INTEGRATED WEED MANAGEMENT IN COWPEA
(*Vigna unguiculata* L.)

by
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(2019-11-171)

THESIS

Submitted to the partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
PADANNAKKAD, KASARAGOD-671314
2022

DECLARATION

I hereby declare that this thesis entitled '**Integrated weed management in cowpea (*Vigna unguiculata* 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, associateship, fellowship or other similar title, of any other university or society.

Padannakkad
19.04.2022

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CERTIFICATE

Certified that this thesis entitled '**Integrated weed management in cowpea (*Vigna unguicalata* L.)**' is a record of research work done independently by **Ms. Amaya C. P. (2019-11-171)** under my guidance and supervision and that it has not previously formed the basis for the award of any degrees, fellowship or assocateship to her.

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ACKNOWLEDGEMENT

This thesis would not have been possible without the support and inspiration from a number of wonderful individuals. My sincere thanks to all of them for being a part of this journey and making this possible.

There are no words to convey my profound gratitude and indebtedness to my major advisor, ***Dr. Gayathri Karthikeyan P****., Assistant Professor, Department of Agronomy, College of Agriculture, Padannakkad for her valuable guidance, suggestions, support, constant motivation, care and affectionate dealing during the entire course period and research work. I confess that it has been a great fortune and proud privilege for me to be associated with her during my M.Sc. programme.*

I wish to express my sincere thanks to ***Dr. Jinsy V. S.*** *Assistant Professor and Head (i/c), Department of Agronomy, College of Agriculture, Padannakkad and member of my advisory committee for her guidance, concern, motivation and valuable suggestions throughout the course period and research work.*

I would like to express my sincere thanks to ***Dr. Manikandan N****, Assistant Professor, Department of Agricultural Meteorology, College of Agriculture, Padannakkad and member of my advisory committee for his insightful comments and encouragement during the research work,* ***Dr. Sumesh K. V,*** *Assistant Professor, Department of Plant Physiology, College of Agriculture, Padannakkad for his support and guidance during the research work and* ***Dr. Meera V. Menon****, Professor (Agronomy), Cashew Research Station, Madakkathara, Thrissur and member of my advisory committee for her valuable suggestions, sensible criticism and treasured guidance for successful completion of research work and thesis preparation.*

I wish to express my sincere thanks to Professor ***Dr. Bridgit T.K*** *for her kindness, love, motherly affection and constant encouragement during the research work.*

I am also thankful to my teachers ***Ms. Ancy Francis, Dr. K. M Sreekumar, Dr. Raji Vasudevan and Dr. G. V. Sudarsana Rao*** *for their valuable guidance during the course of study. I express my sincere thanks to* ***Dr. V. P. Ajithakumari****, Assistant librarian, College of Agriculture, Padannakkad for providing me the library facilities during the study period. I am also thankful to* ***Ms. Ramya. V****, Research Assistant, Department of Soil Science and Agricultural Chemistry for helping me in laboratory analysis and* ***Mr. Manjunath****. I also express my sense of obligation to all administrative staff, teaching assistants and non-teaching* *staff of college of Agriculture, Padannakkad and Instructional farm Karuvacheri who were involved for my smooth completion of the course.*

I express my heartfelt gratitude to ***Mr. Ratheesh. P. K****, farm manager for his immense support, care and timely help that made me confident in difficult situations and also farm staffs including* ***Renjithetan, Manojetan, Satheeshettan, Raviyettan*** *and labours for their help.*

I feel boundless pleasure to express the help of my seniors ***Faisy, Deepa, Sugina, Billy Cherian, Sarin, Asok Madala, Giffy, Reni, Jazeera and Sajay,*** *my batchmates* ***Sreelekshmi, Arya, Veena, Haritha, Archana, Swathy, Aiswarya, Sai Parvathy, Alan, Aswin, Ramesh, Thejas and Vishnu*** *and my juniors* ***Aparna and Sai Kumar.***

Words cannot describe my thanks to my dearest friend ***Anjitha*** *who have always given encouragement and support with love and care during my struggled period.*

I wish to acknowledge with gratitude the award of junior research fellowship by the ***Kerala Agricultural University*** *during the tenure of the M. Sc. (Ag) programme.*

This thesis would be incomplete if I do not reckon the sacrifice, love, affection and support of my father ***Chandran*** *and mother* ***Pushpa*** *who brought me to this world and have been beside me, helping me psychologically, emotionally, morally and materially to overcome all the obstacles I faced during my study. Thanks to my brother* ***Anjal*** *for his encouragement and unquantifiable love. Thanks to my relatives for their kind blessings.*

Any omission of this acknowledgement does not indicate lack of gratitude.

Dedicated to

Achan and Amma

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LIST OF ABBREVIATIONS & SYMBOLS

&	- And
DAS	- Days after sowing
cm	- Centimeter
m^2	- meter square
GRDC	- Grain Research and Development Corporation
WCE	- Weed Control Efficiency
WI	-Weed Index
WAE	- Weeks After Emergence
DAP	- Days After Planting
WAS	- Weeks After Sowing
kg	- Kilogram
g	- Gram
WDWC	- Weed Dry Weight in Control plot
WDWT	- Weed Dry weight in Treated plot
LAI	- Leaf Area Index
DMP	- Dry Matter Production
^{o}C	- Degree Celsius
^{o}N	- Degree North
^{o}E	- Degree East
N	- Nitrogen
P	- Phosphorus

K	- Potassium
EC	- Electrical Conductivity
pH	- Power of Hydrogen (pouvoir hydrogene)
CD	- Critical Difference
BCR	- Benefit-cost Ratio
POP	- Package of Practices
K_2O	- Potassium Oxide
P_2O_5	- Phosphorus Pentoxide
BLW	- Broad leaved weeds

INTRODUCTION

1. INTRODUCTION

Pulses are the major source of protein in the Indian diet. Pulses contain significant amount of fibre, vitamins and minerals like, iron, folate, zinc and magnesium. They can play a vital role to address national food and nutritional security. India is the largest producer, consumer and importer of pulses in the world (Abraham and Pingali, 2021) with a production of 23.15 MT from an area of 28.34 mha with a projected production demand of 35 MT by 2030 (GoI, 2021). Pulse cultivation enhances soil fertility due to the presence of nitrogen fixing bacteria in their root nodules which can fix up to 400 kg nitrogen per ha (GRDC, 2009), thereby enhancing the soil nutrient status and reducing the nitrogen demand of the next crop in rotation by up to 25 per cent (Panda, 2011).

In Kerala, cowpea is the major pulse crop cultivated followed by black gram, green gram and pigeon pea. Grain purpose cowpea is grown during *rabi* and summer seasons. Farmers, especially in Kasaragod district are reluctant to adopt proper weed management practices for pulses owing to the high cost of labour and lack of awareness regarding herbicide usage. Weed invasion is a considerable constraint that limits the yield of cowpea. Weed invasion during the critical period of crop weed competition can be detrimental to crop production and the extend of yield reduction can go even up to 90 per cent (Amador-Ramirez *et al.*, 2001). Therefore, the field should be maintained weed free up to a period of 30 - 35 DAS (Pooniya *et al.,* 2014). There was about 82 per cent yield increase noticed when weeds were effectively controlled up to 45 DAS (Tripathi and Govindra, 2001).

High cost of labour has led to the use of herbicides in pulses; but compared to cereals the choice of herbicides is less. Amalgamation of cultural, mechanical and chemical means of weed control have been found to result in better management of weeds compared to any of the methods alone. Hand weeding is the oldest and the efficient weed management practice and it also helps to loosen the soil which has resulted even upto 90 per cent yield improvement in cowpea when done 25 DAS (Ahlawat *et al*., 2005). Hand weeding becomes difficult during persistent rains and due to lack of timely availability of labour.

Green leaf mulching is an effective non chemical method of weed control, especially against annual weeds and some perennial weeds. A study led by Sapkota *et al*. (2015) discovered that significantly promising yield could be obtained for cowpea from the plots which were mulched compared to the non-mulched ones and they have also opined that mulching is beneficial to cowpea for getting higher yields and also aids availability of soil nutrients. Higher numbers of nodules were recorded in plants treated with organic mulches compared to that of plastic mulches (Dukare *et al.,* 2017). Junior *et al*. (2018) opined that density of *Cyperus rotundus* and *Digitaria horizontalis* were reduced by mulching.

Managing weeds using herbicides is comparatively easier and economic while considering labour cost. Most commonly used pre-emergence herbicide in cowpea is pendimethalin. Pre-emergence usage of pendimethalin @ 2 l ha^{-1} in addition to hand weeding done 30 days after sowing (DAS) resulted in better weed control and improved yield in cowpea (Yadav *et al.,* 2015). Application of pendimethalin @ 3.5 l ha^{-1} combined with one hand weeding at 45 DAS could result in significant yield increase in cowpea (Usman, 2013). In fodder cowpea, lowest weed density and dry matter were obtained by the spraying of pendimethalin @ 1 kg ha^{-1} along with a single hand weeding at 30 DAS (Jaibir *et al.,* 2004).

Imazethapyr is a post-emergence herbicide employed in weed management in pulses and has been proved to be safe for application in cowpea as the herbicide gets converted to nontoxic metabolites within the plant tissue. Laboratory experiments have revealed that cowpea could tolerate even upto a dose of 700 g ha^{-1} (Bearg and Barrett, 1996). Application of the imazethapyr could decrease the weed population and biomass (Kumar *et al*., 2016) with reduced phytotoxicity to crops (Sinchana and Raj, 2020).

Greater herbicide efficiency was recorded by pre-emergence application of pendimethelin @ 1 kg ha^{-1} along with hand weeding at 40 DAS; followed by the post-emergence spraying of imazethapyr @ 0.75 kg ha^{-1} at 20 DAS with single hand weeding at 40 DAS (Gupta *et al*., 2013). Pre-emergence use of pendimethalin @ 1 kg ha^{-1} along with one hand weeding done at 40 DAS and post emergent application of imazethapyr @ 0.075 kg ha^{-1} along with a single hand weeding at 40 DAS decreased weed density (Yadav *et al.,* 2015). Gupta *et al.* (2016) suggested that greater net income and B:C ratio was obtained in cowpea treated with imazethapyr @ 40 g ha^{-1}.

Integration of different weed management techniques rather than depending on a single method has resulted in better management of weeds. This would be reflected in the weed parameters, growth and yield attributes of cowpea. Hence, the present study was undertaken with the following objective.

- To evaluate the efficacy of different weed management practices and to find out the economics of weed management in cowpea.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Cowpea is the major pulse crop cultivated in Kerala and like any other crop, cowpea is also sensitive to weed infestation specially during the initial period of crop growth. Farmers have several approaches to manage weeds in cowpea which includes physical, cultural and mechanical methods. Several studies have revealed that integration of various management practices gave better results than a single method of management. This chapter reviews quite a lot of research results relating to the effect of integrated weed control methods on growth attributes, growth, yield attributes and yield of cowpea. Wherever there was dearth of literature in cowpea, efforts were made to include results of works done in other pulse crops. Efforts were also made to evaluate the economics of different weed control techniques.

2.1. EFFECT OF WEED MANAGEMENT PRACTICE ON WEED PARAMETERS IN COWPEA

Hand weeding is the oldest and highly effective method of weed control in cowpea especially if the field is to be kept weed free for about 30-35 DAS (Anon., 2014). Hand weeding twice along with one intercultural operation resulted in greater yield and the increment in yield was in a pattern of 25.2 per cent compared to that of weedy check in cowpea (Kumar *et al*., 2016).

In order to formulate an economic weed management strategy for cowpea, a study was conducted at Regional Agricultural Research Station (RARS), Pattambi. Maximum weed control efficiency was found in the treatments where pre-emergence application of pendimethalin was done @ 0.75 kg ha^{-1} along with hand weeding done at 35 DAS (Mathew *et al*., 1995). Comparable results were portrayed by Jabir *et al*. (2004).

Hanumanthappa *et al*. (2012) reported that in the diverse weed management methods tried in cowpea, pre-emergence spray of pendimethalin @ 0.75 kg ha^{-1} with a single hoeing done 20-25 DAS controlled weeds effectively and reduced the dry weight of weeds. Improved weed control efficiency of 80 per cent was obtained by the usage of pendimethalin @ 0.75 kg ha^{-1} accompanied by imazethapyr @ 0.75 kg ha^{-1} (Jha and Soni, 2013).

Kumar (2014) reported that maximum value for weed control efficiency (WCE) was recorded in the treatment of black polythene mulching along with a hand weeding done 20-45 DAS and imazethapyr application @ 1.2 l ha^{-1} along with one hand weeding compared to that of weed free check.

An investigation by Sah *et al*. (2015) revealed that the dry weight and density of weeds decreased and WCE increased with the poly ethylene mulch which was followed by the treatment in which usage of quizalofop-ethyl @ 0.05 kg ha^{-1} was done along with hand weeding once in cowpea. Application of metolachlor @ 1 kg ha^{-1} + hand weeding at five weeks after emergence (WAE) and a spray of pendimethalin @ 1 kg ha^{-1} + hand weeding at 5 WAE significantly decreased the weed dry weight (Mekonnen and Dessie, 2016).

According to Gupta *et al*. (2016) the lowest dry weight and highest weed control efficiency for both monocot and dicot weeds were recorded by the efficient usage of imazethapyr along with imazemox @ 40 g ha^{-1} at 20 DAS. Similar observation was made by Kumar and Singh (2017) by the application of imazethapyr @ 75 g ha^{-1} or quizalofop-p-ethyl @ 40 g ha^{-1} at 20-25 DAS followed by a hand weeding and an intercultural practice at 40-45 DAS.

Sinchana and Raj (2020) evaluated different weed management methods in cowpea and the evaluation revealed that application of herbicides such as imazethapyr or pendimethalin or diclosulam after the manual weeding or post emergent application of same herbicides or mulching with post emergent usage of imazethapyr or quizalofop-p-ethyl were found to be effective in controlling a wide range of weeds.

An investigation done by Teli *et al*. (2020) also revealed that pre-emergence application of pendimethalin @ 750 g ha^{-1} along with post emergent spraying of imazethapyr and imazamox both @ 33.75 g ha^{-1} recorded an elevated WCE and lower weed dry weight.

Mulching had the ability to suppress weed emergence and also lower the weed seed bank population (Pullaro *et al*., 2006). Organic mulches improved soil fertility by incorporating organic matter; decreased the soil temperature and weed density (Sinkeviciene *et al*., 2009; Mahmood *et al*., 2015). They also helped in reducing soil erosion and weed density (Monquero *et al*., 2009; Pereira *et al*., 2011).

Sinchana (2020) has reported that grasses, sedges and broadleaved weeds could be successfully controlled by mulching using banana leaves @ 10 t ha^{-1}. Mulching inhibited sunlight from reaching the soil and thus prevented germination, growth and establishment of weeds (Sinchana and Raj, 2020).

2.2. GROWTH PARAMETERS OF COWPEA AS INFLUENCED BY WEED MANAGEMENT

Weed infestation adversely affects different crop growth parameters which in turn result in poor development and crop yield. The effect of various weed control techniques on biometric factors *viz*. plant height, number of branches per plant, number of nodules per plant, leaf area index and total dry matter content are reviewed in this section.

2.2.1. Plant height, number of branches and number of nodules per plant

Plant height, number of branches, nodules, weight of pods, and number of seeds of cowpea were found to be reduced due to weed infestation and the effect was more under higher weed densities (Remison, 1978). Cultural practices like mulching with grasses has recorded enhancement in the number of nodules in pulses compared to unweeded plots (Gupta and Gupta, 1983).

As a result of better weed management practice, number of branches per plant, plant height and number of leaves per plant were enhanced by the application of pre-emergence herbicide pendimethalin @ 1.5 l ha^{-1} or 2 l ha^{-1} at 3 days after planting (DAP) along with one hand weeding done at 30 DAS in cowpea (Parasuraman, 2000).

Inference of two year experimental data on the influence of various weed management practices and spacing on field bean was revealed that plant height and first pod insertion were not influenced in the first year; however in the plots where mechanical control and herbicide application were done, there was an improvement in plant height compared to the control in the second year (Avola *et al*., 2008).

A study done by Madukwe (2012) to evaluate the effect of different weed control methods on growth and yield of cowpea have shown that usage of herbicides at 2-3 leaf stage increased plant height compared to that of hand weeded cowpea. Another study by Na-allah *et al.* (2017) revealed that plant height, canopy spread and crop growth rate were improved by the application of pendimethalin @ 2 kg ha^{-1} and two hand weedings at 3^{rd} and 6^{th} week after planting.

Hanumanthappa *et al*. (2012) conducted an investigation to assess the effect of weed management practices on growth and yield of cowpea. Out of the different weed control methods, pre-emergence usage of pendimethalin @ 0.75 kg ha^{-1} along with a hand hoeing at 20-25 DAS gave highest number of branches per plant. Similar results were claimed by Usman (2013), wherein pendimethalin @ 2.5 l ha^{-1} was applied followed by one hand weeding 6 weeks after planting (WAP).

A study by Dukare *et al*. (2017) showed that number of nodules were greater in plants treated with organic mulch with respect to that of plastic mulching in cowpea. Similar enhancement in the number of nodules was also reported by Mekonnen and Dessie (2017) in the treatment where hand weeding was done followed by hoeing at 21 days after emergence (DAE) of cowpea in comparison with herbicidal treatment such as metolachlor @ 1 kg ha^{-1} and pendimethalin @ 1 kg ha^{-1}.

Sinchana (2020) has also reported that nodulation in cowpea was improved by the use of pre-emergence herbicide diclosulam @ 12 g ha^{-1} as compared to hand weeding done at 25 DAS along with mulching of dried banana leaves @ 12 t ha^{-1}.

2.2.2. Leaf area and total dry matter

A study conducted by Kumar and Das (2008) showed that leaf area index (LAI) was not significantly affected by weed control treatments at 20 DAS in cowpea. However, at 40 DAS, LAI was significantly influenced by weed control treatments. He has also reported that higher values for leaf area was observed in plots where hand weeding was carried out at 15 and 30 DAS along with earthing up at 30 DAS; dry matter production was also influenced by the weed control treatments. An increase in dry matter production was recorded by hand weeding on 15 and 30 DAS along with earthing up at 30 DAS. However, Usman (2013) has reported that weed infestation and weed control treatments did not significantly influence LAI in cowpea.

A study conducted by Mekonnen and Dessie (2016) brought out that dry weight of cowpea was influenced by many factors like weed density, location, management practices and their interaction. Higher dry matter production was observed in the treatments in which the plants were treated with metolachlor @ 1.0 kg ha^{-1} with a hand weeding done 5 WAS. This result was on par with metolachlor treatment at all application rates, two hand weeding at 2 and 5 WAE, pendimethalin @ 1 kg ha^{-1}, low level of both herbicides combined along with one hand weeding, use of pendimethalin along with a hand weeding 5 WAE and the weed free check. In another study, it was observed that smallest dry matter content was obtained from the weedy check than the other treatments in cowpea and highest dry matter was obtained from one hand weeding along with hoeing at 4 WAS which was also comparable with weed free plot (Mekkonnen *et al*., 2017).

The highest dry matter production of 16.70 g per plant was obtained in cowpea when the field was kept weed free upto 50 DAS and it was comparable with the usage of pendimethalin @ 750 g ha^{-1} and with imazethapyr and imazamox @ 33.75 g ha^{-1}. Maximum leaf area was also noticed in the weed free plot and was comparable with the herbicide treatments in cowpea (Teli *et al*., 2020).

2.3. YIELD AND YIELD ATTRIBUTES OF COWPEA AS INFLUENCED BY WEED MANAGEMENT

Yield and yield attributes include number of pods per plant, number of seeds per pod, pod weight per plant, test weight, pod yield and seed yield.

Adigun *et al.*, (2014) concluded that weeds were the root cause of potential yield depletion in cowpea which was about 25 to 60 per cent and it significantly affected the yield attributes of cowpea. Similar opinion was also made by Mekonnen and Dessie (2016).

Patel *et al.* (2003) found that yield attributes and yield of cowpea were improved due to the effective usage of pendimethalin @ 3.75 l ha^{-1} with a hand weeding at 5 WAS. Yield and quality of cowpea was decreased by weed infestation due to the competition with crops for nutrients, light and water (Ohanmu and Ikhajiagbe, 2019). According to Sinchana and Raj (2020) integrated weed management (IWM) using pre and post emergent herbicides such as pendimethalin, diclosulam and imazethapyr quizalofop-p-ethyl; and manual weeding along with mulching resulted in better yield.

2.3.1. Effect of weed management practices on yield attributes

Test weight of cowpea seeds were highest in the plots where hand weeding was carried out at 20 and 40 DAS which was comparable with the treatments where pendimethalin was applied @ 750 g ha^{-1} along with one hand weeding done at 40 DAS and application of imazethapyr @ 75g ha^{-1} along with single hand weeding at 40 DAS (Mathew *et al*., 1995). Patel *et al*. (2003a) found that spraying of pendimethalin was effective in managing weeds and it resulted in higher number of pods per plant in cowpea. In another study by Patil *et al*. (2014), it was suggested that use of pendimethalin @ 3.75 l ha^{-1} along with one hand weeding at 5 WAS in cowpea improved the number of pods per plant.

A study conducted by Chattha *et al.* (2007) at National Agriculture Research Centre, Islamabad during 2 crop years to evaluate the efficacy of weed control methods on yield and yield attributes of mung bean revealed that application of methabenzthiazuron @ 2 kg ha^{-1} during 2-3 leaf stage of weeds followed by one hand weeding on 50 DAS gave increased number of pods per plant and seeds per pod. Madukwe *et al.* (2012) noticed that weed management using chemical herbicides increased the number of pods per plant in cowpea when the plant was at its two to three leaf stage. Similar results were also reported by Usman (2013). However, he has reported that the test weight was not significantly influenced by the weed control treatments in cowpea. Least number of pods per plant was observed in control plot compared to all other weed control treatments in cowpea (Sunday and Udensi, 2013). Kujur *et al*. (2015) observed that test weight of cowpea was enhanced with hand weedings at 20 and 40 DAS.

A study carried out by Mekonnen and Dessie (2016) revealed that higher number of pods per plant was obtained by spraying of metolachlor @ 1 kg ha^{-1} with a combination of hand weeding at 5 WAE. They have also reported that test weight was highest in weed free plot which was on par with hand weeding at second and fifth WAE, application of pendimethalin @ 1 kg ha^{-1} along with one hand weeding at 5 WAE, metolachlor @ 1 kg ha^{-1} along with one hand weeding at 5 WAE and combined application of pendimethalin @ 1.3 kg ha^{-1} and metolachlor @ 2 kg ha^{-1}. Mekonnen *et al*. (2017) obtained highest test weight for cowpea in the weed free plots which was similar to the test weight in plots where hand weeding was done at 3 WAS or 4 WAS.

2.3.2. Effect of weed management practices on yield

Tripathy and Govindra (2001) reported substantial increase in pod yield of cowpea in the plots which were maintained weed free upto 45 DAS. There was remarkable increase in pod yield in cowpea when there was proper weed management upto 45 DAS and there was about 82 per cent yield reduction in unweeded plots (Muhammad *et al*., 2003). Application of herbicides during two to three leaf stage along with hand weeding at 50 DAS increased the grain yield of cowpea by 68 per cent in comparison with the unweeded plot (Dadari, 2003; Silva *et al*., 2003). Weed management by applying pendimethalin @ 0.75 kg ha^{-1} together with hand weeding done five WAS showed improved seed yield in comparison with the plots where hand weeding was done alone (Patel *et al*., 2003). Comparable result was reported in cowpea by Jaibir *et al*. (2004).

Rathi *et al*. (2004) disclosed the application of pendimethalin @ 0.5 kg ha^{-1} along with a hand weeding at 60 DAS was effective in controlling weeds and it has resulted in increased seed yield.

Madukwe *et al*. (2012) concluded that weed management using chemical herbicides at two to three leaf stage in cowpea resulted in highest seed yield compared to that of plots in which hand weeding was done at 50 DAS.

Hanumanthappa *et al.* (2012) indicated that greater seed yield was obtained by the IWM practice of applying pendimethalin @ 0.75 kg ha^{-1} along with a hand hoeing at 20-25 DAS in cowpea and highest seed yield was also obtained for this treatment. Hand weeding done at the reproductive stage of cowpea, caused mechanical injury to the crop resulting in decreased pod yield (Adigun *et al*., 2014).

A variation was seen in pod yield with respect to the different weed management practices and every treatment recorded considerably better results compared to the control plot. (Sah *et al*., 2015). A seed yield of 736 kg ha^{-1} was obtained by the application of pre-emergence herbicide pendimethalin @ 750 g ha^{-1} followed by the use of imazethapyr and imazamox @ 33.75 g ha^{-1} at 15-20 DAS in cowpea (Teli *et al*., 2020).

Weed management practices carried out in different crops like groundnut (Malligawad *et al*., 2000) and soybean (Kurchania *et al*., 2001) has also revealed that combined application of pendimethalin along with cultural practices and combined application of herbicides resulted in enhanced seed yield respectively. Yadav *et al*. (2017) suggested that integration of various weed control techniques would result in better management of weeds compared to any single management method; weed control using herbicides only or along with manual weeding was found to be the most efficient method.

2.4. EFFECT OF WEED MANAGEMENT PRACTICES ON NUTRIENT UPTAKE OF COWPEA

Kujur *et al*. (2015) opined that compared to the weedy check, nutrient assimilation by cowpea was greater in plots where hand weeding and herbicide treatment was done. Nutrient depletion was highest in weedy check. Hand weeding with pre-emergence application of fluchloralin @ 1kg ha^{-1} shown better uptake of N, P and K.

Similar outcomes of heavy nutrient depletion in weedy check was reported in soybean also and nutrient uptake was increased in the plots where soil solarization was done along with pre-plant application of glyphosate and two hand weeding (Kumar and Das, 2008).

2.5. EFFECT OF WEED INFESTATION AND WEED MANAGEMENT PRACTICES ON PEST AND DISEASES IN COWPEA

Weeds act as alternate hosts to pests and diseases, thereby increasing their infestation (Jackai and Adalla, 1997). *i.e*, there are chances of interaction effect of insects and weeds which is more fatal than their individual effects (Gurr and Wratten, 1999; Mensah, 1999). In certain cases, the presence of certain weed species may result in pest or disease incidence (White and Whitham, 2000). Takim and Uddin (2010) have reported that the intensity of pest and diseases was also influenced by the different weed management practices and weedy check proved to harbour more pests and diseases compared to other treatments.

2.6. WEED FLORA IN PULSE FIELDS

Soil, location, biodiversity of the region and the prevailing climate determines the type of weed flora in any crop field. Weeds like *Imperata cylindrica*, *Talinum triangulare*, *Euphorbia heterophylla*, *Synedrella nodiflora*, *Ageratum conezoides*, *Spigelia anthelmia*, *Amaranthus* spp., *Ipomoea* spp., *Cynodon dactylon* etc. are the dominant weed flora seen associated with cowpea (Akinyemiju and Echendu, 1987). According to Mathew and Sreenivasan (1998) dicotyledonous weeds were mostly seen in summer season and during kharif season sedges & grasses dominated. Tripathi and Govindra (2001) noticed that cowpea cultivated under summer season was infested with weeds like *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Echinochloa crusgalli*, *Eleusine indica*, *Gnaphalium indicum*, and *Sorghum halapense* whereas Hoe (2007) observed the presence of weeds like *Amaranthus retroflexus, Digitaria sanguinalis and Portulaca oleracea* in summer cowpea.

Likewise, Kumar and Singh (2017) has reported the prominent weed flora seen in cowpea fields included *Commelina nudiflora, Portulaca oleracea, Cynodon dactylon, Echinochloa colona, Brachiaria* spp., *Leucas aspera, Phyllanthus niruri, Tridax procumbens,* and *Cyperus rotundus. Cyperus rotundus, Trianthema monogyana, Commelina benghalensis, Echinochloa colona and Digera arvensis* were reported by Yadav *et al*. (2018).

2.7. ECONOMICS OF DIFFERENT WEED MANAGEMENT PRACTICES IN PULSES

Fontes *et al*. (2010) suggested that weed control using herbicides was the most cost effective method compared to mechanical methods. An efficient weed management practice should have high WCE and should also be economic; so that farmers would be ready to adopt it in their field (Khaliq *et al*., 2002). Higher weed control efficiency (WCE), lower weed dry weight etc. were resulted when hand weeding was done at 15 and 30 DAS in cowpea. This was followed by the application of quizalofop ethyl @ 50 g ha^{-1} combined with hand weeding at 30 DAS. This particular treatment has also resulted in greater B:C ratio (Kundu *et al*., 2011). Greater net income and B:C ratio were obtained with the use of oxyfluorfen @ 0.1 kg ha^{-1} followed by imazethapyr @ 75 g ha^{-1} in soyabean (Manjunath and Hosmath, 2016).

Malligawad *et al*., (2000) reported that IWM practices such as pre-emergence application of pendimethalin along with cultural practices gave higher net returns. Highest B:C ratio was obtained by the application of fluchloralin @ 1 kg ha^{-1} followed by hand weeding and application of pendimethalin @ 1.5 kg ha^{-1} (Rana, 2002). Study conducted by Patil *et al*. (2014) to evaluate the efficacy and economics of IWM in vegeTable cowpea shown that mulching with black polythene along with pendimethalin application @ 1 kg ha^{-1} and pendimethalin application @ 1 kg ha^{-1} along with hand weeding at 30 DAS successfully controlled weeds and also enhanced the pod yield which reflected in highest net returns and B:C ratio. Application of pendimethalin @ 1.5 kg ha^{-1} along with two hand weeding at 30 and 60 DAS gave highest B:C ratio with efficient reduction in weed growth (Ratnam and Rao, 2014). Higher net profit was recorded when 2 hand weeding were done at 20 and 40 DAS but the post-emergence herbicide imazethapyr applied @ 75 g ha^{-1} with one hand weeding at 40 DAS recorded highest B:C ratio in cowpea (Kujur *et al.,* 2015). A study conducted to analyse the effect of weed management practices on cowpea grown under rainfed conditions revealed that lowest dry weight was obtained, when imazethapyr + imazemox were applied @ 40 g ha^{-1} at 20 DAS and highest seed yield, net returns and B:C ratio was also obtained in this treatment (Gupta *et al*., 2016). Integrated weed management practices including use of herbicides, hand weeding and cultural practices at 20 DAS recorded highest net return, gross return and B:C ratio than any single method of weed management (Kumar and Singh, 2017). Dried banana leaves mulched @ 10 t ha^{-1} followed by post-emergence application of quizalofop-p-ethyl or imazethapyr @ 50 g ha^{-1} resulted in great benefit and highest B:C ratio in bush type vegeTable cowpea compared to hand weeding @ 20 and 40 DAS (Sinchana, 2020).

Application of herbicides like pendimethalin, diclosulum and subsequent application of imazethapyr, quizalofop-p-ethyl and manual weeding along with mulching recorded high B:C ratio in cowpea (Sinchana and Raj, 2020).

2.8. RESIDUAL EFFECT OF PENDIMETHALIN

When pendimethalin was analysed for its persistence and depletion at two different doses of 1 and 2 kg ha^{-1} in soil, leaves and pods of pea, no harmful effects were recorded at 60 to 74 days after application for both the doses (Pandey and Tandom, 2006). Pendimethalin when applied as pre-emergence had enough persistence in soil which provided good weed control during the initial growth stages of chickpea but doesn't have any ill effect on the crop and the residue effects were below the maximum permissible levels (Sondhia, 2012). Similar results were reported by Tandon (2016) in soybean. Pendimethalin is the most popularly used herbicide for the effective management of weeds in cereals, fruits and vegetables and there were no harmful effects detected for the soil microorganisms even when applied at double dose (Martin *et al*., 2016). Kaur and Bhullar (2017) claimed that degradation of pendimethalin herbicide differed remarkably under field and laboratory conditions; however, residue was below maximum permissible limit during the crop harvest period.

2.9. RESIDUAL EFFECT OF IMAZETHAPYR

Pre-plant incorporation, pre-emergence and post emergent application of imazethapyr @ 80-100 g ha^{-1} managed weeds and did not impart any harmful effects on succeeding crops like wheat, barley and chickpea but it caused injury to mustard (Punia *et a*l., 2011). In a study conducted by Sangeetha *et al*. (2012) it was observed that imazethapyr was effective in managing weeds in soybean and there were no harmful residual effects observed in subsequent crops like sunflower and pearl millet. In an experiment to test the residual effects of imazethapyr in soil and soybean, it was observed that soil residues were less than that in plants; however, it was below maximum permissible limit. After the application of herbicide, a pre-harvest time interval of 80-90 days in soybean was recommended (Sondhia, 2015).

An investigation was done to assess the residue of imazethapyr in soil and soybean and it was observed the residual level in both soil and grains were below minimum threshold level. However, a pre-harvest time gap of 90-102 days was advised after imazethapyr application in the case of soybean (Sondhia *et al*., 2015). Singh (2017) carried out a two year experiment for evaluating the efficiency of pre and post emergent herbicides for weed management in soybean and to study the residual effects in succeeding mustard crop. Pendimethalin, imazethapyr and imazamox were the herbicides used and the results revealed that these herbicides have no harmful effect on the succeeding crop.

2.10. EFFECT OF PENDIMETHALIN ON SOIL MICROBIAL POPULATION

Soil microorganisms play a crucial role in nutrient recycling and maintenance of soil fertility (Lupwayi *et al*., 2004) and are an essential parameter for determining the quality of soil and metabolic processes (Wang *et al.*, 2008).

Berra *et al*. (2013) noticed that soil microorganisms took part in the degradation of herbicides and utilized them for their physiological processes. However, these herbicides inhibited the growth of microbes during the initial days of application and decreased their abundance before the degradation process. A study was conducted to assess the response of soil microbes on application of pendimethalin and imazaquin herbicides in cowpea fields and it was observed that the herbicide application decreased the colonization of vesicular arbuscular mycorrhizal fungi (Chikoye, 2014).

Adhikary *et al*. (2014) conducted an investigation to assess the impact of three herbicides viz. pendimethalin, oxyfluorfen and propaquizafop on soil microbes and it was found that microbial population in soil were significantly influenced by these chemicals and the intensity of inhibition was different with different herbicides used. Compared to fluazifop and pendimethalin, oxyflourfen caused maximum suppression of the bacterial colonies. These herbicides inhibited the fungal colonies up to 54 per cent. Sapundjieva *et al*. (2012) also reported similar findings. An experiment performed by Kocarek *et al*. (2016) showed that when pendimethalin was applied at double the recommended dose, there were no difference in potential or basal respiration in soil and dehydrogenase activity.

2.11. EFFECT OF IMAZETHAPYR ON SOIL MICROBIAL POPULATION

When imazethapyr was applied @ 10 to 100 times more than the recommended dose, it reduced the microbial biomass, carbon and dehydrogenase activity; and enhanced the activity of protease, catalase and hydrolytic capacity of the treated soil (Perucci and Sacrponi, 1994). Soil microbial biomass was changed by the application of imazethapyr in soil and the population of gram positive and gram negative bacteria and fungi were higher than other soil samples in the untreated than the treated soil (Zhang *et al*., 2010).

Xu *et al*. (2013) conducted an experiment to compare the effect of two higher doses of imazethapyr viz., ten and fifty times more than the recommended dose and it was found that there was an initial reduction in the microbial biomass carbon, total phospholipid fatty acids (PLFA) and bacterial PLFA. However, these parameters regained the initial status later on. A study carried out by Pertile *et al*. (2020) to evaluate the response of soil enzyme activity and soil microbial biomass towards the application of imazethapyr and flumioxazin revealed that microbial biomass soil was not influenced by the herbicide application and there was improvement in soil dehydrogenase activity, respiration and respiratory quotient.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present research work entitled ‘Integrated weed management in cowpea (*Vigna unguiculata* L.)’ was conducted during the period from December 2019 to March 2020, at Instructional farm II, Karuvacheri, College of Agriculture, Padanakkad. The work comprises of field experiment and laboratory studies to assess the efficacy and economics of different weed management techniques in cowpea. The details of materials used and the methods adopted for the works are described in this chapter.

3.1. SITE DESCRIPTION

The experimental field was located in the block 4 of Instructional farm II, Karuvacheri, College of Agriculture Padannakkad. The site is situated at 12º14’45’’N latitude and 75º 8’6’’E longitude at an elevation of 9 m above mean sea level. The geographical location of the experimental plot is given in the Fig. 1. The images used for showing the geographical location are written in the reference section (Google image 2021 a, b, c, d).

3.2. WEATHER

The data on weather parameters viz. rainfall, maximum and minimum temperature during the crop period were collected. The daily data was converted into standard meteorological weeks and shown graphically in Fig. 2. The weather data are given in the Appendix 1 and the abstract of weather data is given in Table 1.

3.3. SOIL TYPE

Soil samples were collected from the experimental plot for the analysis of physico-chemical properties. Soil texture is red sandy loam. The physico-chemical properties of the soil are presented in Table 2.

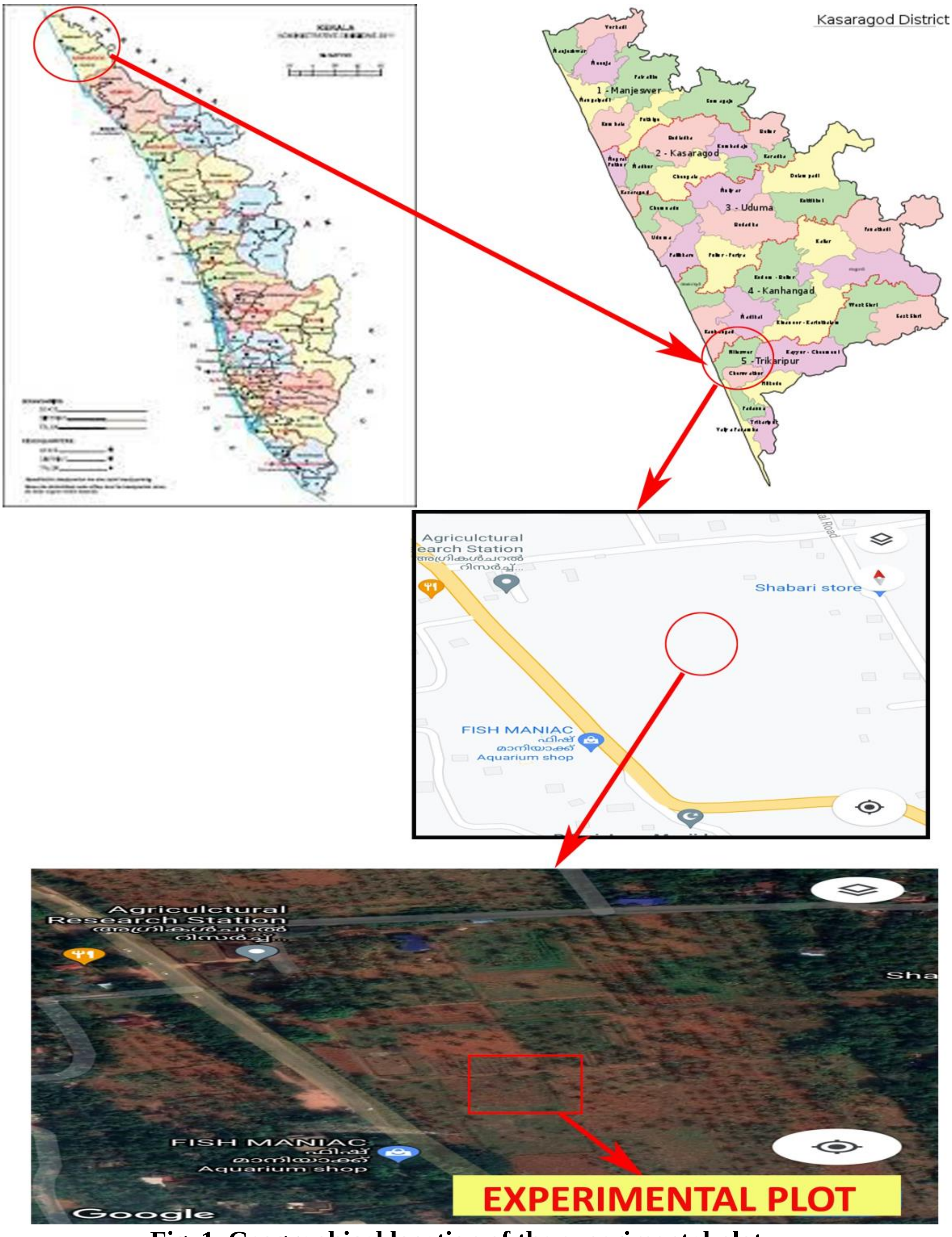


Fig. 1. Geographical location of the experimental plot

Table 1. Abstract of the weather data during the experimental period

Weather parameters	**Range**	**Mean**
Maximum temperature (ºC)	33.1 – 37.5	33.41
Minimum temperature (ºC)	19.8 – 24.8	22.32
Total rainfall (mm)	-	91.2

3.4. FIELD EXPERIMENT

The experiment was laid out in Randomized Block Design (RBD) with 11 treatments and 3 replications. Seed treatment was done *Rhizobium* culture (RH 15) purchased from COA, Vellayani and nutrient management practices were followed as recommended in POP (KAU, 2016). The layout of the experimental plot is presented in fig. 3.

3.4.1. Design and layout

Crop : Cowpea

Variety : PGCP 6

Design : RBD

Spacing : 30 cm x 25 cm

Plot size : 4 m x 5 m

Treatments : 11

Replications : 3

3.4.2 Treatment details

T_1 - Pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} (0-3 DAS)

T_2 - Pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} (0-3 DAS) + hand weeding (20-25 DAS)

T_3 - Pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} (0-3 DAS) + mulching

T_4 - Post-emergence application of imazethapyr @ 75 g ha^{-1} (20 DAS)

T_5 - Post-emergence application of imazethapyr @ 75 g ha^{-1} (20 DAS) + hand weeding (35 DAS)

T_6 - Post-emergence application of imazethapyr @ 75 g ha^{-1} (20 DAS) + mulching

T_7 - Mulching + hand weeding (20 DAS)

T_8 - Hand weeding alone (15 and 30 DAS)

T_9 - Mulching alone

T_{10} - Weedy check/control

T_{11} - Weed free check

(Mulching with green leaves @ 7 t ha^{-1}; 7 DAS)

Details of the herbicides used for the experiment is given in Table 3.

Table 3. Details of the herbicide treatments

Common name	**Chemical name**	**Trade name**	**Formulation**	**Manufacturer**
Pendimethalin	N-(1ethyl propyl) - 3,4 dimethyl -2- 6 – dinitro benzene amine	Stomp	30% EC	Rallis India Ltd., crop science pvt. ltd., Aimco pesticides Ltd.
Imazethapyr	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 *H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid	Pursuit	10% SL	Adama India Private Ltd.

3.5. CROP HUSBANDRY

3.5.1. Land preparation

Initially, the land was tilled two times using tiller; weeds and stubbles were removed and then levelled after which layout was done as per the technical programme. The experimental plots were laid out in 5 m x 4 m dimension with beds of 15 cm height and 30 cm spacing was maintained between the plots.

3.5.2. Seeds and sowing

Cowpea seeds of variety PGCP 6 were purchased from GB Pant University of Agriculture and Technology, Uttarakhand. The seeds were sown by dibbling with a spacing of 30 cm between the rows and 25 cm between the plants @ 60 kg ha^{-1}.

3.5.3. Application of organic manures and fertilizers

The application of lime ($CaCO_3$) was done @ 250 kg ha^{-1} as per the recommendation given in KAU POP (2016) at the time of first ploughing. After 7 days, farm yard manure FYM) was incorporated uniformly in the experimental plots @ 20 t ha^{-1} at the time of land preparation. Urea, rajphos and muriate of potash were applied in all the plots as per recommendations given in the KAU package of practices @ 20:30:10 kg ha^{-1} of N, P_2O_5 and K_2O. Half of nitrogen, whole of phosphorous and potassium were applied at the time of final ploughing. Remaining half quantity of nitrogen was applied at 20 DAS.

3.5.4. Plant protection

Field surveillance was done for the incidence of pests and diseases and recommended management practices were given accordingly.

3.5.5. Harvesting

Harvesting of matured pods started at 65 DAS and there were 4 harvests done at weekly intervals. The harvested pods were sundried; then threshed and cleaned to obtain the grain cowpea.

3.6. BIOMETRIC OBSERVATIONS

Sample plants were tagged leaving the border rows in each treatment plots to record biometric observations like plant height, number of branches per plant, number of nodules per plant, leaf area, total dry matter production, yield and yield attributes. The parameters were measured and the values recorded. The observations of different parameters were made, the values recorded and tabulated.

3.6.1 Plant height

Plant height was measured from ground level to the tip of the plant from five index plants at flowering and harvesting stages. During both stages, the average plant height was calculated from the observed values and expressed in cm.

3.6.2 Number of branches per plant

Numbers of branches per plant were counted at flowering and harvesting stages and the average number of branches from five index plants were counted and recorded.

3.6.3. Number of nodules per plant

Number of nodules per plant was counted at flowering and harvesting stages. Five plants were selected randomly from each plot by leaving the border plants and uprooted. The plant roots were carefully washed to remove the soil particles and the number of root nodules was calculated and the average value was expressed as number of nodules per plant.

3.6.4. Leaf area index (LAI)

Leaf area was calculated by area: weight method (Watson, 1952). Leaf area of five matured leaves from five plants in each plot was found out using leaf area meter (PorTable leaf area meter, model: LI- 3000 A, LI COR). After drying in the oven, dry weight of these five sample leaves and dry weight of total number of leaves in the plant were also recorded. The data on leaf area of the plant was used to compute the LAI.

3.6.5. Total dry matter

Five plants were tagged and uprooted randomly for the estimation of total dry matter production at harvesting stage. After uprooting, the plants were cleaned carefully to remove the soil and dirt; then the fresh weights of the plants were recorded immediately. These plants were shade dried for 2 days and then dried in the hot air oven at 60°C until stable weights were obtained consecutively. The dry weight was recorded and used for the calculation of total dry matter produced per plot and it was expressed in kg ha^{-1}.

3.7. YIELD AND YIELD ATTRIBUTES

The observations on number of seeds per plant, number of seeds per pod, pod weight per plant, test weight, pod yield and seed yield were done at harvesting stage (65 - 70 DAS)

3.7.1. Number of pods per plant

Numbers of pods were counted from five labelled plants and the average value was expressed as number of pods per plant.

3.7.2. Number of seeds per pod

10 pods were collected from each of the tagged plants in the plots. Numbers of seeds in these pods were counted and the average was recorded.

3.7.3. Pod weight per plant

Pods were collected separately from the five tagged plants in each of the plots and weighed. Average weight was taken and expressed in grams.

3.7.4. Test weight (100 seed weight)

Ten seed sample lots, each containing 100 seeds were collected from each plot after threshing and cleaning. The lots from each plot were weighed separately and the average value was recorded and expressed in grams.

3.7.5. Pod yield

Pod yield was recorded from each plot. Total pod yield was obtained by adding the weight of pods after four harvests and expressed in kg ha^{-1}.

3.7.6. Seed yield

During each harvest, pods from each plot were threshed and cleaned; and the seeds were collected. The total yield was obtained by adding the weight of seeds from each harvest and expressed in kg ha^{-1}.

3.8. PLANT ANALYSIS

Five plants were collected from each plot randomly leaving the border plants. The uprooted plants were dried in shade for two days followed by oven drying at a temperature of 60°C. Oven dried samples were ground to a fine powder and the analysis were carried out according to the standard procedures given in Table 4. The composite plant samples were analysed for total N, P and K at harvesting stage.

3.9. SOIL ANALYSIS

Soil analysis was carried out before and after the experiment as per the standard procedures given in Table 2.

Table 4. Analytical method followed for plant analysis

Sl. no.	**Parameter**	**Method**	**Reference**
1	Total N	Modified kjeldahl digestion method	Jackson (1958)
2	Total P	Vanadomolybdate yellow colour method	Piper (1966)
3	Total K	Flame photometry	Jackson (1958)

3.10. SOIL MICROBIAL POPULATION

The effect of application of herbicide on the soil microorganisms were assessed on the basis of the total count of different group of microorganisms in the herbicide treated plots and control plot. The total microbial population was determined using serial dilution plate technique (Johnson and Curl, 1972). The details of the media used are given in Appendix 2. The total microbial population 7 days after application of each of the herbicides was determined and compared with control.

3.11. OBSERVATIONS ON WEED FLORA

Observations on weed flora in the experimental plots were done using a quadrat having a dimension of 0.5 m^2. The weed samples collected were used for the following analysis.

3.11.1. Weed population

The weed population found in the entire area of the experimental field was observed, identified and classified based on botany and ontogeny.

3.11.2. Weed density (no. m^{-2})

The quadrat was randomly placed in three locations in each plot, the numbers of weed species were counted and the average value from the two quadrats were recorded and expressed as no.m^{-2}. Observations for weed density was taken at 15, 30, 45 and 60 DAS and expressed in no. m^{-2}.

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

The quadrat was randomly placed in three locations in each plot, the dry weight of the weed species in each of the quadrats were found out by shade drying the samples initially for two days and then oven drying at 70^{o}C till constant weights were obtained consecutively. The average dry weight of the samples were computed and expressed as kg ha^{-1}. Observations for weed dry weight was taken at 15, 30, 45 and 60 DAS and expressed in kg ha^{-1}.

3.11.4. Weed control efficiency (WCE)

Weed control efficiency of the different weed management practices were obtained by using the following formula (Gautam *et al.*, 1975) at 15, 30, 45 and 60 DAS.

$$\text{Weed control efficiency} = \frac{\text{WDWC -WDWT}}{\text{WDWT}} \times 100$$

WDWC- Weed dry weight in control plot (no m^{-2})

WDWT- Weed dry weight in treated plot (no m^{-2})

3.11.5. Weed index

Weed index of the different weed management practices were calculated by using the following formula (Gill and Kumar, 1969) at 60 DAS.

$$\text{Weed index} = \frac{X - Y}{X} \times 100$$

X – yield from the weed free check.

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

3.13. DISEASES AND PEST INCIDENCE

Surveillance was done to check the incidence of pests and diseases in the experimental field and suitable management practices were adopted.

3.14. ECONOMICS

3.14.1. Gross income

Gross income of cowpea was calculated by multiplying the total seed yield with the market price of grain cowpea and expressed as Rs.ha^{-1}.

3.14.2 Net income

Net income was calculated by subtracting the income from the total cost of cultivation for the field experiment and expressed as Rs.ha^{-1}.

3.14.3. B:C Ratio

The benefit cost ratio was computed by the following formula.

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

3.15. STATISTICAL ANALYSIS

The data obtained from the experimental plot were analysed statistically using the software WASP 2.0 by ICARGOA.

Table 2. Physico- chemical properties of the soil

Sl. no.	**Particulars**	**Value**	**Method**	**Reference**
Physical properties				
1	Particle density (Mg m^{-3})	2.31	Pycnometer method	Black *et al.* (1965)
2	Bulk density (Mg m^{-3})	1.34	Undisturbed core sample	Black *et al.* (1965)
3	Textural analysis	Red sandy loam	International pipette	Robinson (1922)
Chemical properties				
1	pH	5.03	pH meter	Jackson (1958)
2	EC (dS m^{-1})	0.05	Conductivity meter	Jackson (1958)
3	Organic C (%)	0.65	Chromic acid wet digestion method	Walkley and Black (1934)
4	Available N (kg ha^{-1})	240.00	Alkaline permanganate method	Subbiah and Asija (1956)
5	Available P (kg ha^{-1})	60.56	Bray extraction and photoelectric colorimetry	Jackson (1958)
6	Available K (kg ha^{-1})	250.45	Flame photometry	Pratt (1965)

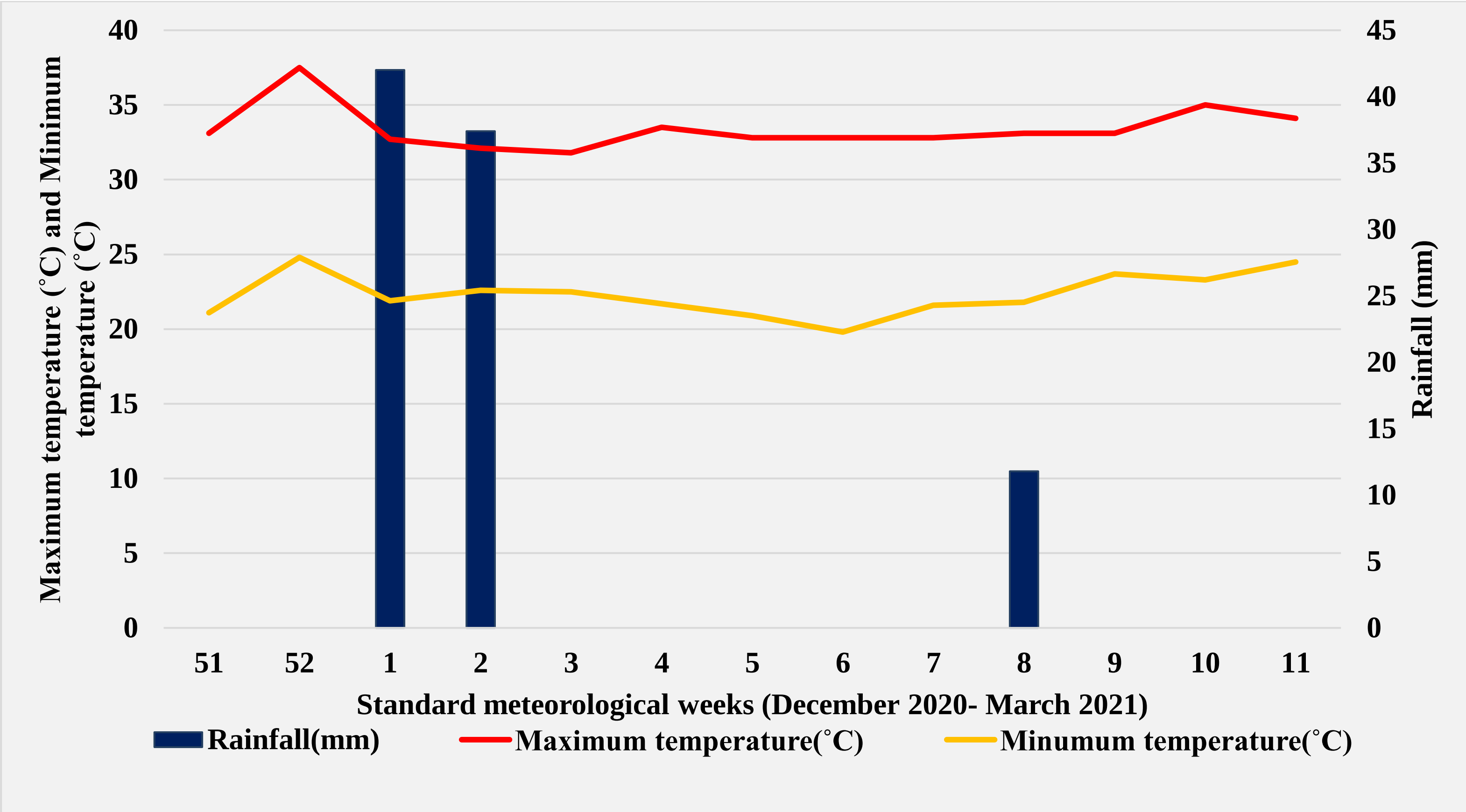
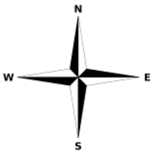


Fig. 2. Weather data during the crop period (December 2020 to March 2021)



R_1T_3	R_2T_2	R_3T_1
R_1T_1	R_2T_{11}	R_3T_2
R_1T_{10}	R_2T_9	R_3T_8
R_1T_6	R_2T_{10}	R_3T_5
R_1T_{11}	R_2T_6	R_3T_7
R_1T_9	R_2T_4	R_3T_3
R_1T_2	R_2T_1	R_3T_{11}
R_1T_8	R_2T_3	R_3T_4
R_1T_5	R_2T_5	R_3T_{10}
R_1T_4	R_2T_8	R_3T_6
R_1T_7	R_2T_7	R_3T_9

Fig. 3. Layout of the experimental plot

Plate 1. Land preparation

Plate 2. Sowing

Plate 3. Mulching

Plate 4. Pre-emergence application of pendimethalin

Plate 5. Hand weeding

Plate 6. Post-emergence application of imazethapyr

RESULTS

4. RESULTS

A field experiment was carried out for the study entitled 'Integrated weed management in cowpea (*Vigna unguiculata* L.) at Instructional Farm II, Karuvacheri, College of Agriculture, Padannakkad during the *rabi* season of the year 2020. The objectives include evaluation of the efficacy of different weed management practices and to find out the economics of weed management in cowpea. This chapter includes the data obtained from the study and their statistically analyzed results.

4.1. WEED INDICES

The data on population of weed flora of the experimental site, weed density, weed dry matter production, weed control efficiency and weed index are presented below.

4.1.1. Composition of the weed flora

Observations were made on the weed biodiversity in the experimental field (Table 5). The different weed species in the field were identified and classified based on ontogeny and morphology. Among the various weed species found, there were about 20 grass species, 35 species of broad leaved weeds and only one species of sedge. Majority of the weed species were annuals and the rest were perennials and there were no biennials found in the field.

4.1.2. Weed density

The variation in weed density at 15, 30, 45 and 60 DAS for different weed control treatments is presented based on the weed count taken at 15 days interval (Table 6). The treatment T_{11} was maintained weed free throughout the cropping period and the weed density was recorded nil in this treatment at 15 DAS. The next best treatment was T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) with a density of 7.00 m^{-2}. This was followed by T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}) and T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) which were on par to each other with a density of 14.66 m^{-2} and 16.33 m^{-2}

respectively. Weed densities in other plots increased in the order of T_6, T_9 and T_7 respectively and the highest value for weed density (142.33 m^{-2}) was in T_{10}.

At 30 DAS, the lowest weed density (4.00 m^{-2}) was obtained in T_2 (pre- emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) compared to all other treatments except that of T_7 (mulching @ 7 t ha^{-1}+ hand weeding at 20 DAS) which was on par, with a density of 5.00 m^{-2} and T_{11} which was maintained weed free throughout the experimental period. This was followed by T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) with a density of 8.66 m^{-2} and T_8 (hand weeding at 15 and 30 DAS) with a weed density 13.66 m^{-2} which were on par to each other. The highest weed density (280.66 m^{-2}) was found in the weedy check (T_{10}).

At 45 DAS, significantly lowest weed density (11.66 m^{-2}) was recorded in T_5 (post emergent application of imazethapyr @ 75 g ha^{-1} + hand weeding at 35 DAS) compared to all other treatments except T_{11} (weed free) and T_5 was on par with T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) with a density of 15.33 m^{-2} and T_8 (hand weeding at 15 and 30 DAS) with a weed density 17.33 m^{-2}. This was followed by T_7 and T_2; the highest weed density being recorded by T_{10} (351.33 m^{-2}).

The weed density values recorded at harvesting stage (60 DAS) indicated lowest in treatment T_8 (hand weeding at 15 and 30 DAS) with a density of 52.00 m^{-2} which was on par with T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}). This was followed by the density value of 70.00 m^{-2} recorded in T_7 (mulching @ 7 t ha^{-1}+ hand weeding at 20 DAS), T_6 (78.33 m^{-2}), and T_5 (82.66 no.m^{-2}) which were on par with each other, followed by T_7 (70.00 m^{-2}) which was on par with T_3 (61.33 m^{-2}). The highest density of weed was recorded in the treatment T_{10} (443.33 m^{-2}) which was the weedy check and the lowest in T_{11}.

4.1.3. Weed dry weight

Data on weed dry weight for different weed control treatments are shown in Table 7. The lowest weed dry matter content was recorded in T_{11} which was maintained weed- free during the entire crop duration.

At 15 DAS, treatment T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) recorded the lowest value (23.94 kg ha^{-1}) for weed dry weight compared to all other treatments except for T_{11} which was maintained weed-free throughout the crop duration. The next significantly low values for weed dry weight were recorded by T_2 (pre- emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 35 DAS) with a dry weight of 71.00 kg ha^{-1} and T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}) with a dry matter production of 76.66 kg ha^{-1} which were on par to each other. This was followed by T_7 (mulching @ 7 t ha^{-1} + hand weeding at 20 DAS) with a dry matter production of 174.26 kg ha^{-1}, T_6 (mulching @ 7 t ha^{-1}+ post-emergence application of pendimethalin @ 75 g ha^{-1}) with a dry weight of 180.93 kg ha^{-1} and T_9 (mulching @ 7 t ha^{-1} alone) with a dry matter production of 214.00 kg ha^{-1}, which were on par to each other. Weedy check recorded with highest weed dry matter production of 1832 kg ha^{-1}.

At 30 DAS, significantly the lowest dry weight was recorded in T_2 (6.26 kg ha^{-1}), which was on par with T_7 (13.46 kg ha^{-1}) and T_3 (33.40 kg ha^{-1}). Next best treatment was T_8 (hand weeding at 15 and 30 DAS) which recorded a weed dry weight of 101.80 kg ha^{-1} which was followed by T_6 (223.53 kg ha^{-1}), T_1 (356.20 kg ha^{-1}), T_9 (382.40 kg ha^{-1}) and T_5 (444.46 kg ha^{-1}); the later three treatments being on par to each other. The highest value of 4158 kg ha^{-1} for weed dry weight was obtained in the treatment T_{10} (weedy check).

At 45 DAS, significantly the lowest weed dry weight was recorded in T_8 (26.33 kg ha^{-1}) among all the treatments which was on par with T_5 (26.60 kg ha^{-1}) and T_7 (26.73 kg ha^{-1}). This was followed by T_2 (120.45 kg ha^{-1}) and T_3 (142.13 kg ha^{-1}) which were on par with each other. The next higher value for dry weight was recorded by T_6 (222.26 kg ha^{-1}), T_4 (626.53 kg ha^{-1}), T_1 (629.00 kg ha^{-1}) and T_9 (936.73 kg ha^{-1}). Treatment T_{10} (weedy check) recorded the highest dry matter production of 4164 kg ha^{-1} and the lowest value (zero) was in T_{11}.

At 60 DAS, lowest dry matter production of 329.66 kg ha^{-1} was recorded by the treatment T_2 which was significantly the lower among all the weed control treatments except for T_3 (362.20 kg ha^{-1}), T_5 (432.46 kg ha^{-1}), T_7 (435.66 kg ha^{-1}) and T_8 (490.33 kg ha^{-1}) which were on par. This was followed by T_6 (738.60 kg ha^{-1}), T_4 (1976.33 kg ha^{-1}) and T_1 (2109 kg ha^{-1}). Highest weed dry weight was obtained in control plot T_{10} (6915 kg ha^{-1}) while the treatment T_{11} remained weed free.

4.1.4. Weed Control Efficiency (WCE)

Weed control efficiencies (WCE) of the different weed management practices were computed from the weed dry weights recorded at 15, 30, 45 and 60 DAS and are presented in Table 8. Treatment T_{11}, which was maintained weed free throughout the cropping period, recorded the lowest value for weed dry matter production and highest WCE cent per cent throughout the period of observation.

The WCE values at 15 DAS indicated that the treatment T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching) with a WCE of 98.70 per cent, T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) with a WCE of 96.06 per cent and T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}) with a WCE of 95.87 per cent were on par with T_{11} which recorded cent percent WCE. This was followed by T_7 (mulching @ 7 t ha^{-1} + hand weeding at 20 DAS) with a WCE of 90.49 per cent, T_6 (mulching @ 7 t ha^{-1}+ post emergent application of imazethapyr @ 75 g ha^{-1}) with a WCE 90.12 per cent and T_9 (mulching alone @ 7 t ha^{-1}) with 88.26 per cent WCE which were also on par to each other. The next best values for WCE was obtained for T_8 (hand weeding at 15 and 30 DAS) with a WCE of 83.06 per cent followed by T_4 (post emergent application of imazethapyr @ 75 g ha^{-1}) with 77.86 per cent WCE and T_5 (post emergent application of imazethapyr @ 75 g ha^{-1} + hand weeding at 35 DAS) with 76.42 per cent WCE which were on par.

At 30 DAS, T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) was recorded with significantly the highest WCE of 99.85 per cent among all the treatments except T_{11}, followed by T_7 (mulching + hand weeding at 20 DAS) and T_3 (pre- emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching) which were on par with each other recording WCE values of cent per cent, 99.67 per cent and 99.20 per cent respectively. This was followed by T_8 (hand weeding at 15 and 30 DAS) with WCE value of 97.55 per cent. Weedy check (T_{10}) recorded the lowest value for WCE.

At 45 DAS, WCE was significantly the highest in T_8 (99.37 per cent) which was superior to all other treatments except T_{11} (weed free check) and on par with T_5 (99.36 per cent), T_7 (99.35 per cent) and T_2 (97.14 per cent). T_2 was on par with T_3. Here also, weedy check (T_{10}) recorded least significant WCE.

At harvesting stage (60 DAS), the treatment T_7 recorded significantly higher value for WCE (96.64 per cent), which was significantly superior to all other treatments except T_{11} (100 per cent), T_3 (94.77 per cent), T_2 (94.60 per cent) and T_5 (93.73 per cent) which were on par with each other. This was followed by T_8 (92.90 per cent), T_6 (89.32 per cent), T_4 (71.41 per cent), T_1 (69.48 per cent) and T_9 (68.82 per cent). The least WCE was obtained for T_{10} (control/weedy check).

4.2. BIOMETRIC OBSERVATIONS

Statistically analyzed data on biometric observations such as plant height, number of branches per plant, number of nodules per plant, leaf area index and total dry matter production at flowering and harvesting stages are presented below.

4.2.1. Plant height

The data obtained on plant height at flowering and harvesting stage are presented in Table 9. At flowering stage, plants in the plot which was maintained weed free (T_{11}) recorded the highest value for plant height (62.60 cm) which was significantly superior to all other treatments except for T_6 (mulching @ 7 t ha^{-1} + post-emergence application of imazethapyr @ 75 g ha^{-1} applied at 20 DAS) which has recorded on par value of 60.66 cm. This was followed by T_7 (mulching followed by hand weeding at 20 DAS) which recorded on par values (59.66 cm) with that of T_6. The treatment T_7 was followed by T_1, T_3 T_9, T_5, T_2 and T_8. The plot which was maintained as weedy check (control), *i.e* T_{10} recorded the lowest plant height (34.73 cm) at flowering stage.

At harvesting stage also, plants in the weed free plots (T_{11}) recorded the highest value for plant height (82.20 cm) which was significantly superior to all other treatments. The next highest plant height was recorded by T_3 followed by T_7 which were on par to each other and significantly superior to rest of the treatments except for T_6 (Post-emergence application of imazethapyr @ 75 g ha^{-1} applied 20 DAS + mulching @ 7 t ha^{-1}) which was on par with T_7. The control plots which were maintained as weedy check (T_{10}) resulted in the lowest plant height (43.13 cm) among all the treatments.

4.2.2. Number of branches per plant

The data on number of branches per plant recorded at flowering and harvesting stage are shown in the Table 9. Treatments T_6 (mulching @ 7 t ha^{-1} + post emergent application of imazethapyr @ 75 g ha^{-1} at 20 DAS) and T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS + mulching @ 7 t ha^{-1}) recorded almost similar number of branches per plant, *i.e*, 7.76 and 7.60 respectively which were significantly superior to all other treatments except T_{11}, T_2 and T_7 which were on par. The lowest value for number of branches per plant (2.40) was recorded by the treatment T_{10}, which was maintained as weedy check.

However, during the harvesting stage, the treatment T_{11} recorded significantly superior number of branches per plant (8.26) among all the treatments except for T_3 and T_7 which recorded on par values of 8.16 and 8.13 respectively. This was followed by T_6 (mulching @ 7 t ha^{-1} + post-emergence application of imazethapyr @ 75 g ha^{-1} applied 20 DAS) which recorded a value of 7.96, which was also on par with T_9 (7.93) followed by T_2 (7.81). As in the case of values recorded during the flowering stage, the lowest number of branches per plant (2.86) was recorded by the treatment T_{10}, which was maintained as weedy check.

4.2.3. Number of nodules per plant

Effect of weed control treatments on number of nodules per plant was statistically analyzed and is presented in Table 10. At flowering stage, the highest number of nodules per plant was recorded by the treatment T_7 (51.06) where mulching @ 7 t ha^{-1} was done followed by hand weeding at 20 DAS; which was on par with T_6 (post-emergence application of imazethapyr @ 75 g ha^{-1} applied 20 DAS + mulching @ 7 t ha^{-1}), T_9 (mulching alone @ 7 t ha^{-1}), T_4 (post-emergence application of imazethapyr @ 75 g ha^{-1} done 20 DAS), and T_{11} (weed free) recording the values 49.18, 48.29, 48.23 and 46.36 respectively. This was followed by the treatments T_5, T_1, T_2, T_3, T_8, and T_{10} (weedy check) which recorded the lowest number of nodules per plant (27.00).

At harvesting stage, number of nodules per plant was significantly superior in T_2 (pre- emergent application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS + hand weeding at 20-25 DAS) with 18.93 nodules among all other treatments except T_7 (18.80) and T_6 (18.43) which were on par with T_2. This was followed by the treatment T_{11} which was on par with T_6 and T_7. Similar to the flowering stage, treatment T_{10} recorded the lowest number of nodules per plant (14.16).

4.2.4. Leaf area index (LAI)

The statistically analyzed data on leaf area index at flowering and harvesting stages are presented in Table 10. The different weed management practices recorded significant effect on the leaf area index (LAI) during the flowering as well as harvesting stages. During flowering stage, the treatment T_{11} (weed free) recorded the highest (2.95), which was on par with treatments T_3 (2.92) and T_7 (2.83). This was followed by T_1 (2.10), T_5 (1.87), and T_2 (1.85). The treatments T_4, T_6, T_9 and T_8 recorded LAI values which were on par with T_2 and T_5, and the lowest was recorded by the treatment T_{10} (1.06).

During the harvesting stage, T_{11} and T_3 recorded same LAI (2.69) which were on par with T_7 (2.58) and these treatments were significantly superior to all other treatments. This was followed by T_5 (1.65) and T_2 (1.59) which were on par with each other. T_1 (1.47), T_4 (1.42) and T_6 (1.42) were followed by T_5 and were on par with each other. Here also the lowest value of LAI (0.866) was obtained for T_{10} (weedy check).

4.2.5 Total dry matter production

Results of total dry matter production (DMP) in cowpea at flowering and harvesting stages were statistically analyzed and presented in the Table 11. At flowering stage, the highest DMP was recorded by the treatment T_7 (3320 kg ha^{-1}) which was on par with T_3 (3316 kg ha^{-1}) and were significantly superior to all other treatments. This was followed by the treatment T_{11} (weed free) which was in turn followed by T_6 and T_9. Similar to the other biometric observations, the least DMP of 1326 kg ha^{-1} was recorded by T_{10} (control).

At the harvesting stage, treatment T_7 recorded significantly superior DMP (5709.68 kg ha^{-1}) which was on par with T_3 (5566.93 kg ha^{-1}). This was followed by T_{11} (5158.18 kg ha^{-1}). The treatment T_9 recorded the next best value which was on par with T6. This was followed by T_2, T_8, T_1, T_5 and T_4. The lowest DMP (1823.73 kg ha^{-1}) was obtained for the treatment T_{10} (control).

4.3. YIELD AND YIELD ATTRIBUTES

The data on yield attributing factors such as number of pods per plant, number of seeds per pod, pod weight per plant, test weight, pod yield and the seed yield were recorded during the harvesting stage. The data were statistically analysed and the results are as follows.

4.3.1. Number of pods per plant

The data on number of pods per plant are presented in Table 12. Number of pods was significantly the highest in T_{11} (19.92) plots which were kept weed free followed by T_3 (19.83) and T_7 (19.70) which were on par. This was followed by T_4 (17.26), T_2 (16.46) and T_8 (16.20) which were on par to each other. The least number of pods per plant were recorded in the treatment T_{10} (3.53) which were maintained as weedy check throughout the period of study.

4.3.2. Number of seeds per pod

The data on number of seeds per pod are given in Table 12. The treatment T_7 (19.93) recorded significantly higher value for number of seeds per pod and was on par with T_{11} (19.86). This was followed by T_3 which recorded a value of 18.60. This was followed by T_4 (17.30), T_6 (17.20), T_8 (16.70) and T_5 (16.20). The lowest number of seeds per pod (7.63) was recorded in the plot which was maintained as weedy check (control).

4.3.3. Pod weight per plant

The statistically analysed data on pod weight per plant are shown in Table 12. Among the different treatments, T_7 (mulching + hand weeding @ 20 DAS) recorded the significantly the highest pod weight (39.41 g) per plant which was almost equal to the value recorded by the treatment T_{11} (39.26 g), and was on par with T_3 (36.06 g). This was followed by the treatment T_6 (mulching @ 7 t ha^{-1}+ post emergent application of imazethapyr @ 75 g ha^{-1}) recording 29.23 g of pod weight. The next highest values were recorded by the treatments T_5 (24.73 g) T_2 (22.96 g), T_4 (22.93 g) and T_9 (21.80 g) which were on par to each other. Lowest value for pod weight (9.00 g) was recorded by T_{10} (control).

4.3.4. Test weight

Weight of 100 seeds was computed as test weight and the analysed data are presented in Table 13. The highest value for test weight (13.70 g) was found in the treatment T_7 (mulching @ 7 t ha^{-1}+ hand weeding at 20 DAS) which was on par with T_{11} (13.46 g) and T_3 (13.40 g). This was followed by T_6 (12.35 g) and T_5 (12.00 g) which were on par to each other and followed by T_8 (hand weeding at 15 and 30 DAS) recording a value of 11.75 g. The lowest test weight (8.66 g) was recorded in the treatment T_{10} which was maintained as weedy check during the entire study period.

4.3.5. Pod yield

Results of pod yield are shown in the Table 13. The pod yield was significantly the highest in the weed free plots, T_{11} (2993 kg ha^{-1}) compared to all other treatments except T_3 (2942 kg ha^{-1}) and T_7 (2929 kg ha^{-1}) which were on par to T_{11}. This was followed by T_1, T_2 and T_6. The next best values for pod yield were recorded by T_5 and T_4 which were on par to each other. The lowest significant value for pod yield was obtained by the plot maintained as weedy check (T_{10}).

4.3.6. Seed yield

The data on seed yield are presented in Table 14. Significant difference was present between the different weed control treatments with respect to seed yield. The treatment T_{11} (weed free) recorded significantly the highest value for seed yield (2697 kg ha^{-1}). The next highest significant seed yield (2366 kg ha^{-1}) was recorded by T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) which was on par with T_7 (mulching @ 7 t ha^{-1} + hand weeding at 20 DAS) with a seed yield of 2336 kg ha^{-1}. This was followed by T_6 (mulching @ 7 t ha^{-1} + post-emergence application of imazethapyr @ 75 g ha^{-1}) with a seed yield of 1261 kg ha^{-1}. The next best treatment T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) recorded a seed yield of 1219 kg ha^{-1} which was on par with T_5 (post-emergence application of imazethapyr @ 75 g ha^{-1} + hand weeding at 35 DAS) recording a seed yield of 1200 kg ha^{-1}. This was followed by the treatment T_4 (post-emergence application of imazethapyr @ 75 g ha^{-1}) which recorded a seed yield of 1170 kg ha^{-1}. The treatment T_8 (hand weeding at 15 and 30 DAS) recorded the next highest value *i.e.*, 1120 kg ha^{-1} followed by T_1 (1028 kg ha^{-1}) and T_9 (851 kg ha^{-1}). The lowest seed yield (182 kg ha^{-1}) was recorded in T_{10} (weedy check/control).

4.3.7. Weed index (WI)

Weed index (WI) values were calculated for different weed control treatments and are presented in Table 14. Significantly the lowest weed index value (4.63) was obtained by the treatment T_7 (mulching + hand weeding at 20 DAS). The next significantly lower value of 6.19 was recorded by T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}). This was followed by T_6 (mulching @ 7 t ha^{-1}+ post emergent application of imazethapyr @ 75 g ha^{-1}), T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20- 25 DAS), T_5 (post emergent application of imazethapyr @ 75 g ha^{-1} + hand weeding at 35 DAS), T_4 (post emergent application of imazethapyr @ 75 g ha^{-1}) and T_8 (hand weeding at 15 and 30 DAS) which were on par to each other and the highest value of WI was obtained in weedy check (T_{10}).

4.4. SOIL ANALYSIS

After harvest, the available nutrient content of the soil was analyzed in the laboratory (Table 15).

4.4.1. Organic carbon

The results obtained from the soil analysis indicated that there was no significant difference in the organic carbon content of the soil due to the different treatments.

4.4.2. Available nitrogen

The highest significant value for available nitrogen (264.25 kg ha^{-1}) in soil (Table 15) was recorded by the treatment T_8 (hand weeding at 15 and 30 DAS) which was on par with T_2 (pre- emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) in which available nitrogen content was 259.65 kg ha^{-1}. The treatment T_2 was on par with T_3 (pre- emergent application of pendimethalin + mulching @ 7 t ha^{-1}) and T_7 (mulching @ 7 t ha^{-1}+ hand weeding at 20 DAS) with available nitrogen content of 257.09 kg ha^{-1} and 254.71 kg ha^{-1} respectively. The lowest available nitrogen of 211.19 kg ha^{-1} was obtained in the treatment T_{10} (weedy check).

4.4.3. Available phosphorus

The data on available phosphorous in the soil showed that the weed management practices did not have any significant influence on available phosphorus in the soil.

4.4.4. Available potassium

The data on available potassium in the soil showed that the weed management practices did not have any significant influence on available potassium in the soil.

4.5. PLANT ANALYSIS

The data regarding nutrient content in the plant samples at harvesting stage were statistically analysed and given Table 6.

4.5.1. Nitrogen

Weed management practices had resulted in significant effect on plant nitrogen content. The treatment T_7 (mulching @ 7 t ha^{-1} + hand weeding 20 DAS) had resulted in significantly the highest total nitrogen content (2.59 per cent) among all the treatments except T_6 (mulching @ 7 t ha^{-1} + post-emergence application of imazethapyr @ 75 g ha^{-1}), T_{11} (weed free) and T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}) which were on par with T_7 recording values of 2.49 per cent, 2.48 per cent and 2.33 per cent respectively. The next highest value for total nitrogen was recorded by the treatments T_2 and T_8 which were on par with each other; the lowest total nitrogen content being recorded by T_{10} (weedy check/control).

4.5.2. Phosphorus

The different weed control practices did not have any significant effect on the total phosphorus content in cowpea.

4.5.3. Potassium

Total potassium in the plant samples was significantly higher in T_7 (mulching + hand weeding at 20 DAS) recording a value of 2.02 per cent among the different weed management treatments but was on par with T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}), T_{11} (weed free check) and T_6 (mulching @ 7 t ha^{-1}+ post-emergence application of imazethapyr @ 75 g ha^{-1}). This was followed by T_8 and T_5 which were on par to each other. T_{10} recorded the lowest total potassium content (1.02 per cent) which was on par with T_1 and T_9. The least value for total potassium was recorded in the treatment T_{10} (control plot).

4.5. SOIL MICROBIAL POPULATION

The effect of different herbicide treatments on the soil microbes were analysed by taking the count of total microbial population. The total microbial population in the herbicide treated were compared with that of the control plot and the results are given in Table 17. In the treated plots, the soil bacterial population were comparable to that of the control plots. Similar results were obtained in the case of fungi, bacteria as well as actinomycetes with that of control plot.

Table 17. Effect of weed control techniques on soil microbial population

Soil samples	Bacterial colonies (no.)		Fungal colonies (no.)		Actinomycetes
	10^{-5}	10^{-6}	10^{-3}	10^{-4}	10^{-2}
Pendimethalin	89	80	9	10	18
Imazethapyr	90	95	12	12	18
Control	80	80	12	11	20

4.6. PEST AND DISEASE INCIDENCE

The major pest observed in the experimental field during the crop period was aphid (*Aphis craccivora*). The attack was noticed during initial period especially at 2 WAS. The infestation was observed in 15 experimental plots. The major disease found was collar rot caused by *Rhizoctonia solani* and it was noticed in the field at 15 DAS. Necessary control measures were taken to manage the pest and disease and it could be successfully controlled. Aphid was controlled by spraying acephate @ 2 g L^{-1} at the early stages of attack. Collar rot was controlled by drenching with copper oxy chloride @ 2 g L^{-1}.

4.7. ECONOMIC ANALYSIS

4.7.1 Gross return

Gross return, net return and benefit-cost ratio (BCR) were calculated for the different treatments and statistically analyzed data are presented in Table 18. Gross return was significantly the highest in the treatment T_{11} (Rs.2,29,258 ha^{-1}) which was maintained weed-free throughout the period of investigation. This was followed by the treatments T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS + mulching @ 7 t ha^{-1}) and T_7 (mulching @ 7 t ha^{-1} and hand weeding at 20 DAS) which were on par to each other with a gross return of Rs. 2,01,122 ha^{-1} and Rs.1,98,602 ha^{-1} respectively. The next best gross return was obtained by T_6; followed by T_2 and T_5 which were on par. The lowest gross returns was computed for T_{10} (Rs.15,464 ha^{-1}).

4.7.2 Net returns

The treatment T_{11} has recorded the significantly highest net returns (Rs.1,34,580 ha^{-1}) compared to all other treatments followed by T_3 (mulching @ 7 t ha^{-1} + pre- emergent application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS) with a net return value of Rs.1,19,033 ha^{-1} and T_7 (mulching @ 7 t ha^{-1}+ hand weeding at 20 DAS) with a net return value of Rs.1,17,604 ha^{-1} which were on par to each other. This was followed by T_6 (24,766 ha^{-1}) and T_2 (23,100 ha^{-1}) which were on par to each other. The treatments T_9 and T_{10} recorded negative values for net return.

4.1. OBSERVATION ON WEED FLORA

Table 5. Weed biodiversity in the cropped field

	Annuals	**Perennials**
Grasses	*Dactyloctenium aegyptium, Panicum maximum, Panicum repens, Brachiaria reptans, Digitaria sanguinalis, Ischaemum rugosum, Eragrostis pilosa, Cenchrus carthamus, Leptochloa chinensis, Poa annua, Eleusine indica*	*Cynodon dactylon, Axonopus compressus, Desmostachya bipinnata, Dicanthium annulatum, Stenotaphrum secundatum, Agropyron repens, Sorghum halepense*
Sedges	*Kyllinga monocephala*	NIL
Broad leaved weeds	*Commelina benghalesis, Commelina diffusa, Amaranthus viridis, Ageratum conyzoides, Euphorbia hirta, Scoparia dulcis, Achyranthes aspera, Chenopodium album, Cleome viscosa, Cleome burmanii, Eclipta alba, Ipomoea pes-tigridis, Vernonia cinerea, Phyllanthus niruri, Setaria verticillata, Leucas aspera, Aerva lenata, Alternanthera sessilis, Ludwigia parviflora, Trianthema portulacastrum, Emilia sonchifolia*	*Convolvulus arvensis, Oxalis corniculata, Boerhavia diffusa, Tridax procumbens, Sida acuta, Sida rhombifolia, Desmodium triflorum, Hemidesmus indicus, Mimosa pudica, Arachis pintoi, Hyptis suaveolens, Physalis minima, Urena lobata, Rhynchosia minima*

Table 6. Weed density in cropped field at successive crop growth stages

Treatments	**Weed density (no.m^{-2})***			
	15 DAS	30 DAS	45 DAS	60 DAS (at harvest)
T$_1$	14.66 (3.89)^{d}	29.00 (5.42)^{c}	62.66 (7.92)^{c}	150.00 (12.23)^{b}
T$_2$	16.33 (4.09)^{cd}	4.00 (2.11)^{e}	36.66 (6.03)^{d}	95.67 (9.80)^{c}
T$_3$	7.00 (2.47)^{e}	8.66 (3.43)^{d}	15.33 (4.50)^{ef}	61.33 (7.84)^{de}
T$_4$	136.00 (11.67)^{a}	44.33 (6.68)^{b}	97.66 (9.88)^{b}	156.67 (12.50)^{b}
T$_5$	140.00 (11.84)^{a}	45.00 (6.71)^{b}	11.66 (3.47)^{f}	82.66 (9.11)^{cd}
T$_6$	22.33 (4.75)^{bc}	29.33 (5.45)^{c}	38.00 (6.16)^{d}	78.33 (8.83)^{cd}
T$_7$	26.66 (5.20)^{b}	5.00 (2.33)^{e}	23.00 (4.79)^{e}	70.00 (8.33)^{de}
T$_8$	127.33 (11.29)^{a}	13.66 (3.74)^{d}	17.33 (4.17)^{ef}	52.00 (7.23)^{e}
T$_9$	25.66 (5.11)^{b}	45.00 (6.71)^{b}	80.00 (8.95)^{bc}	138.33 (11.78)^{b}
T$_{10}$	142.33 (11.94)^{a}	280.66 (16.76)^{a}	351.33 (18.73)^{a}	443.33 (21.06)^{a}
T$_{11}$	0.000 (0.707)^{f}	0.000 (0.707^{f}	0.000(0.707)^{g}	0.000 (0.707)^{f}
C.D (0.01)	**0.987**	**1.03**	**1.52**	**1.75**
SE (m)	**0.238**	**0.254**	**0.375**	**0.434**

*Transformed values are given in parentheses

Table 7. Dry matter production of weeds at successive crop growth stages

Treatments	Weed dry matter (kg ha^{-1})*			
	15 DAS	30 DAS	45 DAS	60 DAS (at harvest)
T_1	76.66 (2.06)^{e}	356.20 (4.27)^{cd}	629.00 (5.55)^{c}	2109.00 (10.60)^{b}
T_2	71.00 (1.99)^{e}	6.26 (0.89)^{g}	120.45 (2.52)^{e}	329.66 (4.22)^{d}
T_3	23.94 (1.29)^{f}	33.40 (1.57)^{ef}	142.13 (2.82)^{e}	362.20 (4.30)^{d}
T_4	400.40 (4.50)^{bc}	454.46 (4.89)^{b}	626.53 (5.63)^{c}	1976.33 (9.96)^{b}
T_5	428.20 (4.67)^{b}	444.46 (5.20)^{bc}	26.60 (1.42)^{f}	432.46 (4.93)^{d}
T_6	180.93 (3.08)^{d}	223.53 (3.74)^{d}	222.26 (3.54)^{d}	738.60 (6.13)^{c}
T_7	174.26 (3.03)^{d}	13.46 (1.08)^{fg}	26.73 (1.35)^{fg}	435.66 (4.71)^{d}
T_8	311.20 (3.99)^{c}	101.80 (2.20)^{e}	26.33 (1.33)^{fg}	490.33 (4.99)^{d}
T_9	214.00 (3.34)^{d}	382.40 (4.41)^{c}	936.73 (7.00)^{b}	2154.40 (10.27)^{b}
T_{10}	1832.80 (9.59)^{a}	4158.46 (14.10)^{a}	4164.26 (14.44)^{a}	6915.53 (18.41)^{a}
T_{11}	0 (0.707)^{g}	0 (0.707)^{g}	0 (0.707)^{g}	0 (0.707)^{e}
C.D (0.01)	**0.714**	**0.897**	**0.917**	**1.10**
SE (m)	**0.173**	**0.219**	**0.224**	**0.274**

*Transformed values are given in parentheses

Table 8. Weed control efficiency as influenced by the different weed control treatments

Treatments	Weed Control Efficiency (%)*			
	15 DAS	30 DAS	45 DAS	60 DAS
T_1	95.87 (9.81)[a]	91.41 (9.58)[d]	84.79 (9.23)[d]	69.48 (8.36)[ef]
T_2	96.06 (9.82)[a]	99.85 (10.01)[a]	97.14 (9.88)[abc]	94.60 (9.75)[bc]
T_3	98.70 (9.96)[a]	99.20 (9.98)[a]	96.58 (9.85)[bc]	94.77 (9.76)[bc]
T_4	77.86 (8.84)[d]	89.07 (9.46)[e]	84.91 (9.24)[d]	71.41 (8.48)[e]
T_5	76.42 (8.76)[d]	89.31 (9.47)[e]	99.36 (9.99)[ab]	93.73 (9.70)[bc]
T_6	90.12 (9.52)[b]	94.63 (9.75)[c]	94.67 (9.75)[c]	89.32 (9.47)[d]
T_7	90.49 (9.53)[b]	99.67 (10.00)[a]	99.35 (9.99)[ab]	96.64 (9.85)[b]
T_8	83.06 (9.14)[c]	97.55 (9.90)[b]	99.37 (9.99)[ab]	92.90 (9.66)[c]
T_9	88.26 (9.42)[b]	90.78 (9.55)[d]	77.29 (8.81)[e]	68.82 (8.32)[f]
T_{10}	0 (0.707)[e]	0 (0.707)[f]	0.000 (0.707)[f]	0.000 (0.707)[g]
T_{11}	100.00(10.02)[a]	100.00 (10.02)[a]	100.00(10.02)[a]	100.00 (10.02)[a]
C.D (0.01)	**0.348**	**1.36**	**2.82**	**0.170**
SE (m)	**0.086**	**0.461**	**0.959**	**0.698**

Transformed values are given in parentheses

4.2. BIOMETRIC OBSERVATIONS

Table 9. Effect of weed management practices on plant height and number of branches per plant

Treatments	Plant height (cm)		Number of branches per plant	
	Flowering stage	Harvesting stage	Flowering stage	Harvesting stage
T_1	57.40^{c}	62.56^{de}	6.50^{cd}	7.64^{d}
T_2	50.53^{fg}	56.40^{f}	7.42^{b}	7.81^{cd}
T_3	57.00^{cd}	72.26^{b}	7.60^{a}	8.16^{ab}
T_4	48.90^{g}	54.76^{f}	6.13^{d}	6.80^{f}
T_5	52.03^{ef}	65.10^{cd}	6.20^{d}	6.53^{f}
T_6	60.66^{ab}	68.70^{bc}	7.76^{a}	7.96^{bc}
T_7	59.66^{bc}	72.06^{b}	7.33^{ab}	8.13^{ab}
T_8	44.13^{h}	50.76^{g}	6.06^{d}	7.16^{e}
T_9	54.50^{de}	61.00^{e}	6.33^{bc}	7.93^{bcd}
T_{10}	34.73^{i}	43.13^{h}	2.40^{e}	2.86^{g}
T_{11}	62.60^{a}	82.20^{a}	7.50^{ab}	8.26^{a}
C.D (0.01)	**3.90**	**4.91**	**0.831**	**0.404**
SE (m)	**0.971**	**1.221**	**0.207**	**0.109**

Table 10. Effect of weed management practices on number of nodules per plant and leaf area index of cowpea

Treatments	Nodules per plant (nos.)		Leaf area index	
	Flowering stage	Harvesting stage	Flowering stage	Harvesting stage
T_1	37.80^{b}	17.80^{cd}	2.10^{b}	1.47^{cd}
T_2	36.93^{b}	18.93^{a}	1.85^{c}	1.59^{bc}
T_3	34.10^{b}	17.50^{de}	2.92^{a}	2.69^{a}
T_4	48.23^{a}	17.20^{e}	1.73^{cd}	1.42^{de}
T_5	39.26^{b}	16.90^{e}	1.87^{c}	1.65^{b}
T_6	49.18^{a}	18.43^{ab}	1.73^{cd}	1.42^{de}
T_7	51.06^{a}	18.80^{ab}	2.83^{a}	2.58^{a}
T_8	34.53^{b}	16.13^{f}	1.63^{d}	1.32^{e}
T_9	48.29^{a}	16.96^{e}	1.69^{cd}	1.32^{e}
T_{10}	27.00^{c}	14.16^{g}	1.06^{e}	0.866^{f}
T_{11}	46.36^{a}	18.33^{bc}	2.95^{a}	2.69^{a}
C.D (0.01)	**7.08**	**0.818**	**0.295**	**0.190**
SE (m)	**1.76**	**0.203**	**0.073**	**0.047**

Table 11. Effect of weed management practices on total dry matter production of cowpea

Treatments	**Total dry matter (kg ha^{-1})**	
	Flowering stage	Harvesting stage
T_1	2124.65 (46.08)^{ef}	3393.91 (58.24)^{de}
T_2	2246.37 (47.38)^{de}	3573.58 (59.77)^{d}
T_3	3316.50 (57.55)^{a}	5566.93 (74.58)^{ab}
T_4	1969.03 (44.37)^{fg}	2866.72 (53.53)^{f}
T_5	1854.02 (43.05)^{g}	3238.03 (56.88)^{e}
T_6	2614.45 (51.11)^{c}	4328.74 (65.76)^{c}
T_7	3320.01 (57.61)^{a}	5709.68 (75.55)^{a}
T_8	1856.23 (43.07)^{g}	3563.95 (59.69)^{d}
T_9	2407.05 (49.06)^{cd}	4422.42 (66.49)^{c}
T_{10}	1326.91 (36.41)^{h}	1823.73 (42.67)^{g}
T_{11}	3019.11 (54.94)^{b}	5158.18 (71.81)^{b}
C.D (0.01)	**3.09**	**3.77**
SE (m)	**0.769**	**0.937**

*Transformed values are given in parentheses

Table 12. Effect of weed management practices on number of pods per plant, number of seeds per pod and pod weight per plant

Treatments	Pods per plant (nos.)	Seeds per pod(nos.)	Pod weight per plant (g)
T_1	12.60[c]	15.16[d]	25.60[cd]
T_2	16.46[b]	13.93[e]	22.96[d]
T_3	19.83 [a]	18.60[b]	36.06[ab]
T_4	17.26[b]	17.30[c]	22.93[d]
T_5	13.43[c]	16.20[cd]	24.73[d]
T_6	12.33[c]	17.20[c]	29.23[c]
T_7	19.70[a]	19.93[a]	39.41[a]
T_8	16.20[b]	16.70[c]	35.03[b]
T_9	12.20[c]	13.06[e]	21.80[d]
T_{10}	3.53[d]	7.63[f]	9.00[e]
T_{11}	19.92[a]	19.86 [a]	39.26[a]
C.D (0.01)	**2.51**	**1.51**	**5.28**
SE (m)	**0.625**	**0.375**	**1.314**

Table 13. Effect of weed management practices on test weight and pod yield of cowpea

Treatments	**Test weight (100 seed weight) (g)**	**Pod yield (kg ha^{-1})***
T_1	10.0 ^{e}	2031.66(45.07)^{b}
T_2	10.75^{d}	1983.17(44.53)^{b}
T_3	13.40^{a}	2942.84(54.24)^{a}
T_4	11.13^{cd}	1523.69(38.99)^{c}
T_5	12.00^{b}	1618.69(40.22)^{c}
T_6	12.35^{b}	1981.01(44.50)^{b}
T_7	13.70^{a}	2929.54(54.12)^{a}
T_8	11.75^{bc}	1375.64(37.08)^{d}
T_9	10.60^{de}	1082.00(32.89)^{e}
T_{10}	8.66^{f}	587.78(24.24)^{f}
T_{11}	13.46^{a}	2993.78(54.71)^{a}
C.D (0.01)	**0.894**	**1.83**
SE (m)	**0.222**	**0.456**

*Transformed values are given in the parentheses

Table 14. Effect of weed management practices on seed yield and weed index

Treatments	**Seed yield (kg ha^{-1})***	**Weed Index (%)***
T_1	1028.52(32.07)^{g}	59.75(7.76)^{c}
T_2	1219.63(34.91)^{d}	52.25(7.26)^{de}
T_3	2366.14(48.64)^{b}	6.19(2.57)^{f}
T_4	1170.43(34.21)^{e}	54.20(7.39)^{de}
T_5	1200.24(34.64)^{de}	53.03(7.31)^{de}
T_6	1261.00(35.51)^{c}	50.66(7.15)^{e}
T_7	2336.50(48.33)^{b}	4.63(2.20)^{g}
T_8	1120.26(33.47)^{f}	56.46(7.52)^{cd}
T_9	851.40(29.17)^{h}	66.68(8.19)^{b}
T_{10}	181.94(13.48)^{i}	92.88(9.66)^{a}
T_{11}	2697.16(51.93)^{a}	0.000(0.707)^{h}
C.D (0.01)	**0.651**	**0.437**
SE (m)	**0.012**	**0.103**

*Transformed values are given in parenthesis

4.4. SOIL ANALYSIS

Table 15. Effect of weed management practices on organic carbon, available N, P and K content in soil after harvesting stage

Treatments	Organic Carbon (%)	Nitrogen (kg ha^{-1})	Phosphorous (kg ha^{-1})	Potassium (kg ha^{-1})
T_1	0.884	242.90^{e}	78.48	198.44
T_2	0.897	259.65^{ab}	79.15	197.39
T_3	0.918	257.09^{bc}	78.36	205.53
T_4	0.873	224.43^{f}	80.77	196.52
T_5	0.897	251.67^{cd}	81.28	199.05
T_6	0.897	250.33^{d}	79.25	205.68
T_7	0.907	254.71^{bcd}	76.69	209.84
T_8	0.913	264.25^{a}	78.16	209.66
T_9	0.880	223.80^{f}	78.26	199.40
T_{10}	0.883	211.17^{g}	76.89	195.15
T_{11}	0.863	250.49^{d}	80.19	201.61
C.D (p= 0.01)	**NS**	**7.59**	**NS**	**NS**
SE (m)	**0.222**	**1.88**	**1.25**	**3.59**

4.5. PLANT ANALYSIS

Table 16. Effect of weed management practices on total N, P and K content in the plant after harvesting stage

Treatments	**Nitrogen (%)**	**Phosphorous (%)**	**Potassium (%)**
T_1	1.87 [d]	0.170	1.23 [cd]
T_2	2.15[bc]	0.187	1.41 [c]
T_3	2.33 [ab]	0.187	2.01 [a]
T_4	1.32 [e]	0.180	1.34 [c]
T_5	2.04 [cd]	0.180	1.68 [b]
T_6	2.49 [a]	0.162	1.95 [a]
T_7	2.59 [a]	0.200	2.02 [a]
T_8	2.10 [bcd]	0.187	1.71 [b]
T_9	1.20 [ef]	0.167	1.19 [cd]
T_{10}	1.00 [f]	0.173	1.02 [d]
T_{11}	2.48 [a]	0.200	1.99 [a]
C.D (p= 0.05)	**0.374**	**NS**	**0.309**
SE (m)	**0.093**	**0.006**	**0.077**

4.7. ECONOMIC ANALYSIS

Table 18. Effect of weed control methods on net income and BC ratio

Treatments	Economics			
	Cost of cultivation (Rs/ha^{-1})	Gross income (Rs/ha^{-1})	Net income (Rs/ha^{-1})	BCR
T_1	79049	87424 ^{g}	8375^{f}	1.10^{e}
T_2	80569	103669 ^{d}	23100^{cd}	1.28^{bc}
T_3	82089	201123 ^{b}	119034^{b}	2.45^{a}
T_4	78309	99487 ^{e}	21178^{d}	1.27^{bc}
T_5	80899	102021de	21122^{d}	1.26 ^{c}
T_6	82419	107185^{c}	24766^{c}	1.30 ^{b}
T_7	80999	198603^{b}	117604^{b}	2.45^{a}
T_8	81759	95222 ^{f}	13463^{e}	1.16^{d}
T_9	80239	72369 ^{h}	-7870^{g}	0.902^{f}
T_{10}	77959	15465 ^{i}	-62494^{h}	0.198^{g}
T_{11}	94679	229259 ^{a}	134580^{a}	2.42^{a}
CD (0.01)		**4026.33**	**1001**	**0.050**
SE(m)		**1001.37**	**1487.67**	**0.012**

T1

T2

T3

T4

T5

T6

T_7 T_8

T_9 T_{10}

T_{11}

Plate 7. General view of the experimental plots

Plate 8. Harvesting stage

Plate 9. Aphid infestation

Plate 10. Collar rot

Plate 11. Harvested pods

Plate 12. Threshed grains

DISCUSSION

5. DISCUSSION

The results obtained from the field experiment entitled 'Integrated weed management in cowpea (*Vigna unguiculata* L.) was detailed in the previous chapter. The inference of the results were discussed in the present chapter with an aim to justify the study which tested the efficacy of the different weed management practices in cowpea and the economics of weed management in cowpea is analysed thereafter. The detailed discussion of the results obtained along with their graphical representation are included in this chapter.

5.1. OBSERVATIONS ON WEED FLORA

5.1.1. Effect of weed management practices on weed population

The weed flora present in the experimental field was diverse and interfered with the growth of cowpea (Fig 3). Even though tillage and land preparation had a little control over initial weed flora, weed infestation increased with time. The weed flora found in the experimental field was classified based on morphology as well as ontogeny. There were about 53 different weed species which included 34 broad leaved weeds, 18 grass species and only one sedge. The major broad leaved weeds found in the site included *Boerhavia diffusa, Axonopus compressus, Tridax procumbens, Alternanthera sessilis, Mimosa pudica, Digitaria sanguinalis, Cleome viscosa, Cleome burmanii, Phyllanthus niruri, Commelina etc.* The grass species includes *Dactyloctenium aegyptium, Panicum maximum, Panicum repens, Brachiaria reptans, Digitaria sanguinalis, Ischaemum rugosum, Eragrotis pilosa, Cenchrus carthamus, Leptochloa chinensis, Poa annua, Eleusine indica, Cynodon dactylon, Axonopus compressus, Desmostachya bipinnata, Dicanthium annulatum, Stenotaphrum secundatum, Agropyron repens* and *Sorghum halepense* and the only sedge present in the field was *Kyllinga monocephala*. The weed species were mostly annuals (31 numbers) and the rest were perennials (22 numbers) and no biennials were found.

5.1.2. Effect of weed management practices on weed density

During all the observations taken at various crop growth stages weed density was least in treatment T_{11} which was maintained weed free throughout the experimental period (Fig. 4).

At 15 DAS, weed density was found minimum in T_3 (pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS + mulching @ 7 t ha^{-1}) which was on par with T_1 and T_2 where in pendimethalin was applied as pre-emergence spray in both these plots which has resulted in weed free situation. However, in T_2 pre-emergence application of pendimethalin followed by hand weeding (at 20 DAS) could effectively control the later emerged weeds. Similar observations of lower weed density in the initial stages due to pre-emergence application of herbicides were made by Yadav *et al.* (2017). The densities of weeds were higher in other treatments like T_6, T_9 and T_7. The highest density of weeds were found in weedy check (T_{10}) with 142.33 m^{-2}.

At 30 DAS, significantly the lowest weed density was found in plots where pre-emergence application of pendimethalin was done @ 0.75 kg ha^{-1} followed by hand weeding at 20-25 DAS (T_2) with a density of 4.00 m^{-2}. Delayed emergence of weeds in these plots due to pendimethalin application along with hand weeding of later emerged flushes (20 DAS) minimized the density of weed flora in these plots. This was comparable with T_7 (5.00 m^{-2}) wherein mulching was followed by hand weeding at 20 DAS. This was followed by T_3 (pre-emergence herbicide application and mulching) which again indicated that pre-emergence application of herbicide could delay the weed emergence but the flushes which emerged later could not be effectively controlled even though these plots were mulched. Here, hand weeding has resulted in lesser weed density and mulching seems to have lesser effect in plots other than when done along with pre-emergence application. This was followed by T_8 (hand weeding at 15 and 30 DAS), T_1 (pre-emergence alone) and T_6 (mulching and post-emergence application of imazethapyr). In the case of T_8, even though hand weeding was done at 15 DAS, there were weed flushes in the plots and imazethapyr seems to have lesser control for weeds when applied beyond a period of 15 days although several successful results have been reported earlier where application was done at 20-25 DAS (Ram *et al*., 2013).

Moreover, imazethapyr had comparatively better effect in controlling grasses and sedges than broad leaved weeds (Kumar *et al.*, 2015) which might have influenced the effect of imazethapyr as the weed flora in the experimental field was dominate by broad leaved plants (64 %). In the case of T_6, mulching alone could not suppress the weed flushes.

At 45 DAS, lowest weed density was found in T_5 (post emergent application of imazethapyr @ 75 g ha^{-1} at 20 DAS + hand weeding at 35 DAS) with a density of 11.66 m^{-2}. This was probably because the observation was done just 10 days after hand weeding which indicated the efficiency of hand weeding in addition to the application of imazethapyr. Imazethapyr has the capacity to inhibit cell division, destroy microtubules and also inhibition of chlorophyll synthesis; however, the weeds which were not controlled by the imazethapyr were controlled by the hand weeding; ultimately led to lowest weed density in these plots. Similar results were reported by Markam (2012). Treatment T_5 was on par with that of T_3 (pre-emergence application of herbicide + mulching) which indicated that pre-emergence herbicide application could effectively delay the weed emergence and the later emerged weeds could be successfully controlled by mulching which was equivalent to two hand weeding done 15 and 30 DAS (T_8) with a density of 17.33 m^{-2}. This was followed by T_7 (23.00 m^{-2}), T_2 (36.66 m^{-2}) and T_1 (62.66 m^{-2}). Highest value for weed density was recorded by the control plot as in the case of previous observations.

At 60 DAS, significantly the lowest weed density was recorded in the plots where two hand weeding were done at 15 and 30 DAS (T_8) which was on par with T_3 (pre-emergence application of herbicide and mulching) indicating the prolonged efficiency of this pre- emergence herbicide application. This was followed by T_7 (70.00 m^{-2}), T_6 (78.33 m^{-2}) and T_5 (82.66 m^{-2}) which were on par with each other indicating the efficiency of IWM compared to following any one weed management practice. Here also, weedy check recorded significantly the least weed density.

Weed density of an area depends on the weed seed bank, tillage, type of weed seeds present etc. (Grundy and Jones, 2002). The data on weed density indicates variation in results in different time periods which is because of the varying time of application of the different weed management practices, alone or in combination. The weedy check or control plot recorded a steady increase in weed density which may be attributed to the absorption of water and nutrients efficiently with minimum competition from the crop.

The application of pre-emergence herbicide pendimethalin alone could not control the weeds efficiently at later stages of the crop growth even though there was delay in weed emergence in these plots as indicated by the weed density values especially at 15 DAS. There was significant reduction in weed population when the pre-emergence herbicide application was combined with that of other weed management practices like mulching or hand weeding. Pendimethalin application delayed weed emergence in the initial stages and the later emerged weeds could be suppressed well especially when mulching was done within a week.

Mulching alone could not effectively reduce weed density unless it was combined along with other management practices like pre-emergence herbicide application or hand weeding which resulted in good weed control at different stages depending on the time of application of the different treatments. Throughout the observation period, it could be seen that, singular application of herbicides or cultural methods could not suppress the weeds. Effective weed control during the critical period of crop weed competition as indicated by the weed density was reflected in the crop yield also. IWM practice of pre-emergence herbicide along with mulching and the combination of mulching and hand weeding resulted in the highest crop yield. The weed free plots recorded the highest yields which were devoid of weeds throughout the cropping period.

5.1.3. Effect of weed management practices on weed dry weight

Dry weight of weeds significantly varied with respect to the different weed management practices throughout the crop growing period (Fig. 5). At 15 DAS, least value for dry weight was obtained by the combined application of pendimethalin @ 0.75 kg $ha^{-1}$and mulching @ 7 t ha^{-1}. This was followed by the treatment where pre-emergence application of pendimethalin @ 0.75 kg $ha^{-1}$was done along with hand weeding at 35 DAS which was on par with pre-emergence application of pendimethalin

@ 0.75 kg ha^{-1}. The initial observation on dry weight obviously could indicate only the effect of pre-emergence herbicide as the effect of other management practices could be observed only in the later stages due to the variation in time of application of these control methods.

At 30 DAS, dry weight of weeds was significantly the lowest in T_2 due to the effect of the hand weeding done at 25 DAS along with pre-emergence application of pendimethalin which was equivalent to the dry weight obtained in plots where mulching and hand weeding was done; both the results indicate the immediate effect of hand weeding. Crop weed competition was highest in weedy check due to higher density and dry weight of weeds due to the absence of weed control measures as indicated by Mekonnen *et al.,* (2017). Application of pendimethalin followed by hand weeding reduced the dry weight of weeds in cowpea. Mulching suppressed the weed population and hand weeding at later stages removed the remaining weeds which minimized the dry weight of weeds at 30 DAS.

At 45 DAS, dry weight was lowest in plots where two hand weeding were done at 15 and 30 DAS. The dry weight in these plots were on par with T_5 (post-emergence herbicide application and hand weeding) and T_7 (mulching @ 7 t ha^{-1} + hand weeding at 20 DAS). The result obtained for these three treatments could be attributed to the effect of second hand weeding done at 30 DAS. Highest dry weight was obtained in control plot.

At 60 DAS, T_2 (pre-emergence application of pendimethalin and hand weeding) recorded the lowest value for dry weight. This treatment recorded on par values for dry weight with pre-emergence application of herbicide along with mulching (T_3); post-emergence along with hand weeding (T_5); mulching along with hand weeding (T_7) and two hand weeding (T_8). The results indicated that different IWM combinations could effectively influence the dry weight of weeds as in the case of density, throughout the observation period. Even though the time of application were, towards the later stage of growing season, these treatment combinations were on par.

Hand weeding, mulching and other intercultural operations and their combination with pre and post emergent herbicide application at different period of crop duration has resulted in lower weed dry weights and density in the treated plots;

which could also be attributed to the better utilization of resources by cowpea in these plots as reported by Kumar (2008).

On comparing the effect of weed density and dry weight on the yield attributes and yield it can be inferred that lower weed density and dry weights could effectively reduce the competition between crop and weed for resources which has resulted in higher number of pods per plant which in turn has increased the total yield; which could be attributed to enhanced photosynthesis and high net assimilation rate as opined by Freitas *et al.* (2009).

5.1.4. Effect of weed management practices on weed control efficiency

Weed control efficiency computed based on the weed dry weight recorded at 15 days interval showed significant difference among the treatments. At 15 DAS, the highest WCE of cent per cent was recorded in the weed free check (T_{11}) which was on par with that of pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching (T_3) reording 98.75 per cent WCE, pre-emergence application of pendimethalin 0.75 kg ha^{-1} at 0-3 DAS along with hand weeding @ 20-25 DAS (T_2) recording 96.06 per cent WCE and pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS (T_1) recording a WCE of 95.87 per cent.

At 30 DAS, WCE was highest in the plots where pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} was done along with hand weeding at 20-25 DAS (T_2) recording 99.85 per cent, mulching and hand weeding at 20 DAS (T_7) and pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} along with mulching (T_3) recording a value of 99.20 per cent WCE were superior to all other treatments except T_{11} (cent per cent).

At 45 DAS, significantly the higher WCE was obtained in T_8 (99.37 per cent) which was on par with post emergent application of imazethapyr @ 75 g ha^{-1} at 20 DAS along with hand weeding at 35 DAS (T_5), mulching and hand weeding at 20 DAS (T_7) and T_2 (97.14 per cent) was recorded with greater WCE and on par with T_3 except that of T_{11}. Pre and post emergent herbicides applied plots showed higher WCE.

At 60 DAS, the treatment T_7 showed significantly higher WCE which was superior to all other treatments and on par with $T_{3,}$ T_2 and T_5 except the weed free treatment (T_{11}). According to Freitas *et al.* (2009) critical period of weed competition in cowpea was 11-35 DAS. In this study, at 30 DAS treatments T_2, T_7 and T_3 registered higher WCE except that of T_{11} which had led to decreased weed interference at the critical stage of crop growth. Treatments in which herbicides were applied alone only could not control the weeds efficiently. Better control of weeds resulted decrease in density and dry weight of weeds and improved yield and yield attributes which gave higher WCE. Naidu *et al.* (2012) opined that rate of photosynthesis and dry matter production of crop was enhanced due to the decrease in dry weight and density of weeds ultimately leading to the greater WCE.

Similarly, Mathew *et al.* (1995) noticed that treatment with pendimethalin 0.75 kg ha along with one hand weeding at 35 DAS recorded greater WCE in cowpea. Another study conducted by Singh and Sekhon (2013) concluded that application of pendimethalin @ 0.45 kg ha^{-1} along with hand weeding at 30 DAS resulted improved WCE in pigeon pea.

5.2. EFFECT OF DIFFERENT WEED MANAGEMENT PRACTICES ON BIOMETRIC PARAMETERS OF COWPEA

Cowpea is sensitive to weed infestation especially during the initial growth stages. If the weed problem is not properly addressed, it can cause yield reduction up to 60 per cent (Yadav *et al.*, 2017). Weed infestation results in crop-weed competition and adversely affects the biometric parameters like plant height, number of branches per plant, number of nodules per plant, leaf area index and total dry matter production. Similarly, yield and yield attributes are also affected. The efficacy of various weed management practices depends on the extent of weed infestation and vice versa.

The results of the weed management practices indicated that throughout the crop growth period, the treatment T_{11} which was maintained weed free recorded significantly superior results compared to all other treatments for the parameters like plant height (at flowering and harvesting stage), number of branches per plant (at harvesting stage), leaf area index (at flowering and harvesting stage), number of pods per plant, number of seeds per pod, pod yield, seed yield, seed to pod ratio, seeds per pod, BCR etc. In the case of certain other parameters like number of branches per plant (at flowering stage), nodules per plant (at flowering and harvesting stage), pods per plant, pod weight per plant, test weight etc., the results of the weed free plots were on par. Weedy check or control plot (T_{10}) was significantly inferior in all the analyzed results.

The weeds in the T_{11} plots were cleared of weeds as and when required and maintained weed free throughout crop duration. This might have resulted in the better utilization of resources like sunlight, water, nutrients and space in the absence of weeds. Even though the critical period of crop weed competition is about 40 DAS for cowpea (Yadav *et al*., 2017), the weed free situation beyond this period has resulted in better utilization of resources and assimilation of photosynthates towards the sink even during the later stages of crop growth which might have resulted in the superiority of the parameters.

5.2.1. Plant height

The data on plant height shows that weed management measures have positively influenced the plant height. Weed free plots resulted significantly the highest plant height among different treatments at flowering and at harvesting stages.

At flowering stage, plant height of weed free plot (62.60 cm) was comparable with that of T_6, which was followed by T_7 with a plant height of 59.66cm and it was on par with that of T_1 with a height of 57.40 cm. The treatments where mulching was done has recorded superior results next only to that of weed free plots.

At harvesting stage, taller plants were produced in weed free plots in which mulching was done at 7 t ha^{-1} along with pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} (T_3) recording a height of 72.26 cm and mulching @ 7 t ha^{-1} and hand weeding at 20 DAS (T_7) which was on par with that of mulching @ 7 t ha^{-1} and post emergent application of imazethapyr @ 70 g ha^{-1} (T_6). Lowest plant height was observed in the weedy check (T_{10}).

Mulching along with pre-emergence herbicide application and mulching along with hand weeding produced taller plants except that of weed free check due to the better control of weeds during the critical period of crop weed competition. Mulching leads to increased soil moisture status as well as nutrient status which would have resulted in increased plant height throughout the observation period in addition to the smothering capacity of mulches to suppress the weed growth (Sapkota *et al*., 2015; Sinchana and Raj, 2020).

Increase in plant height under reduced weed pressure might have resulted due to better availability of water and nutrients to crop plants which in turn enhanced the rate of photosynthesis improving the translocation of carbohydrates to different parts of the plant which boosts the division, multiplication and elongation of cell leading to increased plant height as reported by (Kumar, 2008). He has also opined that lowest plant height in the weedy check might have resulted due to the lesser absorption of resources due to severe crop weed competition which affects the photosynthesis thereby reducing the carbohydrate translocation which negatively influenced the plant height.

Similar results of IWM using pre-emergence application of pendimethalin along with physical removal of weeds were reported by Na-allah *et al*. (2017).

5.2.2. Number of branches per plant

At flowering stage, significantly highest number of branches per plant was noticed in treatments T_6 and T_3, which were on par with that of $T_{2,}$ T_7 and $T_{11.}$ At harvesting stage, weed free plots (T_{11}) recorded the highest number of branches per plant which was comparable with T_3 and T_7. The results indicated that reduction in weed competition due to better availability of space and improved water holding capacity has led to vigorous growth of plants (Kumar and Manoj, 1998). This was in conformity with the result of Yadav *et al.* (1985). Similarly, Parasuraman (2000) noticed that application of pendimethalin as pre-emergence @ 1.5 L ha^{-1} or 2.0 L ha^{-1} at 3 DAP along with one hand weeding at 30 DAP resulted in more number of branches per plant. Usman (2013) claimed that application of pendimethalin @ 2.5 $lha^{-1}$with one hand weeding at 6 weeks after sowing (WAS) improves the number of branches per plant.

5.2.3. Number of nodules per plant

Nodules are the mini nitrogen factories of legumes (Imran *et al.,* 2021). The different weed management practices has resulted in significant difference with respect to the number of nodules per plant. At flowering stage, highest number of nodules per plant was recorded in plots where mulching was done @ 7 t ha^{-1}along with hand weeding at 20 DAS (T_7) which was on par with the treatment where mulching was done along with post emergent application of imazethapyr (T_6), post emergent application of imazethapyr @ 75 g ha^{-1}at 20 DAS (T_4), mulching alone (T_9) and weed free check (T_{11}). This was followed by T_1, T_2, T_8 and T_5. Lowest number of nodules per plant was observed in the weedy check. In general, the number of nodules per plant was higher in all other treatments except that of weedy check. This is in line with the result of Kumar and Ranjan (2017) who has noticed that weedy check has experienced highest competition for resources than that of other treatments that resulted in poor crop growth and lesser number of nodules per plant. However, there are several other factors which influence the root nodule formation such as soil condition, moisture content, soil organic matter and climatic factors (Walley *et al.*, 2006).

At harvesting stage, treatment T_2 (pre-emergence application of pendimethalin + hand weeding) has recorded the highest number of nodules which was comparable with that of T_6 and T_7. The pre-emergence application of herbicide has helped in delaying the emergence of weeds in these plots and the weeds which have emerged later could be effectively managed by hand weeding which has resulted in lesser competition for nutrients by crops.

In the case of mulched plots also, the early emergence of weeds could be effectively controlled along with hand weeding (T_6) or post-emergence application of herbicides (T_7). Mulching also blocks solar radiation from reaching the soil and thus prevents weed germination and weed growth (Sinchana and Raj, 2020). Mulching also has the ability to decrease soil temperature and increase the nodule formation in cowpea (Gupta and Gupta, 1983). Similar observation was also made by Dukare *et al.* (2017).

5.2.4. Leaf area index (LAI)

LAI indicates the extent of leaf surface area available for the interception of sunlight. There was significant difference in LAI with respect to the different IWM practices both at flowering as well as at harvesting stage. Also, there was a general decline in LAI as the plant growth proceeded from flowering to harvesting stage. At flowering and harvesting stage, leaf area index was significantly the highest in the treatment T_{11}which was weed free and was on par with that of pre-emergence application of pendimethalin along with mulching (T_3) and mulching along with hand weeding at 20 DAS (T_7). In addition to the suppression of weed growth, mulching would also have resulted in increasing the nutrient status of the soil which might have resulted in enhanced LAI. Similar observations were made by Kanteh *et al*. (2014) in cowpea. The treatment T_{10} recorded the least value for LAI which might be due to the severe competition for nutrients between weeds and cowpea. The absence or less density of weeds have helped to improve availability of nutrients to plants that enhanced the vegetative growth leading to increased rate of photosynthesis which might be the reason behind the higher leaf area index (Kumar and Manoj, 1998). Mulching also helps to suppress weed growth and enhance organic matter content and water holding capacity of soil so that it may contribute to vegetative growth. However, Usman (2013) has claimed that leaf area was not affected by weed control treatments.

In the case of LAI at flowering, the next best result was recorded by the treatment T_1 (pre -emergence alone) which indicates the importance of maintaining the field weed free during critical period of crop - weed competition.

5.2.5. Total dry matter content

Weed control treatments significantly influenced the total dry matter production in cowpea (Fig. 6). At flowering and harvesting stage, highest dry matter production was obtained in plots where mulching was done together with hand weeding at 20 DAS (T_7) and together with application of pendimethalin @ 0.75 kg ha^{-1} (T_3) followed by the weed free check (T_{11}). Treatment T_{10} recorded the lowest dry matter content. Competition between the weeds and crop plants were highest in the control plot probably due to better absorption of nutrients and other resources by the weeds resulting in lower absorption of dry matter. In the case of weed free plot, higher DMP might have resulted due to the transfer of metabolites for longer period as reported by Kumar and Manoj (1998).

In the treatments T_7 and T_3 mulching has also played an important role in enhancing the biomass yield by suppressing the emergence of weeds and also improving the soil fertility by adding organic matter to the soil (Adnan *et al.*, 2020). The absence of weeds helped the crop to exploit the available resources effectively which might have resulted in higher dry matter accumulation. Similar observations were made by Mekonnen *et al*. (2017) wherein, weedy check has recorded the smallest dry weight and the highest dry weight was obtained from one hand weeding along with hoeing at 4 WAS which was comparable with the weed free check.

Mekonnen and Dessie (2016) opined that there was greater dry matter production in the treatments where the plants were treated with metolachlor @ 1.0 kg ha^{-1} with one hand weeding five weeks after emergence (WAE) of cowpea plants and this was on par with that of two hand weeding done at two and five WAE, pendimethalin application @ 1 kg ha^{-1}, application of pendimethalin along with one hand weeding at five WAE and the weed free check.

5.3. EFFECT OF DIFFERENT WEED MANAGEMENT PRACTICES ON YIELD AND YIELD ATTRIBUTES OF COWPEA

The management practices had significant effect on yield attributes and yield of cowpea like number of pods per plant, number of seeds per pod, pod weight per plant, test weight, pod yield and seed yield.

5.3.1. Number of pods per plant

Weed free plot (T_{11}) recorded the highest number of pods per plant which was on par with T_3 (mulching @ 7 t ha^{-1} and pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}) and T_7 (mulching @ 7 t ha^{-1} followed by hand weeding at 20 DAS). Green leaf mulching has the ability to smother the emergence of weeds during the early stages of growth and also helps in moisture conservation, managing soil temperature and nutrient supply (Sinchana, 2020). Similar observations were made by Chaudhari

(2004) who has reported that proper weed management practices especially during the initial stages of crop would result in better absorption of nutrients resulting in higher number of pods per plant. All the IWM practices obtained higher number of pods per plant compared to that of single weed management practice and weedy check. Likewise, environmental and management practices also influenced the number of pods per plant (Hodgson and Blackman, 2005). According to Eisa and Ali (2014) higher number of pods per plant was due to the enhanced vegetative growth and accumulation of chlorophyll that contributed to the photosynthesis in cowpea.

5.3.2. Number of seeds per pod

Weed management practices had significant effect on number of seeds per pod. Treatment T_{11} (weed free) recorded the highest number of seeds per pod compared to that of all other treatments except T_7 (mulching @ 7 t ha^{-1} followed by hand weeding at 20 DAS) which were on par to each other, followed by mulching @ 7 t ha^{-1} and application of pendimethalin @ 0.75 kg ha^{-1} (T_3). Mekonnen *et al.* (2017) reported that number of seeds per pod was more in weed free plots and least number of seeds per pod was obtained in the weedy check. This might be due to the fact that assimilation and translocation improved due to the suppression of weeds that resulted in higher number of seeds per pod in plots where IWM was practiced (Borras *et al.*, 2004). The lowest number of seeds per pod might be due to the decreased translocation and assimilation of photosynthates to the seeds (Kumar, 2008). Similar observation was made by Raklia (1999) who noticed that improvement in the formation of grains was observed in cowpea due to better weed suppression and the control plot obtained lowest number of seeds per pod (T_{10}) which is in line with the observation of Sunday and Udensi (2013) that weedy check obtained least number of seeds per pod.

5.3.3. Pod weight per plant

Mulching @ 7 t ha^{-1}along with hand weeding done at 20 DAS (T_7) and the weed free plots (T_{11}) recorded the highest pod weight of 39.41 g per plant and 39.26 g per plant respectively compared to that of all other treatments. It was comparable with the treatments where mulching alone was done @ 7 t $ha^{-1}$and pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} (T_3). Weed free situation has helped to achieve higher yield and yield attributes in $T_{11;}$ mulching suppressed the weeds in T_7 and hand weeding controlled the weeds which had emerged later. Pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}has helped in delaying the emergence of weeds and mulching has helped to smother the later emerged weeds. The higher pod yield under these treatments may be due to the better absorption and assimilation of resources which has resulted from better weed management as reported by Kumar (2008) that IWM in cowpea resulted in higher number of nodules per plant and higher number of branches per plant which ultimately led to enhanced rate of photosynthesis and partitioning of assimilates followed by higher number of pods per plants, pod weight per plant, pod yield, seed yield etc. Similar observations were made by Tiwari and Mathew (2002) and Idapuganti *et al.* (2005).

The next best result was recorded by the treatment where mulching was done along with post-emergence application of imazethapyr @ 75g ha^{-1} at 20 DAS, which was followed by post-emergence application of imazethapyr @ 75g ha^{-1} at 20 DAS along with hand weeding at 35 DAS. When comparing these treatments, it can be observed that weed management practices done during early periods gave better weed control and that it is important to maintain the critical period of crop weed competition weed free so that the economic yield is not affected. Lowest pod weight of 9 g was obtained in weedy check (T_{10}) which can be attributed to the heavy weed infestation in the plots which has resulted in the higher competition for nutrients and other resources (Chaudhari, 2004).

5.3.4. Test weight

The test weight of seeds also recorded significant variation among the different IWM practices. Test weight was highest in the plots where mulching was done along with hand weeding at 20 DAS (T_7) which was comparable with that of weed free plots (T_{11}) and T_3 (mulching done along with pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS) followed by T_6 where mulching was done along with post emergent application of imazethapyr @ 75 g ha^{-1} at 20 DAS. The IWM practices of mulching along with hand weeding have resulted in delaying the weed emergence and smothering of later emerged ones. Mulching along with hand weeding also has resulted in keeping the fields almost weed free for the critical period of crop weed competition which contributed to better accumulation of nutrients and other resources thus enhancing the translocation of photosynthates from source to the sink (Mekonnen *et al.,* 2017). The test weight from the weedy check plots recorded the lowest value as reported by Cheema and Akther (2005) that the test weight was decreased by weed infestation in mungbean. However, Kumar and Singh (2017) have reported that there was no significant difference in the test weight of cowpea due to the different weed management practices.

5.3.5. Pod yield

The significant variation observed in the yield attributes due to the various IWM practices has resulted in significant difference in pod yield also. Pod yield was highest in weed free plots (2993 kg ha^{-1}) which were comparable with that of T_3 and $T_{7.}$ As observed in the case of test weight, mulching along with hand weeding; and pre-emergence herbicide application along with mulching has resulted in maintaining the fields almost weed free during the critical period of crop weed competition.

A similar observation of higher pod yield was also recorded by Malligawad *et al.* (2000) in plots where pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS was done along with mulching. The different IWM combinations have resulted in effective management of weeds in the field for about 40 days with significant enhancement in the pod yield which would otherwise have resulted in about 80 per cent reduction in pod yield as observed in weedy check which recorded the lowest value for pod yield, similar observations were made by Muhammad *et al.* (2003).

The weedy check plot recorded the least values for all the parameters due to poor resource availability that has resulted from competition between crops and weeds.

The different combinations of IWM practices could effectively manage weed infestation which resulted in better growth, development and assimilation of photosynthates which was realised due to the better utilisation of resources *viz.*, nutrients, sunlight, soil moisture and space. (Mekonnen and Dessie, 2016).

5.3.6. Seed yield

The different IWM treatments have resulted in significant variation in seed yield. Highest seed yield of 2967 kg ha^{-1} was recorded in weed free plots (T_{11}) which was followed by the treatments T_3 and T_7 which were on par; wherein a combination of mulching was done along with pre-emergence herbicide application and hand weeding at 20 DAS (T_7). Weedy check has recorded lowest seed yield compared to all other weed control treatments (Fig. 7). Efficient weed control measures help in the growth and development of crop plants by providing a suitable atmosphere for the photosynthetic process and by decreasing the crop weed interference. Therefore, it leads to improved seed yield in cowpea (Mekonnen *et al.,* 2017). Application of mulches reduced the weed flora and competition between the weeds and crop plants from sowing to harvesting by providing the favourable and good environment for plant growth and thereby it contributes to final yield. Treatments including mulching and hand weeding improved the growth attributes like plant height, total dry matter accumulation and nutrient uptake, number nodules etc which has helped in noticeable increment in the yield and yield attributes (Singh, 2017). These results are in confirmity with Idapuganti *et al.* (2006) who opined that notable improvement in yield of soyabean was recorded with the application of two hand weeding at 20 and 40 DAS and mulching with straw @ 10 t ha^{-1} compared to that of weedy check (control). In agreement with this result weedy check was recorded smallest seed yield in which plants experienced severe competition for resources (Mekonnen *et al.,* 2017).

The growth and yield parameters have been significantly influenced by the different IWM practices which have resulted from suppression of weeds during the critical period compared to the control plot. Difference between the weedy check and the treated plots could be attributed to the deleterious effects of weed on crops which might have resulted from the poor number of leaves and poor nodule formation (Madukwe *et al*., 2012).

5.1.4. Effect of weed management practices on weed index

The influence of weed management practices were seen reflected in the weed index also (Fig. 7). The efficiency of certain weed control methods compared to that of weed free condition is called weed index or it is the percentage yield loss compared to that of weed free condition. Higher the weed index values means greater the yield loss. The weed index values were significantly lower in T_7 where mulching followed by hand weeding at 20 DAS was given except that of weed free check (T_{11}), followed by T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}). The next best treatment was T_6 (mulching @ 7 t ha^{-1} + post emergent application of imazethapyr @ 75 gha^{-1}). This was followed by T_2, T_5, T_4, T_8, T_1 and T_9. The highest value for weed density was recorded in weedy check/control (92.88). The competition between weeds and crop plants in the entire crop growing period resulted highest WI and very low yield in the control plot. T_7 was recorded with least WI due to the higher seed yield. Lower WI was seen in all the plots where any of the weed management practices are followed compared to control. The effect of higher seed yield and lower dry weight of weeds might be the reason behind low WI (Kumar, 2008) as indicated by the results. These results are in line with the results of Idapuganti *et al.* (2005).

5.4. EFFECT OF WEED MANAGEMENT PRACTICES ON NUTRIENT CONTENT IN SOIL

The nutrient status in soil after and before the experiment was analyzed and it is given in the Table 7. The weed control methods were not significantly different with respect to organic carbon content, available phosphorous and potassium content in the soil. The available nitrogen content was significantly influenced by the weed control treatments.

Nitrogen content was highest in the plots where hand weeding was done at 15 and 30 DAS (T_8) which was comparable with pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} along with one hand weeding at 20-25 DAS (T_2) which was being followed by pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} along with mulching @ 7 t ha^{-1} (T_3) and mulching + hand weeding at 20 DAS (T_7). Lowest nitrogen content was obtained in control plot (T_{10}). Application of imazethapyr only could not control weeds effectively without any mechanical or cultural method might be the reason behind this. Some treatments also recorded low soil nitrogen because of the less competition of weeds, crop plants could absorb maximum amount of nutrients in T_{11}, T_7, T_6, T_3 etc. Nutrient depletion can be minimized and the availability of nutrients can be enhanced by the effective control of weeds (Kumar *et al.,* 2010). In comparison with the weed free check the depletion of NPK was less in all the manual and herbicidal treatments (Kujur *et al.,* 2015).

5.5. EFFECT OF WEED MANAGEMENT PRACTICES ON NUTRIENT CONTENT OF COWPEA

The total nitrogen content in the plants was different in different weed control treatments at harvesting stage (Table 16). Nitrogen content was highest in weed free check (T_{11}), mulching and hand weeding at 20 DAS (T_7) and mulching and post-emergence application of imazethapyr @ 75 g ha^{-1} at 20 DAS (T_6) followed by pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS (T_3). Nitrogen content was low in T_4 and T_9 and most low nitrogen was obtained in T_{10}. This might be due to the increased number of nodules per plant in these treatments. Mulching improved the number of nodules per plant which may help to increase the total nitrogen content in plants.

Total phosphorous content did not show any significant difference between the treatments. Total potassium content in the plant shows significant difference between the treatments. The treatments T_7 (2.02 per cent), T_3 (2.01 per cent), T_{11} (1.99 per cent) and T_6 (1.95 per cent) contains highest amount of potassium in plant samples. Least value of total potassium was obtained in weedy check (T_{10}). Mulched plots and weed free treatment helped to absorb more nutrients than other treatments. Higher density of weeds in the control plot led to greater competition and which reduced the absorption of nutrients. Weed free plot enhanced the absorption of available nutrients by the plant (Kumar, 2008).

5.6. SOIL MICROBIAL POPULATION

The results shows that soil microbial population was not affected by the application of pre-emergence herbicide pendimethalin and post emergent herbicide imazethapyr @ 0.75 kg $ha^{-1}$and 75 g ha^{-1} respectively in cowpea. The microbial count of soil bacteria, fungi and actinomycetes was taken from the herbicides treated plots and compared with the count of control plot where no herbicides were applied. Chemicals seem to have no significant effect on the soil microbial count. According to Chikoye *et al.* (2014) higher rates of pendimethalin reduced nodule formulation, nitrogen fixation, and vesicular arbuscular mycorrhizal fungi colonization in cowpea and soyabean. Application of imazethapyr 10 fold or 100 fold higher rates of standard recommendation in soyabean reduced the dehydrogenase activity, biomass carbon content and improves the activity of protease and catalase and hydraulic conductivity (Perucci and Scarponi, 1994). However, such effects were not observed in the present study.

5.7. PEST AND DISEASE INCIDENCE

Aphid infestation was observed in the plots at two WAS. Aphid infestation can be seen in any season and any stages of the crop growth like early seedling, flowering, pod setting, and seed filling stage. Nymphs and adults attacked the crop by sucking the sap and it injects a toxin for transmitting disease causing viruses (Annan *et al.,* 1994). The infestation was observed in 15 plots. Good climatic conditions and proper management tactics at the correct time helped to maintain the pest and disease incidence below the economic threshold level (ETL). It was controlled using acephate @ 2g L^{-1} at the early stage of attack.

Collar rot was observed in the entire experimental plot. The symptoms included water soaked lesions that appeared at the collar region of the plant and it widened upto 3cm above the ground level. These lesions turn sunken and rotten leading to toppling of the plant. Pre-flowering stage is the most susceptible stage of infection by *Rhizoctonia solanii* (Vavilapalli *et al.,* 2014). Control measures were taken during the initial stage of infection occurred at all the experimental plots. Copper oxy chloride (Blitox) was used to control the disease @ 2 g L^{-1}.

5.8. ECONOMICS OF WEED MANAGEMENT PRACTICES

The data regarding economic aspects of the field experiment was analysed. Except for the variation in the application of weed management practices, the cost of cultivation and labour requirement was same in all the plots. Highest cost of cultivation was computed for the weed free plots (T_{11}) due to the increased labour days as weeding had to be continuously done throughout the crop duration. No weed control strategies were applied in the control plot (T_{10}) and it has recorded the lowest cost of cultivation. The treatment T_1 (pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS) and T_4 (post-emergence application of imazethapyr @ 75 g ha^{-1}applied 20 DAS) resulted lesser cost of cultivation due to less labour incurred for spraying herbicide compared to their combined application along with mulching (T_3, T_9 andT_6) and hand weeding (T_7, T_8 and T_2).

The weed free plots recorded highest gross returns (Rs.2, 29,259 ha^{-1}) followed by T_3 (pre-emergence herbicide application along with mulching) with a gross return of Rs. 2,01,122 ha^{-1} which was on par with T_7 (mulching @ 7 t ha^{-1} along with hand weeding done at 20 DAS) with a gross return of Rs.1,98,601 ha^{-1}. Eventhough the cost of cultivation was highest in the weed free plots, it was compensated by the highest total yield obtained in these plots which resulted in highest gross returns. Gross return was significantly lowest in control plots as no weeding was done. (Rs.15,465 ha^{-1}).

Net income was highest in the weed free plots (Rs.229259 ha^{-1}) which was followed by the pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS along with mulching @ 7 t ha^{-1} (T_3) and mulching @ 7 t ha^{-1} and hand weeding @ 20 DAS (T_7). Net returns were also highest in the weed free plots which have resulted due to the higher seed yield obtained.

The treatments T_3, T_7 andT_{11} showed highest B:C ratio among the weed control treatments followed by T_6 that is on par with that of T_4. The higher seed yield may be the reason behind the higher BCR. Control plot obtained the lowest B:C ratio. The results showed that in control plot and plots where mulching alone was done recorded B:C ratio less than 1 and which is not economically viable treatment. The different B:C ratio obtained among the treatments may be due to the variation in cost of cultivation and the yield. Fonts *et al.* (2010) opined that use of herbicides corresponding to the mechanical measures leads to higher efficacy and less production cost. Similarly, integration of various weed management methods leads to efficient control of weeds instead of any single method. Herbicide application along with the manual way of weed management is the productive method (Yadav *et al.*, 2017). According to higher gross income with lower cost of cultivation was responsible for higher BCR. These findings are in close conformity with Sasikala *et al.* (2004). Yadav *et al*. (2018) reported that even though critical period of crop-weed competition in cowpea 25-57 days and if the field is kept weed free for the first 60 days, it resulted in higher net returns and B:’C ratio.

Therefore, it can be concluded that application of herbicides along with mulching and provision of mulching followed by hand weeding at most critical stage and maintenance of weed free condition is the better and most economical method of weed management in cowpea. Integration of different weed management practices especially during the initial stages along with the control of new weed flushes in the later stages has resulted in better weed management during the critical period of crop weed competition. IWM practices indicated that combination of weed management practices especially when affected at different crop growth stages provided maximum protection against weeds during the critical period. Combination of chemical and non-chemical practices would give better results compared to that of any one method of weed management This would result in higher yield and better returns (Sinchana, 2020).

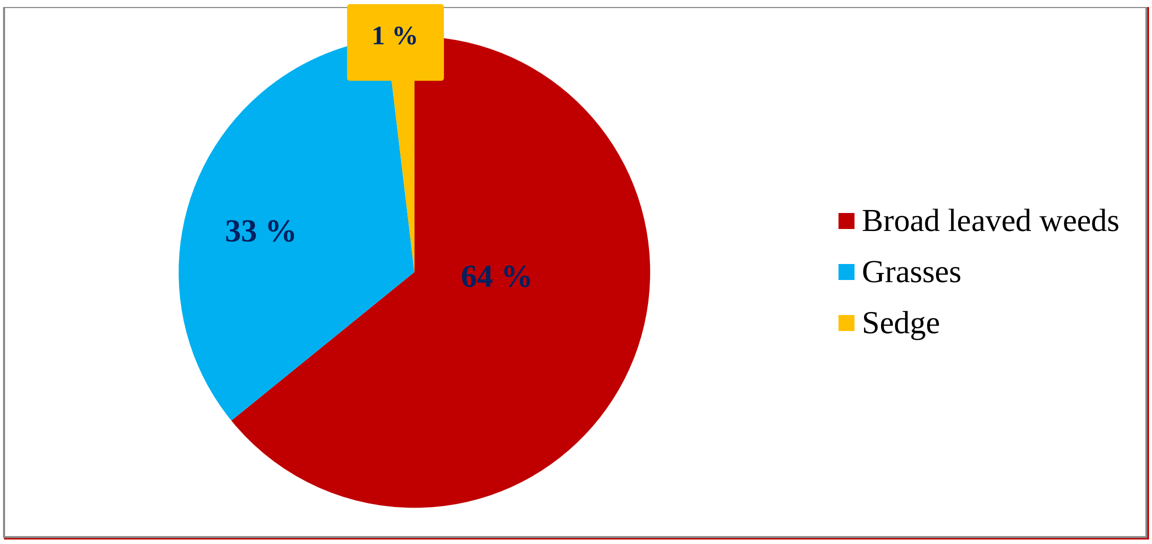


Fig. 4. Weed flora of the experimental field

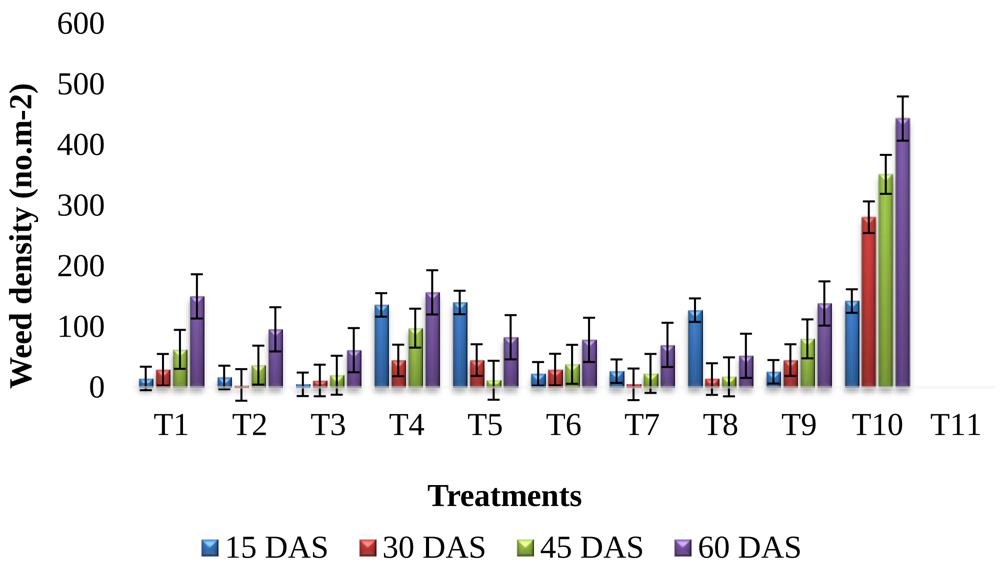


Fig. 5. Effect of weed management practices on weed density

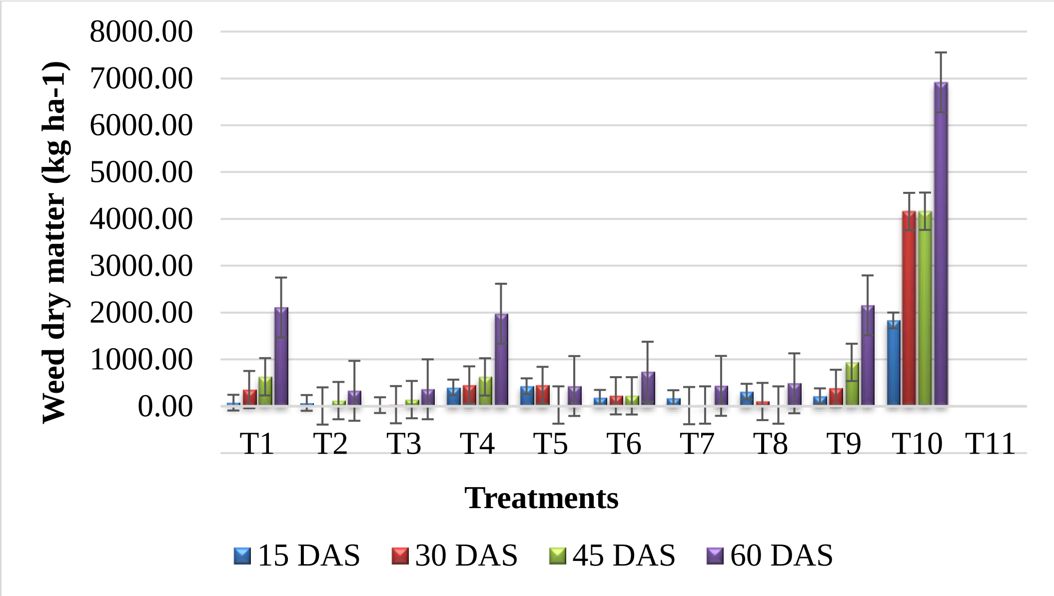


Fig. 6. Effect of weed management practices on weed dry matter production

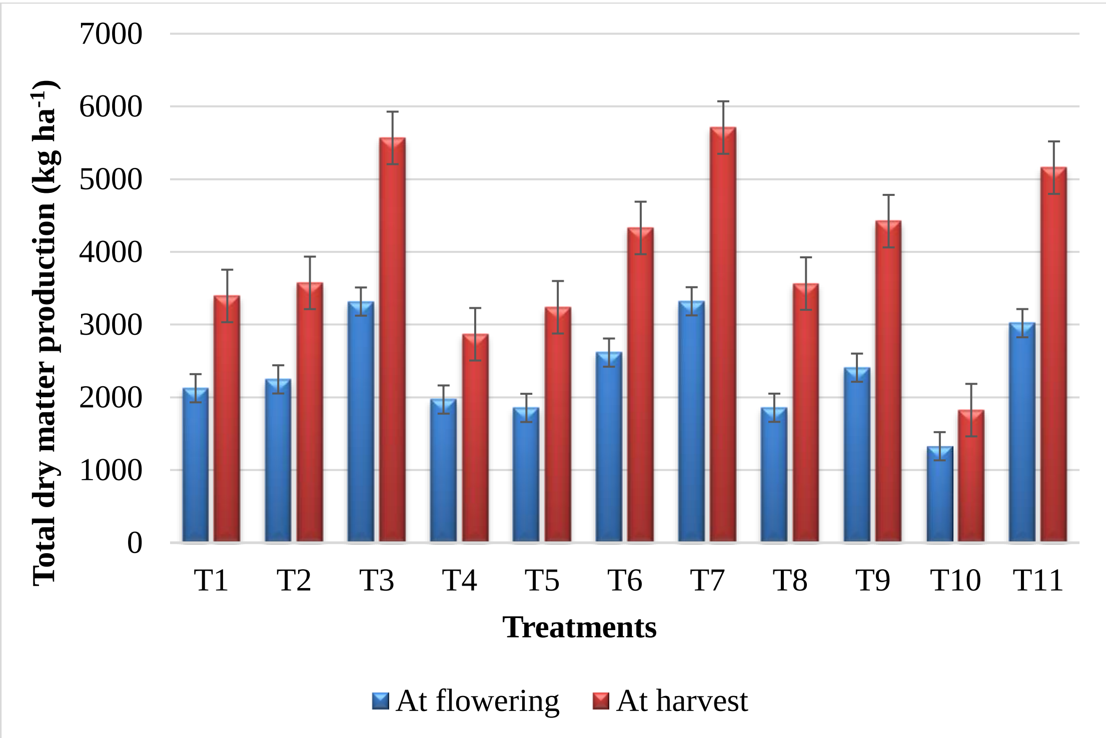


Fig 7. Effect of weed management practices on total dry matter production of cowpea

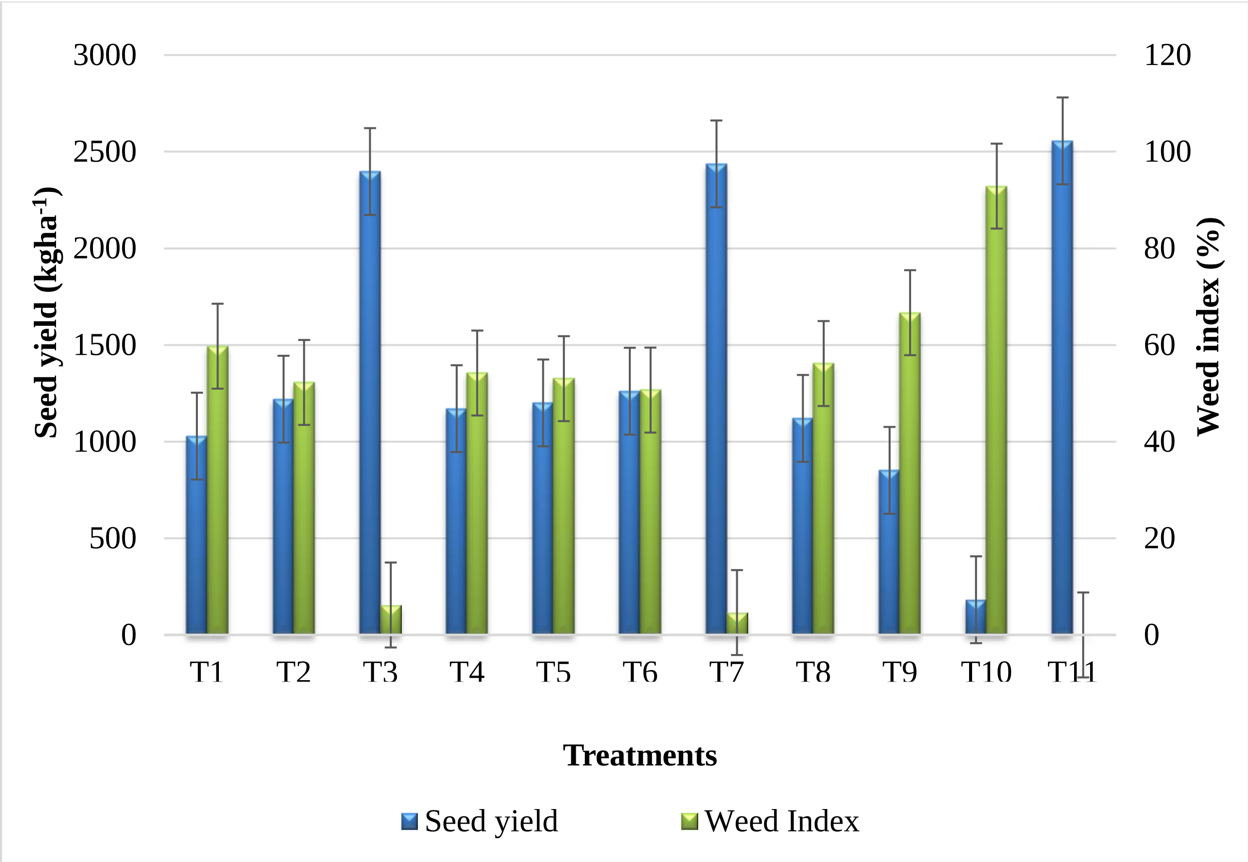


Fig. 8. Effect of weed management practices on seed yield and weed index

SUMMARY

6. SUMMARY

Weed infestation is one of the most important constraints in crop production and it contributes even upto 60 per cent yield reduction in cowpea depending on the weed infestation, location and season. Cowpea is the major pulse crop grown in Kerala, mostly grown in summer rice fallows. Farmers seldom do weed management practices owing to the high labour charge and are mostly unaware of proper herbicide usage in pulses. Hence, an experiment entitled ‘Integrated weed management in cowpea (*Vigna unguiculata* L.) was conducted at the Instructional farm II of College of Agriculture Padannakkad located at Karuvacheri during the *rabi* season of the year 2020. The objectives of the study include comparison of efficacy of different weed management practices in managing weeds and thereby improving the yield was studied. The economic comparisons of the different weed management practices were also done. The summary of the study is given below.

The field experiment was laid out in randomized block design with 11 treatments replicated three times. The treatments comprised of T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}), T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) , T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1}), T_4 (post-emergence application of imazethapyr @ 75 g ha^{-1}), T_5 (post-emergence application of imazethapyr @ 75 g ha^{-1} + hand weeding at 35 DAS), T_6 (mulching @ 7 t ha^{-1} + post-emergence application of imazethapyr @ 75 g ha^{-1}) , T_7 (mulching @ 7 t ha^{-1} + hand weeding at 20 DAS), T_8 (hand weeding alone at 15 and 30 DAS), T_9 (mulching alone @ 7 t ha^{-1}), T_{10} (weedy check/ control) and T_{11} (weed free).

The observations on weed parameters include weed population, weed density, dry matter production, weed index and weed control efficiency. Soil and plant analysis were done for determining nutrient status. The economics of different weed management practices were computed. The biometric observations studied include plant height, number of branches per plant, number of nodules per plant, leaf area index, total dry matter production, number of pods per plant, number of seeds per pod, pod weight per plant, test weight, pod yield and seed yield. The important findings of the present investigation are summarized below.

At 15 DAS, the density of weeds was lowest in T_3 (pre-emergence herbicide @ 0.75 kg ha^{-1} along with mulching @ 7 t ha^{-1}) except that of weed free plot followed by T_1 and T_2. At 30 DAS, pre-emergence herbicide @ 0.75 kg ha^{-1} accompanied by hand weeding at 20-25 DAS in T_2 and mulching @ 7 t ha^{-1} with hand weeding at 20 DAS in T_7 recorded lowest density of weeds. At 45 DAS, significantly lower density of weeds was recorded in post emergent application of imazethapyr @ 75 g ha^{-1} with hand weeding at 35 DAS in T_5, T_3 and hand weeding alone at 15 and 30 DAS in T_8 which were on par to each other. At 60 DAS, lower density of weeds was recorded in T_8, T_3 and T_7.

The weed dry matter was significantly lower in all other treatments compared to that of weedy check. At 15 DAS, pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching @ 7 t ha^{-1} lowest value for weed density compared to all other treatments except for T_{11}. At 30 DAS, T_2 recorded the significantly lower value for weed dry weight which was on par with T_7 and T_3. At 45 DAS, significantly lower value for weed dry weight was recorded in T_8 among all the treatments which was on par with T_5 and T_7. At 60 DAS, dry weight was lowest in T_2 which was significantly the lower among all the weed control treatments except for T_3, T_5, T_7 and T_8 which were on par to each other.

The weed control efficiency (WCE) was recorded at 15, 30, 45 and 60 DAS. Treatment T_{11}, which was maintained weed free throughout the cropping period, recorded the lowest value for weed dry matter production and highest WCE (cent per cent) throughout the period of study. The WCE values at 15 DAS indicated that the treatment T_3 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + mulching), T_2 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} + hand weeding at 20-25 DAS) and T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1}) were on par with T_{11}. At 30 DAS, T_2 was recorded with significantly highest WCE among all the treatments except T_{11}. At 45 DAS, WCE was significantly highest in T_8 which was superior to all other treatments except T_{11} (weed free check) and on par to T_5, T_7

and T_2. At harvesting stage (60 DAS), the treatment T_7 recorded significantly highest value for WCE which was significantly superior to all other treatments except T_{11} T_3, T_2 and T_5 which were on par with each other. Significant difference was recorded by the different weed management practices with respect to weed index (WI). Significantly lowest weed index value was obtained by the treatment T_7 which was followed by T_3.

The effect of weed management practices on weed density and dry weight was reflected in the biometric parameters both at flowering as well as harvesting stage. Weed free plot has resulted in highest value for almost all the parameters and the weedy check resulted in least values. Mulching and post-emergence application of imazethapyr enhanced the plant height and was on par with weed free plot at flowering stage. Pre-emergence application of pendimethalin and mulching and mulching with hand weeding were followed by weed free plot at harvesting stage.

Mulching and post emergent application of imazethapyr and pre-emergence application of pendimethalin and mulching resulted in higher number of branches per plant at flowering stage, which was significantly superior to all other treatments except to that of weed free plot (T_{11}), pre-emergence application of pendimethalin and hand weeding (T_2) and mulching and hand weeding (T_7) which were on par.

Number of nodules per plant was highest in the plots where mulching was done along with hand weeding and were on par with post emergent application of imazethapyr and mulching (T_6), mulching alone (T_9) and weed free plots (T_{11}) at flowering stage. At harvesting stage, number of nodules per plant was significantly superior pre-emergence application of pendimethalin and hand weeding (T_2) among all other treatments except T_7 and T_6 which were on par with that of T_2.

Among the different weed control treatments, weed free plot recorded the highest value for LAI was on par with that of pre-emergence application of pendimethalin in T_3 and mulching and hand weeding in T_7. During the harvesting stage, highest plant height was recorded in weed free (T_{11}) and pre-emergence application of pendimethalin and mulching (T_3) recorded same value for LAI and, along with T_7 were significantly superior to all other treatments. Mulching and hand weeding resulted highest dry matter production which was on par with pre-emergence application of pendimethalin and mulching at flowering and harvesting stage.

Weed free plot produced highest number of pods per plant followed by pre-emergence application of pendimethalin and mulching and mulching + hand weeding. The highest number of seeds per pod and pod weight per plant was recorded by mulching and hand weeding (T_7) and was on par with weed free (T_{11}).

Highest pod yield was recorded in the treatment T_{11} among the other treatments except that of T_3 and mulching and hand weeding in T_7 which were on par to T_{11}. Seed yield was highest in weed free plot followed by T_3 and T_7.

The total nitrogen content in the plant sample was highest in T_7 among all the treatments except T_6, T_{11} (weed free) and T_3 (pre-emergence application of pendimethalin with mulching) which were on par with T_7. Total phosphorous content was not significantly influenced by the weed control techniques. The total potassium content was highest in T_7 which was on par with T_3, T_{11} and T_6 (mulching and post emergent application of imazethapyr). Total nitrogen content and total potassium content was recorded lowest in weedy check/ control plot (T_{10}).

Highest net income of Rs. 1,34,580 ha^{-1} as obtained from the weed-free plot followed by pre-emergence application of pendimethalin with mulching (T_3) with a net income of Rs. 1,19,033 ha^{-1} and mulching and hand weeding (T_7) with a gross income of Rs.1,17,604 ha^{-1}. Highest value for B: C ratio was recorded by T_7 (2.45) and T_3 (2.45) which was on par with T_{11} (2.42).

It can be concluded that:

- Weed infestation significantly affected yield attributes and total yield in cowpea and yield was higher in plots where IWM was practiced compared to those plots where any one method (chemical/physical/cultural) was followed. Integrated weed management is always better than following a single method of weed management practice.

- It is important to keep the field weed free during the initial growth stages of cowpea for effective weed management and this would reflect positively in enhancing the yield.
- Pre-emergence application of pendimethalin along with mulching and mulching done along with hand weeding could effectively keep the field weed free for the critical period of crop weed competition and this reflected in the yield and yield attributes
- The total yield was highest in the weed free plots which indicate that maintaining the field weed free even beyond critical period of crop weed competition can contribute to higher yields.
- Even though the cost of cultivation was highest in the weed free plots, the B:C was on par with that of the best IWM practices owing to the superior yield in these plots.

Future line of work

- IWM experiments with different combinations of management practices should be carried out for different seasons and agroclimatic conditions.
- Phytosociology of the weed flora in the experimental sites should be studied for different seasons.
- Allelopathic effects of the major weed species on other weeds as well as crops need to be studied.
- Studies may be conducted under organic crop production systems.
- Studies may be conducted with herbicides having different mode of action.

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APPENDICES

Appendix 1. Weather parameters during the crop season in standard weeks

Standard meteorological week	Maximum temperature (°C)	Minimum temperature (°C)	Rainfall (mm)
51	33.1	21.1	0
52	37.5	24.8	0
1	32.7	21.9	42
2	32.7	22.6	37.4
3	31.8	22.5	0
4	33.5	21.7	0
5	32.8	20.9	0
6	32.8	19.8	0
7	32.8	21.6	0
8	33.1	21.2	1
9	33.1	23.7	0
10	35	23.3	0
11	34.1	24.5	0

Appendix 2. Details of media used for serial dilution technique

1. Nutrient Agar medium (Atlas and Parks, 1993)

Sl. No.	**Reagents**	**Quantity**
1.	Peptone	5g
2.	NaCl	5g
3.	Beef extract	3g
4.	Agar	20g
5.	pH	7
6.	Distilled water	1000 ml

2. Kenknight's Agar medium (Martin, 1950)

Sl. No.	Reagents	Quantity
1.	DextrosKH	1.0g
2.	2PO4	0.1g
3.	NaNO3	0.1g
4.	KCl	0.1g
5.	MgSO4.7H2O	0.1g
6.	Agar Distilled	15.0g
	water	1000 ml

3. Martin's Rose Bengal Agar medium (Cappuccino and Sherman, 1996)

Sl. No.	Reagents	Quantity
1.	Glucose	10g
2.	Peptone	5g
3.	KH2PO4	1g
4.	$MgSO_4.7H_2O$	0.5g
5.	Streptomycin	30 mg
6.	Agar	15g
	Rose Bengal	35 mg
	Distilled water	1000 ml

INTEGRATED WEED MANAGEMENT IN COWPEA
(*Vigna unguiculata* L.)

by
AMAYA C.P.
(2019-11-171)

ABSTRACT OF THE THESIS

Submitted to the partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY
COLLEGE OF AGRICULTURE
PADANNAKKAD, KASARAGOD-671314
2022

ABSTRACT

Abstract

Integrated weed management in cowpea (*Vigna unguiculata* L.)

An experiment entitled 'Integrated weed management in cowpea (*Vigna unguiculata* L.) was conducted at Instructional farm II of College of Agriculture, Padannakkad located at Karuvacheri, from December 2020 to March 2021 with the objectives of evaluating the efficacy of different weed management practices and to find out the economics of weed management in cowpea.

The experimental design was Randomized Block Design (RBD) with 11 treatments replicated thrice. The short duration cowpea variety namely PGCP 6 was used for the study. The treatments consisted of T_1 (pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} at 0-3 DAS), T_2 (T_1 + hand weeding at 20-25 DAS), T_3 (T_1 + mulching @ 7 t ha^{-1}), T_4 (post-emergence application of imazethapyr @ 75 g ha^{-1} at 20 DAS), T_5 (T_5 + hand weeding at 35 DAS), T_6 (mulching @ 7 t ha^{-1} + T_5), T_7 (mulching @ 7t ha^{-1} + hand weeding at 20 DAS), T_8 (hand weeding alone at 15 and 30 DAS), T_9 (mulching alone @ 7 t ha^{-1}), T_{10} (weedy check/control) and T_{11} (weed free).

Weed density, dry matter and weed control efficiency (WCE) was lowest in weed free plots throughout the observation period and weedy check (control) recorded highest density dry matter and WCE among all other treatments. At 15 DAS, pre-emergent herbicide treated plots recorded lowest density of weeds in the order $T_3 > T_1 > T_2$. At 30 DAS, T_2 and T_7 recorded lowest density of weeds. At 45 DAS, T_5, T_3, T_8 and T_7 were recorded with lowest density of weeds and which were on par to each other. At 60 DAS, T_8, T_3, T_7 and T_6 were recorded lowest density of weeds and which were on par to each other.

In the case of weed dry weight at 15 DAS, T_3 recorded the lowest value for dry weight compared to all other treatments except for T_{11}. At 30 DAS, significantly lower value for dry weight was recorded in T_2, which was on par with T_7 and T_3. At 45 DAS, significantly lower value for weed dry weight was recorded in T_8 among all the treatments which were on par with T_5 and T_7. At 60 DAS, dry weight recorded by the treatment T_2 was significantly lower among all the weed control treatments except for

T_3, T_5, T_7 and T_8 which were on par to each other. Lowest WCE was observed in control plot or weedy check (T_{10}). At 15 DAS, the treatments T_3, T_2 and T_1 recorded the highest WCE. At 30 DAS, T_2 was recorded with significantly higher WCE. At 45 DAS, WCE was significantly higher in T_8 and was on par to T_5, T_7 T_2 and T_3. At harvesting stage (60 DAS), the treatment T_2 recorded significantly higher value for WCE which was on par to T_3. Significantly lower value for weed index (WI) was recorded in weed free plots and T_7.

Plant height, number of branches per plant (harvesting stage) and leaf area index was highest in weed free plot compared to that of all other treatments. Number of nodules per plant was recorded significantly superior in T_7 at flowering stage and T_2 at harvesting stage. Total dry matter production was highest in T_7 which was on par with T_3 at flowering and harvesting stages. Number of pods per plant, pod yield and seed yield were highest in weed free plots compare to that of all other treatments. Treatment T_7 recorded significantly superior results in the case of number of seeds per pod, pod weight per plant and test weight and which was on par with that of pre-emergent application of T_3 and T_{11}. Among the available soil nutrients, depletion of available N was highest in T_{10} and treatment T_8 recorded highest soil N content. Gross returns and net returns were highest in weed free plots compare to all other treatments which was followed by T_3. Similar trend was shown in the case of net return also. The highest B:C ratio of 2.45 was obtained for T_7 and T_3 which were on par with T_{11} (2.42).

The overall results indicated that weed infestation significantly affected yield in cowpea and integrated weed management (IWM) especially during the critical period of crop weed competition in cowpea is inevitable for getting an economic yield and could reduce yield loss even upto 67 per cent. Even though the cost of cultivation was highest in the weed free plots, the B:C was on par with that of the best IWM practices owing to the superior yield in these plots. Pre-emergence application of pendimethalin along with mulching; and mulching along with hand weeding could effectively keep the field weed free for the critical period of crop weed competition and this treatment resulted in highest B:C ratio and highest on par yields.

സംക്ഷിപ്തം

സംക്ഷിപ്തം

വിവിധ കളപരിപാലന രീതികളുടെ ഫലപ്രാപ്തി വിലയിരുത്തുന്നതിനും പയറിലെ കളപരിപാലനത്തിന്റെ സാമ്പത്തികാവലോകനത്തിനുമായി 2020 ഡിസംബർ മുതൽ 2021 മാർച്ച് വരെ 'പയറിൽ സംയോജിത കളപരിപാലനം' എന്ന പേരിൽ ഒരു പരീക്ഷണം പടന്നക്കാട് കാർഷിക കോളേജിന്റെ ഭാഗമായ കരുവാച്ചേരി ഫാർമിൽ നടത്തുകയുണ്ടായി.

ഫാക്ടോറിയൽ റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈനിൽ 12 പരിചരണമുറകൾ 3 തവണ ആവർത്തനത്തോടു കൂടിയാണ് പരീക്ഷണം കൃഷിയിടത്തിൽ ആവിഷ്കരിച്ചത്. പിജിസിപി 6 എന്ന ഹ്രസ്വകാല പയർ ഇനമാണ് പഠനത്തിനായി ഉപയോഗിച്ചത്. T_1 (വിത്ത് വിതച്ച് 0 മുതൽ 3 ദിവസങ്ങൾക്കുള്ളിൽ 0.75 കി.ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ പെൻഡിമെത്തലിന്റെ പ്രിഎമർജൻസ് പ്രയോഗം), T_2 (വിത്ത് വിതച്ച് 0 മുതൽ 3 ദിവസങ്ങൾക്കുള്ളിൽ 0.75 കി.ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ പെൻഡിമെത്തലിന്റെ പ്രിഎമർജൻസ് പ്രയോഗം + വിത്ത് വിതച്ച് 20 ആം ദിവസം കളപറിക്കൽ), T_3 (വിത്ത് വിതച്ച് 0 മുതൽ 3 ദിവസങ്ങൾക്കുള്ളിൽ 0.75 കി.ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ പെൻഡിമെത്തലിന്റെ പ്രിഎമർജൻസ് പ്രയോഗം + പുതയിടൽ 7 ടൺ ഒരു ഹെക്ടറിന് എന്ന തോതിൽ), T_4 (വിത്ത് വിതച്ച് 20 ദിവസത്തിനുള്ളിൽ 75 ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ ഇമാസെതാപൈർന്റെ പോസ്റ്റ്-എമർജൻസ് പ്രയോഗം), T_5 (വിത്ത് വിതച്ച് 20 ദിവസത്തിനുള്ളിൽ 75 ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ ഇമാസെതാപൈർന്റെ പോസ്റ്റ്-എമർജൻസ് പ്രയോഗം + വിത്ത് വിതച്ച് 35 ആം ദിവസം കളപറിക്കൽ), T_6 (പുതയിടൽ 7

ടൺ ഒരു ഹെക്ടറിന് എന്ന തോതിൽ + വിത്ത് വിതച്ച് 20 ദിവസത്തിനുള്ളിൽ 75 ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ ഇമാസെതാപൈർന്റെ പോസ്റ്റ്-എമർജൻസ് പ്രയോഗം), T_7 (പുതയിടൽ 7 ടൺ ഒരു ഹെക്ടറിന് എന്ന തോതിൽ 1 + വിത്ത് വിതച്ച് 20 ആം ദിവസം കളപറിക്കൽ), T_8 (വിത്ത് വിതച്ച് 15 ആം ദിവസം കളപറിക്കൽ + വിത്ത് വിതച്ച് 15 ആം ദിവസം കളപറിക്കൽ), T_9 (പുതയിടൽ 7 ടൺ ഒരു ഹെക്ടറിന് എന്ന തോതിൽ), T_{10} (കളകളുള്ള ചെക്ക്/നിയന്ത്രണം), T_{11} (കളരഹിതം).

കള സാന്ദ്രത, കളകളുടെ ഡ്രൈ മാറ്റർ, കള നിയന്ത്രണ കാര്യക്ഷമത എന്നിവ നിരീക്ഷണ കാലയളവിലുടനീളം കള രഹിത പ്ലോട്ടിൽ ഏറ്റവും കുറവായിരുന്നു. വിതച്ച് 15 ദിവസങ്ങൾക്കുള്ളിൽ, പ്രിഎമർജൻസ് കളനാശിനി ഉപയോഗിച്ച പ്ലോട്ടുകൾ $T_3 > T_1 > T_2$ എന്ന ക്രമത്തിൽ കളകളുടെ ഏറ്റവും കുറഞ്ഞ സാന്ദ്രത രേഖപ്പെടുത്തി. വിതച്ച് 30 ദിവസത്തിനുള്ളിൽ, T_2, T_7 എന്നിവയിൽ കളകളുടെ ഏറ്റവും കുറഞ്ഞ സാന്ദ്രത രേഖപ്പെടുത്തി. 45 ദിവസങ്ങൾക്കുള്ളിൽ, $T_5 > T_3 > T_8 > T_7$ എന്നിവ കളകളുടെ ഏറ്റവും കുറഞ്ഞ സാന്ദ്രത രേഖപ്പെടുത്തി ഇവ പരസ്പരം തുല്യവുമായിരുന്നു. വിതച്ച് 60 ദിവസങ്ങൾക്കുള്ളിൽ, $T_8 > T_3 > T_7 > T_6$ എന്നിവ ഏറ്റവും കുറഞ്ഞ കള സാന്ദ്രത രേഖപ്പെടുത്തി. വിതച്ച് 15 ദിവസങ്ങൾക്കുള്ളിൽ, T_{11} ഒഴികെയുള്ള മറ്റെല്ലാ ട്രീട്മെന്റുകളെയും അപേക്ഷിച്ച് ഡ്രൈ മാറ്റർ ഏറ്റവും കുറവ് T_3 ൽ ആയിരുന്നു. വിതച്ച് 30 ദിവസത്തിനുള്ളിൽ, T_2-ൽ ഡ്രൈ മാറ്റർ ഗണ്യമായ കുറവ് രേഖപ്പെടുത്തി, ഇത് T_7, T_3 എന്നിവയ്ക്ക് തുല്യമായിരുന്നു. വിതച്ച് 45 ദിവസത്തിനുള്ളിൽ, ട്രീറ്റ്മെന്റ് T_8-ൽ ഡ്രൈ മാറ്റർന്റെ ഗണ്യമായ കുറവ് രേഖപ്പെടുത്തി. T_5, T_7 എന്നിവയിൽ ഡ്രൈ മാറ്റർ തുല്യമായിരുന്നു. വിതച്ച് 60 ദിവസങ്ങൾക്കുള്ളിൽ, മറ്റെല്ലാ ട്രീട്മെന്റുകളെയും അപേക്ഷിച്ച് ട്രീറ്റ്മെന്റ് T_2-ൽ ഡ്രൈ മാറ്റർ വളരെ കുറവായിരുന്നു അത് T_3, T_5, T_7, T_8 എന്നിവയ്ക്ക് തുല്യമായിരുന്നു.

നിരീക്ഷണ കാലയളവിലുടനീളം കള നിയന്ത്രണ കാര്യക്ഷമത ഏറ്റവും കുറഞ്ഞത് കള നിയന്ത്രണം നടത്താത്ത പ്ലോട്ടിൽ ആയിരുന്നു. വിതച്ച് 15 ദിവസത്തിനുള്ളിൽ, T_3, T_2, T_1 എന്നീ ട്രീട്മെന്റുകൾ ഏറ്റവും ഉയർന്ന കള നിയന്ത്രണ കാര്യക്ഷമത രേഖപ്പെടുത്തി. വിതച്ച് 30 ദിവസത്തിനുള്ളിൽ, T_2 ഗണ്യമായി ഉയർന്ന കള നിയന്ത്രണ കാര്യക്ഷമത രേഖപ്പെടുത്തി. വിതച്ച് 45 ദിവസത്തിനുള്ളിൽ, T_8-ൽ കള നിയന്ത്രണ കാര്യക്ഷമത ഗണ്യമായി ഉയർന്നു. കൂടാതെ, T_5, T_7, T_2, T_3 എന്നീ ട്രീട്മെന്റുകൾക്ക് തുല്യമായ കള നിയന്ത്രണ കാര്യക്ഷമത രേഖപ്പെടുത്തി. വിളവെടുപ്പ് ഘട്ടത്തിൽ, കള നിയന്ത്രണ കാര്യക്ഷമതയിൽ ട്രീറ്റ്മെന്റ് T_2 ഗണ്യമായി ഉയർന്ന മൂല്യം രേഖപ്പെടുത്തി. കള രഹിത പ്ലോട്ടുകളിലും T_7-ലും കള സൂചിക (WI) കുറവായിരുന്നു.

ചെടിയുടെ ഉയരം, ശാഖകളുടെ എണ്ണം, ഇല വിസ്തീർണ്ണ സൂചിക എന്നിവ മറ്റെല്ലാ ട്രീട്മെന്റുകളെയും അപേക്ഷിച്ച് കള രഹിത പ്ലോട്ടിൽ ഏറ്റവും ഉയർന്ന മൂല്യം രേഖപ്പെടുത്തി (പൂവിടുന്ന ഘട്ടവും വിളവെടുപ്പ് ഘട്ടവും). പൂവിടുന്ന ഘട്ടത്തിൽ T_7-ലും വിളവെടുപ്പ് ഘട്ടത്തിൽ T_2-ലും ചെടിയിലെ നോഡ്യൂളുകളുടെ എണ്ണത്തിൽ ഗണ്യമായി ഉയർന്ന മൂല്യം രേഖപ്പെടുത്തിയിട്ടുണ്ട്. ഡ്രൈ മാറ്റർ ഉൽപ്പാദനം T_7-ൽ ഉയർന്നതായി കാണാം, ഇത് പൂവിടൽ ഘട്ടത്തിലും വിളവെടുക്കുന്ന ഘട്ടത്തിലും T_3-ക്ക് തുല്യമായിരുന്നു.

ഒരു ചെടിയിലെ കായ്കളുടെ എണ്ണം, കായ്കളുടെ വിളവ്, വിത്ത് വിളവ് എന്നിവ മറ്റെല്ലാ ട്രീട്മെന്റുകളെയും അപേക്ഷിച്ച് കള രഹിത പ്ലോട്ടുകളിൽ ഏറ്റവും ഉയർന്ന മൂല്യം രേഖപ്പെടുത്തുകയുണ്ടായി.

മണ്ണിലെ ലഭ്യമായ നൈട്രജന്റെ ഏറ്റവും ഉയർന്ന മൂല്യം ട്രീറ്റ്മെന്റ് T_8 ലും T_2 വിലും രേഖപ്പെടുത്തി. മൊത്ത വരുമാനവും അറ്റാദായവും കള രഹിത പ്ലോട്ടുകളിൽ മറ്റെല്ലാ ട്രീട്മെന്റുകളെയും അപേക്ഷിച്ച് ഉയർന്ന തായി കണ്ടെത്തി. അറ്റാദായത്തിന്റെ

കാര്യത്തിലും സമാനമായ പ്രവണത കാണപ്പെട്ടു. ട്രീറ്റ്മെന്റ് T_3 ലും T_7 ലും B:C അനുപാതം ഏറ്റവും ഉയർന്നതായിരുന്നു. അവ ട്രീറ്റ്മെന്റ് T_{11} നുമായിട്ട് തുല്യവുമായിരുന്നു.

കള ആക്രമണം പയറിലെ വിളവിനെ സാരമായി ബാധിച്ചതായി മൊത്തത്തിലുള്ള ഫലങ്ങൾ സൂചിപ്പിക്കുന്നു. കള-വിള മത്സരത്തിന്റെ നിർണായക കാലഘട്ടത്തിലുള്ള സംയോജിത കള നിയന്ത്രണം വിളവ് ഉയരുവാൻ സഹായിച്ചതായി കാണാം. വിളവ് നഷ്ടം 67% വരെ കുറയ്ക്കാനും ഇതുവഴി സാധിച്ചു. കള രഹിത പ്ലോട്ടുകളിൽ കൃഷിച്ചെലവ് ഏറ്റവും ഉയർന്നതാണെങ്കിലും, ഈ പ്ലോട്ടുകളിലെ ഉയർന്ന വിളവ് കാരണം B:C അനുപാതം മികച്ച സംയോജിത കള പരിപാലന രീതികൾക്ക് തുല്യമായിരുന്നു. പുതയിടലിനൊപ്പം പെൻഡിമെത്തലിൻ പ്രീമെർജൻസ് പ്രയോഗവും, കൈ ഉപയോഗിച്ചു കളകൾ നീക്കം ചെയ്യുന്നതിനൊപ്പം പുതയിടുന്നതും വിള-കള മത്സരത്തിന്റെ നിർണായക കാലയളവിൽ പ്ലോട്ടുകളെ കളകളില്ലാതെ ഫലപ്രദമായി നിലനിർത്താൻ സഹായിച്ചു. കൂടാതെ, ഈ ട്രീട്മെന്റുകൾ ഏറ്റവും ഉയർന്ന B:C അനുപാതത്തിനും തുല്യമായ ആദായത്തിനും കാരണമായി.