	5.26[c]	5.26[b]	0.65[d]	0.86[a]	1.18[e]	1.18[d]
T_7: Unweeded control	5.43[b]	5.26[b]	0.73[b]	0.78[b]	1.01[g]	0.98[f]
C D (0.05)	**0.12**	**0.13**	**0.03**	**0.06**	**0.01**	**0.02**
S E (m)	**0.04**	**0.04**	_	**0.02**	_	_
Pre-experimental condition	5.20		0.80		1.36	

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

DAT - Days after transplanting

Table 4.15. Available N, P and K of soil as influenced by non-chemical weed management practices

Treatments	Available N (kg/ha)		Available P (kg/ha)		Available K (kg/ha)	
	At 60 DAT	After final harvest	At 60 DAT	After final harvest	At 60 DAT	After final harvest
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	*210.63[e]	202.26[d]	65.11[de]	62.07[e]	266.93[d]	259.10[e]
T_2: Stale seed bed followed by a hand weeding at 45 DAT	239.16[b]	238.86[a]	63.87[e]	63.57[d]	365.33[c]	364.00[c]
T_3: Black polythene mulch	247.40[a]	238.23[a]	73.14[b]	72.96[b]	396.83[b]	394.60[b]
T_4: Straw mulch	226.13[d]	219.26[c]	76.51[a]	79.17[a]	413.70[a]	408.13[a]
T_5: Straw mulch followed by one hand weeding at 60DAT	246.16[a]	232.26[b]	68.87[c]	68.58[c]	365.63[c]	357.03[d]
T_6: Hand weeding at 30 and 60 DAT	229.36[c]	219.33[c]	65.90[d]	64.56[d]	249.30[e]	244.13[f]
T_7: Unweeded control	195.63[f]	198.30[e]	50.11[f]	50.04[f]	227.83[f]	224.53[g]
C D (0.05)	**1.74**	**0.91**	**1.91**	**1.19**	**2.84**	**1.92**
S E (m)	**0.56**	**0.29**	**0.62**	**0.39**	**0.92**	**0.29**
Pre-experimental condition	189.00		51.23		437.80	

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

DAT-Days after transplanting

Table 4.16. Economics of production of chilli as influenced by non-chemical weed management practices

Treatments	Cost of cultivation/ha (lakh Rs)	Gross returns/ha (lakh Rs)	Net returns/ha (lakh Rs)	B : C ratio
T_1: Stale seed bed followed by two hand weedings at 30 DAT and 60 DAT	12.19	12.33	0.14	1.01
T_2: Stale seed bed followed by a hand weeding at 45 DAT	11.80	9.53	-2.27	0.80
T_3: Black polythene mulch	12.15	22.44	9.94	1.84
T_4: Straw mulch	13.30	18.89	5.59	1.42
T_5: Straw mulch followed by one hand weeding at 60 DAT	13.69	18.38	4.69	1.34
T_6: Hand weeding at 30 and 60 DAT	12.19	13.37	1.18	1.09
T_7: Unweeded control	11.41	1.44	-9.97	0.12

- DAT- Days after transplanting
- Labour charge (1 labourer- Rs. 628/day)
- Cost of seedling (Rs. 2/seedling)
- Cost of polythene sheet (Rs. 7/m^2)
- Cost of straw (Rs. 10/kg)
- Sale price of chilli (Rs. 100/kg)

Discussion

5. DISCUSSION

Chilli is an important vegetable crop grown in most parts of Kerala. Formulation of good weed management practices in chilli help in increasing the yield. Important results of the research programme entitled “Non-chemical weed management in chilli (*Capsicum annuum* L.)” are discussed in this section based on related literature.

5.1. Weed spectrum

Weeds are serious problem in chilli cultivation and they reduce the economic yield by 60 to 70 per cent (Patel *et al.*, 2004). Weeds compete with the crop for various factors like nutrients, soil moisture, light, space and finally cause reduction in yield of the crop. Mennan *et al*. (2020) claimed that due to weed-vegetable competition, the yield of vegetables may be decreased by 45-95 per cent. So it is very essential to control the weed flora in order to get a profitable yield.

The important broad leaved weed species present in the experimental site were *Borreria hispida*, *Cleome burmanii*, *Cleome monophylla*, *Lindernia crustacea, Scoparia dulcis, Alternanthera bettzickiana, Ludwigia perennis, Ageratum conyzoides, Phyllanthus amara, Sida acuta, Mollugo disticha,* and *Catharanthus pusillus*. *Eleusine indica, Panicum maximum, Echinochloa colona, Eragrostis tenella*, *Digitaria ciliaris* and *Pennisetum pedicellatum* were the grass weeds in the field. The sedges found in the field were *Cyperus rotundus* and *Kyllinga monocephala.*

At all stages of observation, the density of broad leaved weeds was higher than grass weeds and sedges. Daramola *et al.* (2021) also observed that broad leaved weeds were dominant in chilli field over grasses and sedges. Figure 1 depicts that at 30 DAT the broad leaved weeds constituted about 87 per cent out of the total weeds in the experimental area. At this stage of observation, grass weeds and sedges constituted about 8 and 5 per cent out of total weeds respectively. At 30

DAT *Borreria hispida* and *Cleome* spp were the dominant broad leaved weeds. The broad leaved weeds were about 88 per cent, grasses 9 per cent and sedges 3 per cent out of the total weeds in the experimental site at 60 DAT and the dominant dicot weeds at this stage were *Borreria hispida*, *Cleome* spp and *Lindernia crustacea*. At 90 DAT also, broad leaved weeds formed the major share of weed density when compared with grasses and sedges. Broad leaved weeds constituted about 84 percent, grasses 11 percent and sedges were 5 per cent out of the total weeds. At 90 DAT, the prominent broad leaved weeds were *Borreria hispida*, *Lindernia crustacea* and *Scoparia dulcis.* At all stages of observation, *Cyperus* spp were the major sedges, while *Panicum maximum* and *Eleusine indica* were the prominent grasses present at the experimental site. From the observations at different stages, it was clear that the major share of weeds in the experimental plot were broad leaved weeds while grasses and sedges were very low. It can be due to the predominance of broad leaved weeds at the experimental area. Similar results were obtained by Bottenberg *et al*. (1997) who stated that broad leaved weeds were important in causing problems in chilli fields. Thus it could be concluded that broad leaved weeds offered greater competition to the chilli plants than grasses and sedges.

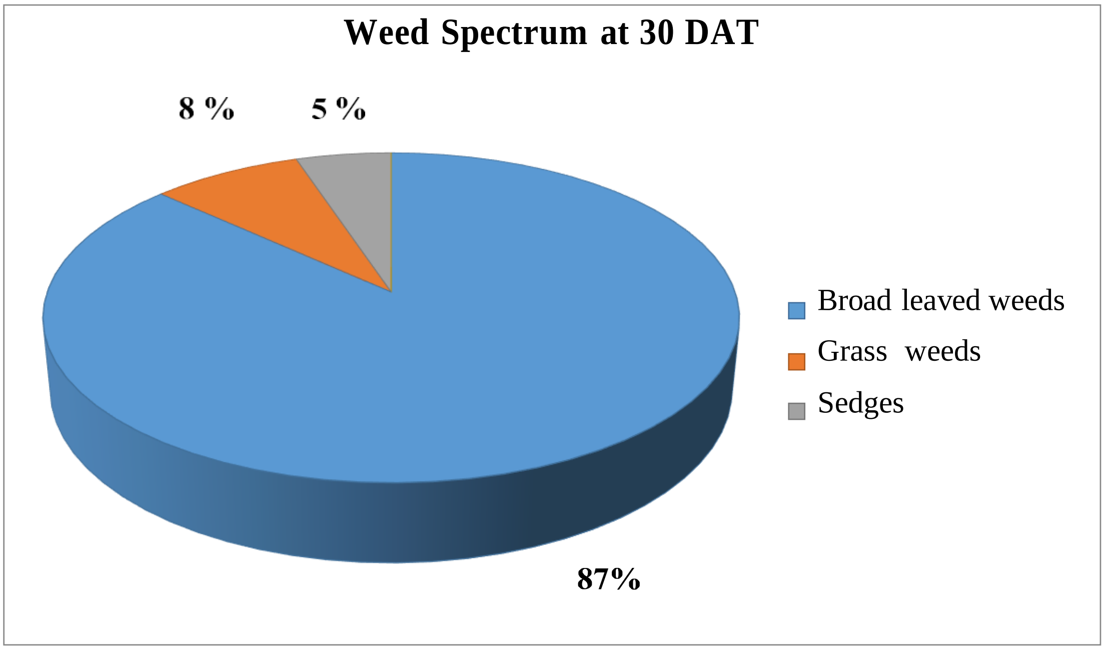

Figure 5.1. Weed spectrum at 30 DAT

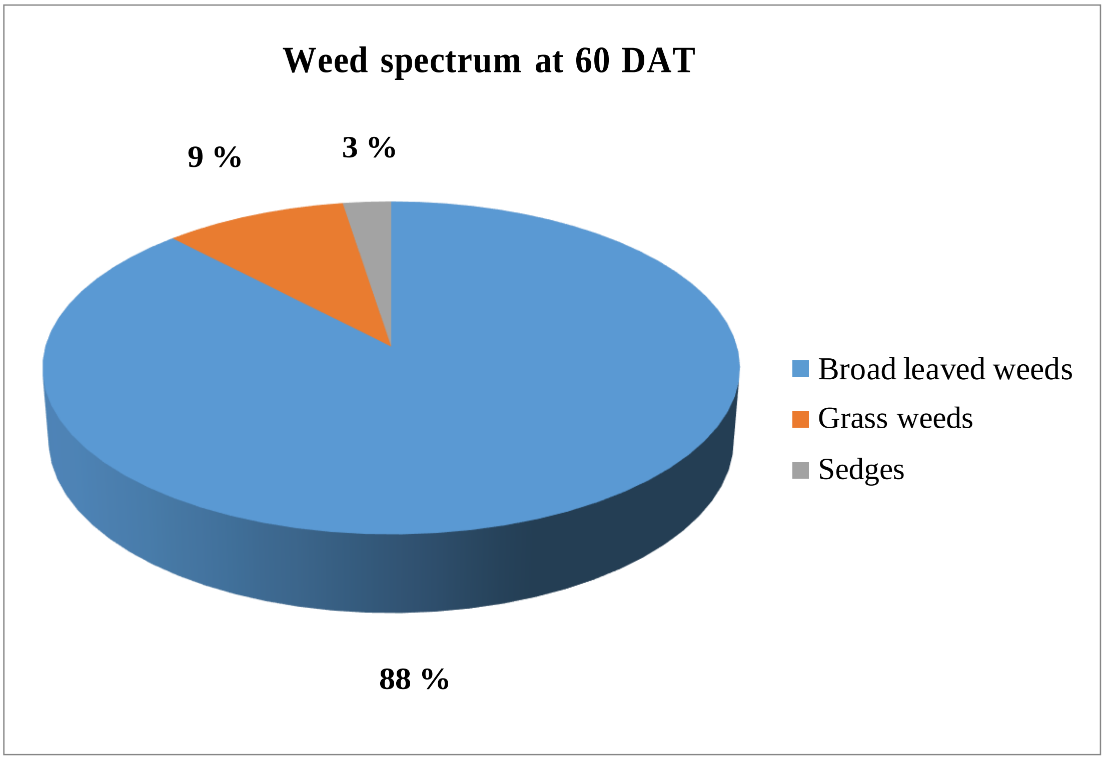

Figure 5.2. Weed spectrum at 60 DAT

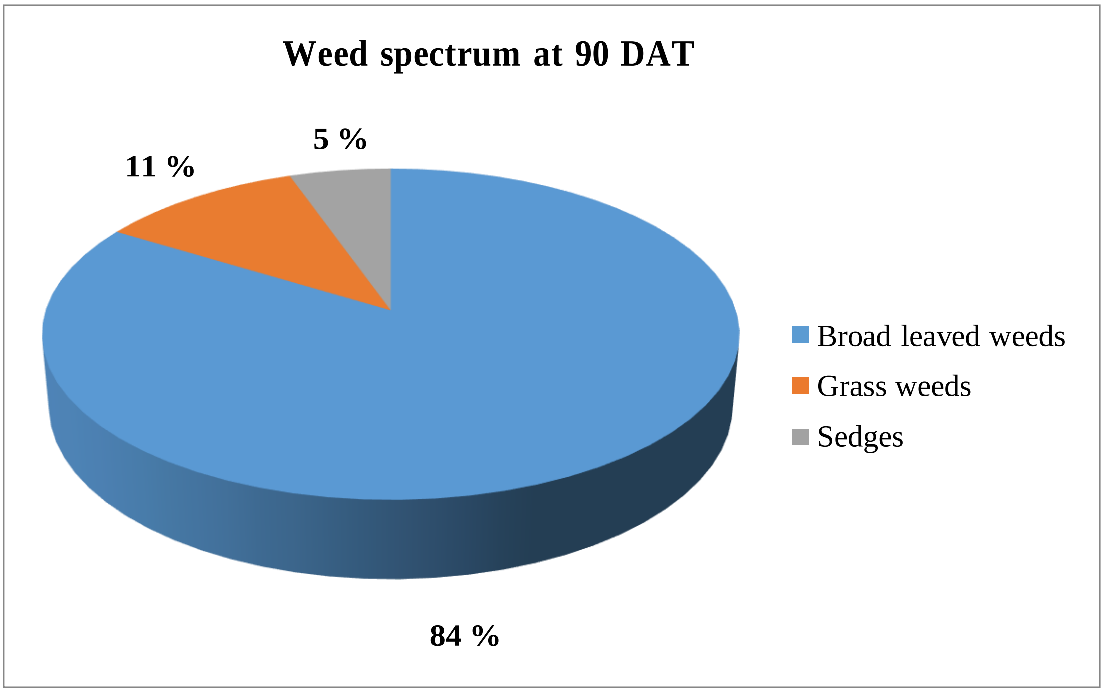

Figure 5.3. Weed spectrum at 90 DAT

5.2. Effect of weed management practices

Various weed management practices had significant effect on species wise weed density, weed dry matter production, weed control efficiency and weed index. The weed density was significantly lower in polythene mulching and it was higher in unweeded control at all stages of observation. Polythene mulching was an effective method for controlling all types of weed species and almost maintained a weed-free condition throughout the observation period. Only those weeds which emerged through the holes along with the chilli plants were present in the polythene mulch. It could be due to the ability of black polythene sheet to absorb solar radiation and thereby increase the soil temperature, which prevented germination of weed seeds. Lament (1993) claimed that the soil temperatures under black plastic mulch during the day time were generally 2.8°C higher at a depth of 5 cm and 1.7°C higher at 10 cm depth compared to that of bare soil. This property of black plastic mulch could reduce weed emergence. According to Narayan *et al*. (2017), black polythene mulch of 30 micron thickness (double coated) had the lowest weed density while comparing with paddy straw mulch. Chandran and Nelson (2018) claimed that in organically-grown chilli, weed count was lower in plots with plastic mulch. Relf and Appleton (2009) also stated that weed growth was more likely in organic mulches than inorganic mulches.

Straw mulch, both when applied alone and when followed by a hand weeding at 60 DAT, controlled weeds effectively but not to the extent of polythene mulch. Sekhon *et al.* (2008) had observed that paddy straw mulch suppressed the weed growth, and the weed biomass in straw mulch was lower than that of unmulched plots. At 30 DAT both the straw mulch treatments were on par but at 90 DAT the straw mulching followed by a hand weeding at 60 DAT was better in weed control than straw mulching alone. Stale seed bed followed by both two hand weedings and one hand weeding was not effective in controlling weeds in chilli and had higher weed density than straw mulching. But at 60 DAT, less weed density was recorded in stale seed bed followed by a hand weeding at 45 DAT than in straw mulching. The necessity of hand weeding once after straw mulching and stale seed bed was brought out. Hand weeding at 30 and 60 DAT was found to be less effective in controlling weeds as compared to other weed management practices and at 30 and 60 DAT, the number of weeds in the hand weeding treatment was just below the number of weeds in unweeded control. However, at 90 DAT, hand weeding was observed to be better in controlling the weeds than stale seed bed technique. The highest weed density was observed in the unweeded plot at all stages of observation.

The weed dry matter production at 30, 60 and 90 DAT was greatly influenced by the weed management practices. As with the case of weed density, at all stages of observation, black polythene mulching had the lowest weed dry matter production. Similar results were also obtained by Ashrafuzzaman *et al*. (2011) who claimed that the weed dry weight was lowest in the black polythene mulch as compared to transparent and blue mulches. At 30 DAT, polythene mulching was followed by straw mulching which had 216 per cent high weed dry matter production than polythene mulching. Weed dry matter production in straw mulch was closely followed by straw mulching followed by a hand weeding. Zaag *et al*. (1986) observed that the practice of mulching reduced weed seed germination, weed growth and resulted in overall reduction in weed infestation. All the other treatments had comparatively higher weed dry matter production. At 60 DAT, stale seed bed followed by a hand weeding recorded less weed dry matter production but it was about 350 per cent higher than that in polythene mulching. At 90 DAT, the lowest weed dry matter production was in polythene mulching followed by straw mulching with a hand weeding and straw mulching alone. At all stages of observation, the unweeded control recorded the highest weed dry matter production. The dry matter production of weeds increased from 30 DAT to 90 DAT except in stale seed bed with two hand weedings, straw mulch with one hand weeding and unweeded control. In polythene mulching, the increase in weed dry matter production was 198 per cent and 13 per cent from 30 to 60 and 60 to 90 DAT respectively. However, compared to other treatments, the increase in weed dry matter production was low in polythene mulching.

As the weed management practices had significant effect on weed density and weed dry matter production, the weed control efficiency was also influenced by various weed control methods. At all stages of observation, polythene mulching recorded the highest weed control efficiency. Similar results were also obtained by Shehata *et al.* (2019) in potato who stated that black and biodegradable mulches recorded higher weed control efficiency than hoeing treatment. Lament (1993) stated that weeds could not survive in polythene mulches and hence their weed control efficiency could be higher. High WCE in polythene mulch was followed by straw mulch at 30 DAT, stale seed bed followed by a hand weeding at 60 DAT and straw mulch followed by a hand weeding at 90 DAT. Abouziena and Radwan (2014) claimed that application of rice straw mulch provided weed control efficiency of about 65 per cent in onion field. The stale seed bed both when followed by one hand weeding and two hand weedings recorded low weed control efficiencies. But at 60 DAT, the stale seed bed when followed by one hand weeding at 45 DAT recorded weed control efficiency value close to polythene mulching. The weed control efficiency of straw mulching when done alone and when followed by one hand weeding were higher than all treatments except polythene mulching. Hand weeding at 30 and 60 DAT resulted in low weed control efficiency. Comparing all treatments, unweeded control recorded lowest weed control efficiency.

As per the observations recorded, the weed index was significantly affected by various non-chemical weed management practices which is shown in Figure 9. The lowest weed index was recorded in polythene mulching which depicted the efficiency of polythene mulching in controlling weeds. According to Chandran and Nelson (2018), plastic mulch registered lowest weed count while comparing with straw mulch. The next best treatment was straw mulching, which was closely followed by straw mulching followed by a hand weeding. Hand weeding, stale seed bed when followed by both two hand weedings and one hand weeding recorded comparatively higher weed index values. The unweeded control had the highest weed index value. Bhardwaj *et al*. (2018) also concluded that the highest weed infestation was recorded in unmulched and unweeded plot when compared with mulched plots.

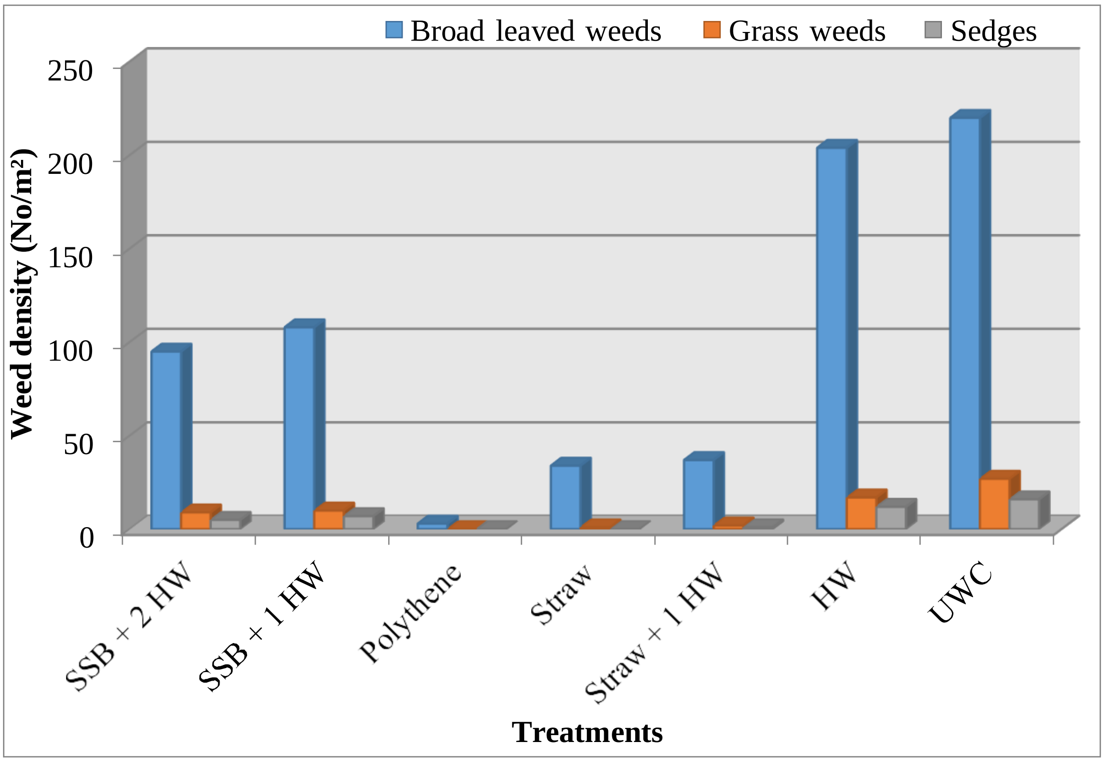

Figure 5.4. Effect of weed management practices on weed density at 30 DAT

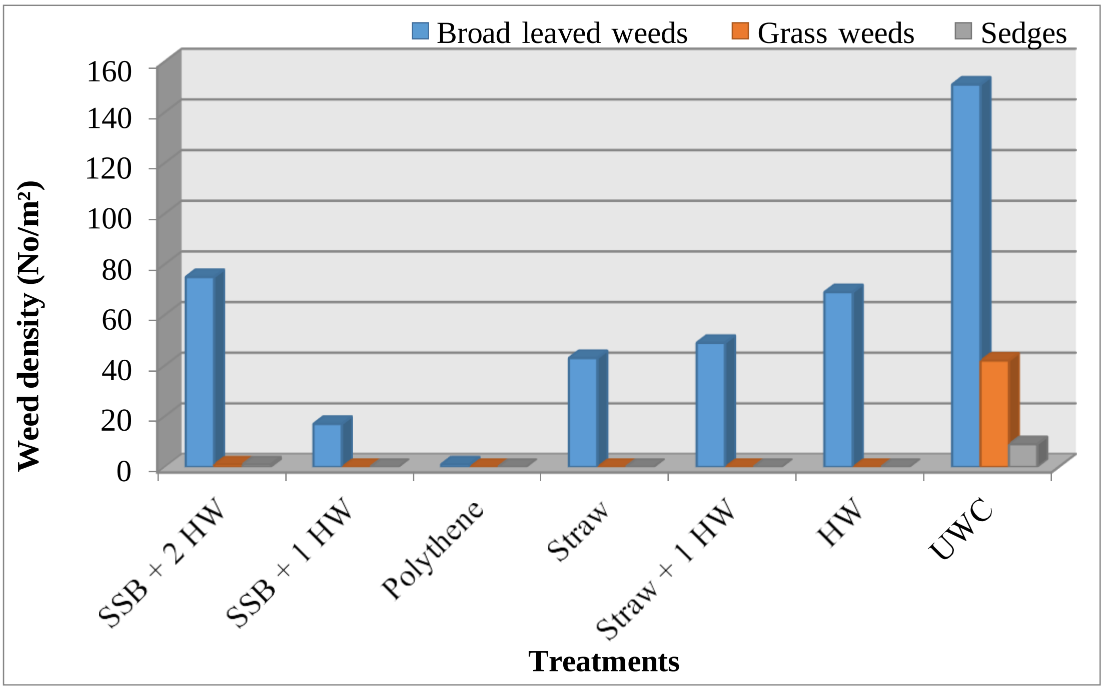

Figure 5.5. Effect of weed management practices on weed density at 60 DAT

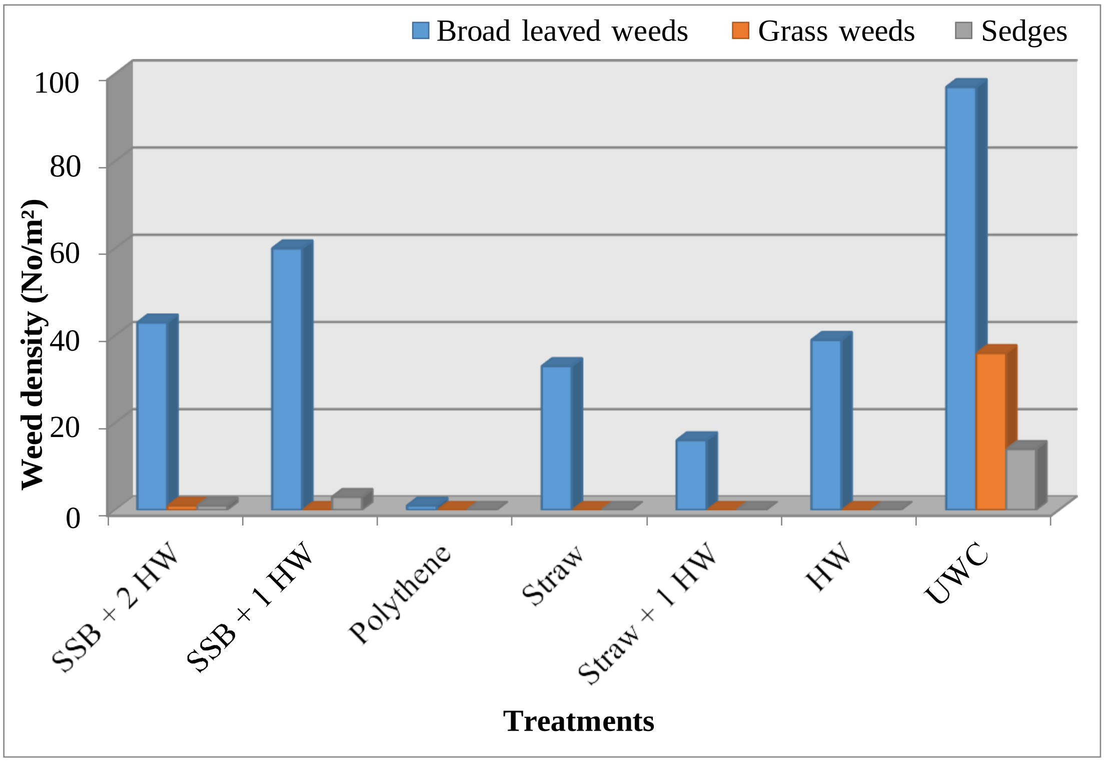

Figure 5.6. Effect of weed management practices on weed density at 90 DAT

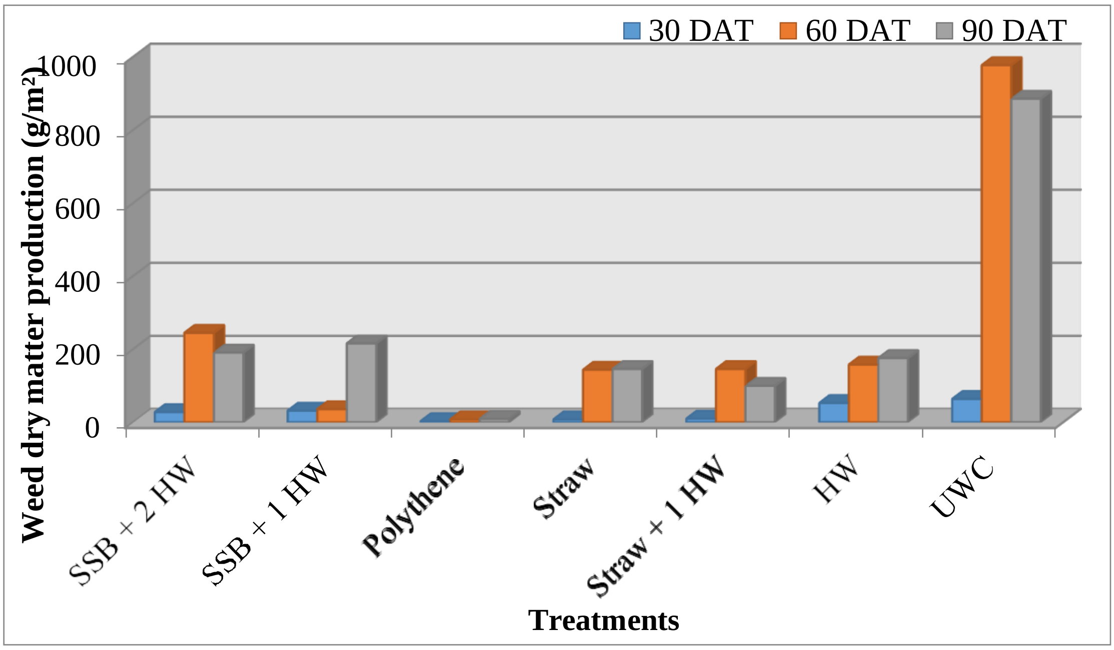

Figure 5.7. Effect of weed management practices on weed dry matter production

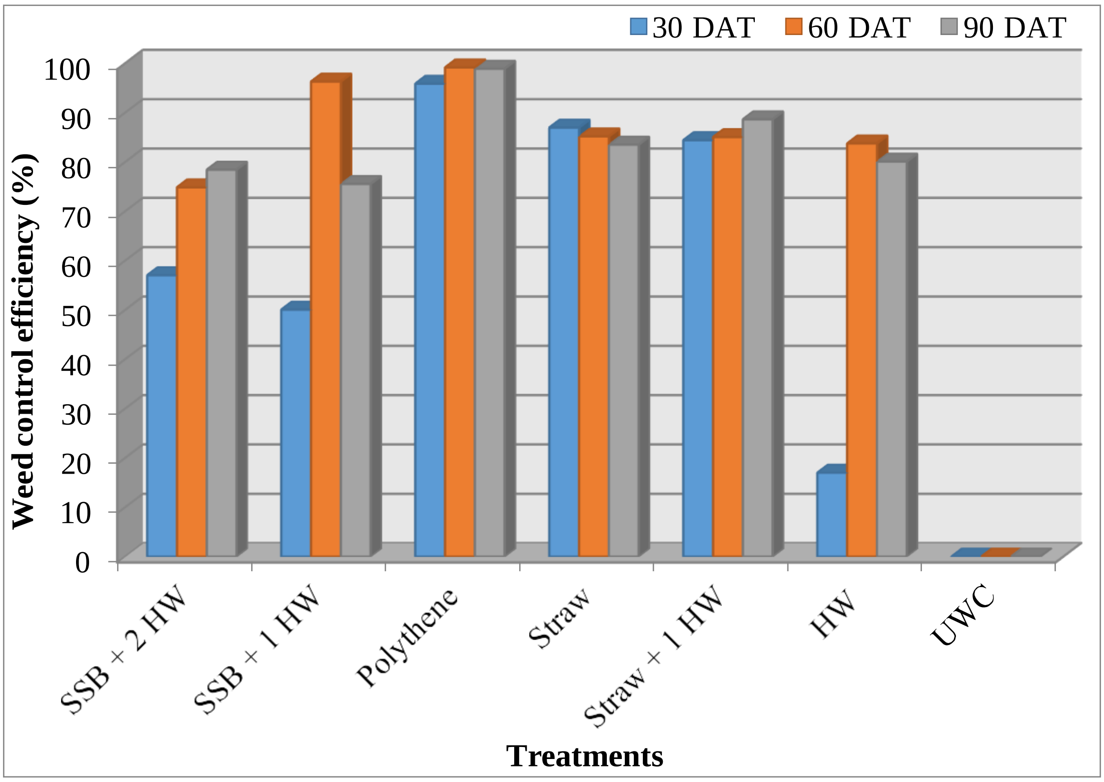

Figure 5.8. Effect of weed management practices on weed control efficiency

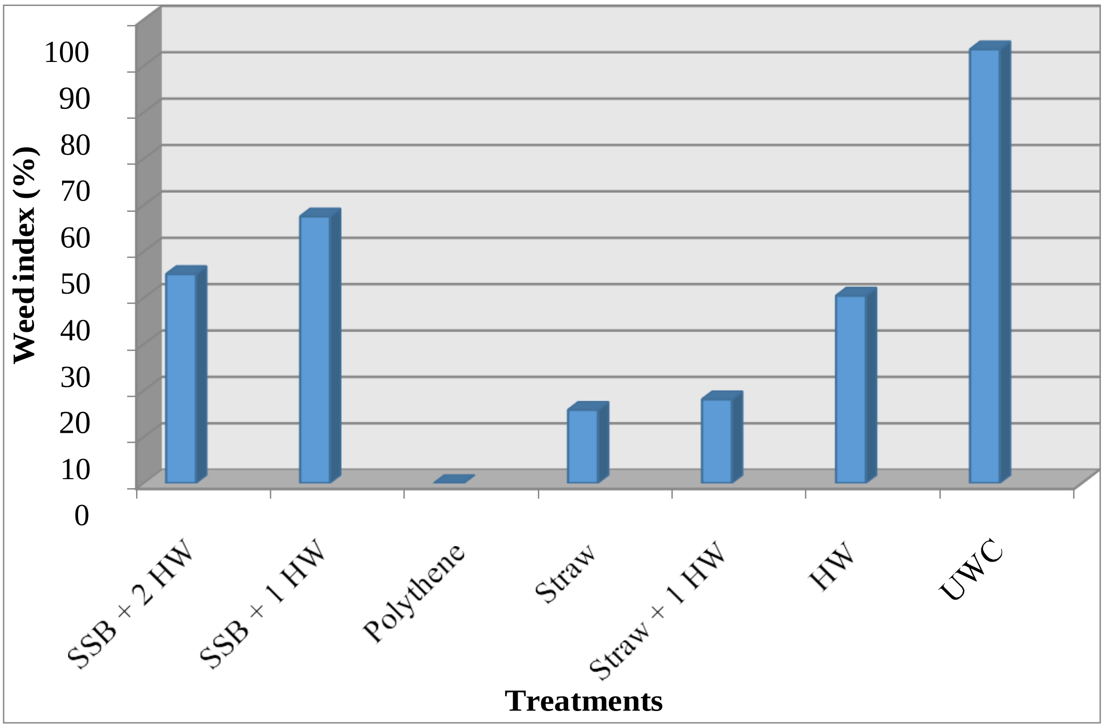

Figure 5.9. Effect of weed management practices on weed index

5.3. Effect of weed management practices on growth of chilli

Various weed control methods had significant effect on growth of chilli. Growth parameters such as height of plant at different stages, number of branches per plant at different stages, leaf area index and total chlorophyll content were observed. It was seen that all the treatments except the unweeded control recorded similar values for the parameters leaf area index and total chlorophyll content. It was noticed that plant height and number of branches per plant at different stages were significantly different for all the treatments.

In chilli, plant height and number of branches at different stages of observation were influenced by various weed management practices. At all stages of observation, the plant height in polythene mulching was found to be the greatest. In terms of number of branches per plant also, polythene mulching was found as the best. According to Vibhute and Singh (2019), when chilli was grown in black polythene mulch (25-micron) and drip fertigation with 125 per cent RDF, maximum plant height and number of primary branches were recorded. Ashrafuzzaman *et al.* (2011) also reported similar findings and stated that plastic mulches had positive effect on the growth and development of chilli, and the chilli plants in polythene mulch recoded superior value in plant height to control. They also added that the highest number of structural branches per plant in chilli was observed in black plastic mulch, followed by blue and transparent plastic mulch. Bhardwaj *et al.* (2018) reported that when chilli was grown on raised bed with 100 micron Linear Low Density Poly Ethylene plastic mulch and drip irrigation, significantly higher seedling survival at 15 and 30 days after transplanting (95 % and 92 %), greatest plant height (47.10 cm at 45 DAT and 54.60 cm at harvest), highest number of branches per plant (14.93), maximum stem girth (2.32 cm) and number of roots per plant (138.5) were recorded.

Straw mulching when done alone and when followed by a hand weeding were the next best treatments while considering the plant height and number of branches per plant. Sekhon *et al.* (2008) claimed that the chilli biomass increased significantly when paddy straw was used as mulch. Hasan (2013) reported that the use of rice straw mulch significantly increased the plant height, number of leaves per plant and plant dry matter in potato. Hand weeding and stale seed bed treatments recorded lower values for height than straw mulching at all stages of observation.

The unweeded control had the lowest plant height, number of branches per plant, leaf area index and total chlorophyll content compared with the other treatments. Weed interference reduced the leaf area index and crop growth rate, compared to weed-free treatment (Mondani *et al.*, 2011). Ngouajio *et al.* (2008) also claimed that high weed population could reduce chlorophyll content in leaves. Presence of weeds in chilli caused reduction in plant dry weight and plant height (Hajebi *et al.*, 2016). Daramola *et al.* (2021) also reported that the number of branches, leaves, fruits and fruit yield in chilli were significantly reduced due to crop-weed competition. Similar observations were also made by Amador-Ramirez *et al.* (2007) who stated that the plant height of chilli was greater under weed-free conditions compared to weed interference. The lowest value of vegetative growth in the unweeded plot might have been because of the crop-weed competition for nutrients and water (Pattanaik *et al.*, 2003; Agrawal and Agrawal, 2005).

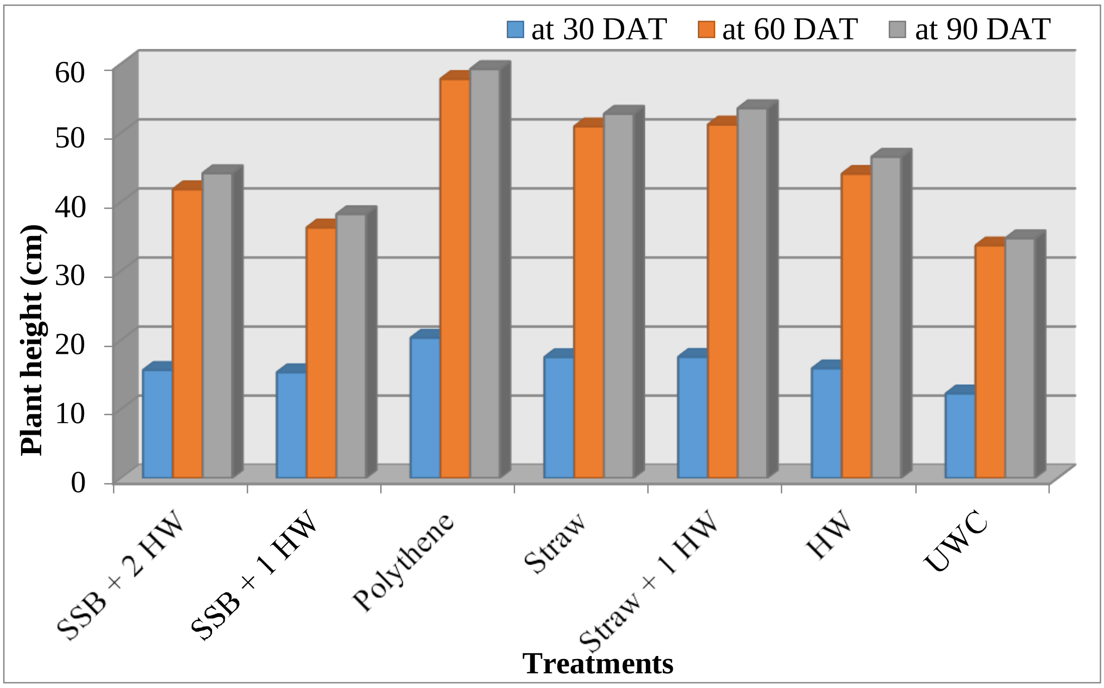

Figure 5.10. Effect of weed management practices on plant height

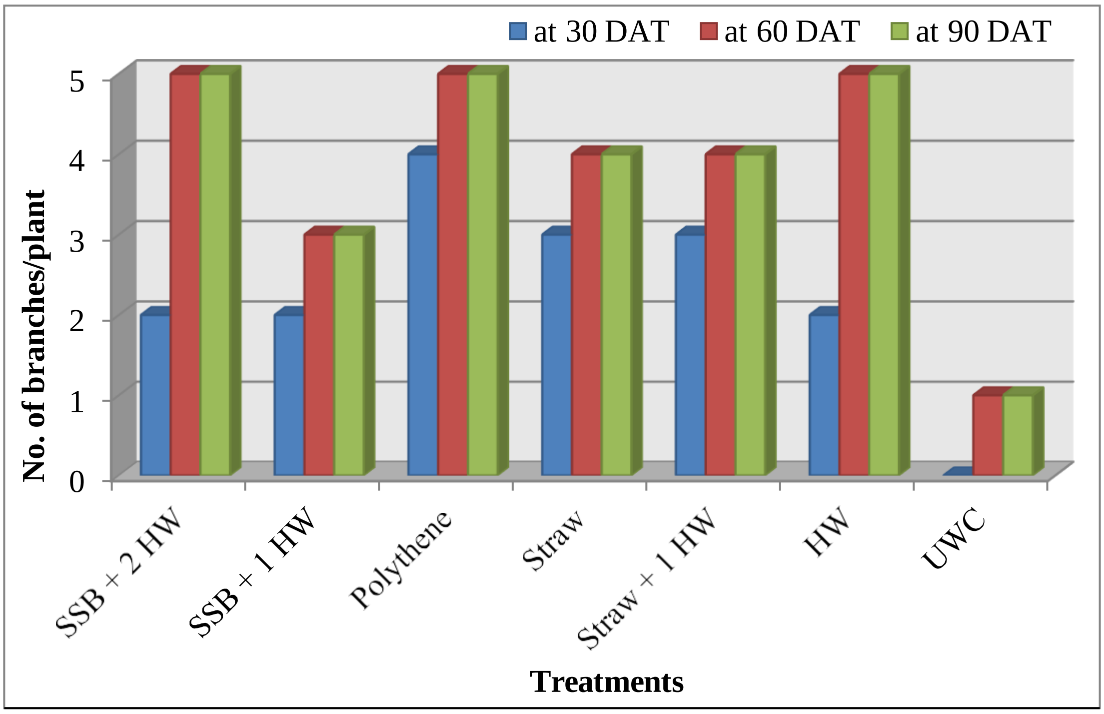

Figure 5.11. Effect of weed management practices on number of branchesper plant

5.4. Effect of weed management practices on yield of chilli

Various weed control methods had significant effect on yield of chilli. The yield parameters observed were days to first flowering, number of fruits per plant, fruit length, fruit girth, average fruit weight, fruit yield and number of harvests. Among this, the parameters days to first flowering, fruit length, fruit girth, average fruit weight and number of harvests were approximately similar for all treatments except for the unweeded control. But there were significant differences in the parameters number of fruits per plant and fruit yield.

There are many factors that affect the per cent of yield reduction in vegetables like: the crop-weed competition, the densities of weeds and vegetable plants, time of weed emergence and the duration of competition (Weiner, 1982). It was noticed that chilli plants in polythene mulching recorded highest number of fruit per plant and fruit yield. This could be due to the weed free situation prevailed in polythene mulching along with the improved soil physico-chemical properties. According to Ashrafuzzaman *et al.* (2011), plants on black plastic mulch had highest number of fruits and highest yield. Mulching significantly increased the number of fruits per plant and reduced the per cent fruit abortion when compared to unmulched control (Ravinder *et al.,* 1997; Ashrafuzzaman *et al*., 2011). Black polythene mulch of 30 micron thickness (double coated) recorded highest number of fruits per plant (140/plant) and total fruit yield (463.08 q/ha) when compared with paddy straw mulch (Narayan *et al*., 2017). Moisture storage, higher yield, maximum water and fertilizer use efficiency and higher weed control were the benefits of black plastic mulch with drip fertigation (Vibhute and Singh, 2019). Fan *et al.* (2017) stated that, in addition to weed control, application of plastic mulches also accelerated plant growth, resulted in earlier crop maturity, improved crop biomass, yield and water use efficiency. Filipovic *et al.* (2016) also reported that black plastic mulches could enhance the number of fruits and flowers of bell pepper. Bhardwaj *et al*. (2018) claimed that when chilli was grown on raised bed with 100 micron Linear Low Density Poly Ethylene plastic mulch and drip irrigation, maximum fruit set (38.47

per cent), fruit length (12.56 cm), fruit diameter (3.52 cm) and fresh fruit weight (8.42 g) were recorded.

Straw mulching both when done alone and when followed by one hand weeding were the second best treatments in terms of yield of chilli. The fruit yield of chilli in polythene mulching was about 19 per cent higher than that in straw mulching and 22 per cent higher than that in straw mulching followed by one hand weeding. The number of fruits per plant in polythene mulching was 20 per cent higher than straw mulching and 23 per cent higher than straw mulching followed by one hand weeding. Chandran and Nelson (2018) stated that when chilli was grown in polythene mulch the yield was 250 per cent higher than that in straw mulching. Agele *et al*. (2000) claimed that straw mulching reduced soil temperature, conserved soil moisture and improved growth and yield of crops. Sekhon *et al.* (2008) observed that when chilli was grown in straw mulch, the yield increased and it might have been due to the decreased day time soil temperature and increased moisture retention capacity of soil.

Hand weeding and stale seed bed when followed by two hand weedings recorded lower yield than straw mulching. The chilli fruit yield in straw mulching was 41 per cent higher than hand weeding and 53 per cent higher than stale seed bed when followed by two hand weedings. The number of fruits per chilli plant in straw mulching was 51 per cent higher than hand weeding and 55 per cent higher than stale seedbed when followed by two hand weedings. The chilli yield in both stale seed bed treatments was low and it could be due to the weed interference which occurred in these plots. Comparing the chilli yield in stale seedbed treatments with that in polythene mulching, it was noticed that the yield in polythene mulching was 82 per cent higher than the yield in stale seedbed when followed by two hand weedings and 136 per cent higher than the yield in stale seedbed when followed by one hand weeding. The number of fruits per plant in polythene mulching was 86 per cent higher than stale seed bed when followed by two hand weedings and 137 per cent higher than stale seed bed when followed by a single hand weeding.

Unweeded control recorded low values for fruit length, fruit girth and average fruit weight. The number of days for the first flower to emerge was higher and the number of harvests was less in the unweeded control. Moreover, the unweeded control registered the lowest number of fruits per plant and fruit yield. The fruit yield and number of fruits per chilli plant in unweeded control was about 16 times lower than that in polythene mulching. Adigun (2018) concluded that, 81-90 per cent yield reduction in chilli was noticed due to weed interference. Mari *et al.* (2020) observed that the yield of chilli was negligible when weed infestation was found high. Similarly, Frank *et al.* (1992) claimed that the presence of weeds during the critical stages of crop-weed competition could reduce the fruit weight and fruit number in bell pepper.

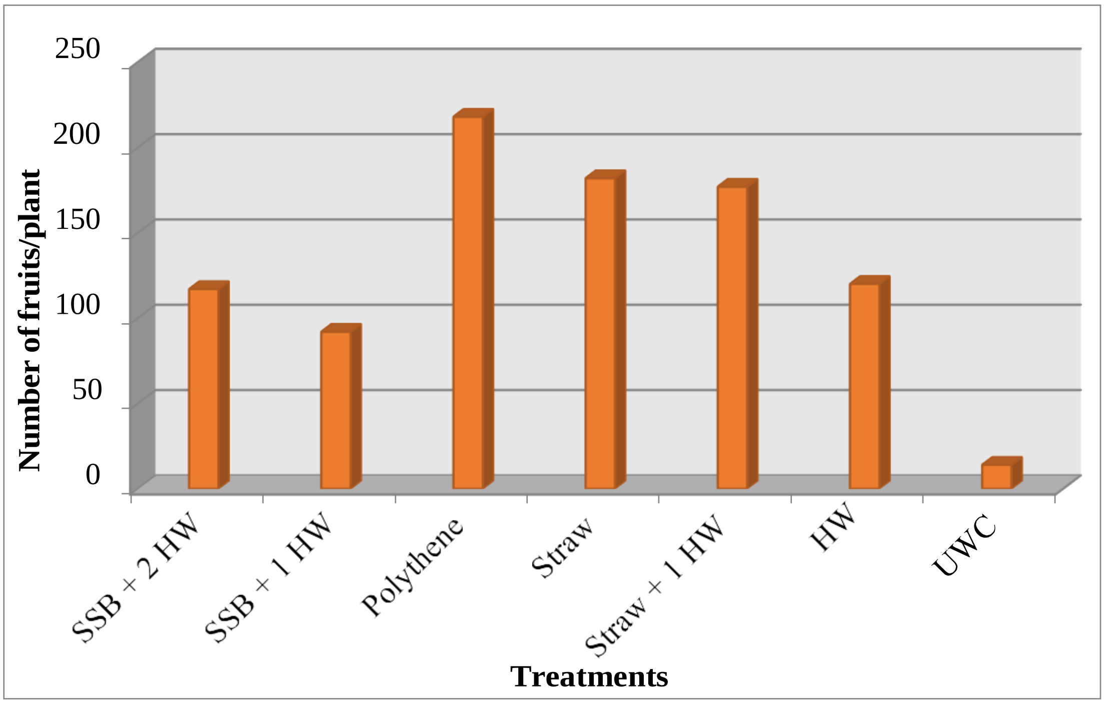

Figure 5.12.Effect of weed management practices on number of fruits per plant

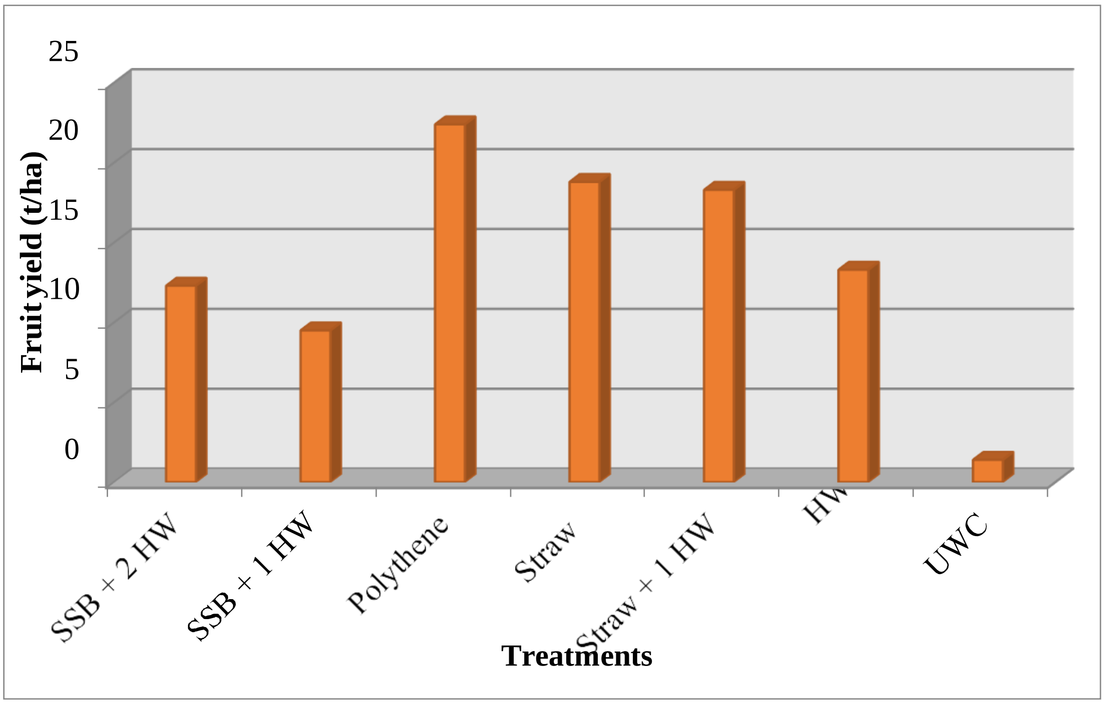

Figure 5.13. Effect of weed management practices on fruit yield

5.5. Effect of weed management practices on soil physico-chemical properties

Various soil characteristics such as pH, EC, organic carbon, available N, P and K were influenced by different weed management practices. The soil pH was found to be increased from the initial condition in all the treatments at the two stages of observation. This implied that the soil in all treatments became less acidic than the initial soil condition. The EC values of soil in some treatments were higher than the pre-experimental condition, but in most treatments it was lower. Highest EC value was observed in stale seed bed followed by two hand weedings and the lowest in black polythene mulching. The values of organic carbon and available nutrients in soils of different treatments varied that of the pre-experimental condition. The per cent of organic carbon present in the soil was higher in polythene mulching at 60 DAT and after the final harvest. Liu *et al.* (2015) claimed that when polythene mulches were used, the exhaustion of soil organic carbon found to be reduced. This was followed by organic carbon per cent in stale seed bed with one hand weeding and straw mulching at 60 DAT and after the final harvest respectively. Straw mulch added organic matter to the soil, reduced bulk density and mechanical impedance and increased infiltration (Tindall *et al.*, 1991). Bhullar *et al.* (2015) also observed that organic mulches like rice straw added organic matter to the soil. The lowest soil organic carbon content was reported in unweeded control at all stages of observation.

The available N, P and K were estimated at 60 DAT and after the final harvest. At both stages of observation, straw mulching had highest values of available P and K, whereas available N was found higher in black polythene mulch at 60 DAT and stale seed bed with one hand weeding after the final harvest. Plastic mulch enhanced soil fertility by reducing the exhaustion risk of nitrogen present in the soil (Liu *et al.*, 2015). The available nutrient status was lowest in the unweeded control.

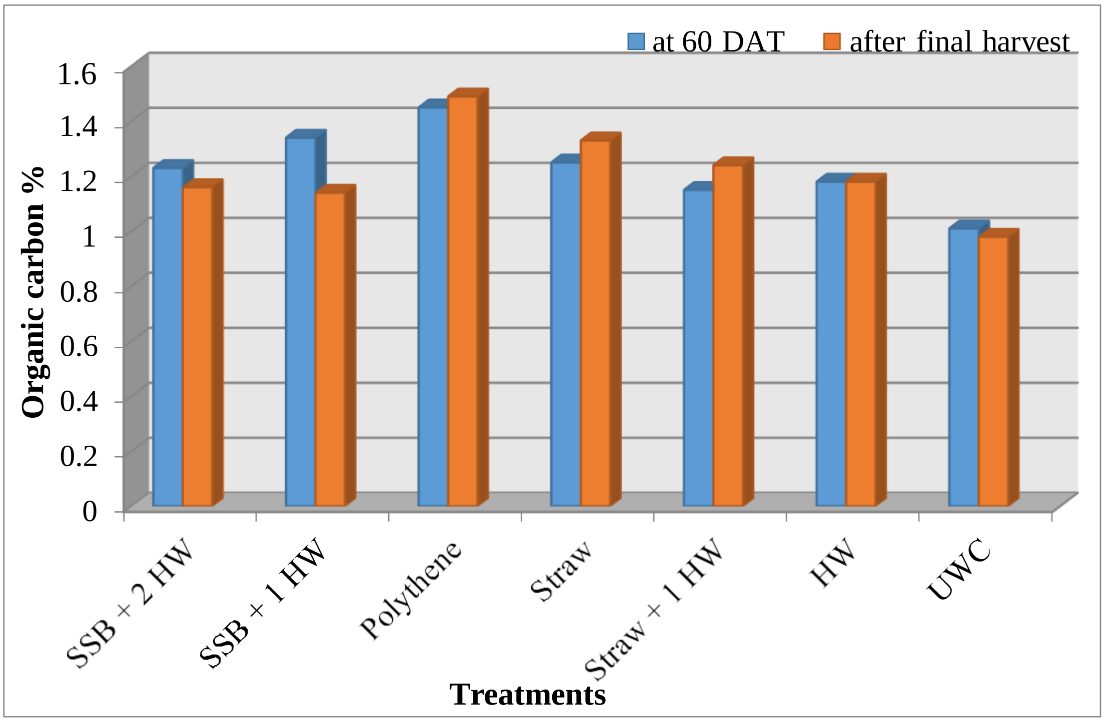

Figure 5.14. Effect of weed management practices on soil organic carbon

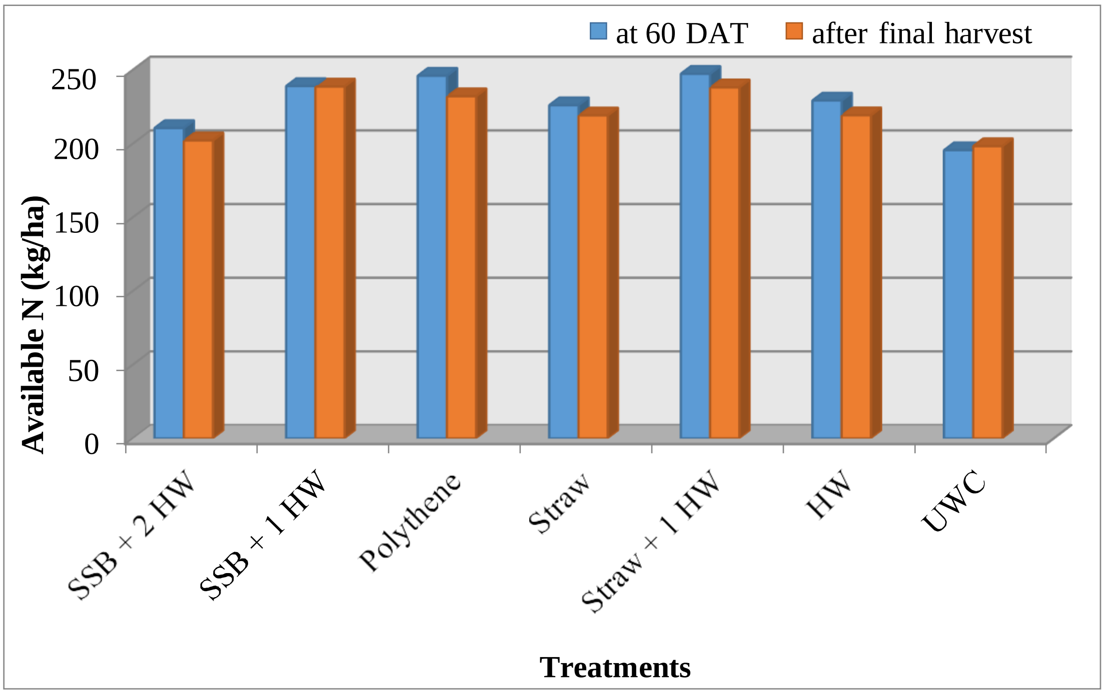

Figure 5.15. Effect of weed management practices on soil available nitrogen

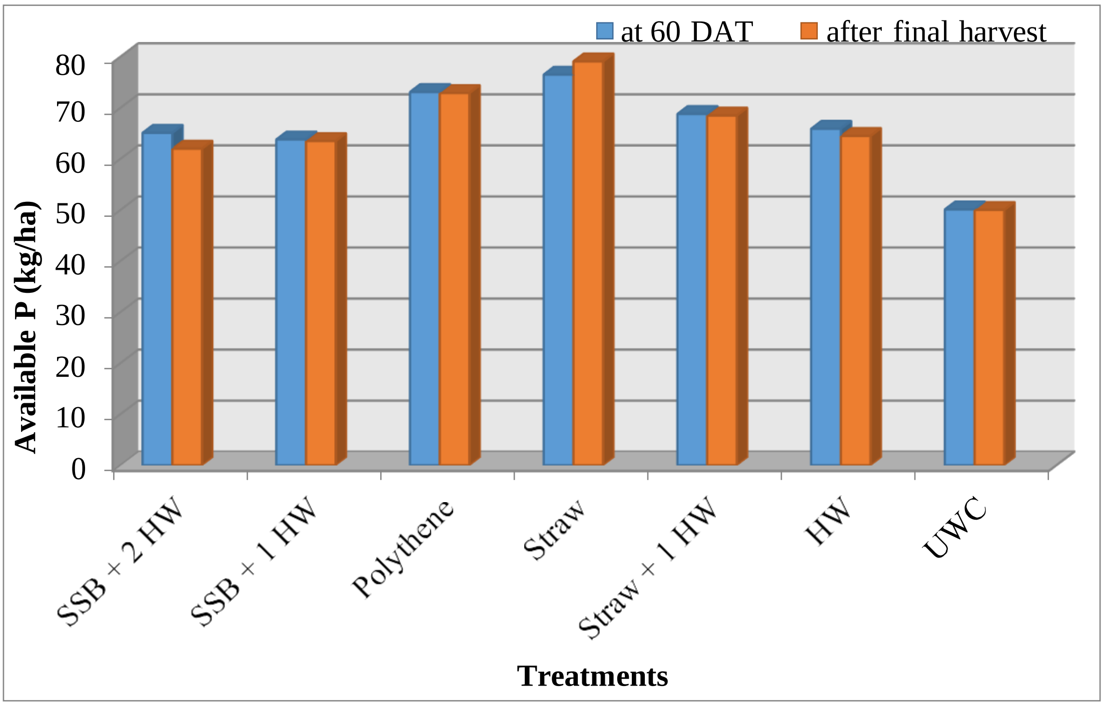

Figure 5.16. Effect of weed management practices on soil available phosphorus

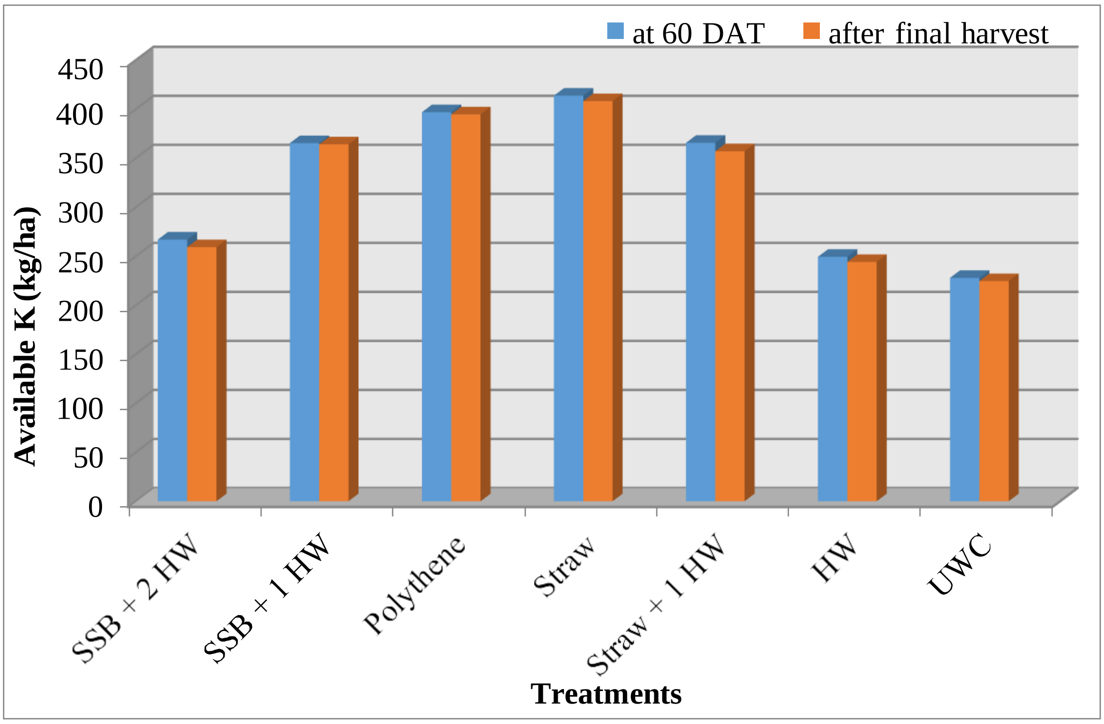

Figure 5.17. Effect of weed management practices on soil available potassium

5.6. Effect of weed management practices on economics of production of chilli

Various weed management practices had effect on cost of cultivation, gross returns, net returns and B:C ratio of chilli production. Black polythene mulching recorded highest gross returns, net returns and B:C ratio followed by straw mulching. Under temperate conditions, mulching with double coated black polythene recorded highest B:C ratio of 3.49 and therefore it could be used as a viable tool to increase yield in chilli (Narayan *et al.,* 2017). The important economic benefits of polythene mulching were water savings (up to 25%) and reduced labour costs for weed and pest control (Ingman *et al.,* 2015; Jabran *et al*., 2015). Bhardwaj *et al.* (2018) also arrived at similar conclusions and stated that when chilli was grown in polythene mulch, a benefit:cost ratio of 3.41 was reported and it was higher than other treatments. Straw mulching alone and straw mulching with one hand weeding were the next best treatments. Biswas *et al.* (2015) reported that straw mulching along with 50 per cent water application resulted in high net return and benefit-cost ratio. Hand weeding and stale seed bed treatments had low net returns and B:C ratio. The unweeded control recorded the lowest net returns and B:C ratio.

Black polythene mulching was thus identified as the best non-chemical weed management technique in chilli, having highest weed control efficiency leading to enhanced growth and yield parameters and highest net returns and B:C ratio. Straw mulching when done alone or when followed by one hand weeding were the next best treatments with respect to weed control efficiency, growth, yield and net returns of chilli.

Summary

6. SUMMARY

A research programme entitled 'Non-chemical weed management in chilli (*Capsicum annuum* L.) was conducted at the Department of Agronomy, College of Agriculture, Vellanikkara from June 2020 to September 2020. The objective of the experiment was to evaluate different non-chemical methods of weed management in chilli.

There were seven treatments viz., T_1: stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by two hand weedings at 30 DAT and 60 DAT, T_2: stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by a hand weeding at 45 DAT, T_3: black polythene mulch (30 micron), T_4: straw mulch at 7.5 t/ha applied twice, at planting and one month after planting, T_5: straw mulch at 7.5 t/ha applied twice, at planting and one month after planting followed by one hand weeding at 60 DAT, T_6: hand weeding at 30 and 60 DAT and T_7: unweeded control.

Several observations were made on weeds, growth parameters and yield parameters of chilli at different stages of the crop and the findings of the experiment are summarised below.

- Major broad-leaf weeds found in the field were *Borreria hispida*, *Cleome burmanii*, *Cleome monophylla*, *Lindernia crustacea* and *Scoparia dulcis*. Other minor weeds were *Alternanthera bettzickiana*, *Ludwigia perennis*, *Ageratum conyzoides*, *Phyllanthus amara*, *Sida acuta*, *Mollugo disticha* and *Catharanthus pusillus.*

- Grass weed species observed were *Eleusine indica*, *Panicum maximum*, *Echinochloa colona*, *Eragrostis tenella*, *Digitaria ciliaris* and *Pennisetum pedicellatum* whereas *Cyperus rotundus* and *Kyllinga monocephala* were the sedges observed in the experimental field.

- Black polythene mulch recorded highest weed control efficiency (96 %, 99 %, 99 % at 30, 60 and 90 DAT respectively) and lowest weed density, weed dry matter production and weed index at all stages of observation.

- Straw mulch when done alone (WCE – 87 %, 85 % and 84 % at 30, 60 and 90 DAT respectively) and when followed by one hand weeding (WCE - 84 %, 85 % and 89 % at 30, 60 and 90 DAT respectively) were the next best treatments with high weed control efficiency and low weed index.

- The treatments like hand weeding, stale seed bed when followed by two hand weedings and one hand weeding were not effective in controlling weeds and they recorded low weed control efficiencies and high weed index values.

- The lowest weed control efficiency and the highest weed index were recorded for the unweeded control at all stages of observation.

- At all stages of observation, the plant height of chilli in polythene mulching was found to be the greatest followed by straw mulching when done alone and when followed by one hand weeding. Unweeded control had the lowest values.

- Various weed management practices had significant effect on yield of chilli, especially the parameters like number of fruits per plant and fruit yield were significantly influenced by the treatments.

- However, yield parameters like days to first flowering, fruit length, fruit girth, average fruit weight and number of harvests were similar for all treatments except for unweeded control.

- Chilli plants in polythene mulching recorded the highest number of fruits per plant (218) and fruit yield (22.44 t/ha), followed by straw mulching both when done alone and when followed by one hand weeding.

- The fruit yield of chilli in polythene mulching was about 19 per cent higher than that in straw mulching and 22 per cent higher than that in straw mulching when followed by one hand weeding.

- Hand weeding and stale seed bed when followed by two hand weedings recorded lower yield than straw mulching.

- Unweeded control recorded lowest values for fruit length, fruit girth, average fruit weight, number of fruits per plant and fruit yield.

- The soil physico-chemical characteristics like pH, EC, organic carbon, available N, P and K were influenced by different weed management practices.

- The per cent of organic carbon present in the soil was higher in polythene mulching at 60 DAT (1.45 %) and after the final harvest (1.49 %).

- At both stages of observation, straw mulching had highest values of available P and K, whereas available N was found higher in black polythene mulch at 60 DAT and in stale seed bed with one hand weeding after the final harvest.

- Black polythene mulching recorded highest gross returns (Rs. 22.44 lakh/ha), net returns (Rs.9.94 lakh/ha) and B:C ratio (1.84) which was followed by straw mulching (gross returns: Rs. 18.89 lakh/ha, net returns: Rs. 5.59 lakhs/ha and B:C ratio: 1.42).

- Black polythene mulch was the best treatment which recorded maximum weed control efficiency, highest growth and yield parameters in chilli, as well as highest net returns and B:C ratio.

- Straw mulching when done alone and when followed by a hand weeding were the next best treatments.

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Appendix

Weekly weather data during experimental period

Std. week No.	Date	Max. temp (°C)	Min. temp (°C)	Mean RH %	Total rain (mm)	Rainy days	Evaporation (mm)
23	4/6-10/6	31.2	24.3	86.0	10.7	1.0	2.5
24	11/6-17/6	31.4	23.2	86.0	18.0	1.0	2.3
25	18/6-24/6	30.7	23.5	85.6	13.0	0.7	2.0
26	25/6-1/7	31.1	23.4	82.0	17.1	1.0	2.5
27	2/7-8/7	29.9	23.3	92.0	23.4	1.0	2.0
28	9/7-15/7	30.2	23.3	86.0	12.0	0.5	2.3
29	16/7-22/7	31.8	22.4	86.5	15.0	0.6	2.4
30	23/7-31/7	30.9	23.1	85.6	16.3	0.8	2.4
31	1/8-6/8	29.3	22.3	92.0	22.6	1.0	2.3
32	7/8-13/8	28.5	22.5	91.2	54.0	1.0	1.4
33	14/8-20/8	30.6	23.3	91.3	6.6	0.5	2.6
34	21/8-27/8	31.5	23.5	79.2	0.9	0.1	2.7
35	28/8-2/9	32.8	23.5	77.0	1.5	0.1	3.9
36	3/9-9/9	31.5	22.8	85.6	19.3	0.5	2.1

NON-CHEMICAL WEED MANAGEMENT IN CHILLI (*Capsicum annuum* L.)

By

FASNA P.
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ABSTRACT OF THE THESIS

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Faculty of Agriculture

Kerala Agricultural University

Department of Agronomy

COLLEGE OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

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ABSTRACT

One of the major problems in any crop production system is weed infestation which causes reduction in both the yield and quality of produce. Although the use of herbicides provides effective and sustained weed control, it is not a preferred option because of environmental concerns. This is particularly true in the case of vegetables, some of which are consumed either partially cooked or raw. The research programme entitled 'Non-chemical weed management in chilli (*Capsicum annuum* L.)' was carried out with the objective of evaluation of non-chemical methods of weed management in chilli.

The experiment was conducted at the Department of Agronomy, College of Agriculture, Vellanikkara from June 2020 to September 2020. The field was infested with broad leaf weeds, grasses and sedges. Randomized block design used for laying out the experiment, with seven treatments and three replications. The treatments were, T_1: stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by two hand weedings at 30 DAT and 60 DAT, T_2: stale seed bed for 14 days followed by shallow digging and planting of chilli, followed by one hand weeding at 45 DAT, T_3: black polythene mulch (30 microns), T_4: straw mulch at 7.5 t/ha applied twice, at planting and one month after planting, T_5: straw mulch at 7.5 t/ha applied twice, at planting and one month after planting followed by one hand weeding at 60 DAT, T_6: hand weeding at 30 and 60 DAT and T_7: unweeded control.

Black polythene mulch (T_3) recorded highest weed control efficiency and lowest weed density, weed dry matter production and weed index, whereas straw mulch when applied alone (T_4) and when followed by one hand weeding (T_5) were the next best treatments with high weed control efficiency and low weed index. The treatments hand weeding (T_6), stale seed bed when followed by two hand weedings (T_1) and one hand weeding (T_2) were not effective in controlling weeds. The lowest weed control efficiency and the highest weed index values were recorded for the unweeded control (T_7) at all stages of observation.

Various weed management practices had significant effect on growth and yield parameters of chilli. At all stages of observation, the plant height of chilli in polythene mulching (T_3) was found to be the greatest followed by straw mulching when done alone (T_4) and when followed by one hand weeding (T_5). Unweeded control (T_7) had the lowest values. Chilli plants in polythene mulching (T_3) recorded the highest number of fruits per plant (218) and fruit yield (22.44 t/ha), followed by straw mulching both when done alone (T_4) (182 nos. and 18.89 t/ha respectively) and when followed by one hand weeding (T_5) (177 nos. and 18.38 t/ha respectively). Hand weeding (T_6) and stale seed bed when followed by two hand weedings (T_1) recorded lower yields than straw mulching. Unweeded control (T_7) recorded lowest values for fruit length, fruit girth, fruit weight, number of fruits per plant and fruit yield.

The soil physico-chemical characteristics pH, EC, organic carbon, and available N, P and K were influenced by different weed management practices. The organic carbon content in soil was highest in polythene mulching (T3) at 60 DAT (1.45 %) and after the final harvest (1.49 %). At both stages of observation, straw mulching (T4) had highest values of available P (77 and 79 kg/ha respectively) and K (414 and 408 kg/ha respectively), whereas available N was found higher in black polythene mulch (T_3) at 60 DAT (246 kg/ha) and in stale seed bed followed by one hand weeding (T_2) after the final harvest (239 kg/ha).

Considering the economics of cultivation, black polythene mulching (T_3) recorded highest gross returns (Rs.22.44 lakhs/ha), net returns (Rs. 9.94 lakhs/ha) and B:C ratio (1.84) and was followed by straw mulching when done alone (T_4) and when followed by a hand weeding (T_5). Black polythene mulching was thus identified as the best non-chemical weed management technique in chilli, having highest weed control efficiency leading to enhanced growth and yield parameters and highest net returns and B:C ratio. Straw mulching when done alone or when followed by one hand weeding were the next best treatments with respect to weed control efficiency, growth, yield and net returns of chilli.

സംഗ്രഹം

മുളകുകൃഷിയിലെ കളകളെ ഫലപ്രദമായി നിയന്ത്രിക്കാനുള്ള ഏറ്റവും അനുയോജ്യമായ രാസവസ്തുരഹിത മാർഗം കണ്ടെത്തുക എന്ന ലക്ഷ്യത്തോടു കൂടി ജൂൺ 2020 മുതൽ സെപ്റ്റംബർ 2020 വരെയുള്ള കാലയളവിൽ തൃശൂരിലെ കാർഷിക സർവകലാശാലക്ക് കീഴിലുള്ള കോളേജ് ഓഫ് അഗ്രിക്കൾച്ചർ വെള്ളാനിക്കരയിലെ അഗ്രോണമി വിഭാഗത്തിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി.

അനുഗ്രഹ എന്ന മുളകിനം ഉപയോഗിച്ചു നടത്തിയ പഠനത്തിൽ ഏഴു വ്യത്യസ്ത രാസവസ്തുരഹിത കള നിയന്ത്രണ മാർഗങ്ങളുടെ മികവ് പരീക്ഷിച്ചു. നടീൽ നിലം ഒരുക്കി ഉടനടി നടാതെ വെറുതെ ഇട്ട് കളകൾ മുളക്കാൻ അനുവദിച്ചു പതിനാലാം ദിവസം ചെറിയ തോതിൽ മണ്ണിളക്കി കളകളെ നശിപ്പിച്ചതിന് ശേഷം മുളക് തൈകൾ പറിച്ചു നടുകയും പിന്നീട് 30, 60 ദിവസങ്ങൾക്ക് ശേഷവും (T_1) 45 ദിവസങ്ങൾക്ക് ശേഷവും (T_2) കൈ കൊണ്ട് കള പറിച്ചു നീക്കുന്ന രീതി, കറുത്ത പോളിത്തീൻ ഷീറ്റ് ഉപയോഗിച്ചു പുതയിടൽ (T_3), വൈക്കോൽ ഉപയോഗിച്ചു പുതയിടൽ (T_4), വൈക്കോൽ ഉപയോഗിച്ചു പുതയിടുകയും, നട്ട് 60 ദിവസങ്ങൾക്ക് ശേഷം കൈ കൊണ്ട് കള പറിക്കുന്ന രീതി (T_5), നട്ട് 30, 60 ദിവസങ്ങൾക്ക് ശേഷം കൈ കൊണ്ട് കള പറിക്കുന്ന രീതി (T_6), കളകൾ ഒട്ടും തന്നെ നീക്കം ചെയ്യാതെയുള്ള രീതി (T_7) തുടങ്ങിയവയായിരുന്നു പരീക്ഷണത്തിൽ ഉൾപ്പെടുത്തിയിരുന്നത്.

വീതിയുള്ള ഇലകളോട് കൂടിയ കളകളായിരുന്നു കൃഷിയിടത്തിൽ പ്രധാനമായും കണ്ടിരുന്നത്. ബൊറേറിയ ഹിസ്പിട, ക്ലിയോം സ്പീഷിസ്സ്, ലിൻഡർണിയ ക്രസ്റ്റാഷ്യ, സ്കോപാറിയ ഡൽസിസ് തുടങ്ങിയ ശാസ്ത്ര

നാമങ്ങളുള്ള കളകളായിരുന്നു ഭൂരിഭാഗവും. പുല്ലു വർഗ്ഗത്തിൽ പെട്ട കളകളുണ്ടായിരുന്നെങ്കിലും അവയുടെ എണ്ണം തീരെ കുറവായിരുന്നു .

വിവിധ തരം രാസരഹിത കള നിയന്ത്രണ മാർഗങ്ങൾ മുളകിന്റെ വളർച്ചയെയും വിളവിനെയും ചെടികൾക്കിടയിൽ വളരുന്ന കളകളുടെ എണ്ണത്തെയും സാരമായി തന്നെ സ്വാധീനിക്കുന്നുണ്ട് എന്ന് പഠനത്തിൽ നിന്ന് വ്യക്തമായി. ഏറ്റവും കുറവ് കളകൾ കണ്ടത് പോളിത്തീൻ ഷീറ്റ് കൊണ്ടുള്ള പുതയിടൽ രീതിയിലായിരുന്നു. മുളക് തൈകളുടെ വളർച്ച, വിളവ് എന്നിവയും സാമ്പത്തിക ലാഭവും ഈ കള നിയന്ത്രണ മാർഗത്തിലാണ് കൂടുതലായി കണ്ടത്.

പ്രസ്തുത പഠനത്തിന്റെ വെളിച്ചത്തിൽ പ്ലാസ്റ്റിക് ഷീറ്റ് കൊണ്ടുള്ള പുതയിടൽ മുളക് കൃഷിയിലെ മികച്ച രാസരഹിത കള നിയന്ത്രണ മാർഗമായി ശുപാർശ ചെയ്യാവുന്നതാണ്. വൈക്കോൽ കൊണ്ടുള്ള പുതയിടലാണ് അടുത്ത മികച്ച രീതിയായി നിരീക്ഷിച്ചത്.