BIO-EFFICACY OF PRE-MIX HERBICIDE COMBINATIONS FOR BROAD SPECTRUM WEED CONTROL IN WET SEEDED RICE

By

MOUNISHA J.

(2018-11-135)

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

BIO-EFFICACY OF PRE-MIX HERBICIDE COMBINATIONS FOR BROAD SPECTRUM WEED CONTROL IN WET SEEDED RICE

By

MOUNISHA J.

(2018-11-135)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

(AGRONOMY)

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

DECLARATION

I, Mounisha J. (2018-11-135) hereby declare that this thesis entitled **"Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 28-09-2020

Mounisha J.

(2018-11-135)

CERTIFICATE

Certified that this thesis entitled **"Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice"** is a bonafide record of research work done independently by **Ms. Mounisha J. (2018-11-135)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellanikkara

Date: 28-09-2020

Dr. Meera V. Menon
(Chairperson, Advisory committee)
Professor & Head
Department of Agronomy
College of Horticulture, Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Mounisha J. (2018-11-135)**, a candidate for the degree of **Master of Science in Agriculture** with major field in **Agronomy**, agree that this thesis entitled **"Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice"** may be submitted by **Ms. Mounisha J.** in partial fulfillment of the requirement for the degree.

Dr. Meera V. Menon
(Chairperson, Advisory committee)
Professor & Head
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. P. V. Sindhu
(Member, Advisory committee)
Assistant Professor (Agronomy)
AICRP (MAP & B)
College of Horticulture, Vellanikkara

Dr. Syama S. Menon
(Member, Advisory committee)
Assistant Professor
Department of Agronomy
College of Horticulture, Vellanikkara

Dr. K. M. Durga Devi
(Member, Advisory committee)
Professor
Soil Science & Agricultural Chemistry
College of Horticulture, Vellanikkara

ACKNOWLEDGEMENT

I am in dearth of words to express my love towards my beloved parents ***Mrs. Kirubarani J*** *and* ***Mr. Jayachandran V*** *for their prayers, blessings, support and sacrifice without which this endeavour would never have become a reality.*

My words cannot express the deep sense of immeasurable gratitude and undoubtful indebtedness to ***Dr. Meera V. Menon****, Professor and Head, Department of Agronomy, chairperson of my advisory committee. With great respect and devotion, I wish to place my heartfelt thanks to her for the inspiring guidance, untiring interest, unstinted co-operation, esteemed advice, constructive criticism, valuable suggestion and immense help rendered by her during the investigation and preparation of the thesis. I am genuinely indebted to her for the constant encouragement and affectionate advice rendered throughout the academic programme. I consider myself being fortunate in having the privilege of being guided by mam.*

I would like to express my extreme indebtedness and obligation to ***Dr. P. V. Sindhu****, Assistant Professor, Department of Agronomy and member of my Advisory Committee for her expert advice, valuable suggestions, critical evaluation and support rendered during thesis work.*

I feel highly privileged to express the deep sense of gratitude to my advisory committee member, ***Dr. Syama S. Menon,*** *Assistant Professor, Department of Agronomy for her propitious guidance, keen interest, and encouragement during the course of study.*

I express my heartfelt gratitude to ***Dr. K. M. Durga Devi****, Professor, Department of Soil Science and Analytical chemistry, and member of my advisory committee for her advice, valuable suggestions, constant support and cooperation throughout the course of study.*

I express my gratitude towards ***Dr. P. Prameela,*** *Professor, Department of Agronomy for her valuable comments, innumerable help and moral support during the entire course of study.*

It is with my heartfelt feelings, I wish to express my deep sense of gratitude and sincere thanks to my beloved teachers ***Dr. S. Anitha, Dr. Sreelakshmi, and Dr. Savitha Antony*** *for their encouragement, valuable help and advice rendered during the course of study.*

I express my heartfelt gratitude to ***Dr. C. George Thomas****, Former Associate Dean and Head, Department of Agronomy, for his scientific advice, valuable suggestions, constant support and cooperation throughout the course of study.*

I am extremely thankful to the farmer ***Mr. Kesavaraj,*** *Pulapally house, Purathur, Alappad, Thrissur district and his labourers for their co-operation and support.*

Let me express my sincere thanks to ***Sri. George Joseph P,*** *Farm Officer,* ***AICRP on weed control,*** *for his whole hearted co-operation, mental support and assistance during the course of research work.*

I take this opportunity to thank ***Mrs. Sreela and Mrs. Symala*** *for their affection, support and concern. I am extremely thankful to the labourers attached to the Department of Agronomy for their co-operation during the conduct of research.*

It gives me great pleasure in acknowledging the support and help of my dear classmates ***Ms. Liz, Ms. Parmoi, Ms. Minu, Ms. Basila and Mr. Suhas*** *who helped and supported me during all my hard times. It is also great to mention my beloved seniors,* ***Dr. Vandana, Dr. Saravana Kumar, Dr. Shobha Rani, Mr. Reddy and Ms. Vidhu*** *for their constant support and guidance.*

*I have infinite pleasure to express my love towards "****Tamil Pasanga" team*** *and my best friends* ***Nidharsan, Pavithra, Nirmal, Harish, Sivadharshana, Nivethitha, Nithya, Nagadevi, Pavithrakumar, Riaz*** *for their affection, moral support, innumerable help and encouragement.*

I also thank all the ***staff members of KAU*** *and* ***librarian of central library*** *who assisted and helped me during the completion of the course.*

It would be impossible to list out all those who have helped me in one way or another, for the completion of my work. I once again express my heartfelt thanks to all those who helped me in completing my work on time. ***Thanking the Almighty.***

Mounisha J

CONTENTS

LIST OF TABLES

LIST OF TABLES (Contd.)

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

1. INTRODUCTION

Rice is the best nutritive and, unarguably the oldest, known food that remains widely consumed today by billions of people around the globe. South East Asiatic region is central for rice production in the world. The production of rice has increased from 496.5 million tonnes (2016-17) to 506.3 million tonnes (2018-19) in the world (FAO, 2020). India is the second largest producer as well as consumer of rice in the world. As the world population is increasing at a higher rate than the rice supply levels, there is an urgent need to reduce the yield gap. The productivity of rice is dependent on the stress levels induced by several abiotic and biotic factors. Weeds are considered as the most serious pests among the biotic stresses caused to rice plants. Possessing the inherent ability to grow faster than rice, weeds quickly deplete the available nutrients and water from the topsoil, seriously affecting the growth and productivity of rice. Weed management in rice is quite complex and expensive, but is crucial to prevent yield losses and to preserve good grain quality. Thus, proper weed control practices at the right time should be employed to reduce crop-weed competition and enhance rice production, leading to higher economic returns for the farmers.

In South Asia, manual transplanting of rice seedlings into puddled soil is the common method of rice establishment. However, direct seeded rice is gaining popularity due to its lower cost of cultivation. Direct seeding includes both the dry and wet seeding of rice, practiced depending on water availability in the region. Weeds are a severe problem in direct seeded rice as weed growth occurs throughout the season, causing yield reduction of about 35% compared to weed-free situation. Joy *et al.* (1991) found that in wet seeded rice areas of Kerala, weed spectrum was composed of 22 % grasses, 40 % sedges and 32 % broad leaved weeds. The weed losses due to weed competition in direct seeded rice could go up to 100 % where weeds were not controlled throughout the season (Singh *et al.*, 2014).

Manual weed control is undoubtedly the most efficient and the commonly followed method to control weeds. However, due to scarcity and rising wages of labour, there is difficulty in adopting hand weeding at the proper time. Among the various weed control measures, the use of herbicide is the most preferred option nowadays to overcome weed infestation as it is considered as the most reliable, easy, time saving and cost effective option. Rice ecosystems usually harbour a variety of weeds and thus, the use of a single herbicide cannot give satisfactory results. Grasses are the most dominant weeds in earlier stages of crop growth, with sedges and broad leaf weeds occurring only later in the season (Jiang, 1989).

Most herbicides used in rice are selective and weed specific, controlling only a small spectrum of the wide diversity of weeds. Weed control in wet seeded rice cultivation needs intensive use of herbicides, either by increasing the number of post-emergence herbicide sprays or by the sequential application of such herbicides (Chauhan, 2012). Application of mixtures of post-emergence herbicides in a single spray to control a broad spectrum of weeds is a viable option as the cost of application would also be reduced. Hence, selection of herbicides with broad spectrum action is essential for an effective and feasible weed control programme for successful rice production.

Commercial mixtures of herbicides are now available in the market and different compatible herbicides can also be tank mixed before application (Lagator *et al.*, 2013). Several new ready mix combinations are now available, which exclude the labour of tank mixing as well as the possibility of non-compatibility. The efficacy of some of the ready mix herbicides have been reported by several workers. Lap *et al.* (2013) reported that a combination of cyhalofop-butyl + penoxsulam could increase rice productivity in direct-seeded and transplanted rice production systems. Similar findings were reported by Raj and Syriac (2015). Also, Madhavi *et al.* (2018) found that pre-emergence application of herbicide combination pendimethalin + penoxsulam at 4-7 DAS/DAT gave the highest benefit:cost ratio as compared to other treatments. Uraon and Shrivastava (2018) also reported similar results. However, the effectiveness of many of these new products has not been evaluated under Kerala conditions, and their effect on soil microorganisms has not been assessed. It is also essential to find out the optimum time of application of these new herbicide combinations so as to bring the weed population below the threshold levels. Such information would be of utmost practical utility to farmers of Kerala.

Under these circumstances, the present study entitled “Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice” was undertaken with the major objective of studying the efficacy of different pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice.

Review of literature

2. REVIEW OF LITERATURE

Rice production faces severe challenges from weeds, the management of which adds to the cost of cultivation. Farmers often prefer chemical weed control methods due to ease in application and reduced labour requirement. New generation herbicides as well as several pre-mix herbicidal combinations are now available in the market which could be used to control broad spectrum of weed species in a single spray application. Available literature on weed dynamics, crop-weed competition, and herbicidal weed control including that with pre-mix combinations are listed in this chapter.

2.1 WEED DYNAMICS IN RICE

In direct-wet seeded rice, weed species adversely affect the crop yields if not managed at the proper time. Knowledge on the weed species, densities and their competing power with rice is useful in developing proper weed management measures. Also, all these factors are influenced by type of crop, season, method of cultivation, sowing time, climate, edaphic and biotic factors.

Nair *et al.* (1974) reported that the weed flora in wet seeded rice fields of Kerala consisted mainly of *Echinochloa crus-galli, Cyperus* sp., *Fimbristylis miliacea* and *Monochoria vaginalis*. However, Moorthy and Dubey (1978) found that sedges were the major weed species contributing to 90 % of the population in wet seeded rice. The major weeds observed in wet seeded rice fields at International Rice Research Institute, Los Banos, Philippines were *Paspalum distichum, Monochoria vaginalis, Sphenoclea zeylanica, Echinochloa glabrescens* and *Cyperus difformis* (Mabbayad and Moody, 1984). Joseph (1986) reported that a high density of *Scirpus supines* was found, followed by *Cyperus difformis* and *Cyperus iria*, in wet seeded rice in Kerala.

Grasses, the most dominant weeds, occur at early crop growth period, and sedges and broad leaf weeds occurs only at the later stage (Jiang, 1989). Joy *et al.* (1991) reported that in wet seeded rice in Kerala, the weed population was composed of 22 % grasses, 40 % sedges and 32 % broad leaf weeds.

The plant densities of *Echinochloa colona, Leptochloa chinensis* and *Eleusine indica* were highest in wet seeded rice, and the weed density of *Leptochloa chinensis* was low when pre-emergence herbicides were applied, followed by two hand weedings at 30 and 60 DAS (Singh *et al*., 2005). Halder and Patra (2007) observed that the composition of grasses, sedges and broad leaf weeds was about 27 %, 35 % and 38 % respectively in weedy check plots. Mann *et al.* (2007) recorded the major weeds in direct seeded rice to be namely *Echinochloa crus-galli, Eclipta prostata, Trianthema portulacastrum, Cyperus difformis, Cyperis iria* and *Paspalum distichum.* Ravisankar *et al.* (2008) reported that grasses constituted about 51.5 % of the total weeds, followed by sedges, which accounted for about 30.9 %.

Sanjoy (2009) observed the major weeds in rice ecosystem to be *Echinochloa crus-galli, Cyperus iria, Fimbristylis miliacea, Ludwigia parviflora, Sphenochlea zeylanica,* and *Commelina benghalensis.* Yadav *et al.* (2009) observed the major wed flora in wet seeded rice and found that grasses, broad leaved weeds and sedges constituted about 85 %, 8 % and 7 % respectively. Mukherjee and Malty (2011) reported that broad leaf weeds like *Monochoria hastate* and *Nymphoides indicum* were active only until the tillering stage of rice but *Ludwigia perennis*, *Cyperus flavidus*, *Cyperus difformis* and *Cynodon dactylon* were present in the entire crop season.

In direct-wet seeded rice, *Echinochloa colona, Echinochloa crus-galli, Eleusine indica, Cyperus rotundus, Cyperus iria, Fimbristylis miliacea, Amaranthus viridis, Ammania baccifera*, and *Caesulia axillaris* were the major weed species (Chaudhary *et al.,* 2011). Singh (2012) found that the major weeds in rice fields of Uttar Pradesh were *Echinochloa crus-galli, Echinochloa colona, Commelina benghalensis, Caesulia axillaris, Cynotis axillaris, Ammania baccifera, Cyperus* spp and *Cynodon dactylon.* The dominant weed flora in wet seeded rice consisted of *Echinochloa colona, Echinochloa crus-galli* and *Cynodon dactylon* under grasses, *Cyperus difformis* and *Cyperus rotundus* under sedges, and *Eclipta alba, Marsilea quadrifolia* and *Sphaeranthus indicus* under broad leaved weeds (Chinnamani *et al.,* 2018).

Dhage and Srivastava (2020) reported that dominant weeds in aerobic rice comprised of grasses like *Cynodon dactylon, Echinochloa colona*, *Echinochloa crus-*

galli and sedges like *Cyperus rotundus, Cyperus difformis, Cyperus iria* and *Fimbristylis maliacea*, and broad-leaf weeds like *Caesulia axillaris, Phyllanthus niruri* and *Anagallis arvensis*. Presence of predominant weeds such as *Echinochloa* spp, *Commelina benghalensis*, *Digitaria sanguinalis* and *Ammania baccifera* in rice areas of Indo-Gangetic plains was reported by Sharma *et al.* (2020).

2.2 CROP-WEED COMPETITION

Competition between crops and weeds increases when any of the resources like nutrients, light, moisture and space fall short of the total requirement. Weeds have higher adaptability and faster growth, and thus dominate over the crop, reducing its yield potential. The extent of crop-weed competition depends on various crop factors like cultivar, crop density, crop age and plant spacing.

Thomas and Abraham (1998) stated that crop-weed competition period was from 15 to 45 days after sowing (DAS) in rice. Weeds were self-grown and appeared simultaneously with crop plants creating severe competition for nutrients, space, moisture, and solar energy, and resulted in lower yield of the rice crop (Rekha *et al.,* 2003). Competition offered by weeds reduced 15 to 45 % of the total grain yield (Chopra and Chopra, 2003) and the reduction could go up to 76 % (Singh *et al.,* 2004). Singh *et al.* (2008) reported that in direct seeded rice, critical period for crop-weed competition was from 15-45 DAS.

Severe weed infestation was observed in direct seeded culture compared to transplanted rice (Chauhan and Johnson, 2009). The majority of weeds emerged during the first 60 days and after that, smothering effect of the crop lowered the weed population in rice (Nath *et al*., 2014). Weed losses due to weed competition in direct seeded rice could even go up to 100 % as they were not controlled during the non-crop season (Singh *et al.*, 2014).

Weeds in rice fields caused yield losses ranging from 15 to 20 % and in severe cases it was even more than 50 % (Teja *et al.*, 2015). The yield reduction in rice due to the presence of weeds was greatest in unweeded checks, and was to the tune of 29.2 % (Islam and Kalita, 2016).

2.3 NUTRIENT REMOVAL BY WEEDS

Weeds had higher nutrient use efficiency than rice (Loonis, 1958). The degree of weed infestation is calculated based on the nutrient removal by them as they are highly inter-related. The higher quantum of nutrients taken up by the weeds lowers the crop nutrient uptake and affects the growth and yield parameters of rice.

Nanjappa and Krishnamurthy (1980) recorded that the highest nutrient removal by weeds was seen in unweeded control (42, 22.15 and 56.04 kg N, P and K per ha respectively) and the lowest was observed in the weeded plots (27.83, 13.25 and 24.0 kg N, P and K per ha respectively). Weeds had growth patterns and photosynthetic pathway (C_4) similar to crops, which resulted in higher nutrient removal by weeds than by crops (Singh *et al.*, 1986). Weeds accumulated higher fraction of the available nutrients in their tissues than crops (Chungi and Ramteke, 1998).

Singh *et al.* (2005) reported that the uptake of nutrients by weeds was higher in weedy check (34.8, 15.6 and 42.3 kg N, P and K per ha respectively) in direct seeded rice and lowest in twice hand weeded checks (4.5, 1.9 and 5.2 kg N, P and K per ha respectively) at 20 and 40 DAS. The grain yield could be improved by enhancing the weed control efficiency and lowering the weed biomass which in turn could result in greater crop nutrient uptake (Singh *et al.*, 2007). The highest nitrogen use efficiency (59 kg grain/kg N) was observed with application of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 8 g/ha and the lowest was in the weedy check (Singh *et al.*, 2007).

Hand weeding twice (at 20 and 40 DAT) recorded the greatest crop nutrient uptake (Subhalakshmi and Venkataramana, 2009). Kumar *et al.* (2010) reported that the nutrient uptake by weeds in direct seeded rice could be reduced with hand weeding and application of pendimethalin @1.0 kg/ha + anilophos @ 0.4 kg/ha. In general, weeds in unweeded or untreated plots removed 50.9, 15.7 and 63.7 kg N, P and K per ha in direct-wet seeded rice (Mukherjee and Malty, 2011). The use of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha at 20 DAT prevented the removal of 28, 6.9 and 35 kg N, P and K per ha in transplanted rice (Mukherjee and Malty, 2011).

Uma *et al.* (2014) recorded the maximum nutrient uptake by weeds in weedy checks and the minimum on hand weeding twice at 20 and 40 DAT. The application of pre-mix herbicide combination of cyhalofop-butyl + penoxsulam @ 135 g/ha effectively increased the plant height (78 cm), number of tillers (393 per m^2), crop yield (4167 kg/ha) and thus, minimized the nutrient uptake to about 6.37, 2.53 and 4.17 kg N, P and K per ha by weeds (Patil *et al.,* 2016).

2.4 WEED MANAGEMENT IN RICE

2.4.1 Hand weeding

Hand weeding is the commonly followed and effective method to control weeds in rice, but it becomes uneconomical due to high daily wages and unavailability of labourers at peak seasons of requirement (Singh and Kumar, 1999).

Prasad *et al.* (2001) found that manual weeding at 20 and 40 DAS was superior to all the chemicals used and recorded the greatest grain yield (2876 kg/ha). Verma *et al*. (2004) reported that hand weeding twice at 20 and 40 DAS in rice recorded lower weed count (15.2 per m^2), lower dry matter production of weeds (2.05 t/ha), higher weed control efficiency (79.36 %) and higher grain yield (3.66 t/ha).

Hand weeded checks (20 and 40 DAS) recorded least weed biomass (0.34 t/ha), highest weed control efficiency (75 %) and grain yield (2.92 t/ha) in rice (Saha, 2005). Manual weeding twice in rice recorded lowest weed biomass (27.63 g per m^2) and highest grain yield of 5.30 t/ha (Singh *et al.,* 2005). Continuous rains during the crop period and non-availability of man power for agricultural activities could also make hand weeding operations difficult (Puniya *et al*., 2007b). In addition to that, labourers were not able to eradicate the weeds to maximum extent due to the similarity between grass weeds and rice seedlings at early stages of growth.

Hand weeding resulted in the highest grain yield of 2439 kg/ha in rice (Gopinath and Kundu, 2008). Hand weeding twice in rice resulted in lower weed count and weed dry matter production (3.15 g per m^2) and highest grain yield (6.4 t/ha) at 20 and 40 DAT (Prakash *et al*., 2011). The greatest grain yield was obtained in twice hand weeded checks (20 and 40 DAT) (Duary *et al.,* 2015). On hand weeding the lowest weed density

(0.71 per m^2) and weed biomass (1.19 g/m) were recorded when done at 20 and 40 DAT in rice (Das *et al*., 2017).

2.4.2 Use of herbicides

Use of herbicides for weed control reduced labour wages and became a cost effective solution for weed suppression (Akhtar *et al.,* 2000). Chemical weed control method was easy and thus, economical (Prasad *et al.,* 2008). In places where weed infestation was a main problem, intensive use of herbicides, either by increasing its number or by sequential application of herbicides was needed (Chauhan, 2012). Commercial herbicidal combinations were now available in the market and also, compatible herbicides could be mixed together before application to control diverse weed flora (Lagator *et al.*, 2013).

a) Pendimethalin + penoxsulam

Penoxsulam, an acetolactate synthase (ALS) inhibitor herbicide for post-emergence control of annual grasses, sedges and broad leaved weeds in rice culture, did not control *Leptochloa chinensis* (Jabusch and Tjeerdema, 2005). Pendimethalin is a dinitroaniline class herbicide and prevents plant cell division, and is commonly applied in dry seeded rice as pre-emergence spray.

Kogan *et al.* (2011) reported the application of pendimethalin @ 1 kg a.i./ha as pre-emergence and penoxsulam @ 22.5 g a.i./ha as post-emergence recorded the highest grain yield compared to when these herbicides were applied alone. Thakur *et al.* (2011) observed that sequential application of pendimethalin @ 1 kg a.i./ha followed by penoxsulam @ 22.5 g a.i./ha effectively reduced the weed density and biomass, and increased the grain filling percentage (77.61 %), test weight (19.47 g), grain yield (1401.6 kg/ha) and harvest index (45.59) in direct seeded rice. Farooq *et al.* (2012) reported that application of early post-emergence herbicide penoxsulam @ 15 g a.i. /ha in direct seeded rice reduced all weeds and increased plant growth compared to the application of pendimethalin at all doses.

Uraon (2016) observed that application of pendimethalin + penoxsulam (240+10 g/l) SE @ 2400 + 100 g a.i./ha at 7 DAS resulted in maximum yields and effective weed control in direct seeded rice. Uraon and Shrivastava (2018) reported that the herbicide combination pendimethalin + penoxsulam (240+10 g/l) SE @ 2400 + 100 g a.i./ha at 7 DAS fetched the highest returns as well as benefit:cost ratio. It also registered maximum growth characters of rice like plant height, dry matter, number of tillers, leaf area, leaf area index and crop growth rate.

Madhavi *et al.* (2018) found that application of the herbicide combination pendimethalin + penoxsulam as pre-emergence application at 4-7 DAS/DAT in rice gave the highest benefit:cost ratio as compared to other treatments. Kashyap *et al.* (2019) found that integrated weed management approaches like pre-emergence application of pendimethalin @ 1000 g /ha with sesbania mulching at 25 DAS and one hand weeding at 45 DAS showed similar results as of post-emergence application of penoxsulam @ 22.5 g/ha with mulching at 25 DAS and one hand weeding at 45 DAS.

b) Cyhalofop-butyl + penoxsulam

In the conventional tillage system, herbicidal efficacy of oxadiazon @ 0.75 kg/ha followed by cyhalofop-butyl + penoxsulam @ 0.072 kg/ha was higher and thus, recorded 23 to 35 % higher yield over untreated plots as reported by Chauhan and Opena (2012). Pre-emergence application of pretilachlor or pendimethalin as followed by cyhalofop-butyl + penoxsulam resulted in excellent control of flatsedge in direct seeded rice as reported by Chauhan and Abugho (2013).

Lap *et al.* (2013) reported that a combination of cyhalofop-butyl + penoxsulam could increase rice productivity in direct-seeded, water seeded and transplanted rice production systems. Raj and Syriac (2015) found that the pre-mix herbicide mixture, cyhalofop-butyl + penoxsulam, was effective in reducing the weed density and dry matter at 30, 45 and 60 DAS and also it enhanced the crop growth and grain yield in rice. Application of cyhalofop-butyl + penoxsulam @ 150 g/ha lowered weed biomass compared to untreated plots (Singh *et al.,* 2015).

Application of cyhalofop-butyl + penoxsulam @ 150 g/ha provided effective control for all weeds resulting in lower weed density, DMP and higher grain yield of (5.49 and 4.12 t/ha) in 2013 and 2014, respectively (Abraham and Menon, 2015). The lowest weed count, weed biomass and nutrient uptake by weeds were recorded in application of pre-mix herbicide cyhalofop-butyl + penoxsulam @ 135 g/ha compared to untreated plots (Raj and Syriac, 2017).

c) Florpyrauxifen-benzyl + cyhalofop-butyl

Florpyrauxifen-benzyl + cyhalofop-butyl, belonging to the herbicide family, arylpicolinate, mimicked the action of the plant growth hormone auxin (Weimer *et al*., 2015). In 2016, Dow AgroSciences submitted registration application for Rinskor™ active (300 g/L florpyrauxifen-benzyl ester), a herbicide for broad spectrum control of grasses, sedges and broadleaf weeds in rice (Wells and Taylor, 2016). It provided control over difficult-to-control weeds and could be used as a potential source of early post-emergence weed control in rice.

Miller and Norsworthy (2018) concluded that florpyrauxifen-benzyl provided good control of many problematic weeds in rice and was also as a suitable tank-mix partner with numerous rice herbicides. They also suggested commercialization of pre-mix herbicide combinations containing cyhalofop-butyl or penoxsulam with florpyrauxifen-benzyl to maximize the broad spectrum of weed control in rice and other crops.

Sreedevi *et al.* (2020) concluded that rice weeds grown under aerobic conditions could be controlled by application of early post-emergence pre-mix herbicide combination of florpyrauxifen-benzyl + cyhalofop-butyl @ 150 to 180 g/ha and that the herbicide did not have any residual toxicity. It provided excellent control of grasses, sedges and broadleaf weeds and was considered as the best herbicide available. The highest yields (4100 and 3420 kg/ha) were recorded in plots treated with florpyrauxifen-benzyl + cyhalofop-butyl @ 180 g/ha in 2015 and 2016 respectively.

d) Cyhalofop-butyl

Cyhalofop-butyl, available as Clincher® 10 EC, is an aryloxy phenoxy propionate herbicide developed for post-emergence control of grassy weeds in dry and wet seeded rice. It was mobile through phloem and systemic in its action which inhibited Acetyl Co-A carboxylase enzyme activity (Sharma *et al*., 2004). Bahar and Singh (2004) reported that application of cyhalofop-butyl @ 120 g/ha recorded lower weed count at 30, 60, 90 DAS and harvest (3.21, 3.31, 3.21 and 2.65 numbers per m^2 respectively) and higher grain yield (3509 kg/ha).

Rao *et al.* (2008) reported that the post-emergence application of cyhalofop-butyl @ 125 g/ha followed by one hand weeding recorded higher straw yield of 906.3 g per m^2 and grain yield of 4079 kg/ha. Also, pendimethalin @ 1000 g/ha followed by one hand weeding resulted in the same yields as cyhalofop-butyl. Application of adjuvants along with cyhalofop-butyl @ 0.314 kg/ha resulted in the control of *Echinochloa crus-galli* compared to cyhalofop-butyl alone (Jha *et al.,* 2010).

So to improve the weed control efficiency, sequential application or tank mixtures of herbicides and also, herbicidal combination products could be used. Cyhalofop-butyl + bensulfuron methyl *fb* bentazone/MCPA provided excellent control of *Echinochloa* spp (Singh *et al*., 2008). Application of certain other herbicidal combinations like pendimethalin *fb* cyhalofop-butyl + bensulfuron methyl *fb* bentazone/MCPA or pretilachlor + pendimethalin *fb* bentazone/MCPA provided effective and economic weed control in aerobic rice (Suria *et al.,* 2011). It failed to control grasses emerging late in the season like *Dactyloctenium aegyptium, Eleusine indica* and *Sagitaria arvensis* as well as broadleaf weeds (Khaliq *et al.,* 2011).

Sequential application of cyhalofop-butyl + bensulfuron methyl at early stages of growth followed by bentazone/MCPA at mid growth stage of rice was reported to have the highest WCE and profits (Anwar *et al.,* 2012). Effective control of grassy weeds was observed with the application of cyhalofop-butyl @ 80 g/ha at 20 DAS, and the tank mix combination of cyhalofop-butyl + pyrazosulfuron-ethyl recorded the highest grain yield (4.3 t/ha), straw yield (4.4 t/ha), net income (78,240 Rs./ha) and benefit:cost ratio of 2.5 (Atheena *et al.,* 2017). Early post-emergence application of cyhalofop-butyl + (chlorimuron ethyl 10 %+ mestulfuron methyl 10 %) @ 90+20 g/ha at 20-30 DAS was reported to lower weed density and weed biomass, and increase weed control efficiency to 82.13 per cent (Jannu *et al.,* 2017).

e) Bispyribac sodium

Bispyribac sodium, a pyrimidinyl carboxy herbicide, controlled both annual and perennial grasses, sedges and broad leaved weeds in rice (Yun *et al*., 2005). Post-emergent sprays of cyhalofop-butyl, penoxsulam and bispyribac sodium efficaciously controlled the diverse weed flora in aerobic rice systems (Mann *et al.,* 2007; Mahajan *et al.*, 2009).

Application of bispyribac sodium at the rate of 15-60 g/ha had excellent control over the grassy weeds to the tune of 90-100 % and 75-100 % when applied on 15 and 25 DAT respectively (Yadav *et al.,* 2009). Bispyribac sodium @ 25 g/ha at 20 DAT controlled sedge population (Ramachandran *et al*., 2010). Gopal *et al*. (2010) reported that it was effective to reduce barnyard grass (*Echinochloa colona*) population but did not control other weeds like Chinese sprangletop (*Leptochloa chinensis*) and crowfoot grass (*Dactyloctenium aegyptium*).

Veeraputhiran and Balasubramanian, (2013) reported that post-emergence application of bispyribac sodium at 25 g/ha registered grain yield of 6.84 t/ha which was on par with hand weeding twice and significantly higher than all the other herbicides. Application of bispyribac sodium @ 35 g/ha at 15-20 DAT effectively controlled predominant weeds. It recorded significantly higher weed control efficiency in transplanted rice (Prakash *et al*., 2013). Application of post-emergence bispyribac sodium at the rate of 25 g/ha followed by hand weeding at 45 DAT could be recommended for effective weed control and higher productivity in transplanted rice (Parthipan and Ravi, 2014).

Application of bispyribac sodium @ 100 g/ha at 20 DAT caused higher crop growth and yield attributes, and higher benefit:cost ratio in transplanted rice (Rajasekar, 2015). Bispyribac sodium @ 25 g/ha at 15 DAT showed higher grain yield (6.45 t/ha) and straw yield (7.66 t/ha) as compared to untreated plots (Prashanth *et al.,* 2016). The application of bispyribac sodium as early post-emergence at 30 g/ha resulted in broad spectrum weed control and enhanced the weed control efficiency (Soren *et al*., 2017). Bispyribac sodium @ 25 g/ha at 10 DAT showed higher leaf area index (6.90) and tillers (486.7 numbers per m^2), and higher crop biomass (6.70 g/plant) and grain yield (4678 kg/ha) in rice (Pavithra *et al*., 2017). Application of bispyribac sodium at the rate of 25 g/ha at 25 DAT was the most effective treatment to control all types of weed species (Das *et al*., 2017).

Netam *et al.* (2018) reported that the combination of bispyribac sodium, 20 g/ha at 15 DAS/DAT or penoxsulam, 22.5 g/ha at 2-3 leaf stage of weeds followed by one hand weeding at 35 DAS/DAT in rice was best for weed control. Jat *et al.* (2019) reported that sequential combination of the pre-emergence spray of pendimethalin at 1000 g/ha *fb* the post-emergence spray of bispyribac sodium at 25 g/ha provided effectual control of the mixed weed flora encountered in direct seeded rice.

f) Chlorimuron ethyl 10 % + metsulfuron methyl 10 %

Almix® is a ready mix wettable powder formulation comprising of chlorimuron ethyl 10 % + metsulfuron methyl 10 % and belongs to the group sulfonyl ureas which inhibits ALS activity. Also, it was termed as micro herbicide as the sufficient dosage was very less compared to all the other herbicides. Singh *et al.* (2003) reported that chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g a.i./ha at 25 DAS managed to drastically reduce the density of broad leaf weeds and sedges. Chlorimuron ethyl 10 % + metsulfuron methyl 10 % effectively controlled broad leaved weeds and thus, it was usually mixed or rotated with other grass herbicides. Also, several pre-mix combinations were available in the market as ready mix products.

Singh *et al*. (2004) reported that tank mix application of chlorimuron ethyl 10 % + metsulfuron methyl 10 % and butachlor (4+938 g/ha) increased grain yield (6410 kg/ha) of rice compared to all treatments including butachlor. Herbicide mixtures consisting of (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) + 2,4-D @ 15+500 g/ha at 8 DAT was effective in maximizing grain yield (58.3 q/ha) in rice (Mukherjee and Singh, 2005). Chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha recorded weed control efficiency of 90 per cent (Saha, 2006). Application of herbicide tank mixtures of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g and butachlor @ 938 g/ha at 3 DAT recorded less weed count and weed biomass, and high weed control efficiency (Patra *et al.,* 2006).

Singh *et al*. (2007) reported that chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 8 g/ha applied 20 DAT in rice, provided 97 %, 60 % and 23 % control over broad leaved weeds, sedges and grasses respectively. Singh *et al*. (2008) registered that Sofit® @ 500 g/ha at 3 DAS followed by chlorimuron ethyl 10 % + metsulfuron methyl 10 % at 4 g/ha at 21 DAS followed by hand weeding at 35 DAS controlled all the weeds effectively in rice. According to Pal *et al*. (2009), a combination of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha and ethoxysulfuron @ 40 g/ha at 60 DAS controlled all rice weeds. Duary *et al*. (2009) reported that butachlor @ 1 kg/ha at 3 DAT and chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha at 10 DAT controlled most of the weed species in transplanted rice.

Mahbub *et al.* (2017) reported that chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 20 g/ha applied at one to two leaf stage of weeds effectively controlled all the broad leaved weeds in transplanted rice and enhanced the grain yield with maximum weed control efficiency. Yadav *et al.* (2017) observed that sequential application of pendimethalin @ 1000 g/ha followed by bispyribac sodium @ 25 g/ha and chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha significantly reduced weed density and increased weed control efficiency, further enhancing the filled grains per panicle (83.7) and ultimately grain yield (3.97 t/ha).

2.5 EFFECT OF HERBICIDES ON GROWTH AND YIELD OF RICE

Mukherjee and Singh (2005) stated that up to 85% increase in grain yield was observed when the weeds were controlled effectively. Singh and Tripathi (2007) observed the superiority of herbicidal weed control treatments to manual weedings which led to improved growth characters of rice. Mishra *et al.* (2007) reported that weed infestation reduced grain yield by 26 % in rice. Pal and Banerjee (2007) observed that application of penoxsulam @ 22.5 g/ha at 8-12 DAT was effective against a broad spectrum of weeds and maximized crop growth components, grain yield (3.53 t/ha) and straw yield (4.73 t/ha) of rice, which resulted in lowered weed index (5.61%).

Payman and Singh (2008) observed that greatest panicle length (23.2 cm) and test weight (25.2g) in twice hand weeded plots (20 and 40 DAS), which was on par with all herbicide treatments except unweeded check. Singh *et al.* (2009) reported that post-emergent spray of pendimethalin @ 1.5 kg/ha and cyhalofop-butyl @ 90 g/ha controlled *Echinochloa* spp very effectively. Walia *et al.* (2009) found that the weed-free treatments gave significantly higher number of effective tillers and increased grain yield compared to untreated control in rice. Yadav *et al.* (2009) reported that application of bispyribac sodium @ 25 g/ha at 15-25 DAT was the most effective herbicidal treatment, resulting in increased grain yield over the other treatments.

According to Sangeetha *et al.* (2010), weed-free conditions provided high number of effective tillers and filled grains per panicle. Kiran and Subramanyam (2010) reported that sequential application of oxadiargyl @ 75 g/ha and bispyribac sodium @ 30 g/ha or penoxsulam @ 25 g/ha was as effective as hand weeding twice in improving growth parameters such as plant height (73.60 cm), dry matter production (1421 kg/ha) and tillers per m^2 (722 nos.).

Singh (2012) observed that the application of penoxsulam @ 22.5 g/ha at 8-12 DAT, and penoxsulam @ 25 g/ha at 0-5 DAT, recorded the highest grain yields of 3.28 and 2.53 t/ha respectively. Lap *et al.* (2013) reported that combination of products containing penoxsulam + cyhalofop-butyl could increase rice productivity in direct-seeded, water seeded and transplanted rice production system. Prakash *et al.* (2013) reported that highest grain yield was observed in application of bispyribac sodium @ 50 g/ha at 15-20 DAT which was at par with bispyribac sodium @ 35 g/ha followed by the treatment involving two hand weedings.

Nath *et al.* (2014) observed highest grain yield of 4.56 t/ha in weed-free treatment, and application of penoxsulam @ 25 g/ha, bispyribac sodium @ 25 g/ha and pyrazosulfuron ethyl @ 20 g/ha were at at par (4.09 t/ha) with this treatment. Narolia *et al.* (2014) reported that the pre-emergence application of pendimethalin @ 1.0 kg/ha followed by bispyribac sodium @ 35 g/ha increased the plant height by about 16.5% than the average plant heights in weedy checks.

Kumar *et al.* (2015) reported that maximum grain yield of 4.72 t/ha was recorded in twice hand weeded checks (20 and 40 DAS) and it was on par with pre-emergence application of pendimethalin @ of 1.0 kg/ha *fb* post-emergence spray of bispyribac sodium @ 35 g/ha. Das *et al.* (2017) reported that the pre-emergence application of bispyribac sodium @ 30 g/ha recorded the highest number of tillers (400 per m^2), grains per panicle (133 per m^2) and grain yield (6143 kg/ha). Sreedevi *et al.* (2020) recorded the highest yields (4100 and 3420 kg/ha) in plots treated with florpyrauxifen-benzyl + cyhalofop-butyl at 180 g/ha, followed by bispyribac sodium @ 25 g/ha (3320 and 2940 kg/ha) in 2015 and 2016 respectively.

2.6 EFFECT OF HERBICIDES ON WEED CONTROL EFFICIENCY (WCE) AND WEED INDEX (WI)

Hand weeding twice at 20 and 40 DAS was seen to be the best treatment with low weed count and highest weed control index of 70.1 % in transplanted rice (Gnanavel and Kathiresan, 2002). Application of cyhalofop-butyl @ 142.5 to 213.8 g a.i./ha and cyhalofop-butyl @ 213.8 to 285 g a.i./ha gave effective control of barnyard grass and silvertop grass respectively with high weed control efficiency in rice, and post-emergence application of cyhalofop-butyl @ 90 g/ha controlled *Echinochloa* spp effectively (Wells, 2004).

As per Singh *et al*. (2007), application of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 4 g/ha was not effective against grasses and sedges compared to control against broad leaved weeds. Damalas *et al.* (2008) reported that bispyribac sodium @ 24 to 36 g a.i./ha at 3 to 4 leaf growth stage of weeds showed 89-100 % control of early water grass and 84-100 % control of late water grass. Rao and Ratnam (2010) found that the application of post-emergence herbicide bispyribac sodium @ 30, 40 and 50 g/ha on 15 DAS effectively reduced the total weed density (6.0, 4.7 and 4.7 per m^2 respectively) and weed biomass (3.1, 2.9 and 2.5 g per m^2 respectively) in rice.

The lowest weed density and highest WCE at 30, 60 and 90 DAT were observed in the treatment hand weeding twice at 20 and 40 DAT, along with application of penoxsulam @ 22.5 g/ha at 8-12 DAT. This treatment also resulted in lowest weed index of about 18.88 % (Singh, 2012). Similarly, Parthipan *et al.* (2013) observed highest weed control efficiency (90-93%) and the maximum grain yield (5831 to 8783 kg/ha) with two hand weedings in rice.

Application of bispyribac sodium @ 40 g/ha as early post-emergent spray resulted in highest WCE and lowest weed count (Kumaran *et al*., 2015). Sequential application of post-emergent spray of bispyribac sodium @ 30 g/ha *fb* bispyribac sodium @ 25 g/ha gave lesser weed density, weed biomass and higher weed control efficiency at all the stages of crop (Prasanth *et al.,* 2015). Pre-emergence application of penoxsulam @ 25 g/ha recorded the highest number of panicles (per m^2) and highest grain yield (Sureshkumar *et al*., 2016).

Higher doses of penoxsulam @ 25 g/ha and penoxsulam @ 22.5 g/ha showed lower weed biomass production in transplanted rice (Sansa *et al*., 2016). Pre-emergence application of penoxsulam @ 22.5 g/ha resulted in lesser weed count (3 weeds per m^2), lowest weed biomass production (2.34 per m^2), highest weed control efficiency (97 %) and maximum grain yield (5.21 t/ha) at 45 DAT in rice (Saranraj *et al*., 2017). The herbicide combination product florpyrauxifen-benzyl + cyhalofop-butyl @ 180 g/ha significantly reduced the weed density and biomass production, and also, it gave the highest weed control efficiency compared to all the other treatments (Sreedevi *et al.,* 2020).

2.7 EFFECTS OF HERBICIDES ON SOIL MICROFLORA

The activity of different enzymes in soil, soil microbial biomass carbon and total soil microbial population are considered as the bio-indicators of the ecological toxicity of agrochemicals to soil microorganisms

2.7.1 Dehydrogenase activity

Dehydrogenase is an inter-cellular enzyme which is involved in the respiration of microorganisms present in the rhizosphere region of crop during its growth period. It acts as a bio-indicator which is used to determine the microbial biomass in soil.

Shukla (1997) reported that in the puddled soil of rice fields, dehydrogenase activity of the herbicide treated soil increased just after the application and peaked on the 4^{th} day after application, which thereafter reduced significantly in the next coming weeks. Enzymes are frequently referred as the markers for estimating the environmental purity of soils (Aon and Colaneri, 2001).

Nayak and Nanjappa (2010) observed that the dehydrogenase activity of the paddy soils differed according to the amount of rainfall received on it. Thus, it was about 18.47 µg TPF/g soil/day in lowland soils and 19.30 µg TPF/g soil/day in upland soils under low rainfall conditions, whereas under high rainfall conditions it was about 17.45 µg TPF/g soil/day in lowlands and 19.02 µg TPF/g soil/day in uplands. Sebiomo *et al.* (2011) recorded the highest dehydrogenase activity of 20.16 µg TPF/g soil/min in soils treated with glyphosate, compared to the other treatments.

Das *et al.* (2015) evaluated the dehydrogenase activity during the rice cropping seasons (*kharif* and *rabi*) and observed the highest activity in panicle initiation stage during both seasons followed by maximum tillering, active tillering and heading stages. Moreover, highest activity was noticed in *kharif* ranged from 4 to 10.55 µg TPF/g soil/day at all the stages compared to *rabi* which ranged from 1 to 9 µg TPF/g soil/day.

Islam and Borthakur (2016) reported that dehydrogenase activity differed in the various soil depths and it was 315.10 to 572.95 mg TPF/kg soil/day in 0-10 cm depth and 124.25 to 332.56 mg TPF/kg soil/day in 10-20 cm depth. The greatest dehydrogenase activity was found at 90 DAT (flowering stage) and thereafter, it declined significantly until harvest. According to them, this was due to the high carbon input in the form of root biomass which in turn enhanced microbial activity in the soil.

2.7.2 Soil microbial biomass carbon and population of soil microflora

Microbial biomass accounts for about 1-3% of the total soil organic carbon, and is a major driving force for the nutrient cycles (especially nitrogen) in agricultural ecosystems (Jenkinson and Ladd, 1981).

The herbicide spray of imazethapyr drastically decreased the microbial biomass in soils (Lupwayi *et al.,* 2004). The higher doses of herbicides had the lower microbial counts when compared to soils treated with recommended doses (Ayansina and Oso, 2006). Injudicious application of herbicides led to the accumulation of active ingredients of herbicides in agricultural soils and it deteriorated quality of soil and water, and quantity of soil microbial population (Nakatani *et al.,* 2014). Application of imazethapyr and quizalofop-p-ethyl showed inhibitory effects on the microbial population and thus, reduced the MBC present in it (Saha *et al.,* 2016).

2.8 EFFECT OF TIME OF APPLICATION OF HERBICIDES

Herbicides are used for the timely control or reduced growth of the weed flora during the critical period of crop season (Ogborn, 1969). Smith (1961) reported that the method and depth of seeding, time of application of herbicide treatments, and water management after treatment were critical when using chlorpropham to control barnyard grass in rice. Rice *et al.* (1997) compared the effects of herbicide treatments namely picloram, clopyralid and clopyralid + 2,4-D, each at two different times of application at the recommended doses for the control of exotic forb *Centaurea maculosa* in rice for 8 years in Montana, USA. They reported that the time of application of herbicides played a crucial role in controlling the weed species present.

Ottis *et al.* (2003) reported that early post-emergence application of penoxsulam + propanil in rice resulted in higher yields ranging from 6357 to 7660 lb/acre and the treatments receiving mid post-emergence application of penoxsulam + propanil had higher yields than the pre-emergence application. Simultaneously, he also observed that the early post-emergence application of cyhalofop-butyl + penoxsulam effectively reduced the grass weed population.

Carlson *et al.* (2012) reported that the yield and economical returns were maximized when imazethapyr was applied at rice emergence followed by second application of imazethapyr two weeks after emergence. Cox and Askew (2014) reported metamifop as an effective herbicide for controlling smooth crabgrass in cool-season turf grasses when applied once at 300 or 400 g/ha or twice at a 3, 6 or 8 week interval. Singh (2016) recorded the highest reduction of weed DMP in sequential application of pendimethalin as pre-emergence *fb* post-emergence spray of bispyribac sodium + azimsulfuron at 45 DAS.

Godwin *et al.* (2018) reported that rice could tolerate delayed pre-emergence application of pethoxamid and adequate control of barnyard grass and difficult-to-control weeds could be achieved. Metzger *et al.* (2019) determined the effects of timing of herbicide application continuously for two years and reported that several monocot and dicot weed species in corn could be controlled with tolpyralate + atrazine applied at an early to mid post-emergence timing, i.e., before the weeds reached 30 cm in height.

2.9 VISUAL PHYTOTOXICITY OF HERBICIDES ON WEEDS AND CROP

The use of herbicides in direct seeded rice becomes limited as both weeds and rice crop germinate at the same time and herbicides caused phytotoxic symptoms to rice too (De-Datta and Bernasor, 1973). Tank mix herbicides like (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) + butachlor @ 4+1250 g/ha and ready mix of (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) + anilofos @ 280.5 g/ha increased the grain yield of rice without showing any phytotoxicity (Singh *et al.,* 2003).

Saha (2006) reported that chlorimuron ethyl 10 % + metsulfuron methyl 10 % when applied on rice had no phytotoxic symptoms. However, Mukherjee and Singh (2006) reported that chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 25 g/ha showed moderate to severe toxicity in rice which persisted up to 30 DAT in the variety ‘Malwa 36’ and it also lowered plant height and crop biomass. Yadav *et al.* (2008) observed the absence of phytotoxicity due to penoxsulam on rice.

An absence of phytotoxicity for bispyribac sodium on rice was reported by Yadav *et al*. (2009). Rao *et al*. (2009) also observed that bispyribac sodium was safe to apply on rice and rice fallow crops. Post-emergence application of bispyribac sodium @ 20 to 25 g/ha in rice nurseries was not phytotoxic to rice seedlings (Channabasavanna *et al*., 2017).

2.10 ECONOMICS OF RICE PRODUCTION

Subramanian *et al*. (2006) reported the application of bispyribac sodium @ 20 g/ha fetched the highest B:C ratio of 2.38. Singh *et al.* (2007) found that the application of chlorimuron ethyl 10 % + metsulfuron methyl 10 % @ 8 g/ha proved as the most profitable option with highest net returns of Rs. 26269/ha and B:C ratio of 1.46. Sanjay *et al.* (2008) reported that two hand weeding treatments fetched the highest net returns of Rs. 18,296/ha. Veeraputhiran and Balasubramanian (2010) recorded the highest net profit of Rs. 42,452/ha and B:C ratio of 2.89 with the post-emergent application of bispyribac sodium @ 25 g/ha.

Bhurer *et al.* (2013) reported that the stale seed bed followed by pendimethalin 30 EC @ 1 kg/ha *fb* bispyribac sodium @ 25 g/ha at 20 DAS performed better and could be substituted for manual weeding. Prabhakaran *et al.* (2014) reported that cost of cultivation was 23 % lower in application of pendimethalin @ 1000 g/ha followed by bispyribac sodium @ 25 g/ha.

Broad spectrum weed control imposed by spraying herbicide combinations gave higher yield and B:C ratio (Jacob *et al*., 2014). Post-emergent bispyribac sodium @ 0.02 kg/ha at 30 DAT registered highest net returns of Rs. 46,648/ha and B:C of 2.26 in rice (Govindan, 2014). Highest gross return (Rs. 88338.6/ha) was recorded in hand weeding treatments (Hossain, 2015).

Dhakal *et al.* (2019) suggested that integrating a pre-emergence herbicide pendimethalin with some of the post-emergence herbicides like 2,4-D, bispyribac sodium and oxadiargyl, lowered the cost of cultivation and led to higher economic returns in direct seeded rice.

Materials and methods

3. MATERIALS AND METHODS

The research programme entitled "Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice" was conducted from October 2019 to January 2020 at Alappad *padasekharam* in the *Kole* lands of Thrissur district. The details of materials used and methodologies adopted are elaborated in this chapter.

3.1 GENERAL DETAILS

Location

The field experiment was conducted in a farmer's *Kole* field (Mr. Kesavaraj, Kulappully House, Alapad (P.O.), Thrissur Dt.) Geographically, the area is located between 10˚20' to 10˚40' North latitudes and 75˚58' to 76˚11' East longitudes, with an altitude of 0.5 to 1m below Mean Sea Level (MSL).

Climatic condition

The study area enjoys humid tropical climate with an annual average rainfall of 3107 mm distributed mainly through southwest and northeast monsoon. During the month of August 2019, Kerala received the highest amount of rainfall (951.4 mm) in the recorded history of IMD data since 1951. The mean monthly data of the important meteorological parameters recorded during the experimental period are given in Appendix I and Fig.1 & 2.

Soil characters

Kole soils are clayey in texture with pH in surface layers ranging from 4.5 to 6.3 and belonging to the taxonomical order Inceptisol. They are rich in organic carbon and phosphorus, and are medium in nitrogen and potassium, which render them highly productive. The physico-chemical properties of the study area are given in Table 1.

Variety

Manuratna is an awnless red kernelled high yielding rice variety with a potential yield of 9 tonnes in *Kole* lands. It was released in 2018 from the Agricultural Research Station, Mannuthy of the Kerala Agricultural University. It is a short duration variety of 95-105 days duration and is tolerant to stem borer, leaf folder and whorl maggot. It is suitable for cultivation throughout the *Kole* lands of Thrissur.

Season and cropping history

The crop was raised from October 2019 to January 2020 (*Mundakan* season). The Alappad *Kole* region is double cropped with paddy during the seasons *Mundakan* (September-October to January-February) and *Puncha* (January-February to April-May). During the *Mundakan* season, the land is dewatered to cultivate paddy. It remains submerged under water in the *Virippu* season (June to September-October).

Table 1. Physico-chemical properties of soil of the experimental field

Sl. No.	Particulars	Value	Method adopted
1	pH	4.7	1: 2.5 (soil: water) suspension - pH meter (Jackson, 1958)
2	EC (dS/m)	2.3	1: 2.5 (soil: water) suspension - EC meter (Jackson, 1958)
3	Organic C (%)	1.2	Walkley and Black method (Jackson, 1958)
4	Available N (kg/ha)	178.3	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg/ha)	20.5	Bray-1 extractant – ascorbic acid reductant method (Watanabe and Olsen, 1965)
6	Available K (kg/ ha)	142.1	Neutral normal ammonium acetate extractant - flame photometry (Jackson, 1958)

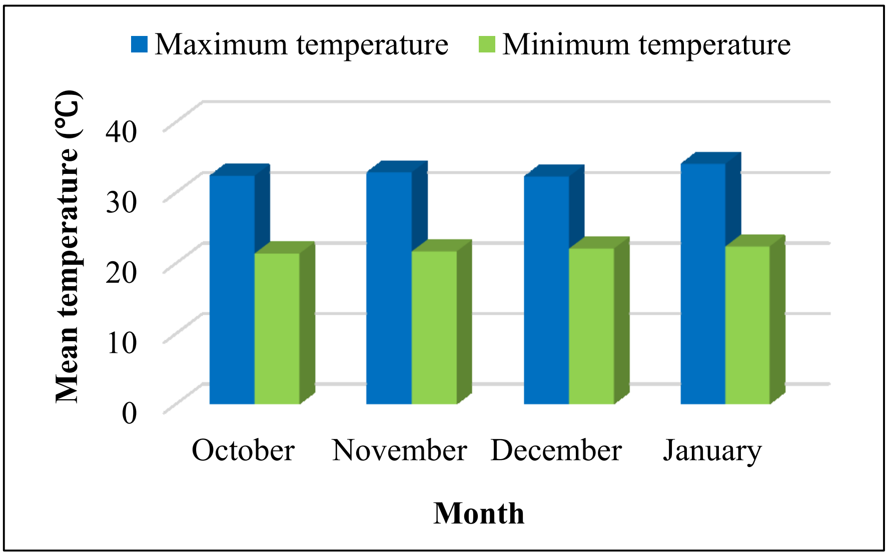

Fig. 1. Mean maximum and minimum temperatures during the crop period

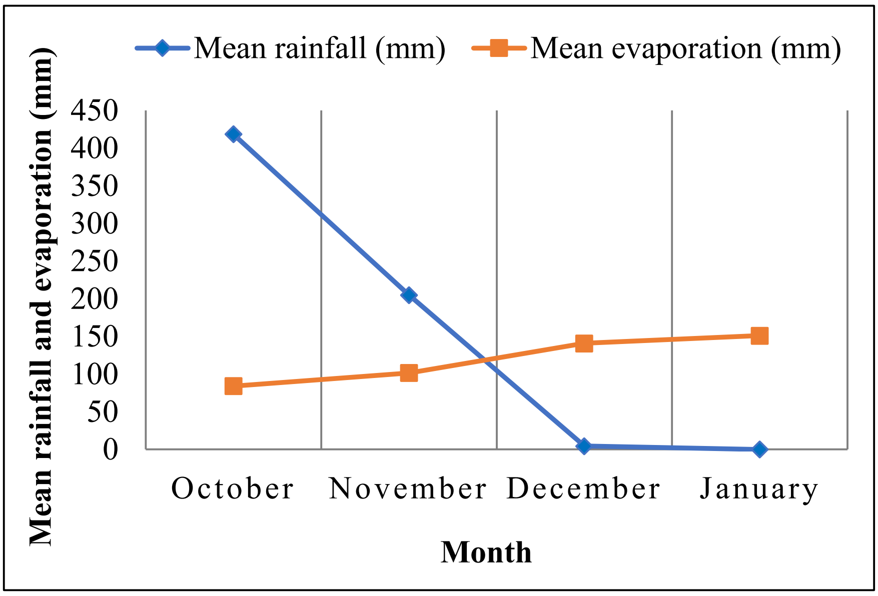

Fig. 2. Mean rainfall and mean evaporation during the crop growth period

3.2 DETAILS OF THE EXPERIMENT

a) Treatments

Ten herbicide treatments with three replications were applied in a Randomized Block Design (RBD). The herbicide combinations, dosages and time of application are given in Table 2.

b) Land preparation and sowing

The experimental field was ploughed, puddled and levelled. Layout for the study was done on 18^{th} October 2019 and the individual plot size was 20 m^2 (5m x 4m). Pre-germinated seeds were broadcasted in the field at the rate of 200g/plot, adopting the seed rate of 80-100 kg/ha. Layout plan of the field experiment was given in Fig.3.

c) Fertilizer application

Fertilizer application was done as recommended in the package of practices recommendations for rice in *Kole* lands (KAU, 2016). Nitrogen, phosphorus and potassium @ 90:35:45 kg/ha were supplied through urea, factomphos and muriate of potash. Full dose of P was applied basally. Potassium was applied in two equal split doses at land preparation and active tillering. N was applied in three equal doses at land preparation, tillering and panicle initiation stages.

d) Plant protection measures

The experimental field was regularly monitored for pest infestation, and timely organic plant protection measures were adopted. In the early stage, dead heart symptoms indicated the attack of rice stem borer and so, surveillance and removal of egg masses was done to control the pest. The incidence of bacterial leaf blight was corrected by application of *Pseudomonas fluorescens* @ 2.5 kg/ha. As a precaution to prevent infestation of leaf folder, stem borer and other pests, organic measures were adopted.

Table 2. Herbicide combinations, their formulations and dosages used

SI. No.	Herbicide combinations	Trade name and formulation	Name of firm	Dose (g/ha)	Time (*DAS)
1.	Pendimethalin + penoxsulam	25 SE*	Rallis India Ltd.	625	5
2.	Pendimethalin + penoxsulam	25 SE	Rallis India Ltd.	625	10
3.	Cyhalofop-butyl + penoxsulam	Vivaya 6 OD*	Corteva Agriscience	135	12
4.	Cyhalofop-butyl + penoxsulam	Vivaya 6 OD	Corteva Agriscience	135	18
5.	Florpyrauxifen-benzyl + cyhalofop-butyl	Novelect 12 EC*	Corteva Agriscience	150	12
6.	Florpyrauxifen-benzyl + cyhalofop-butyl	Novelect 12 EC	Corteva Agriscience	150	18
7.	Cyhalofop-butyl **fb* (Chlorimuron ethyl + metsulfuron methyl)	Clincher 10 EC Almix 20 WP*	Corteva Agriscience	80+4	18 & 19
8.	Bispyribac sodium	Nominee gold 10 SC*	PI Industries	25	18
9.	Hand weeding	-	-	-	20 & 40
10.	Unweeded control	-	-	-	-

fb - followed by

SE - Soluble Emulsion

OD - Oil Dispersible

EC - Emulsifiable Concentrate

WP - Wettable Powder

SC - Soluble Concentrate

DAS - Days After Sowing

4m

5m

R I	T_6	T_2	T_4	T_{10}	T_5	T_1	T_7	T_9	T_8	T_3
R II	T_7	T_{10}	T_6	T_2	T_1	T_5	T_3	T_9	T_4	T_8
R III	T_8	T_6	T_7	T_1	T_2	T_3	T_5	T_9	T_{10}	T_4

Individual plot size = 20 m^2

T_1	Pendimethalin + penoxsulam, 5 DAS
T_2	Pendimethalin + penoxsulam, 10 DAS
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10% + metsulfuron methyl 10%), 18 DAS and 19 DAS
T_8	Bispribac sodium, 18 DAS
T_9	Hand weeding, 20 DAS and 40 DAS
T_{10}	Unweeded control

Fig. 3. Layout plan of the field experiment

Plate 1. Layout of the field experiment

Plate 2. Spraying of pre-emergence herbicide pendimethalin + penoxsulam at 5 DAS

Plate 3. View of the experimental plot at 30 DAS

Plate 4. Performance of hand weeding at 40 DAS

Plate 5. View of the experimental plot at 60 DAS

Plate 6. View of the experimental plot at harvest

e) Phytotoxicity scoring

On the 3rd and 7th day after each herbicidal spray, visual symptoms for phytotoxicity on weeds and crops were recorded. The injury symptoms were graded on a toxicity scale from 0-5 as given by Thomas and Abraham (2007) (Table 3).

Table 3. Rating of herbicidal phytotoxicity symptoms on weeds and crop

Rating	Effects on weeds	Effects on crop
0	None	No injury
1	Slight	Slight injury
2	Moderate	Moderate injury
3	Good control	Severe injury
4	Very good control	Very severe injury
5	Complete control	Complete destruction

f) Harvesting

Harvesting was done on the last week of January, when the crop reached physiological maturity. Manual threshing was done and the produce was cleaned, dried and weighed to estimate the grain yield and straw yield in kg/ha.

3.3 OBSERVATIONS RECORDED

A. Biometric observations on weeds

a) Weed count

Species-wise counts of weeds were recorded using a quadrat of size 50 cm x 50 cm (0.25 m^2). Samples were collected by placing the quadrat randomly in the experimental plots at 30 and 60 DAS, and the weed counts were expressed in numbers/m^2.

b) Dry matter production of weeds

The weeds which were uprooted from the quadrat area at 30 and 60 DAS were cleaned and air dried for two days. They were then oven dried at 70 ± 5˚C to constant weight. Dry weights of the weeds were recorded and expressed in kg/ha.

c) Nutrient removal by weeds

Nutrient removal by weeds at 30 DAS and 60 DAS was estimated by standard procedures given by Jackson (1958) and expressed in kg/ha. For N content, the samples were digested with KELPLUS Digester and then distilled. For total P and K, samples were digested with diacid mixture. For P, vanadomolybdophosphoric acid was added and the yellow colour developed was read in a spectrophotometer at a wavelength of 420 nm. For K estimation, flame photometer was used. Nutrient removal was worked out by multiplying percentage of nutrient with total dry matter production.

d) Weed Control Efficiency (WCE)

Weed control efficiency is calculated based on the weed dry matter production (WDMP) in herbicide treated plots in comparison with the untreated plots and expressed in percentage. WCE was calculated using the formula suggested by Mani *et al*. (1973).

e) Weed Index (WI)

Weed index is the percentage of yield reduction in the treatment plots in comparison with the hand weeded check. WI was calculated using the formula given by Gill and Vijayakumar (1969).

B. Biometric observations on rice

a) Plant height

Plant height (in cm) was recorded at 30 DAS, 60 DAS and at harvest. Height was measured from the base of the plant to the tip of the longest leaf. At harvest, it was measured from the base to the panicle tip.

b) Number of tillers per square metre

The number of tillers were counted from one square metre area using quadrat of size 1m x 1m at 30 DAS, 60 DAS and at harvest, and expressed as numbers per m^2.

c) Number of panicles per square metre

The number of panicles or productive tillers were recorded at harvest from randomly selected areas of one square metre by using quadrat of 1 m^2 size, and expressed in numbers per m^2.

d) Number of grains per panicle

From each experimental plot, ten healthy panicles were collected randomly. The total number of grains per panicle were counted and the mean was calculated.

e) Percentage of filled grains

Grains were collected from ten panicles in each plot, separated into filled and chaffy grains and counted. From these values, percentage of filled grains was worked out.

f) Thousand grain weight

Thousand grain weight or test weight of grain was obtained by recording the weight of 1000 grains from each plot. Mean values were found out and expressed in grams.

g) Grain yield

Net plot area was harvested separately from each treatment, threshed, cleaned and dried, and dry weight was recorded and expressed in kg/ha.

h) Straw yield

The straw harvested from the plots were collected separately and dried under sun. The dry weight was expressed in kg/ha.

i) Harvest Index (HI)

The harvest index was calculated using the formula:

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

C. Biological properties of soil

Soil samples were collected initially at the start of the experiment and at 30 DAS, 60 DAS and harvest from all the plots separately and analysed for biological characteristics such as dehydrogenase activity (DHA) and soil microbial biomass carbon (SMBC).

1. Dehydrogenase activity

The dehydrogenase activity in the soil samples was estimated by the procedure given by Casida *et al.* (1964).

One gram of air dried soil was weighed and taken in an air tight screw capped test tube of 15 ml capacity and 0.2 ml of 3% triphenyl tetrazolium chloride (TTC) solution was added to make the soil saturated. Then 0.5 ml of 1% glucose solution was added in all the tubes. The tubes were gently tapped to drive out the entrapped oxygen, such that a complete water seal was formed above the soil. It was ensured that no air bubbles were formed in the tubes. These tubes were incubated at 28 ± 0.5^0 C for 24 hours. After incubation, 10 ml of methanol was added to these tubes and they were shaken vigorously for proper mixing. They were then allowed to stand for 6 hours. Clear pink or red coloured supernatant was observed which was removed carefully for measuring the readings in a spectrophotometer at a wave length of 485 nm.

The readings of a series of standards were used to plot the calibration curve. The results were expressed as µg TPF/g soil/hr.

2. Microbial biomass carbon

The microbial biomass carbon (MBC) in the soil samples was determined following the procedure described by Jenkinson and Powlson (1976).

Five sets of 10 g soil from each sample were weighed separately and out of that, one set of soil was used to determine the moisture content gravimetrically. Of the remaining four sets taken in beakers, two sets were subjected to chloroform fumigation and the other two sets were kept non-fumigated.

For the fumigation, distilled chloroform was prepared by taking the chloroform in a separating funnel and washing it twice with concentrated sulphuric acid (each with half the volume of chloroform). The bottom acid phase was removed carefully after phase separation. Precaution was taken to open the stopcock after each shaking to release the pressure formed inside. It was again washed twice with distilled water (each with half the volume of chloroform) and the bottom white coloured phase containing distilled chloroform was collected. These washings were given to make the chloroform free of ethanol. This ethanol free chloroform was kept in 100 ml beakers placed at the bottom portion of vacuum desiccator. A few glass beads were added to reduce the bumping.

All the beakers containing soil were kept in the top portion of the vacuum desiccator. Inner surface of the desiccator was lined with moistened filter papers to avoid cracking of the instrument. Vacuum pump was connected to the desiccator until the chloroform was boiled. After that, outlet was closed and the vacuum pump was switched off and it was allowed to stand for 24 hours. Then, vacuum was released and the beaker containing chloroform was taken out. Back suction was performed for five to six times to ensure removal of excess adhered chloroform vapours.

Both the fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4. To each soil sample, 25 ml of 0.5 M K_2SO_4 was added and shaken for 30 minutes. The soil suspension was filtered through Whatman No. 1 filter paper. Filtrate of 10 ml was transferred to 500 ml conical flask. To all the flasks, about two ml of 0.2 N $K_2Cr_2O_7$, 10 ml of concentrated sulphuric acid and five ml of orthophosphoric acid was added. Distilled water of 10 ml was used as blank. These flasks were kept on hot plate at 100^0 C for 30 minutes under reflux condition. Immediately after this, 250 ml distilled water was added to stop the reaction. The contents were allowed to cool to room temperature. To that, two to three drops of diphenylamine indicator was added and the contents were titrated against 0.05 N ferrous ammonium sulphate to develop the brick red coloured end point.

Microbial biomass carbon (MBC) in the soil was calculated using the formula:

$$\textbf{MBC (μg/g soil)} = \frac{\mathbf{EC_f - EC_{nf}}}{\mathbf{K_{EC}}}$$

where EC_f : Extractable C in fumigated samples,

EC_{nf} : Extractable C in non-fumigated samples,

K_{EC} : 0.25 ± 0.05 and this K value was derived based on the efficiency of extraction of microbial biomass carbon.

3.3.4 Economic analysis

The labour charge, inputs and treatment costs, market prices of grain and straw were taken into consideration and the cost of cultivation, net income and gross income were calculated and expressed in rupees/ha. The Benefit-Cost ratio (BCR) was calculated as ratio of gross returns to total cost of cultivation.

3.3.5 Statistical analysis

The data obtained from the experimental field was processed through the online statistical tool WASP (Web based Agricultural Statistics software Package). Data which showed wide variation were subjected to square root transformation $\sqrt{(x + 0.5)}$ to make ANOVA valid (Gomez and Gomez, 1984). Wherever significance was observed, critical difference (CD) at 5% level was calculated for comparison.

Results

4. RESULTS

The field trial of the research programme on "Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice" was conducted from October 2019 to January 2020 (*Mundakan* season) in a farmer's field in the *Kole* area of Alappad in Thrissur district. The data collected from the experimental field were statistically analysed and the results are furnished in this chapter.

4.1 STUDIES ON WEEDS

4.1.1 Weed spectrum

The major weed species found in the study area were grasses and sedges. Grass weeds mainly comprised of weedy rice (*Oryza sativa* f. *spontanea*), *Echinochloa stagnina* (hippo grass) and *Leptochloa chinensis* (Chinese sprangletop). Sedges composed of *Cyperus* sp. (nutsedge) and *Fimbristylis miliacea*. Also, broad leaved weeds such as *Ludwigia perennis* (water primrose), *Limnophila heterophylla* (marsh weed) and *Eichhornia crassipes* (water hyacinth) were also observed. Species wise count of weeds was taken at 30 DAS and 60 DAS.

4.1.2 Weed population

An analysis of data on species-wise count of weeds after the application of various herbicidal combinations and individual herbicides showed that there was significant reduction in weed population due to treatments at 30 DAS and 60 DAS (Tables 4 and 6). The data on the total weed count comprising the grasses, sedges and broad leaf weeds at both 30 and 60 DAS also showed significant effect of herbicide application (Tables 5 and 7).

At 30 DAS, in the case of weedy rice (*Oryza sativa* f. *spontanea*), highest count was recorded in unweeded control (T_{10}). All the plots were infested with weedy rice due to the large soil seed bank from previous seasons. More than 80 per cent of the grass weeds were constituted by weedy rice. An average density of weedy rice of 7.4

nos./m^2 was observed in the treatment plots (Table 4). The herbicide combination treatments pendimethalin + penoxsulam applied at 5 DAS (T_1), as well as cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 12 DAS (T_3 and T_5), were observed to perform better with lower population of weedy rice over the same herbicides sprayed at different application times

At 60 DAS, the highest density of weedy rice was recorded in unweeded control (T_{10}) and the lowest count was in hand weeded control (T_9), probably due to the second hand weeding performed at 40 DAS. The population of weedy rice gradually increased in all the treatment plots over time. Although the herbicides were ineffective in controlling weedy rice, a considerable reduction in weedy rice population was observed in the herbicide treated plots compared to the unweeded control. The herbicide combinations pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam at 12 DAS (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl at 18 DAS (T_6) performed better than the same combinations applied at other periods.

At 30 DAS, *Echinochloa stagnina* was the dominant grass weed found in the experimental area. The highest count was observed in unweeded control (T_{10}). *Echinochloa stagnina* was not observed in plots treated with cyhalofop-butyl with penoxsulam and/or florpyrauxifen-benzyl, i.e., in treatments from T_3 to T_6 and in the treatment bispyribac sodium (T_8). It was also absent in hand weeded control (T_9) (Table 4). Population of 3 to 4 nos./m^2 was observed in the herbicide treated plots, pendimethalin + penoxsulam at 5 and 10 DAS (T_1 and T_2) and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) (Table 4).

At 60 DAS the complete control of *Echinochloa stagnina* was observed in the plots treated with cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS, bispyribac sodium (T_8) and hand weeded control (T_9). Also, considerable reduction in count of *Echinochloa stagnina* was seen in plots treated with T_1 and T_2, i.e., pendimethalin + penoxsulam applied at 5 and 10 DAS and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) (Table 6). Highest count of 6 nos./ m^2 was seen in unweeded control.

Leptochloa chinensis, a grass weed, was not observed at 30 DAS, but emerged at later period and was completely controlled in plots treated with pendimethalin + penoxsulam (T_1) applied at 5 DAS, cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both sprayed at 12 DAS, florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7). The highest count of *Leptochloa chinensis* was observed in unweeded control (T_{10}) i.e., 8 nos./m^2 and in the remaining plots, the density was found very low compared to this (Table 6).

In case of both *Echinochloa stagnina* and *Leptochloa chinensis* at 30 and 60 DAS, the herbicide combination treatments pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS recorded lower weed population compared to the same herbicides applied at alternate times of application.

Next to grass weeds, sedges dominated in the experimental field and the reduction in weed density was attained in almost all the treatments. At 30 DAS, *Cyperus* spp was not observed in plots treated with pendimethalin + penoxsulam at 5 and 10 DAS (T_1 and T_2) and florpyrauxifen-benzyl + cyhalofop-butyl at 12 and 18 DAS (T_5 and T_6). All the remaining plots had an average density of 6 nos./m^2 (Table 4). Among the herbicide combination treatments, pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS recorded lower *Cyperus* density compared to other times of application.

At 60 DAS, complete control of *Cyperus* spp was observed in plots treated with pendimethalin + penoxsulam at 5 DAS (T_1) and florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS (T_5) (Table 6). Reduction in population of *Cyperus* spp was high in plots treated with pendimethalin + penoxsulam at 10 DAS (T_2), cyhalofop-butyl + penoxsulam applied at 12 and 18 DAS (T_3 and T_4), cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8).

At 30 DAS, the sedge *Fimbristylis miliacea* was noticed in plots treated with cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4) and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) (Table 4). However, at 60 DAS, complete control was observed in all the plots treated with herbicides (Table 6).

The major broad leaf weeds such as *Ludwigia perennis* and *Limnophila heterophylla* were completely controlled in all the herbicide treated plots at both 30 and 60 DAS. The population of broad leaf weeds was comparatively low in the study area and at later stages, it was completely absent. By 60 DAS, *Eichhornia crassipes* (2.3 nos./m^2) was seen only in the unweeded control (T_{10}) (Table 6). Thus, all the herbicides used in this study were very effective against broad leaf weeds.

At 30 DAS, the lowest total weed count was observed in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 4 nos./m^2 which was at par with florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) with 4.3 nos./m^2 (Table 5). Pendimethalin + penoxsulam applied at 5 DAS (T_1) had weed density of 6.6 nos./m^2 and was on par with hand weeded control (T_9) which has 7 nos./m^2. At 60 DAS, the lowest weed count was noticed in hand weeded control (T_9) with 11.3 nos./m^2 followed by florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 21.6 nos./m^2 which was on par with pendimethalin + penoxsulam applied at 5 DAS (T_1) with 23.9 nos./m^2 (Table 7). At both 30 and 60 DAS, grasses were the dominant weeds followed by sedges, and the highest weed density was noticed in unweeded control (T_{10}). The weed density of all the herbicide combinations from T_1 to T_6 was low compared to the other treatments except T_4, i.e., cyhalofop-butyl + penoxsulam at 18 DAS. Among the various herbicide combinations, pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5), both applied at 12 DAS, recorded lower weed density compared to other treatments.

Table 4. Effect of pre-mix herbicide combinations on species wise weed count at 30 DAS (no./m^2)

Treatments		Weedy rice	*Echinochloa stagnina*	*Cyperus* spp	*Fimbristylis miliaceae*	*Ludwigia perennis*	*Limnophila heterophylla*
T_1	Pendimethalin + penoxsulam, 5 DAS	1.81^{ef} (3.33)	1.95^{c} (3.33)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_2	Pendimethalin + penoxsulam, 10 DAS	2.30^{d} (5.33)	2.27^{b} (4.67)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	2.71^{c} (7.33)	0.71^{d} (0.00)	2.27^{d} (4.67)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	3.11^{b} (9.67)	0.71^{d} (0.00)	2.54^{c} (6.00)	2.11^{b} (4.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	1.96^{ef} (4.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	2.04^{e} (4.33)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	3.10^{b} (9.67)	2.11^{bc} (4.00)	3.48^{a} (11.67)	1.95^{b} (3.33)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_8	Bispyribac sodium, 18 DAS	2.30^{d} (5.33)	0.71^{d} (0.00)	3.23^{b} (10.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_9	Hand weeding, 20 DAS and 40 DAS	1.72^{f} (3.00)	0.71^{d} (0.00)	2.11^{d} (4.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)
T_{10}	Unweeded control	3.82^{a} (13.67)	3.03^{a} (8.67)	3.67^{a} (13.00)	2.72^{a} (7.00)	1.77^{a} (2.67)	1.66^{a} (2.33)

[redacted] transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.

Table 5. Effect of pre-mix herbicide combinations on weed count at 30 DAS (no./m^2)

Treatments		Weed density (no./m^2)			
		G	S	B	Total
T_1	Pendimethalin + penoxsulam, 5 DAS	2.58^{d} (6.66)	0.71^{e} (0.00)	0.71^{b} (0.00)	2.58^{g} (6.66)
T_2	Pendimethalin + penoxsulam, 10 DAS	3.15^{c} (10.00)	0.71^{e} (0.00)	0.71^{b} (0.00)	3.16^{f} (10.00)
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	2.71^{d} (7.33)	2.27^{d} (4.67)	0.71^{b} (0.00)	3.46^{e} (12.00)
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	3.11^{c} (9.67)	3.17^{c} (10.00)	0.71^{b} (0.00)	4.43^{c} (19.67)
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	1.99^{f} (4.00)	0.71^{e} (0.00)	0.71^{b} (0.00)	1.99^{h} (4.00)
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	2.08^{f} (4.33)	0.71^{e} (0.00)	0.71^{b} (0.00)	2.08^{h} (4.33)
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	3.70^{b} (13.67)	3.90^{b} (15.00)	0.71^{b} (0.00)	5.35^{b} (28.67)
T_8	Bispyribac sodium, 18 DAS	2.31^{e} (5.33)	3.17^{c} (10.00)	0.71^{b} (0.00)	3.91^{d} (15.33)
T_9	Hand weeding, 20 and 40 DAS	1.72^{g} (3.00)	2.08^{d} (4.00)	0.71^{b} (0.00)	2.64^{g} (7.00)
T_{10}	Unweeded control	4.83^{a} (22.34)	4.51^{a} (20.00)	2.32^{a} (5.00)	6.93^{a} (47.34)

G - grasses, S - sedges, B - broad leaf weeds.

[redacted] transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.

Table 6. Effect of pre-mix herbicide combinations on species wise weed count at 60 DAS (no./m^2)

Treatments		Weedy rice	*Echinochloa stagnina*	*Leptochloa chinensis*	*Cyperus* spp	*Fimbristylis miliaceae*	*Eichhornia crassipes*
T_1	Pendimethalin + penoxsulam, 5 DAS	4.76^e (22.64)	1.32^c (1.33)	0.71^d (0.00)	0.71^f (0.00)	0.71^b (0.00)	0.71^b (0.00)
T_2	Pendimethalin + penoxsulam, 10 DAS	4.76^e (22.66)	1.76^b (2.66)	1.48^c (1.69)	1.35^d (1.33)	0.71^b (0.00)	0.71^b (0.00)
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	5.41^d (29.33)	0.71^d (0.00)	0.71^d (0.00)	1.76^b (2.66)	0.71^b (0.00)	0.71^b (0.00)
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	6.05^b (36.66)	1.32^c (1.33)	0.90^d (0.33)	1.35^d (1.33)	0.71^b (0.00)	0.71^b (0.00)
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	4.65^{ef} (21.66)	0.71^d (0.00)	0.71^d (0.00)	0.71^f (0.00)	0.71^b (0.00)	0.71^b (0.00)
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	4.49^f (20.33)	1.57^{bc} (1.99)	0.71^d (0.00)	1.66^{bc} (2.33)	0.71^b (0.00)	0.71^b (0.00)
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	6.22^b (38.66)	1.31^c (1.32)	0.71^d (0.00)	1.47^{cd} (1.66)	0.71^b (0.00)	0.71^b (0.00)
T_8	Bispyribac sodium, 18 DAS	5.66^c (32.00)	0.71^d (0.00)	1.94^b (3.32)	1.07^e (0.66)	0.71^b (0.00)	0.71^b (0.00)
T_9	Hand weeding, 20 DAS and 40 DAS	3.36^g (11.33)	0.71^d (0.00)	0.71^d (0.00)	0.71^f (0.00)	0.71^b (0.00)	0.71^b (0.00)
T_{10}	Unweeded control	6.82^a (45.66)	2.66^a (6.67)	2.88^a (8.00)	3.01^a (8.66)	2.41^a (5.33)	1.66^a (2.33)

[redacted] transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.

Table 7. Effect of pre-mix herbicide combinations on weed density at 60 DAS (no./m^2)

Treatments		Weed count (no./m^2)			
		G	S	B	Total
T_1	Pendimethalin + penoxsulam, 5 DAS	4.89^{f} (23.97)	0.71^{f} (0.00)	0.71^{b} (0.00)	4.89^{fg} (23.97)
T_2	Pendimethalin + penoxsulam, 10 DAS	5.19^{e} (27.01)	1.32de (1.33)	0.71^{b} (0.00)	5.32^{e} (28.34)
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	5.41^{d} (29.33)	1.76^{b} (2.66)	0.71^{b} (0.00)	5.65^{d} (31.99)
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	6.16^{b} (37.99)	1.35^{d} (1.33)	0.71^{b} (0.00)	6.27^{bc} (39.32)
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	4.65^{g} (21.66)	0.71^{f} (0.00)	0.71^{b} (0.00)	4.65^{g} (21.66)
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	4.72^{fg} (22.32)	1.66^{bc} (2.33)	0.71^{b} (0.00)	4.96^{f} (24.65)
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	6.32^{b} (39.98)	1.44^{cd} (1.66)	0.71^{b} (0.00)	6.44^{b} (41.64)
T_8	Bispyribac sodium, 18 DAS	5.94^{c} (35.32)	1.07^{e} (0.66)	0.71^{b} (0.00)	5.99^{c} (35.98)
T_9	Hand weeding, 20 and 40 DAS	3.36^{h} (11.33)	0.71^{f} (0.00)	0.71^{b} (0.00)	3.36^{h} (11.33)
T_{10}	Unweeded control	7.83^{a} (60.33)	3.80^{a} (13.99)	1.66^{a} (2.33)	8.81^{a} (76.65)

G - grasses, S - sedges, B - broad leaf weeds.

[redacted] transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.

4.1.3 Weed dry matter production

At 30 DAS the lowest weed dry matter production of 35.33 kg/ha was recorded in the herbicide combination florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5), followed by florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 18 DAS (T_6) with 35.66 kg/ha. The highest dry matter production of 231 kg/ha was recorded in unweeded control (T_{10}). Among the herbicide treated plots highest dry matter production of 76.33 kg/ha, contributed mainly by grass weeds, was observed in bispyribac sodium (T_8). However, this was statistically on par with cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 72.66 kg/ha (Table 8). All the herbicide treated plots had lower weed dry matter production than unweeded control (T_{10}). In the herbicide combination treatments from T_1 to T_6, the dry weights ranged from 35.33 kg/ha to 54.33 kg/ha, while in unweeded control it was 231 kg/ha (Table 8). All these herbicide combinations were found to be equally effective as hand weeded control (T_9).

By 60 DAS the weed dry matter production in unweeded control (T_{10}) was five times more (1310.26 kg/ha) than at 30 DAS. The lowest dry matter of 96.6 kg/ha was recorded in hand weeded control (T_9), which was statistically superior to all the other treatments. Among the herbicide treated plots, lowest weed dry matter accumulation of 223.3 kg/ha was observed in plots where florpyrauxifen-benzyl + cyhalofop-butyl was sprayed at 12 DAS (T_5), followed by those treated with pendimethalin + penoxsulam at 5 DAS (T_1), with 246.6 kg/ha (Table 8). The treatments pendimethalin + penoxsulam sprayed at 10 DAS (T_2) and florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 18 DAS (T_6) were found to be on par.

Among herbicide treated plots, the highest weed dry matter production of 386.6 kg/ha was recorded in bispyribac sodium (T_8), which was statistically inferior to all the treatments except unweeded control (T_{10}). Dry matter production of weeds in the herbicidal combination treatments (T_1 to T_6) ranged between 223 kg/ha and 346 kg/ha, which was comparatively low.

At both 30 DAS and 60 DAS, the performance of all the herbicidal combination treatments from T_1 to T_6 with regard to weed dry matter production was observed to be superior to cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7), bispyribac sodium (T_8) and unweeded control (T_{10}).

At 30 DAS the herbicide combination treatments pendimethalin + penoxsulam sprayed at 10 DAS (T_2), cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4), and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) recorded less weed dry matter production compared to the same herbicides sprayed at alternative times of application. However, by 60 DAS the lowest weed biomass was recorded in pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS. Thus, best herbicide combination and the optimum time of application observed was florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5).

Table 8. Effect of pre-mix herbicide combinations on weed dry weight (kg/ha)

Treatments		Weed dry weight (kg/ha)	
		30 DAS	60 DAS
T_1	Pendimethalin + penoxsulam, 5 DAS	37.00[de]	246.60[f]
T_2	Pendimethalin + penoxsulam, 10 DAS	36.66[de]	265.00[e]
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	54.33[bcd]	336.60[d]
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	49.33[cde]	346.60[c]
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	35.33[e]	223.30[g]
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	35.66[de]	263.30[e]
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	72.66[bc]	350.00[bc]
T_8	Bispyribac sodium, 18 DAS	76.33[b]	386.60[b]
T_9	Hand weeding, 20 DAS and 40 DAS	42.33[de]	96.60[h]
T_{10}	Unweeded control	231.00[a]	1310.26[a]
C.D. (0.05)		5.59	3.32
SE(m)		1.87	1.11

4.1.4 Nutrient removal by weeds

Nutrient removal is directly related to weed dry matter production. At all stages of observation, the lowest nutrient removal was recorded in hand weeded control (T_9) and the highest in unweeded control (T_{10}). At 30 DAS unweeded check removed 10.78, 0.93 and 5.5 kg NPK/ha, and at 60 DAS corresponding values were 25.98, 4.27 and 15.75 kg NPK/ha (Tables 9, 10 and 11).

Nitrogen removal by weeds

Nitrogen removal was in the range of 0.7 to 10.78 kg/ha at 30 DAS and from 1.69 to 25.98 kg/ha at 60 DAS (Table 9). At 30 DAS, the highest nitrogen removal by weeds was recorded in unweeded control (T_{10}) with 10.78 kg/ha. Among the herbicidal treatments, the highest N removal was observed in bispyribac sodium (T_8) with 3.03 kg/ha which was statistically on par with cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 2.88 kg/ha. The lowest N removal was noted in hand weeded control (T_9) with 0.7 kg/ha, which was statistically on par with pendimethalin + penoxsulam applied at 5 DAS (T_1) with 1.1 kg/ha. The treatments pendimethalin + penoxsulam applied at 5 and 10 DAS (T_1 and T_2), cyhalofop-butyl + penoxsulam sprayed at 18 DAS (T_4), florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 and 18 DAS (T_5 and T_6) were found to be statistically on par (Table 9). The N removal by weeds in the herbicide combinations from T_1 to T_6 ranged between 1.10 and 2.19 kg/ha, and was found less than that in T_7, T_8 and $T_{10.}$

At 60 DAS, a similar trend was observed. Unweeded control (T_{10}) registered the highest N removal by weeds with 25.98 kg/ha followed by bispyribac sodium (T_8) with 6.31 kg/ha and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 6.13 kg/ha. The lowest N removal was noted in hand weeded control (T_9) with 1.69 kg/ha. The next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) with 3.52 kg/ha, which was found to be on par with the treatments pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl (T_6) both applied at 18 DAS (Table 9). The N removal by weeds in the herbicide combination from T_1 to T_6 ranged between 3.52 and 5.25 kg/ha, and was inferior to T_7, T_8 and T_{10}.

Regarding the time of application, at both 30 and 60 DAS, the herbicide combinations pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) recorded less nitrogen uptake compared to the same treatment sprays at 10, 12 and 18 DAS respectively.

Table 9. Effect of pre-mix herbicide combinations on nitrogen removal by weeds (kg/ha)

Treatments		N removal by weeds (kg/ha)	
		30 DAS	**60 DAS**
T_1	Pendimethalin + penoxsulam, 5 DAS	1.10^{de}	4.03^{d}
T_2	Pendimethalin + penoxsulam, 10 DAS	1.35^{d}	5.25^{c}
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	2.19^{c}	5.11^{c}
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	1.47^{d}	4.04^{d}
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	1.46^{d}	3.52^{d}
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	1.58^{d}	3.87^{d}
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	2.88^{bc}	6.13^{bc}
T_8	Bispyribac sodium, 18 DAS	3.03^{b}	6.31^{b}
T_9	Hand weeding, 20 DAS and 40 DAS	0.70^{e}	1.69^{e}
T_{10}	Unweeded control	10.78^{a}	25.98^{a}
C.D. (0.05)		0.49	0.56
SE(m)		0.16	0.19

Phosphorus removal by weeds

The P removal by weeds followed an almost similar trend to that of N removal (Table 10). Phosphorus removal was in the range of 0.16 to 0.93 kg/ha at 30 DAS, and from 0.37 to 4.27 kg/ha at 60 DAS. The P removal by weeds in unweeded control (T_{10}) at 60 DAS was four times more than at 30 DAS, and in hand weeded control (T_9) it was twice that of the P removed at 30 DAS.

At 30 DAS, the highest P removal by weeds was recorded in unweeded control (T_{10}) with 0.93 kg/ha, followed cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 0.36 kg/ha. The lowest P removal was noted in hand weeded control (T_9) with 0.16 kg/ha. Among the herbicide treatments, the lowest P removal was in florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) with 0.17 kg/ha followed by pendimethalin + penoxsulam applied at 5 DAS (T_1) with 0.18 kg/ha (Table 10). The P removal in all the herbicide treatments was in the range of 0.16 to 0.36 kg/ha, which was less than the unweeded control.

At 60 DAS, the highest P removal was noted in unweeded control (T_{10}) with 4.27 kg/ha, followed by cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 1.41 kg/ha. The lowest P removal was observed in hand weeded control (T_9) with 0.37 kg/ha. Among the herbicide combinations, the highest P removal was recorded in cyhalofop-butyl + penoxsulam sprayed (T_4) at 18 DAS (T_4) with 1.28 kg/ha, followed by cyhalofop-butyl + penoxsulam sprayed at 12 DAS (T_3) with 1.27 kg/ha, which was found to be statistically on par with each other (Table 10). The P removal by weeds in all the herbicide combination treatments of T_1 to T_6 ranged from 0.92 to 1.28 kg/ha, was found inferior to T_7, T_8 and T_{10}.

At both 30 and 60 DAS, the herbicide combinations pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS recorded less P uptake due to the low weed dry matter compared to other treatments.

Table 10. Effect of pre-mix herbicide combinations on phosphorus removal by weeds (kg/ha)

Treatments		P removal by weeds (kg/ha)	
		30 DAS	60 DAS
T_1	Pendimethalin + penoxsulam, 5 DAS	0.18^{g}	1.02^{f}
T_2	Pendimethalin + penoxsulam, 10 DAS	0.20^{f}	1.23^{e}
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	0.23^{e}	1.27^{de}
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	0.28^{d}	1.28^{d}
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	0.17^{h}	0.92^{g}
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	0.20^{f}	0.94^{g}
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	0.36^{b}	1.41^{b}
T_8	Bispyribac sodium, 18 DAS	0.29^{c}	1.34^{c}
T_9	Hand weeding, 20 DAS and 40 DAS	0.16^{i}	0.37^{h}
T_{10}	Unweeded control	0.93^{a}	4.27^{a}
C.D. (0.05)		0.03	0.04
SE(m)		0.01	0.02

Potassium removal by weeds

The K removal by weeds followed the similar trend as that of N and P removal by weeds (Table 11). Potassium removal was in the range of 0.46 to 5.5 kg/ha at 30 DAS and from 1.19 to 15.75 kg/ha at 60 DAS. The K removal by weeds in unweeded control (T_{10}) at 60 DAS was thrice the amount of K removed at 30 DAS.

At 30 DAS, the highest K removal by weeds was recorded in unweeded control (T_{10}) with 5.5 kg/ha followed by cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 2.03 kg/ha. The lowest K removal in weeds was noted in hand weeded control (T_9) with 0.46 kg/ha (Table 11). The next best treatment was pendimethalin + penoxsulam applied at 10 DAS (T_2) with 0.64 kg/ha was found to be on par with pendimethalin + penoxsulam applied at 5 DAS (T_1) and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5). The herbicide combination treatments T_3 and T_4 i.e., cyhalofop-butyl + penoxsulam applied at 12 and 18 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) were found statistically on par. The K removal by weeds in all the herbicide combination treatments from T_1 to T_6 ranged from 0.64 to 1.04 kg/ha, and was found statistically inferior to the other treatments except hand weeded control (T_9).

At 60 DAS, the highest K removal by weeds was noted in unweeded control (T_{10}) with 15.75 kg/ha followed by bispyribac sodium (T_8) with 6.65 kg/ha. The lowest K removal was recorded in hand weeded control (T_9) with 1.19 kg/ha followed by florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 2.84 kg/ha (Table 11). The sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) registered K removal of 4.30 kg/ha by weeds, which was even less than one of the herbicidal combination treatments viz., cyhalofop-butyl + penoxsulam (T_4) applied at 18 DAS (4.44 kg/ha) and was found to be statistically on par with cyhalofop-butyl + penoxsulam sprayed at 12 DAS (T_3). The herbicide combinations pendimethalin + penoxsulam i.e., T_1 and T_2 applied at 5 and 10 DAS were statistically on par.

By 30 DAS, the lowest K uptake was observed in the herbicide combinations pendimethalin + penoxsulam (T_2), cyhalofop-butyl + penoxsulam (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) applied at 10, 18 and 12 DAS respectively, whereas at 60 DAS, the lowest K uptake was noted in pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5), both applied at 18 DAS.

Table 11. Effect of pre-mix herbicide combinations on potassium removal by weeds (kg/ha)

Treatments		K removal by weeds (kg/ha)	
		30 DAS	**60 DAS**
T_1	Pendimethalin + penoxsulam, 5 DAS	0.68^{e}	3.23^{f}
T_2	Pendimethalin + penoxsulam, 10 DAS	0.64^{e}	3.32^{f}
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	0.98^{d}	4.26^{d}
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	0.93^{d}	4.44^{c}
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	0.71^{e}	2.84^{g}
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	1.04^{d}	3.04^{e}
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	2.03^{b}	4.30^{cd}
T_8	Bispyribac sodium, 18 DAS	1.74^{c}	6.65^{b}
T_9	Hand weeding, 20 DAS and 40 DAS	0.46^{f}	1.19^{h}
T_{10}	Unweeded control	5.50^{a}	15.75^{a}
C.D. (0.05)		0.15	0.15
SE(m)		0.05	0.05

4.2 STUDIES ON RICE

4.2.1 Visual phytotoxicity on weeds and rice

Phytotoxicity scoring on both crop and weeds was done on a 0-5 scoring scale (Thomas and Abraham, 2007) based on injury symptoms at three and seven days after herbicide spraying.

Application of the herbicide combination pendimethalin + penoxsulam (T_1 and T_2) at both 5 DAS and 10 DAS caused slight injury on rice (Table 12). At three days after spraying, the leaf tips became slightly yellowish; however, the crop completely recovered within seven days. No other herbicide produced visual phytotoxicity symptoms on rice (Plate 7 and 8).

All the herbicides resulted in visual injury symptoms on weeds at both three and seven days after spraying. The score was three or four, indicating good to very good control. At three days after spraying, herbicide combination treatments of pendimethalin + penoxsulam (T_1) sprayed at 5 DAS and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) sprayed at 12 DAS showed very good weed control over the same combinations sprayed at 10 and 18 DAS, and the other herbicide treatments. At seventh day after spraying, cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) showed less phytotoxicity symptoms (score 3) on weeds compared to other treatments which had a score of 4 (Table 12).

Table 12. Effect of pre-mix herbicide combinations on phytotoxicity scoring

Treatments		3 days after spraying		7 days after spraying	
		Score on crop	**Score on weed**	**Score on crop**	**Score on weed**
T_1	Pendimethalin + penoxsulam, 5 DAS	1	4	0	4
T_2	Pendimethalin + penoxsulam, 10 DAS	1	3	0	4
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	0	3	0	4
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	0	3	0	4
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	0	4	0	4
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	0	3	0	4
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	0	3	0	3
T_8	Bispyribac sodium, 18 DAS	0	3	0	4

Plate 7. Phytotoxicity symptom of the herbicide combination pendimethalin + penoxsulam at three days after spraying

Plate 8. Slight yellowing noticed at three days after spraying of the herbicide combination pendimethalin + penoxsulam

4.2.2 Plant height

There was no significant difference in plant height between treatments and the average plant heights were 51.19 cm, 87.95 cm and 96.97 cm at 30 DAS, 60 DAS and harvest respectively (Table 13).

4.2.3 Number of tillers per m^2

At 30 DAS there was no significant difference between herbicidal and hand weeded or unweeded treatments for the number of tillers per m^2.

At 60 DAS higher tiller count (325 nos./m^2) was observed in hand weeded control (T_9) which was on par with pendimethalin + penoxsulam sprayed at 10 DAS (T_2) (323 nos./m^2). The next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) (290 nos./m^2) followed by florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) (280 nos./m^2). The lowest tiller count was observed in unweeded control (T_{10}) (201 nos./m^2) (Table 14). The sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and the herbicide treatment of bispyribac sodium (T_8) were found to be on par with each other. Also, the treatments cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and pendimethalin + penoxsulam applied at 5 DAS (T_1) were statistically on par with each other.

Table 13. Effect of pre-mix herbicide combinations on plant height of rice (cm)

Treatments		Plant height (cm)		
		30 DAS	**60 DAS**	**Harvest**
T_1	Pendimethalin + penoxsulam, 5 DAS	49.30	85.40	94.77
T_2	Pendimethalin + penoxsulam, 10 DAS	50.60	86.26	97.78
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	53.43	88.03	95.52
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	51.73	88.83	101.98
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	50.13	90.07	93.11
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	51.40	88.86	97.27
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	50.96	85.43	98.54
T_8	Bispyribac sodium, 18 DAS	52.56	90.46	93.66
T_9	Hand weeding, 20 DAS and 40 DAS	50.96	91.53	103.98
T_{10}	Unweeded control	50.86	84.59	93.05
C.D. (0.05)		NS	NS	NS

Table 14. Effect of pre-mix herbicide combinations on tiller count (no./m^2)

Treatments		No. of tillers / m^2	
		30 DAS	60 DAS
T_1	Pendimethalin + penoxsulam, 5 DAS	125	262^{e}
T_2	Pendimethalin + penoxsulam, 10 DAS	136	323^{a}
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	130	247^{g}
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	122	255^{f}
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	138	290^{b}
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	140	280^{c}
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	131	268^{de}
T_8	Bispyribac sodium, 18 DAS	134	271^{d}
T_9	Hand weeding, 20 DAS and 40 DAS	145	325^{a}
T_{10}	Unweeded control	94	201^{h}
C.D. (0.05)		NS	6.12
SE(m)		-	2.05

4.2.4 Yield attributes

Number of panicles per m^2

Higher number of panicles (221 nos./m^2) was recorded in hand weeded control (T_9), which was statistically on par with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with a panicle number of 216 nos./m^2. The next best treatment was pendimethalin + penoxsulam applied at 5 DAS (T_1) with 208 nos./m^2 (Table 15). The lowest number of panicles was observed in unweeded control. All the herbicidal combination treatments (T_1 to T_6) were found to be statistically superior to all the other treatments except hand weeded control (T_9).

Grains/panicle and test weight

Higher number of grains per panicle was recorded in hand weeded control (T_9) (120.13 nos.), which was on par with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) (118.85 nos.) and pendimethalin + penoxsulam applied at 5 DAS (T_1) (115.87 nos.) (Table 15). The next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) and cyhalofop-butyl + penoxsulam applied at 12 DAS, and the lowest grains per panicle was seen in unweeded control (T_{10}).

Percentage of filled grains per panicle was observed to be higher in the hand weeded treatment (T_9) with 91.86 per cent followed by florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) with 91.65 per cent, and these treatments were on par with each other and with all the other treatments except bispyribac sodium (T_8) and unweeded control (T_{10}).

Test weight or 1000 grain weight of paddy was in the range of 27.24 to 29.2 g and there was no significant difference between the treatments.

Table 15. Effect of pre-mix herbicide combinations on yield attributes of rice

Treatments		Yield attributes of rice			
		Panicles per m^2	Grains per panicle	% of filled grains	Test weight (g)
T_1	Pendimethalin + penoxsulam, 5 DAS	208.89^b	115.87^a	90.60^a	29.05
T_2	Pendimethalin + penoxsulam, 10 DAS	198.44^d	106.65^c	89.05^a	28.71
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	204.96^c	109.76^b	90.44^a	29.08
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	191.76^e	108.32^c	89.73^a	28.37
T_5	Florpyrauxifen-benzyl + cyhalofopbutyl, 12 DAS	216.57^a	118.85^a	91.65^a	29.13
T_6	Florpyrauxifen-benzyl + cyhalofopbutyl, 18 DAS	201.47^d	109.43^b	90.56^a	28.84
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 and 19 DAS	187.91^f	106.89^c	88.32^a	28.19
T_8	Bispyribac sodium, 18 DAS	176.64^g	107.93^c	87.34^b	28.55
T_9	Hand weeding, 20 DAS and 40 DAS	221.47^a	120.13^a	91.86^a	29.20
T_{10}	Unweeded control	125.29^h	80.71^d	75.42^c	27.24
C.D. (0.05)		6.04	5.88	4.31	NS
SE(m)		2.02	1.96	1.43	-

4.2.5 Grain and straw yield

The highest grain yield of 4.6 t/ha was recorded in hand weeded control (T_9) followed by florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 4.5 t/ha, and they were statistically on par with each other and to other herbicide combination treatments (Table 16).

The sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) registered grain yield of 3.52 t/ha and was found superior to the treatment bispyribac sodium (T_8) with 3.4 t/ha. The lowest grain yield was recorded in unweeded control (T_{10}) with 1.99 t/ha, which was inferior to all the treatments (Table 16). All the herbicidal combination treatments from T_1 to T_6 were statistically superior to the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7), bispyribac sodium (T_8) and unweeded control (T_{10}).

The lowest straw yield was recorded in unweeded control (T_{10}) with 2.11 t/ha, which was inferior to all the other treatments (Table 16). All the herbicidal treatments from T_1 to T_8 and the hand weeded control (T_9) were found to be statistically on par with each other.

Harvest Index (HI)

There was no significant difference between the herbicidal and hand weeded or unweeded treatments in terms of harvest index and the values were within a range of 0.48 to 0.50 (Table 16).

Table 16. Effect of pre-mix herbicide combinations on grain and straw yield of rice (t/ha)

Treatments		Grain yield (t/ha)	Straw yield (t/ha)	Harvest index
T_1	Pendimethalin + penoxsulam, 5 DAS	4.43[a]	4.47[a]	0.5
T_2	Pendimethalin + penoxsulam, 10 DAS	4.29[ab]	4.51[a]	0.49
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	4.38[ab]	4.40[a]	0.5
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	4.24[ab]	4.41[a]	0.49
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	4.50[a]	4.58[a]	0.5
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	4.32[ab]	4.48[a]	0.49
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	3.52[bc]	3.68[a]	0.49
T_8	Bispyribac sodium, 18 DAS	3.40[c]	3.61[a]	0.49
T_9	Hand weeding, 20 DAS and 40 DAS	4.60[a]	4.67[a]	0.5
T_{10}	Unweeded control	1.99[d]	2.11[b]	0.48
C.D. (0.05)		0.72	0.54	NS
SE(m)		0.24	0.18	-

4.2.6 Weed control efficiency (WCE) and weed index (WI)

Weed control efficiency denotes the efficiency of the herbicides applied. In other words, it is the per cent reduction of weed density or dry matter production due to the application of herbicides, in comparison to the unweeded control.

At 30 DAS the highest WCE of 84.71 per cent was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5), which was on par with the treatments T_1 and T_2 of pendimethalin + penoxsulam applied at 5 and 10 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS (T_6) (Table 17). The hand weeded control (T_9) was recorded with WCE of 81.68 per cent. The lowest WCE was registered in bispyribac sodium (T_8) with 66.96 per cent followed by the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 68.55 per cent. The treatments T_3 and T_4, i.e., cyhalofop-butyl + penoxsulam applied at different growth stages of weeds, were found to be on par with each other.

At 60 DAS highest WCE of 92.63 per cent was observed in hand weeded (T_9) control, which was superior to all the other treatments (Table 17). The next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with WCE of 82.96 per cent, which was on par with pendimethalin + penoxsulam applied at 5 DAS (T_1) with 81.18 per cent. The treatments pendimethalin + penoxsulam (T_1 and T_2) applied at 5 and 10 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl (T_6) at 18 DAS were found to be on par with each other. Also, the treatments T_3 and T_4, i.e., cyhalofop-butyl + penoxsulam applied at 12 and 18 days after sowing were found to be on par with each other. The lowest WCE was observed in the treatment bispyribac sodium (T_8) with 70.49 per cent followed by cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 73.29 per cent.

Among the different times of herbicide combination application, the highest WCE was recorded in the treatments pendimethalin + penoxsulam applied at 10 DAS (T_2), cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) over the same herbicides sprayed at other times of application at 30 DAS. However, at 60 DAS, the highest WCE was recorded in the treatments pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl +

penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS over the other sprays.

Weed Index (WI)

Weed index indicates the yield reduction due to weed competition in different treatments over hand weeded control (*i.e.*, weed free condition). The highest yield reduction was recorded in unweeded control (T_{10}) to the tune of 56.74 per cent, and the lowest was in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) to the tune of 2.17 per cent (Table 17). On an average, about 5.22 per cent of grain yield reduction was observed in all the herbicide combination treatments from T_1 to T_6.

Table 17. Effect of pre-mix herbicide combinations on weed control efficiency and weed index (%)

Treatments		WCE (%)		WI (%)
		30 DAS	60 DAS	
T_1	Pendimethalin + penoxsulam, 5 DAS	83.98	81.18	3.70
T_2	Pendimethalin + penoxsulam, 10 DAS	84.13	79.78	6.74
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	76.48	74.31	4.78
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	78.65	73.55	7.83
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	84.71	82.96	2.17
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	84.56	79.90	6.08
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	68.55	73.29	23.48
T_8	Bispyribac sodium, 18 DAS	66.96	70.49	26.09
T_9	Hand weeding, 20 DAS and 40 DAS	81.68	92.63	-
T_{10}	Unweeded control	-	-	56.74

4.3 STUDIES ON SOIL MICROBIAL ACTIVITY

Results of the effects of the herbicide combinations and the individual herbicides on soil microbial population was assessed and presented below.

4.3.1 Dehydrogenase activity (DHA)

The dehydrogenase activity of the soil tended to increase from the initial phase to tillering phase and was found maximum at the active tillering stage, after which it gradually declined towards the harvest stage.

On initial observation before the application of herbicidal treatments, the mean dehydrogenase activity observed was 63.26 µg TPF/g soil/h (Table 18). At 30 DAS the dehydrogenase activity ranged from 63 to 77.49 µg TPF/g soil/h. The highest dehydrogenase activity was recorded in plots treated with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) which was on par with the treatment pendimethalin + penoxsulam applied at 10 DAS (T_2) (77.49 µg TPF/g soil/h). The treatments T_3 and T_4, i.e., cyhalofop-butyl + penoxsulam applied at both 12 and 18 DAS were found to be on par with each other. The lowest activity was recorded in cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7), with 63 µg TPF/g soil/h (Table 18).

At 60 DAS the dehydrogenase activity ranged from 66.01 to 85.29 µg TPF/g soil/h and it was highest during this stage in all the treatments. The highest dehydrogenase activity was recorded in plots with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 85.29 µg TPF/g soil/h. The next best treatment was cyhalofop-butyl + penoxsulam applied at 12 DAS (T_3) with 82.09 µg TPF/g soil/h, which was on par with pendimethalin + penoxsulam applied at 10 DAS (T_2) and hand weeded control (T_9) (Table 18). The lowest activity was recorded on application of bispyribac sodium (T_8), with 66.01 µg TPF/g soil/h.

At harvest the dehydrogenase activity ranged from 46.05 to 76.56 µg TPF/g soil/h. Higher dehydrogenase activity was recorded in hand weeded control (T_9) which however, was on par with the treatments florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) and cyhalofop-butyl + penoxsulam applied at 12 DAS (T_3). The treatments pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 18 DAS (T_4 and T_6), were also found to be on par with each other. The lowest dehydrogenase activity during all the stages of observation was recorded in the treatment unweeded control (T_{10}) with µg TPF/g soil/h.

Among the herbicide combinations, the highest dehydrogenase activity at 60 DAS and harvest was observed in the plots treated with pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 12 DAS (T_3 and T_5) over the same herbicidal sprays at different times of application. However, at 30 DAS, no specific trend was observed in dehydrogenase activity in the herbicide combination treatments.

Table 18. Effect of pre-mix herbicide combinations on soil dehydrogenase activity (µg TPF/g soil/h)

Treatments		DHA (µg TPF/g soil/h)		
		30 DAS	60 DAS	Harvest
T_1	Pendimethalin + penoxsulam, 5 DAS	72.17[cd]	79.79[b]	64.79[b]
T_2	Pendimethalin + penoxsulam, 10 DAS	75.78[ab]	76.79[c]	55.20[d]
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	68.46[f]	82.09[b]	74.24[a]
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	68.41[ef]	72.89[d]	63.92[b]
T_5	Florpyrauxifen-benzyl + cyhalofopbutyl, 12 DAS	77.49[a]	85.29[a]	75.99[a]
T_6	Florpyrauxifen-benzyl + cyhalofopbutyl, 18 DAS	70.94[de]	72.43[d]	65.38[b]
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	63.00[g]	69.53[e]	57.36[cd]
T_8	Bispyribac sodium, 18 DAS	65.90[f]	66.01[f]	58.94[c]
T_9	Hand weeding, 20 and 40 DAS	74.67[bc]	81.27[b]	76.56[a]
T_{10}	Unweeded control	73.55[bcd]	71.31[de]	46.05[e]
C.D. (0.05)		2.77	2.71	2.37
SE(m)		0.90	0.91	0.79
Initial value		63.26		

4.3.2 Soil microbial biomass carbon (SMBC)

Before the application of herbicides, the microbial biomass carbon present in the soil was estimated to be 298.76 µg/g soil (Table 19). At 30 DAS, the soil microbial biomass carbon in the all the treatments showed a drastic decline and it ranged from 20.56 to 73.48 µg/g soil. The highest microbial biomass carbon of 73.48 µg/g soil was recorded in unweeded control (T_{10}), followed by plots applied with cyhalofop-butyl + penoxsulam at 18 DAS (T_4) which registered a value of 53.36 µg/g soil (Table 19). The lowest microbial biomass carbon of 20.56 µg/g soil was observed in the treatment pendimethalin + penoxsulam applied at 5 DAS (T_1).

By 60 DAS the microbial biomass carbon present in the soil increased slightly and ranged from 44.67 to 118.8 µg/g soil. The highest microbial biomass carbon of 118.8 µg/g soil was recorded on application of pendimethalin + penoxsulam at 10 DAS (T_2). The next best treatment was cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4) with 108.81 µg/g soil, which was found statistically on par with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with 106.96 µg/g soil (Table 19). The treatments cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8) were found to be on par. The lowest microbial carbon of 44.67 µg/g soil was in pendimethalin + penoxsulam applied at 5 DAS (T_1).

At harvest the microbial biomass carbon present in the soil increased furthermore and ranged from 79.21 to 160.44 µg/g soil. The highest soil microbial biomass carbon of 160.44 µg/g soil was observed in hand weeded treatment (T_9). The next best treatment was pendimethalin + penoxsulam applied at 10 DAS (T_2) with 152.51 µg/g soil, which was statistically on par with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5), with 151.29 µg/g soil (Table 19). The lowest microbial biomass carbon of 79.21 µg/g soil was recorded in pendimethalin + penoxsulam applied at 5 DAS (T_1).

With regard to time of application, the highest SMBC at all stages of observation was recorded in pendimethalin + penoxsulam applied at 10 DAS (T_2), cyhalofop-butyl + penoxsulam applied at 18 DAS (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5).

Table 19. Effect of pre-mix herbicide combinations on soil microbial biomass carbon (µg/g soil)

Treatments		Microbial carbon (µg/g soil)		
		30 DAS	60 DAS	Harvest
T_1	Pendimethalin + penoxsulam, 5 DAS	20.56^{h}	44.67^{h}	79.21^{g}
T_2	Pendimethalin + penoxsulam, 10 DAS	37.26^{e}	118.8^{a}	152.51^{b}
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	25.29^{g}	98.89^{c}	124.42^{e}
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	53.36^{b}	108.81^{b}	147.87^{c}
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	48.73^{c}	106.96^{b}	151.29^{bc}
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	36.90^{e}	71.32^{f}	135.84^{d}
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	44.56^{d}	78.86^{e}	124.85^{e}
T_8	Bispyribac sodium, 18 DAS	27.26^{f}	75.64^{ef}	99.28^{f}
T_9	Hand weeding, 20 DAS and 40 DAS	48.79^{c}	86.88^{d}	160.44^{a}
T_{10}	Unweeded control	73.48^{a}	57.60^{g}	100.80^{f}
C.D. (0.05)		1.21	6.62	4.38
SE(m)		0.40	2.21	1.46
Initial value		298.76		

4.4 ECONOMICS OF CULTIVATION

The highest B:C ratio of 2.5 was obtained in two treatments, florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) and pendimethalin + penoxsulam applied at 5 DAS (T_1). The highest net returns were also obtained from the same treatments, i.e., florpyrauxifen-benzyl + cyhalofop-butyl (T_5) and pendimethalin + penoxsulam (T_1) with Rs. 90,286/ha and Rs. 88,080/ha respectively. All the herbicide combinations from T_1 to T_6 recorded B:C ratio ranging from 2.3 to 2.5. The sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8) resulted in B:C ratio of 1.9 (Table 20).

The highest total income was noted in hand weeded treatment (T_9) with Rs. 1,52,220/ha, but due to high total cost of cultivation (mainly contributed by labour charges) of Rs. 82,000/ha, the net returns was reduced to Rs. 70,220/ha. The next highest total income was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) with Rs. 1,48,980/ha.

Among the various herbicidal treatments, the total cost of herbicides plus spraying was lowest when the herbicide combination pendimethalin + penoxsulam (T_1 and T_2) were applied at 5 DAS and 10 DAS respectively, followed by bispyribac sodium (T_8). The additional returns due to weed management treatments were highest in florpyrauxifen-benzyl + cyhalofop-butyl when applied at 12 DAS (T_5) with Rs. 78,896/ha, followed by pendimethalin + penoxsulam applied at 5 DAS (T_1) with Rs. 76,690/ha.

From the economic analysis, pendimethalin + penoxsulam applied at 5 DAS (T_1), cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS fetched higher gross returns, net returns and B:C ratio. Among these treatments, the best herbicide combination on account of economics was observed to be T_5 i.e., florpyrauxifen-benzyl + cyhalofop-butyl whose application window ranges from 12 DAS to 18 DAS as the crop yields were on par with the same treatments applied at 18 DAS (T_6).

Table 20. Effect of pre-mix herbicide combinations on economics of rice cultivation (Rs./ha)

Treatments		Total cost (Rs.)	Gross returns (Rs.)	Net returns (Rs.)	B:C ratio	Additional cost for weed management (Rs.)	Additional returns due to weed management (Rs.)
T_1	Pendimethalin + penoxsulam, 5 DAS	58,350	1,46,430	88,080	2.5	3,350	76,690
T_2	Pendimethalin + penoxsulam, 10 DAS	58,350	1,42,890	84,540	2.4	3,350	73,150
T_3	Cyhalofop-butyl + penoxsulam, 12 DAS	59,275	1,44,660	85,385	2.4	4,275	73,995
T_4	Cyhalofop-butyl + penoxsulam, 18 DAS	59,275	1,40,940	81,665	2.3	4,275	70,275
T_5	Florpyrauxifen-benzyl + cyhalofop-butyl, 12 DAS	58,694	1,48,980	90,286	2.5	3,694	78,896
T_6	Florpyrauxifen-benzyl + cyhalofop-butyl, 18 DAS	58,694	1,43,520	84,826	2.4	3,694	73,436
T_7	Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 DAS and 19 DAS	59,871	1,17,120	57,249	1.9	4,871	45,859
T_8	Bispyribac sodium, 18 DAS	58,415	1,13,460	55,045	1.9	3,415	43,655
T_9	Hand weeding, 20 DAS and 40 DAS	82,000	1,52,220	70,220	1.8	27,000	58,830
T_{10}	Unweeded control	55,000	66,390	11,390	1.2	-	-

* Florpyrauxifen-benzyl + cyhalofop-butyl 12 EC - not yet available in the market, so approximate price of Rs 1,875 / L was used.

Discussion

5. DISCUSSION

A field experiment was conducted in a farmer's field in the *Kole* areas of Thrissur to study the efficacy of different pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice. The results of the experiment are discussed below based on the literature available.

5.1 WEED SPECTRUM

The weed count obtained from the experimental field showed that at 30 DAS, grasses constituted about 58 per cent, sedges 39 per cent and broad leaf weeds 3 per cent of the total population (Fig.4 and Table 5). However, at 60 DAS, the population of grass weeds was increased and they solely constituted about 92 per cent of the total weed population, while the population of sedges constituted about 7 per cent, and broad leaf weeds 1 per cent of the total. The data showed that there was a higher proportion of grass weeds compared to sedges and broad leaf weeds at 60 DAS in the experimental field at *Kole* lands (Fig.5 and Table 7). Similar results were reported by Joy *et al.* (1993), Sindhu (2008) and Menon (2012). This increase in population of grass weeds was mainly due to the infestation of weedy rice (*Oryza sativa* f. *spontanea*). Although weedy rice was present at an average population of about 28 nos./m^2 (at 60 DAS), it was managed by hand weeding in all the treatments, as otherwise it would have adversely affected the crop yields.

Next to weedy rice, *Echinochloa* spp dominated among the grasses with a population of 9 nos./m^2 (at 30 DAS) in unweeded control (Table 4). Similar findings were reported by Sindhu (2008) in *Kole* lands. Moreover, Lubigan and Vega (1971), Noda (1973), Smith (1983), and Rao and Moody (1987) reported *Echinochloa* spp as the most problematic weed species in rice. Another grass weed, *Leptochloa chinensis* was only observed at 60 DAS with a population of 8 nos./m^2 in unweeded check. Jacob (2014) reported *Leptochloa chinensis* (Chinese sprangletop) as a problematic weed in *Kole* areas.

The major sedges noticed at 30 DAS in the experiment field were *Cyperus* spp, with a population of 13 nos./m^2 and *Fimbristylis miliacea*, with a population of 7 nos./m^2 in unweeded check, in addition to minor broad leaf weeds. Uddin *et al.* (2013) observed that noxious weeds like *Cyperus* spp and *Fimbristylis miliacea* in direct seeded rice posed a major threat to rice production activities. Rao *et al.* (2017) reported that *Cyperus* spp was a highly problematic weed species in rice cultivation in all the South Asian countries.

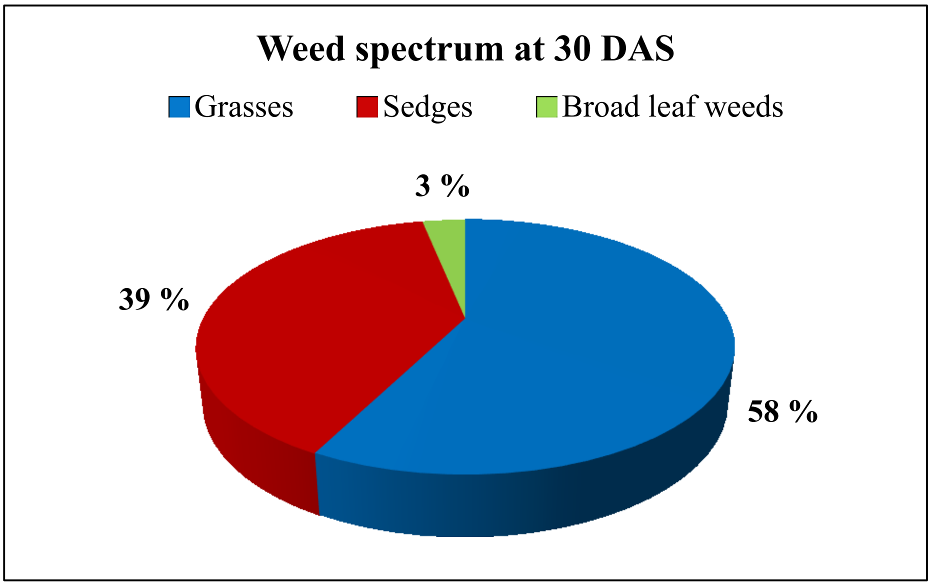

Fig. 4. Weed spectrum at 30 DAS in the experimental area

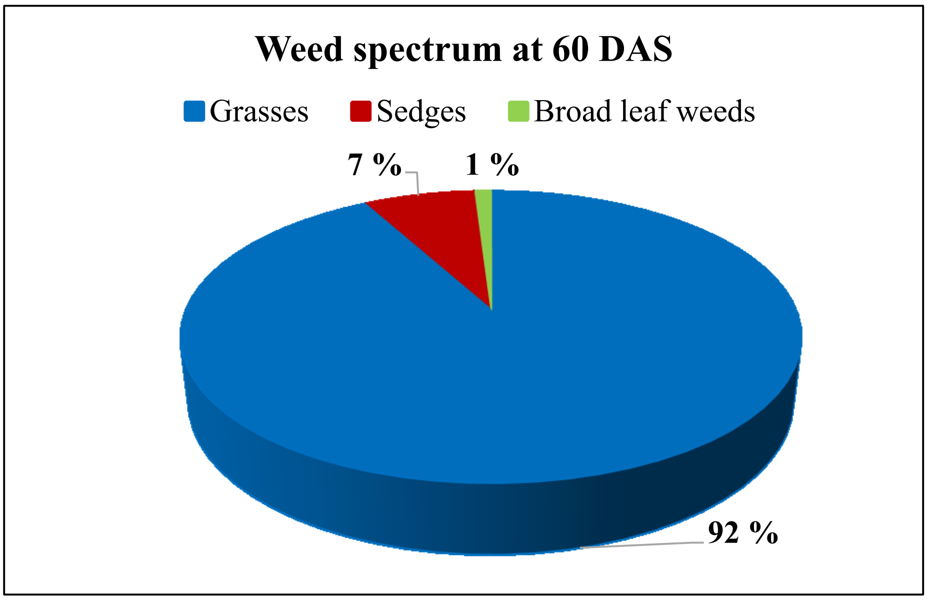

Fig. 5. Weed spectrum at 60 DAS in the experimental area

5.2 RESPONSE OF WEEDS TO PRE-MIX HERBICIDE COMBINATIONS

At 30 DAS, complete control of *Echinochloa* spp was observed in the herbicidal treatments T_3 and T_4, i.e., cyhalofop-butyl + penoxsulam applied at 12 and 18 DAS, and T_5 and T_6, i.e., florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 and 18 DAS, and bispyribac sodium (T_8) (Table 4). The results were in accordance with the observations of Khaliq *et al.* (2011) and Jacob (2014). Atheena (2016) reported that the herbicide bispyribac sodium was very effective in controlling *Echinochloa* spp in addition to cyhalofop-butyl.

The highest population of *Cyperus* spp was recorded in the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) with 12 nos./m^2. Complete control of *Cyperus* spp was observed in the herbicide combination treatments pendimethalin + penoxsulam (T_1 and T_2) applied at 5 and 10 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl (T_5 and T_6) applied at 12 and 18 DAS. High weed control efficiency obtained on application of the herbicide combination pendimethalin + penoxsulam applied at the dose of 2.5 kg/ha at 7 DAS has been reported by Uraon (2019). Among the broad leaf weeds, *Ludwigia perennis* and *Limnophila heterophylla* were noticed in unweeded control (T_{10}) but was not seen in any of the herbicide treatments (Fig.6). The results indicated the effectiveness of these herbicide combinations on the weed flora in rice.

At 60 DAS, weed density in all the plots were significantly affected due to application of different herbicides and their combination products. A pronounced reduction of weed density was noticed in all the herbicide treatments, especially where the application of herbicide combinations was done, along with cyhalofop-butyl (Table 6). Singh *et al.* (2004) reported that cyhalofop-butyl effectively reduced the weed density at different stages of crop growth and at harvest in direct seeded rice. Complete control of *Echinochloa stagnina* was observed in the treatments cyhalofop-butyl + penoxsulam (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl (T_5) both applied at 12 DAS and in bispyribac sodium (T_8). As per Singh (2016), the herbicidal combination cyhalofop-butyl + penoxsulam was found to completely control *Echinochloa* spp in rice ecosystem.

Kailkhura *et al*. (2015) also observed the high efficiency of this pre-mix herbicide combination in reducing weed density.

Among the herbicide treatments, the highest population of *Leptochloa chinensis* was recorded in bispyribac sodium (T_8) with 10 nos./m^2 followed by pendimethalin + penoxsulam (T_2) applied at 10 DAS with 5 nos./m^2. This might have been due to the resistance developed in weeds over time with continuous application, and the poor efficacy of these herbicides to control the resistant biotypes. Brar and Bhullar (2012) reported bispyribac sodium and penoxsulam to be ineffective against *Leptochloa chinensis*. However, the population of *Leptochloa chinensis* in cyhalofop-butyl + penoxsulam (T_4) was comparatively very low (1 no./m^2) due to the broad spectrum control of this herbicide combination. These results were in conformity with the findings of Chauhan and Abugho (2012a).

The population of sedges and broad leaf weeds at 60 DAS was significantly reduced in all the treatments (Fig.7 and Table 6). Among the herbicide treated plots, highest population of *Cyperus* spp was observed in cyhalofop-butyl + penoxsulam (T_3) applied at 12 DAS with 8 nos./m^2. Chauhan and Opena (2012) reported that post-emergence application of cyhalofop-butyl + penoxsulam was ineffective against *Cyperus* spp (purple nutsedge) in direct seeded rice. There was no incidence of the sedge *Fimbristylis miliacea* and the broad leaf weed *Eichhornia crassipes* in any of the herbicide treatments. This might have been due to the effective control brought about by these herbicides.

Both at 30 DAS and 60 DAS, the herbicide combinations pendimethalin + penoxsulam (T_2) sprayed at 10 DAS, cyhalofop-butyl + penoxsulam (T_4) and florpyrauxifen-benzyl + cyhalofop-butyl (T_6) which were both sprayed at 18 DAS recorded higher weed population than the same herbicides sprayed at 5 DAS and 12 DAS respectively (Figs. 6 and 7 and Tables 5 and 7). This was probably due to the early control of all the emerged weeds when spraying was done at 5 and 12 DAS.

At all stages of observation, the population of weedy rice (*Oryza sativa* f. *spontanea*) was found to increase throughout the crop period due to the frequent germination of weed seeds present in the soil seed bank. Even when hand weeding was performed twice at 20 and 40 DAS (T_9), an average weedy rice population of 11 nos./m^2 was noticed. It was evident that alternative methods of weed control other than chemical measures are also to be employed to successfully eradicate the weedy rice infestation.

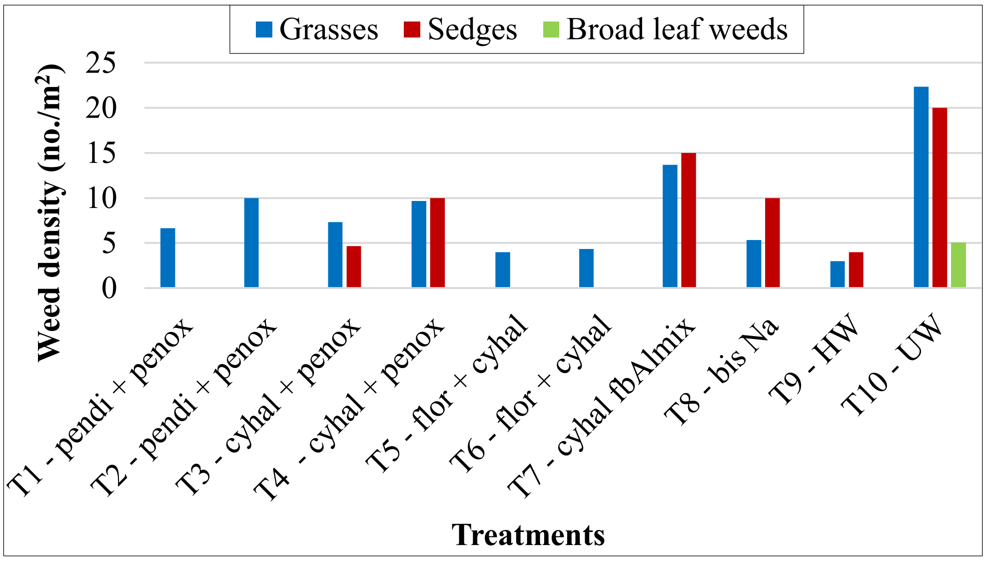

Fig. 6. Effect of pre-mix herbicide combinations on weed count at 30 DAS

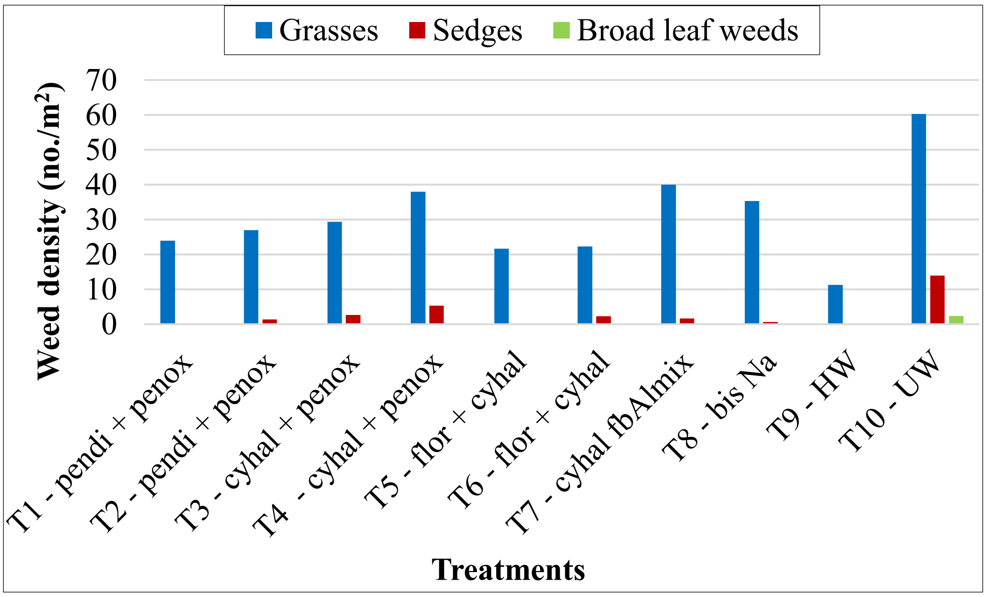

Fig. 7. Effect of pre-mix herbicide combinations on weed count at 60 DAS

5.3 NUTRIENT REMOVAL BY WEEDS

Nutrient removal by weeds is linearly related to weed biomass and nutrient status of soil. When the nutrient uptake by weeds was higher, the nutrient uptake by crop tended to be lower (Atheena, 2016). At both 30 DAS and 60 DAS, the lowest nutrient removal was recorded in hand weeded control (T_9), and the highest in unweeded control (T_{10}) (Tables 9, 10 and 11). The nutrient removal by weeds directly influenced the crop yields.

At 30 DAS the weeds from unweeded control removed about 10.78, 0.93 and 5.5 kg N, P, and K per ha. Generally, the demand for nutrients is in the order of potassium > nitrogen > phosphorus. But in this study, the trend of nitrogen > potassium > phosphorus was observed (Fig.8). Nadeem *et al.* (2018) reported a similar trend of nutrient removal in the major weeds of wheat. Rathod and Somasundaram (2017) recorded nutrient removal by weeds to the tune of 17.18, 1.62 and 15.16 kg N, P, and K per ha at 30 DAT in unweeded check under organic weed management practices in rice. The lowest nutrient removal was observed in hand weeded control (T_9) with 0.7, 0.16 and 0.46 kg N, P, and K per ha.

At 60 DAS, the highest nutrient removal by weeds was 25.98, 4.27 and 15.75 kg N, P, and K per ha observed in unweeded control (T_{10}), and the lowest was in hand weeded control (T_9) i.e., 1.69, 0.37 and 1.19 kg N, P, and K per ha. The uptake of nutrients in unweeded check was reported to be nearly nine times more than that in the chemical or manual weed control treatments (Sankaran and Mani, 1974). Almost the same trend was noticed in this study (Fig.9). In most of the herbicide combination treatments, the nutrient uptake by weeds were comparatively very less which was due to the low weed dry matter production and high weed control efficiency. In sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8), the nutrient removal by weeds was higher compared to the herbicide combinations due to higher weed density and dry matter production.

At both 30 DAS and 60 DAS, the pre-mix herbicides pendimethalin + penoxsulam sprayed at 10 DAS (T_2), cyhalofop-butyl + penoxsulam sprayed at 12 DAS (T_3) and florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 18 DAS (T_6) recorded higher nutrient removal by weeds compared to the same herbicides applied at other times.

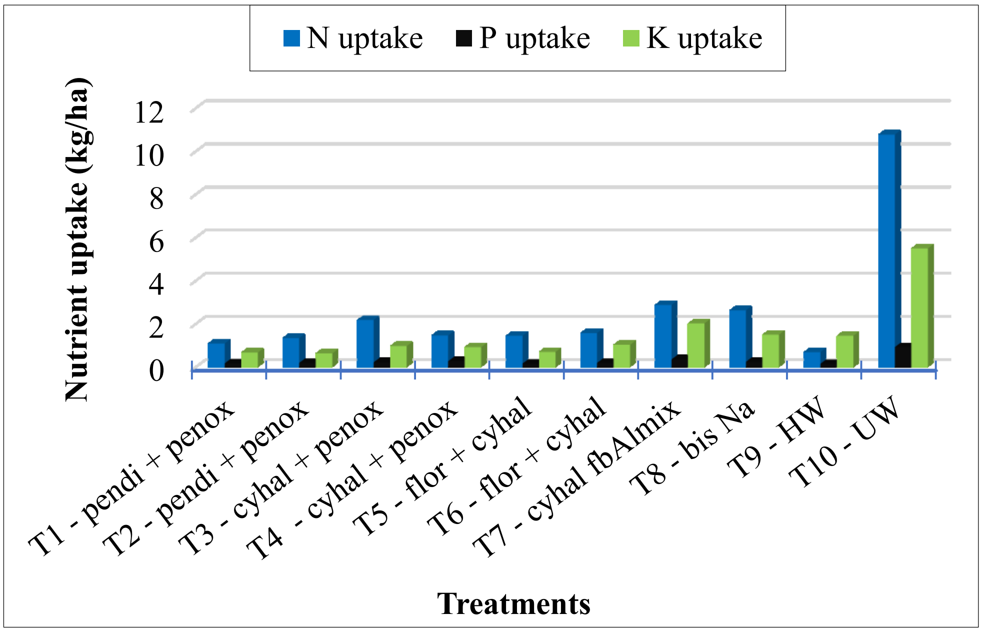

Fig. 8. Effect of pre-mix herbicide combinations on nutrient removal at 30 DAS

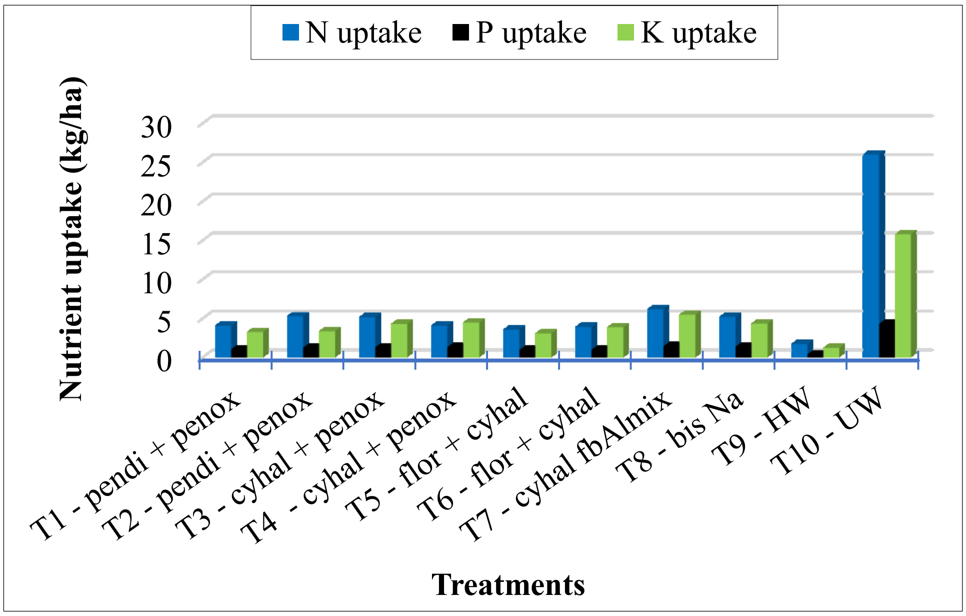

Fig. 9. Effect of pre-mix herbicide combinations on nutrient removal at 60 DAS

5.4 VISUAL PHYTOTOXICITY OF HERBICIDES ON WEEDS AND CROP

New generation rice herbicides are very selective in action and hence do not show any phytotoxic symptoms on rice. But a few herbicides, even though selective, can trigger biochemical changes inside the rice plant which may result in phytotoxicity. In the present experiment, the herbicide combination pendimethalin + penoxsulam sprayed at 5 and 10 DAS (T_1 and T_2) caused mild toxicity symptoms on rice plants at three days after spraying (Table 12). However, the plants completely recovered by seven days after spraying.

Among the herbicide treatments, there were no phytotoxic symptoms on rice crop when cyhalofop-butyl + penoxsulam was sprayed at both 12 and 18 DAS (T_3 and T_4 respectively). Similar results were reported by Lap *et al.* (2013) and Patil (2014). Also, there was no phytotoxicity on rice when the herbicide combination of florpyrauxifen-benzyl + cyhalofop-butyl were sprayed at 12 and 18 DAS (T_5 and T_6 respectively). Sreedevi *et al.* (2018) reported that no toxicity was observed on rice and the succeeding crop when florpyrauxifen-benzyl + cyhalofop-butyl was sprayed at different doses at 20 DAS. Also, the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8) did not produce any phytotoxic symptoms on rice. These results were in close conformity with the observations of Atheena (2016) and Yadav *et al*. (2009) respectively.

All the combinations and individual herbicides, due to their broad spectrum action, showed phytotoxic symptoms on all the weed species and as a result, provided good to very good control. The symptoms were more prominent on broad leaf weeds, showing their vulnerability to these herbicides.

5.5 GROWTH PARAMETERS OF RICE

At 30 DAS, 60 DAS and harvest, there was no significant difference in plant height between the herbicidal and hand weeded or unweeded treatments, and the average plant heights registered were 51.19 cm, 87.95 cm and 96.97 cm respectively (Tables 13). It can therefore be concluded that the herbicidal treatments did not affect the growth of rice plants throughout the crop period. Even in treatments where phytotoxic symptoms were observed, the plant height was not affected due to the quick recovery of the plants within one week's time. Similar findings were reported by Raj *et al.* (2013).

At 30 DAS, the greatest number of tillers (140 nos./m^2) was recorded in the herbicide combination treatment of florpyrauxifen-benzyl + cyhalofop-butyl (T_6) sprayed at 18 DAS. This might have been achieved due to the better weed control and consequent lower crop-weed competition. At 60 DAS, the highest number of tillers was observed in hand weeded control (T_9) (325 nos./m^2) which might have been due to the weed free environment provided by a second hand weeding at 40 DAS, thus boosting the plant growth. Similar reports were given by Awan *et al.* (2001), Sandeep *et al.* (2002), Lakshmi *et al.* (2006), Ramana *et al.* (2007), Akbar *et al.* (2011), Hossain and Mondal (2014), and Menon and Prameela (2015). It can also be inferred that the hand weeded control (T_9) had an advantage in terms of tiller count over the other treatments. The herbicide combination treatment pendimethalin + penoxsulam (T_2) applied at 10 DAS was found to be on par with hand weeded control (T_9). Uraon (2019) reported that the pre-mix herbicide combination pendimethalin + penoxsulam applied at 7 DAS registered greatest plant height, dry matter production, number of tillers, leaf area, leaf area index and crop growth rate over the hand weeded check.

5.6 YIELD AND YIELD ATTRIBUTES OF RICE

Hand weeded control (T_9) registered the highest number of panicles (221 nos./m^2), grains per panicle (120 nos.) and percentage of filled grains (92 %), and the lowest values were recorded in unweeded control (T_{10}) (Table 15). Similar findings were reported by Suganthi *et al*. (2005), Dixit and Varshney (2008), Subhalakshmi and Venkataramana (2009), Menon (2012), Atheena (2016), and Sreedevi *et al.* (2018). Test weight or 1000 grain weight of paddy was in the range of 27.2 g to 29.2 g and there was no significant difference between the herbicidal and hand weeded or unweeded treatments. These findings were in conformity with Menon (2012) and Atheena (2016), confirming that the application of various herbicide combinations and herbicides did not affect the test weight of rice.

Among the herbicide treated plots, florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) recorded the highest number of panicles (216 nos./m^2), grains per panicle (118 nos.) and percentage of filled grains (91.6 %). This treatment was found statistically on par with hand weeded control (T_9). This might be due to the broad spectrum action in weed control which led to the reduction in resource use by the dynamic weed flora. Similar opinions were suggested by Narolia *et al.* (2014), Nath *et al.* (2014), and Mathiyalagan and Arthanari (2015).

The highest grain yield of 4.60 t/ha and straw yield of 4.67 t/ha was recorded in the hand weeded control (T_9) (Table 16). This might be due to the congenial environment for the plant growth and development, provided as a result of better weed control. Similar findings were reported by Singh *et al.* (2006), Singh *et al.* (2007) and Prakash *et al.* (2013).

Among the herbicide treatments, the highest grain yield of 4.5 t/ha was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5), which was on par with pendimethalin + penoxsulam applied at 5 DAS (T_1) with 4.43 t/ha. Both these treatments were found to be statistically on par with hand weeded control (T_9) and to all the other herbicide combinations. The herbicide combination treatments from T_1 to T_6 registered higher grain and straw yields over the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7), and bispyribac sodium (T_8).

Grain yield of all the herbicide combinations ranged from 4.24 to 4.5 t/ha, without much difference from the yield of hand weeded control (T_9) (Fig.10). From these results, it can be inferred that the pre-mix herbicide combination treatments were as effective as hand weeding twice at 20 and 40 DAS. This result was in conformity with the observations of several workers such as Lap *et al.* (2013), Madhavi *et al.* (2018) and Sreedevi *et al.* (2018).

Application of florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS (T_5) resulted in improved yield and yield attributes over the same herbicidal spray at 18 DAS. This might be due to the early control of weeds at 2 to 4 leaf stage. The treatment pendimethalin + penoxsulam (T_1) sprayed at 5 DAS was found to be superior over the same herbicidal spray at 10 DAS. Madhavi *et al.* (2018) reported that the combination pendimethalin + penoxsulam sprayed at 4-7 DAS/DAT gave higher crop yields. Also, cyhalofop-butyl + penoxsulam (T_3) sprayed at 12 DAS was found superior over the application at 18 DAS. Patil (2014) reported the application of cyhalofop-butyl + penoxsulam at 2 to 4 leaf stage of weeds (early control), provided excellent control as compared to the same herbicide applied at other stages. The time of application of pre-mix herbicides was thus crucial in effecting better weed control and consequently, higher grain yields.

The lowest yield was recorded in unweeded control (T_{10}) due to high weed population and weed biomass, which in turn negatively influenced the yield attributes. Similar results were reported by Menon (2012), Singh *et al.* (2016), and Atheena (2016). Harvest index (HI) is the ratio of economic yield to the biological yield, and is a key factor in determining the success of crop production systems. Harvest index was recorded within a narrow range of 0.48 to 0.50 indicating the higher grain yields in herbicidal and hand weeded treatments which were at par.

5.7 WEED CONTROL EFFICIENCY AND WEED INDEX

Weed control efficiency is an indicator of the efficiency of the herbicides applied. At 30 DAS the highest WCE of 84.71 per cent was recorded in florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) (Table 17). Sreedevi *et al.* (2018) recorded a WCE of 78 per cent and 85 per cent in rice in the years 2015 and 2016 respectively with florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha sprayed at 20 DAS. All the herbicide combinations from T_1 to T_6 registered higher WCE over the hand weeded control (T_9) at 30 DAS (Fig.11). Khaliq *et al.* (2013) opined that the application of pre and post-emergence herbicides either alone or supplemented with manual weeding improved the weed control efficiency at 30 DAS, growth and yield of direct seeded rice. As the critical period for crop-weed competition in direct seeded rice was 15-45 days (Singh *et al.*, 2008), it was the WCE at this period that most significantly affected rice grain yields. Hence, even though a reduction in WCE was recorded for all herbicide combinations from 30 DAS to 60 DAS, grain yields on par with hand weeded control were obtained for these treatments. At 60 DAS the WCE gradually decreased and the highest WCE of 92.63 per cent was observed in the hand weeded control (T_9) which might have been realized due to the second hand weeding at 40 DAS. Moorthy and Saha (2002) reported that the hand weeded check registered a WCE of 93 per cent and thus gave highest grain yields. Similar findings were reported by Patil (2014) and Singh (2016).

Weed index represented the percentage of yield reduction with respect to hand weeded control. The highest yield reduction was recorded in unweeded control (T_{10}) to the tune of 56.74 per cent, which was mainly due to the crop limiting factors such as high weed count and dry weight of weeds. The lowest reduction was seen in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) to the tune of 2.17 per cent, which in turn showed the efficacy of this pre-mix herbicide over a wide range of weed flora.

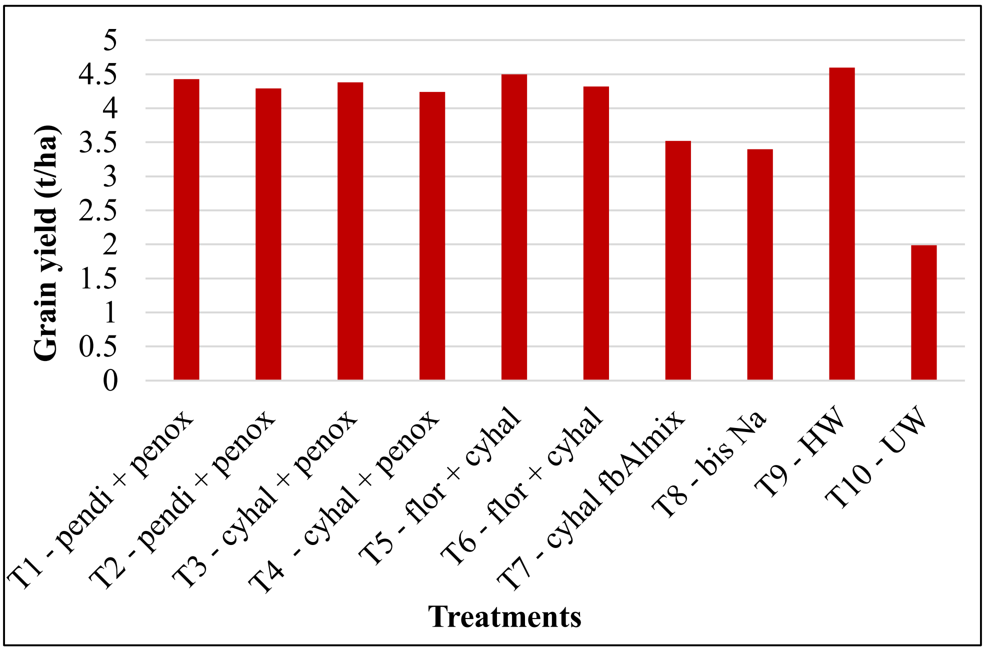

Fig. 10. Effect of pre-mix herbicide combinations on grain yield of rice

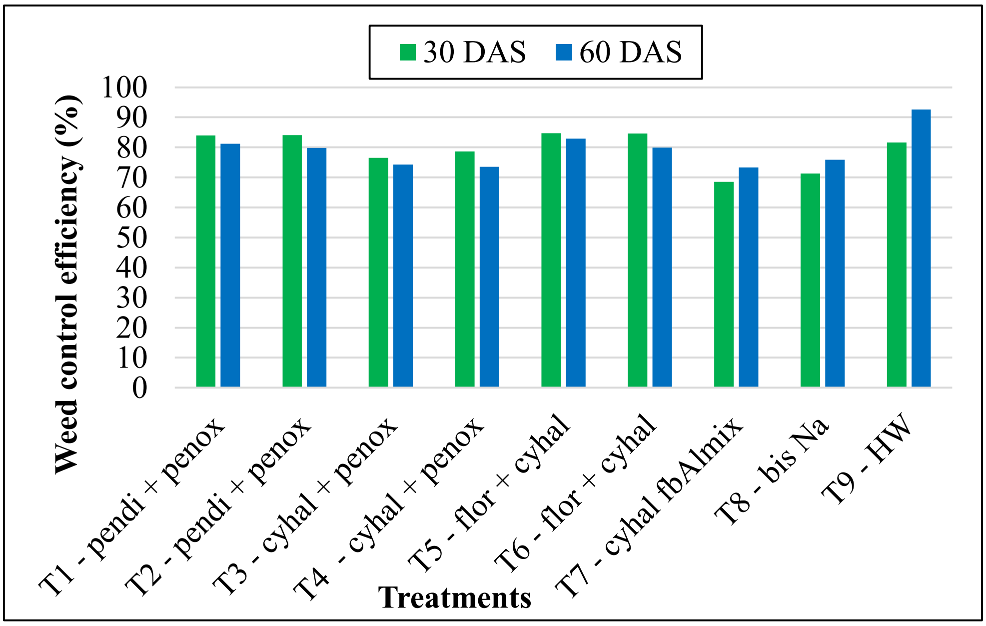

Fig. 11. Effect of pre-mix herbicide combinations on weed control efficiency

5.8 DEHYDROGENASE ACTIVITY

The dehydrogenase activity acts as an indicator for the biological activity in the soil and it is an intracellular enzyme present in all the living cells of microbial population (Quilchano and Maranon, 2002). Herbicides can cause both qualitative and quantitative changes in dehydrogenase activity as reported by Sebiomo *et al.* (2011) and Xia *et al.* (2012).

The dehydrogenase activity of the soil tended to increase from the initial observation (i.e., after herbicide application) up to the tillering phase and recorded highest value at active tillering stage, after which it decreased towards the harvest stage of crop (Table 18). Similar reports were proposed by Amritha and Devi (2017). This fluctuation in dehydrogenase activity might be due to the application of herbicides, which in turn influenced the soil microbial population. Das *et al.* (2015) reported that the highest dehydrogenase activity was recorded during the panicle initiation stage of rice. But in contrast, Islam and Borthakur (2016) reported the highest dehydrogenase activity at 90 DAT (flowering stage) and thereafter, it declined towards the harvest stage of rice. Dipika *et al.* (2017) reported that the post-emergence herbicides applied at different rates showed almost equal degradability period of about 30 days for complete degradation by the microbial population present in the soil.

Among the observations recorded initially, at 30 DAS and at 60 DAS, the highest dehydrogenase activity was recorded in the herbicide combination treatment florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5). The dehydrogenase enzyme activities were observed to be higher in the soil samples treated with herbicides as reported by Hang *et al.* (2002), Sebiomo *et al.* (2011), and Vandana *et al.* (2012). However, at harvest, the highest dehydrogenase activity was recorded in hand weeded control (T_9) and thus, a linear relationship between the dehydrogenase activity of soil and the crop yields in all the treatments was observed. No particular trend in the dehydrogenase activity was observed in the herbicide combination treatments applied at different stages of weed growth.

5.9 SOIL MICROBIAL BIOMASS CARBON

Herbicide applied in the soil can cause both qualitative and quantitative changes in the microbial population (Saeki and Toyota, 2004). Chauhan *et al.* (2006) reported that a healthy population of microorganisms was needed to stabilize the ecological system in soil and thus, changes in the microbial population adversely affected the nutrient regeneration ability of the soil which supported plant growth.

In all the herbicide treated plots, the soil microbial biomass carbon was drastically reduced up to a period of time i.e., 30 DAS (where the values were lowest) and after that it tended to increase until harvest (Table 19). That is, initially it declined at a faster rate at 30 DAS as reported by Baboo *et al.* (2013). Similar trend of reduction just after the herbicide application was reported by Priya *et al.* (2017) who stated that toxic effects of herbicides are generally most severe immediately after application. The increase in microbial biomass carbon after 30 DAS might be due to the degradation of these herbicides by microorganisms. And as a result, degraded organic herbicides were produced which could be used as carbon rich substrates to augment the microbial population in the rhizosphere region of plants.

Amritha and Devi (2017) reported that the microbial biomass carbon after herbicide application showed a decreasing trend up to 30 days, after which it showed a significant increase up to 60 days and again decreased at harvest stage. This decrease in MBC after 60 days might be due to the depletion in the soil moisture regimes towards harvest of rice. But contradictory to this, in this study, the MBC was found to increase after 60 DAS until harvest, which might be due to the high organic carbon present in the soil. Dipika *et al.* (2017) reported that the application of herbicides had an inhibitory effect on microbial activities of soil but their effects were not pronounced and the soil properties were restored. In all the herbicidal treatments, the toxic effects which were pronounced at 30 days after spraying was almost completely restored within a period of time in the experimental field. The MBC in the plots treated with herbicide combination treatments were not influenced by the time of application.

5.10 ECONOMICS OF RICE PRODUCTION

Success of any crop production system is based on the acceptance by farmers which in turn depends on the economic analysis. Farmers often prefer herbicidal weed control options due to their low cost and ease in application and also due to the unavailability of labour at peak periods of requirement and high wage rate.

Data analysis showed that the total cost of cultivation was highest in the hand weeded control (T_9) with Rs. 82,000/ha (Table 20). This was in conformity with the findings of Gowda *et al.* (2009) and Singh (2016). On the other hand, the lowest cost of cultivation was registered in the unweeded control (T_{10}) as no expenditure on weed management was incurred. Among the herbicidal treatments, the lowest cost of cultivation of Rs. 58,350/ha was recorded in the herbicide combination treatments of pendimethalin + penoxsulam (T_1 and T_2) sprayed at 5 DAS and 10 DAS respectively. The total cost incurred in all the herbicidal treatments were more or less equal to each other.

The cost of cultivation in all the herbicidal treatments were roughly brought down to about 80 per cent through the use of herbicides, in comparison with manual weeding. Similar findings were given by Atheena (2016). Thus, in terms of total cost of cultivation, preferring herbicidal weed control measures were advantageous over manual weeding.

Analysis of the data revealed that the highest total income (or gross returns) of Rs. 1,52,220/ha was registered in the hand weeded control (T_9). But, due to the high cost of cultivation (Rs. 82,000/ha) which was mainly contributed by the high number of labourers involved in manual weeding and their high wage rate, the net returns was brought down to Rs. 70,220/ha. Significantly lower gross returns were registered in unweeded control (T_{10}) which was mainly due to the poor grain and straw yields.

Among the herbicidal treatments, the highest gross returns were recorded in the herbicide combination florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5), which registered highest grain and straw yields. The gross returns obtained from the herbicidal and hand weeded or unweeded treatments followed the same trend as that of grain and straw yields.

Net returns from the different herbicide treatments were obtained by deducting total cost from total income. The highest net return of Rs. 90,286/ha was obtained from the herbicide combination treatment florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) followed by pendimethalin + penoxsulam sprayed at 5 DAS (T_1) with Rs. 88,080/ha. Both these herbicide combination treatments registered a high B:C ratio of 2.5. Madhavi *et al.* (2018) found that application of pendimethalin + penoxsulam as pre-emergence herbicide at 4-7 DAS/DAT gave the highest benefit: cost ratio. Similar reports were given by Uraon and Shrivastava (2018). Also, Singh (2016) reported that the post-emergence application of cyhalofop-butyl + penoxsulam at 135 g/ha on 20 DAT was observed on par with hand weeded control with higher net returns and benefit: cost ratio.

Sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7) and bispyribac sodium (T_8) registered a B:C ratio of 1.9. Menon (2012) reported that the application of bispyribac sodium fetched the highest B:C ratio of 1.8 compared to all the other treatments. Although highest yields were recorded in hand weeded control (T_9), the net returns and B:C ratio (1.8) were brought down due to high cost of cultivation.

Among the pre-mix herbicide combinations, the treatments from T_1 to T_6 recorded B:C ratios ranging from 2.3 to 2.5. This might be due to the higher yields as the result of higher WCE obtained. The pre-mix herbicides pendimethalin + penoxsulam sprayed at 5 DAS (T_1) and florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS (T_5) registered the highest B:C ratio of 2.5 and highest net returns over the same treatments applied at other stages of weed growth. The next best combination was cyhalofop-butyl + penoxsulam sprayed at 12 DAS (T_3) which fetched higher returns and B:C ratio (2.4) over the same treatment at 18 DAS.

From the economic analysis, it can be inferred that all the herbicide combinations were comparable to hand weeded control. All the herbicide combinations performed well in terms of yield attributes which had direct relationship with crop yields, and thus net returns and B:C ratio. Among these different pre-mix herbicides, florpyrauxifen-benzyl + cyhalofop-butyl gave highest monetary returns when sprayed at an application window between 12 and 18 DAS, and hence can be regarded as the best combination.

Summary

6. SUMMARY

The research programme entitled "Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice" was conducted with the objective to study the efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice. The study was conducted during the *Mundakan* season, from October 2019 to January 2020 in a farmer's field in *Kole* area of Alappad, Thrissur district.

There were 10 treatments and 3 replications. Three pre-mix herbicide combinations at two different times of application viz., pendimethalin + penoxsulam at 5 and 10 DAS, cyhalofop-butyl + penoxsulam at 12 and 18 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl at 12 and 18 DAS were evaluated in comparison to the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) applied at 18 and 19 DAS, and the broad spectrum rice herbicide bispyribac sodium applied at 18 DAS. A hand weeded control with manual weeding twice at 20 and 40 DAS, and unweeded control were also included. The rice variety used was Manuratna (a short duration, high yielding variety). The experimental design adopted was RBD (Randomized Block Design) and the plot size was 20 m^2 (5m x 4m).

Major weed species observed in the experimental plots were grasses consisting of weedy rice (*Oryza sativa* f. *spontanea*), *Echinochloa stagnina* and *Leptochloa chinensis*, and sedges consisting of *Cyperus* spp and *Fimbristylis miliacea*. Broad leaved weeds were comparatively very low.

At 60 DAS, grasses, sedges and broad leaf weeds constituted about 92 per cent, 7 per cent and 1 per cent of the total weed population respectively. Among the grass weeds, complete control of *Echinochloa stagnina* was observed in the treatments cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS, and bispyribac sodium. *Leptochloa chinensis* was completely controlled in pendimethalin + penoxsulam applied at 5 DAS, cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 12 DAS, florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS and cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %).

Among the sedges and broad leaf weeds, complete control of *Cyperus* spp was observed in the plots applied with pendimethalin + penoxsulam at 5 DAS and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS. Complete control of *Fimbristylis miliacea* and all the broad leaved weeds was noticed in all the herbicidal treatments.

At both 30 and 60 DAS, the herbicide combinations pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS, were observed to perform better with respect to weed density.

At 30 DAS the lowest weed dry matter production of 35.33 kg/ha was recorded in the herbicide combination florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS, followed by florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 18 DAS (35.66 kg/ha), which were on par with pendimethalin + penoxsulam applied at 5 and 10 DAS. At 60 DAS lowest dry matter of 96.6 kg/ha was recorded in hand weeded control, and among the herbicide treated plots, the lowest weed biomass of 223.3 kg/ha was observed in florpyrauxifen-benzyl + cyhalofop-butyl sprayed at 12 DAS, followed by pendimethalin + penoxsulam applied at 5 DAS with 246.6 kg/ha. In both the cases, the performance with regard to weed dry matter production of all the herbicidal combination treatments from T_1 to T_6 was observed to be superior to cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), bispyribac sodium and unweeded control. Among the herbicide combinations applied at different stages of weed growth, the lowest weed biomass was recorded in pendimethalin + penoxsulam sprayed at 5 DAS, and in cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS.

At all stages of observation, the lowest nutrient removal by weeds was recorded in hand weeded control and the highest in unweeded control. At 30 DAS unweeded check removed 10.78, 0.93 and 5.5 kg NPK per ha, and at 60 DAS, it removed 25.98, 4.27 and 15.75 kg NPK per ha.

Among the herbicidal treatments, the lowest N removal at 60 DAS was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (3.52 kg/ha), which was found to be on par with the treatments pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 18 DAS. The lowes[illegible]oval was observed in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (0.92 kg/ha). The lowest K removal was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (2.84 kg/ha).

Application of the herbicide combination pendimethalin + penoxsulam at 5 and 10 DAS caused slight injury on rice. At three days after spraying, the leaf tips became slightly yellowish, however the crop completely recovered within seven days. No other herbicide produced visual phytotoxicity symptoms on rice. All the herbicides resulted in visual injury symptoms on weeds at both three and seven days after spraying. The scoring ranged from three to four, indicating good to very good control.

In rice, at 30 DAS, 60 DAS and harvest, there was no significant difference between treatments and the average plant heights were 51.19 cm, 87.95 cm and 96.97 cm respectively. At 30 DAS there was no significant difference between herbicidal and hand weeded or unweeded treatments for the number of tillers per m^2. However, at 60 DAS the highest tiller count (325 nos./m^2) was observed in hand weeded control which was on par with pendimethalin + penoxsulam sprayed at 10 DAS (323 nos./m^2). Both at 30 and 60 DAS the lowest tiller count was observed in unweeded control.

Among the herbicide combinations, the highest tiller count was recorded in pendimethalin + penoxsulam applied at 10 DAS, cyhalofop-butyl + penoxsulam applied at 18 DAS and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS over the same herbicidal sprays at different stages of growth of weeds.

The highest number of panicles (221 nos./m^2), grains per panicle (120 nos.), and percentage of filled grains per panicle (91.86 per cent) in rice were recorded in hand weeded control. The lowest values for all the yield attributes were observed in unweeded control. Among the herbicide treatments, the highest number of panicles (216 nos./m^2), grains per panicle (118 nos.) and percentage of filled grains per panicle (91.66 per cent) were recorded with florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS followed by the herbicide combination pendimethalin + penoxsulam applied at 5 DAS. Test weight or 1000 grain weight of paddy was in the range of 27.2 to 29.2 g and there was no significant difference between the treatments.

The herbicide combinations pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS, recorded higher values with regard to yield attributes than the same treatments applied at other stages of growth.

The highest rice grain yield of 4.6 t/ha was recorded in hand weeded control, followed by florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS with 4.5 t/ha, which were statistically on par with each other and to the treatment pendimethalin + penoxsulam applied at 5 DAS. All the herbicidal combination treatments from T_1 to T_6 were statistically superior to the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), bispyribac sodium and unweeded control.

Straw yield followed an almost similar trend as that of grain yield. The highest straw yield was observed in hand weeded control with 4.67 t/ha and the next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS with 4.58 t/ha. There was no significant difference between the treatments in terms of harvest index and the values were within a range of 0.48 to 0.50.

With regard to time of application of the herbicide combinations, the highest grain and straw yields were recorded in the treatments pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS.

At 30 DAS the highest WCE of 84.71 per cent was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS, which was statistically on par with the treatments pendimethalin + penoxsulam applied at 5 DAS and 10 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl applied at 18 DAS. At 60 DAS the highest WCE of 92.63 per cent was observed in hand weeded control, which was superior to all the other treatments. The next best treatment was florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS with WCE of 82.96 per cent, which was statistically on par with pendimethalin + penoxsulam with 81.18 per cent. In both the cases, WCE of all the herbicidal combinations were superior to the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), bispyribac sodium and unweeded control.

Among the different times of herbicide combination application, the highest WCE at 60 DAS was recorded in the treatments pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both applied at 12 DAS.

Extent of yield reduction was recorded as highest in unweeded control (56.74%), and the lowest was in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (2.17 %). On an average, about 5.22 per cent of grain yield reduction was observed in the herbicide combination treatments.

The dehydrogenase activity of the soil tended to increase from planting to tillering phase and was found maximum at the active tillering stage, after which it gradually declined as the crop neared harvest stage.

On herbicide application, microbial biomass carbon was drastically reduced from the initial observation up to 30 DAS, and then tended to increase until harvest. Among the different times of application of the herbicide combinations, the highest microbial biomass carbon at all the stages of observation was observed in the treatments pendimethalin + penoxsulam applied at 10 DAS, cyhalofop-butyl + penoxsulam applied at 18 DAS and florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS.

The highest B:C ratio of 2.5 was obtained in two treatments, florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS and pendimethalin + penoxsulam applied at 5 DAS with net returns of Rs. 90,286/ha and Rs. 88,080/ha respectively. All the herbicidal combination treatments from T_1 to T_6 recorded B:C ratios ranging from 2.3 to 2.5. The sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) and bispyribac sodium recorded B:C ratio of 1.9.

Pendimethalin + penoxsulam applied at 5 DAS, and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 12 DAS fetched higher gross returns, net returns and B:C ratio over the same herbicide combinations at other times of application. Among these treatments, the best herbicide on account of economics was observed to be florpyrauxifen-benzyl + cyhalofop-butyl, when applied between 12 DAS and 18 DAS.

References

7. REFERENCES

Abraham, C. T. and Menon, M. V. 2015. Efficacy of combination of penoxsulam and cyhalofop-butyl on weed management in wet-seeded rice. In: *Weed science for sustainable agriculture, environment and Biodiversity.* Proceedings of 25th Asian-Pacific Weed Science Society Conference on Hyderabad, India, p.41.

Akbar, N., Jabran, K., and Ali, M. A. 2011. Weed management improves yield and quality of direct seeded rice. *Aust. J. Crop Sci.* 5(6): 688-694.

Akhtar, M., Ahmad, J., Mehmood, A., and Iqbal, K. 2000. Nitrogen uptake efficiency in wheat (*Triticum aestivum* L.) as influenced by nitrogen level and weed-crop competition duration. *Pak. J. Biol. Sci.* 3(6): 1002-1003.

Amritha, K. and Devi, K. D. 2017. Effect of pre and post-emergence herbicides on microbial biomass carbon and dehydrogenase activity in soils. *J. Trop. Agric.* 55(1): 114-118.

Anwar, M. P., Juraimi, A. S., Puteh, A., Man, A., and Rahman, M. M. 2012. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. *Acta Agric. Scand. Sect. B Soil Plant Sci.* 62(7): 604-615.

Aon, M. A. and Colaneri, A. C. 2001. II. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. *Appl. Soil Ecol.* 18(3): 255-270.

Atheena, A. 2016. Tank mix application of cyhalofop-butyl with selected herbicides for weed control in wet seeded rice. M.Sc. (Ag) thesis, Kerala Agricultural University, 120p.

Atheena, A., Prameela, P., and Menon, M. V. 2017. Tank mix application of cyhalofop-butyl with selected herbicides for weed control in wet-seeded rice. *Indian J. Weed Sci.* 49(3): 283-286.

Awan, I. U., Abbass, T., and Nadeem, M. A. 2001. Production efficacy of six rice cultivars against various herbicides applied for weed control in direct wet-seeded rice (*Oryza sativa* L.) culture. *Online J. Biol. Sci*. 1(9): 828-830.

Ayansina, A. D. V. and Oso, B. A. 2006. Effect of two commonly used herbicides on soil microflora at two different concentrations. *Afr. J. Biotechnol.* 5(2): 129-132.

Baboo, M., Pasayat, M., Samal, A., Kujur, M., Maharana, J. M., and Patel, A. K. 2013. Effect of four herbicides on soil organic carbon microbial biomass C, enzyme activity and microbial populations in agricultural soils. *Int. J. Res. Environ. Sci. Technol.* 3: 100-112.

Bahar, F. A. and Singh, G. 2004. Effect of herbicides on dry seeded rice (*Oryza sativa* L.) and associated weeds. *Indian J. Weed Sci*. 36(3&4): 269-270.

Bhurer, K. P., Yadav, D. N., Ladha, J. K., Thapa, R. B., and Pandey, K. 2013. Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). *Agron. J. Nepal* 3: 53-63.

Brar, H. S. and Bhullar, M. S. 2012. Dry-seeded rice productivity in relation to sowing time, variety and weed control. *Indian J. Weed Sci.* 44(3): 193-195.

Carlson, T. P., Webster, E. P., Salassi, M. E., Bond, J. A., Hensley, J. B., and Blouin, D. C. 2012. Economic evaluations of imazethapyr rates and timings on rice. *Weed Technol.* 26(1): 24-28.

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

Channabasavanna, A. S., Talawar, A. M., Kitturmath, M. S., and Rajkumar, H. 2017. Evaluation of post emergence herbicides on grass weeds in pigeon pea and its bioassay on following crop. *Indian J. Agric. Res.* 51(2): 188-190.

Chaudhary, S. K., Jha, S., and Sinha, N. K. 2011. Influence of nitrogen and weed management practices on productivity and nutrient uptake of wet direct seeded rice. *Oryza* 48(3): 222-225.

Chauhan, A. K., Das, A., Kharkwal, H., Kharkwal, A. C., and Varma, A. 2006. Impact of microorganisms on environment and health. In: Chauhan, A. K. and Varma, A. (eds.), *Microbes: Health and Environment*. Anshan, UK, pp.1-12.

Chauhan, B. S. 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. *Weed Technol.* 26: 1-13.

Chauhan, B. S. and Abugho, S. B. 2013. Weed management in mechanized-sown, zero-till dry-seeded rice. *Weed Technol.* 27(1): 28-33.

Chauhan, B. S. and Johnson, D. E. 2009. Germination ecology of spiny (*Amaranthus spinosus*) and slender amaranth (*A. viridis*): troublesome weeds of direct-seeded rice. *Weed Sci.* 57(4): 379-385.

Chauhan, B. S. and Opena, J. 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crops Res.* 137: 56-69.

Chauhan, B. S., and Abugho, S. B. 2012a. Effect of growth stage on the efficacy of post emergence herbicides on four weed species of direct-seeded rice. *Sci. World J.* [e-journal] p.e123071. Available: https://doi.org/10.1100/2012/123071 [16 May 2020].

Chinnamani, I., Aasif, M., Kumar, N. S., Velayutham, A., and Suresh, S. 2018. Influence of weed management practices on weed dynamics and yield of drum seeded rice under puddled condition. *Int. J. Adv. Agric. Sci. Technol*. 5(7): 17-23.

Chopra, N. K. and Chopra, N. 2003. Effect of doses and stages of application of pyrazosulfuron ethyl on weeds in transplanted rice. *Indian J. Weed Sci.* 35(1&2): 27-29.

Chungi, M. P. and Ramteke, J. R. 1998. Studies on nutrient losses due to weed competition in transplanted rice. *J. Maharastra Agric. Univ*. 13: 263-265.

Cox, M. C. and Askew, S. D. 2014. Metamifop rates, application timings, and broadleaf herbicide admixtures affect smooth crabgrass control in turf. *Weed Technol.* 28(4): 617-625.

Damalas, C. A., Dhima, K. V., and Eleftherohorinos, I. G. 2008. Bispribac sodium efficacy on early watergrass (*Echinochloa oryzoides*) and late watergrass (*Echinochloa Phyllopogon*) as affected by coapplication of selected rice herbicides and insecticides. *Weed Technol.* 22(4): 622-627.

Das, K., Pooniya, V., Choudhary, A. K., Swarnalakshmi, K., Parihar, C. M., Bana, R. S., and Sarkar, S. K. 2017. Integrated crop management modules for enhancing productivity and profitability of direct-seeded basmati rice (*Oryza sativa*). *Indian J. Agron.* 62(4): 528-530.

Das, M., Sarangi, P. K. and Singh, N. J. 2015. Enumeration of microbial population from rice fields and their dehydrogenase activities in two cropping seasons in Eastern India. *Bioscan* 10(4): 1577-1579.

De Datta, S. K. and Bernasor, P. C. 1973. Chemical weed control in broadcast- seeded flooded tropical rice. *Weed Res.* 13(4): 351-354.

Dhage, S. and Srivastava, V. K. 2020. Weed management practices effect on weed dynamics of different rice varieties under aerobic rice system. *J. Pharmacogn. Phytochem.* 9(1): 333-336.

Dhakal, M., Sah, S. K., and Kharel, G. 2019. Integrated weed management in direct-seeded rice: dynamics and economics. *Int. J. Agric. Environ. Food Sci.* 3(2): 83-92.

Dipika, Chowdhury, T., Bhambri, M. C., Gupta, S. B., Soni, R., and Kevat, T. K. 2017. Changes in microbiological characteristics of rice soil by post-emergence herbicides. *Indian J. Weed Sci.* 49(2): 132-135.

Dixit, A. and Varshney, J. G. 2008. Assessment of post-emergence herbicides in transplanted rice. *Indian J. Weed Sci.* 40(3&4): 144-147.

Duary, B., Mishra, M. M., Dash, R., and Teja, K. C. 2015. Weed management in lowland rice. *Indian J. Weed Sci.* 47(3): 224-232.

Duary, B., Roychowdhury, S., and Mukherjee, A. 2009. Effect of sole and sequential application of herbicides on weed growth and productivity of transplanted rice in the lateritic belt of West Bengal. In: *National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity*, TNAU, Coimbatore, 28p.

FAO [Food and Agricultural Organization]. 2020. FAO home page [on-line]. Available: http://www.fao.org/home/en [15 June 2020].

Farooq, M., Jabran, K., Hussain, M., Babar, M., Dogan, M. N., and Lee, D. J. 2012. Application of bispyribac sodium provides effective weed control in direct-planted rice on a sandy loam soil. *Weed Biol. Manag.* 12(3): 136-145.

Gill, G. S. and Vijayakumar, R. 1969. Weed index - a new method of reporting weedicidal trials. *Indian J. Agron.* 14(1).

Gnanavel, I. and Kathiresan, R. M. 2002. Sustainable weed management in rice- rice cropping systems. *Indian J. Weed Sci*. 34: 192-196.

Godwin, J., Norsworthy, J. K., and Scott, R. C. 2018. Weed control and selectivity of pethoxamid alone and in mixture as a delayed pre-emergence application to rice. *Weed Technol.* 32(5): 537-543.

Gomez, A. K. and Gomez, A. A. 1984. *Statistical Procedures for Agricultural Research (2nd Ed.).* A Wiley-Interscience Publication, John Wiley and Sons, New York, USA, 657p.

Gopal, R., Jat, R. K., Kumar, V., Alam, M. M., Jat, M. L., Mazid, M. A., Saharawat, Y. S., McDonald, A., and Gupta, R. 2010. Direct dry seeded rice production technology and weed management in rice based systems. *Tech. Bull. Series No. 7*, International Maize and Wheat Improvement Center, New Delhi, India, 28p.

Gopinath, K. A. and Kundu, S. 2008. Evaluation of metsulfuron-methyl and chlorimuron-ethyl for weed control in direct-seeded rice (*Oryza sativa*). *Indian J. Agric. Sci.* 78(5): 466-469.

Govindan, P. 2014. Evaluation of new herbicide on weed management in transplanted rice cv. ADT 38. M.Sc. (Ag) thesis, Dept. of Agronomy, Annamalai University.

Gowda, P. T., Shankaraiah, C., Jnanesh, A. C., Govindappa, M., and Murthy, K. N. K. 2009. Studies on chemical weed control in aerobic rice (*Oryza sativa* L.). *J. Crop Weed* 5(1): 321-324.

Halder, J. and Patra, A. K. 2007. Effect of chemical weed-control methods on productivity of transplanted rice (*Oryza sativa*). *Indian J. Agron.* 52(2): 111-113.

Hang, M., Yang-fang, Y., Zhong-yun, C., Wei-xiang, W., and Yu-feng, D. 2002. Effects of butachlor on microbial enzyme activities in paddy soil. *J. Environ. Sci.* 14(3): 413-417.

Hossain, A. and Mondal, D. C. 2014. Weed management by herbicide combinations in transplanted rice. *Indian J. Weed Sci.* 46(3): 220-223.

Hossain, M. M. 2015. Recent perspective of herbicide: review of demand and adoption in world agriculture. *J. Bangladesh Agric. Univ.* 13(1): 13-24.

Islam, M. M. and Kalita, D. C. 2016. Studies on root phenology, productivity and economics of wetland rice (*Oryza sativa* L.) as influenced by establishment methods and weed management practices. *Indian J. Agric. Res.* 50(4): 358-361.

Islam, N. F., and Borthakur, S. K. 2016. Effect of different growth stages on rice crop on soil microbial and enzyme activities. *Trop. Plant Res*. 3(1): 40-47.

Jabusch, T. W. and Tjeerdema, R. S. 2005. Partitioning of penoxsulam, a new sulfonamide herbicide. *J. Agric. Food Chem.* 53(18): 7179-7183.

Jackson, M. L. 1958. *Soil Chemical Analysis*. Prentice Hall Inc, New Jersey, 498p.

Jacob, G. 2014. Herbicidal management of Chinese sprangletop (*Leptochloa chinensis* (L.) Nees.) in direct seeded rice. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 96p.

Jacob, G., Menon, M. V., and Abraham, C. T. 2014. Comparative efficacy of new herbicides in direct seeded rice. *J. Trop. Agric.* 52(2): 174-177.

Jannu, N., Raju, M. S., Devi, K. B. S., Sree, G. J., and Srinivas, A. 2017. Economically beneficial weed control practices for direct seeded rice under rainfed condition. *J. Pharmacogn. Phytochem.* 6(4): 1961-1963.

Jat, R. K., Singh, R. G., Gupta, R. K., Gill, G., Chauhan, B. S., and Pooniya, V. 2019. Tillage, crop establishment, residue management and herbicide applications for effective weed control in direct seeded rice of eastern Indo-Gangetic plains of South Asia. *Crop Prot.* 123: 12-20.

Jenkinson, D. S. and Ladd, J. N. 1981. Microbial biomass in soil: measurement and turnover. In: Paul, E. A. and Ladd, J. M. (eds.), *Soil Biochemistry*. Dekker, New York, 5: 415-471.

Jenkinson, D. S. and Powlson, D. S. 1976. The effects of biocidal treatments on metabolism in soil: a method for measuring soil biomass. *Soil Boil. Biochem.* 8(3): 209-213.

Jha, P., Norsworthy, J. K., and Scott, R.C. 2010. Cyhalofop application timing and adjuvant selection for *Echinochloa crus-galli* control in rice. *Crop Prot.* 29(8): 820-823.

Jiang, R. C. 1989. Field weeds chemical control series and systematic management. In: *Proceedings of the 12th Asian-Pacific Weed Science Society Conference*, Seoul, South Korea, pp.731-739.

Joseph, P. A. 1986. Influence of different ecological situations on weed emergence in wetland rice. *IRRI Newsl*. 11(4): 38-39.

Joy, P. P., Syriac, E. K., Ittyaverah, P. J., and Joseph, C. A. 1993. Herbicidal technology for weed control in low land rice of Kerala. In: *Proceedings of the 5th Kerala Science Congress,* January 1993, Kottayam, Kerala State Council for Science, Technology and Environment, pp.135-137.

Joy, P. P., Syriac, E. K., Nair, P. K. C., and Joseph, C. A. 1991. Weed control in wet seeded rice in Kerala, India. *IRRI Newsl.* 16(6):25.

Kailkhura, S., Pratap, T., Singh, V. P., Guru, S. K., and Singh, S. P. 2015. Herbicide combinations for control of complex weed flora in transplanted rice. *Indian J. Weed Sci.* 47(4): 414-416.

Kashyap, S., Singh, V. P., Guru, S. K., Pratap, T., Singh, S. P., and Praharaj, S. 2019. Integrated weed control option for dry direct seeded rice under irrigated ecosystem. *Int. J. Curr. Microbiol. App. Sci*. 8(2): 315-323.

KAU [Kerala Agricultural University] 2016. *Package of Practices Recommendations: Crops (15th Ed.)*. Kerala Agricultural University, Thrissur, 393p.

Khaliq, A., Riaz, M. Y., and Matloob, A. 2011. Bio-economic assessment of chemical and non-chemical weed management strategies in dry seeded fine rice (*Oryza sativa* L.). *J. Plant Breed. Crop Sci.* 3(12): 302-310.

Khaliq, A., Matloob, A., Ihsan, M. Z., Abbas, R. N., Aslam, Z., and Rasool, F. 2013. Supplementing herbicides with manual weeding improves weed control efficiency, growth and yield of direct seeded rice. *Int. J. Agric. Biol.* 15(2): 191-199.

Kiran, Y. D. and Subramanyam, D. 2010. Performance of pre and post emergence herbicides on weed flora and yield of transplanted rice. *Indian J. Weed Sci.* 42(3&4): 229-231.

Kogan, M., Gomez, P., Fischer, A., and Alister, C. 2011. Using penoxsulam ALS inhibitor as a broad-spectrum herbicide in Chilean rice. *Int. J. Agric. Nat. Resour.* 38(1): 83-93.

Kumar, J., Kumar, A., and Sharma, B. C. 2010. Effect of chemical and crop establishment methods on weeds and yield of rice and their residual effects on succeeding wheat crop. *Indian J. Weed Sci.* 42(1&2): 78-82.

Kumar, N., Shukla, A., Shankhdhar, S. C., and Shankhdhar, D. 2015. Impact of terminal heat stress on pollen viability and yield attributes of rice (*Oryza sativa* L.). *Cereal Res. Commun.* 43(4): 616-626.

Kumaran, S. T., Kathiresan, G., Arthanari, P. M., Chinnusamy, C., and Sanjivkumar, V. 2015. Efficacy of new herbicide (bispribac sodium 10 % SC) against different weed flora, nutrient uptake in rice and their residual effects on succeeding crop of green gram under zero tillage. *J. Appl. Nat. Sci.* 7(1): 279-285.

Lagator, M., Vogwill, T., Mead, A., Colegrave, N., and Neve, P. 2013. Herbicide mixtures at high doses slow the evolution of resistance in experimentally populations of *Chlamydomonas reinhardtii*. *New Phytol.* 198(3): 938-945.

Lakshmi, N. V., Rao, Y. H., and Chandrasekhar, K. 2006. Effect of weed management practices on growth and yield of dry sown rice. *Ann. Agric. Res.* 53(1&2): 8-9.

Lap, N., Somsak, S., Yuli, I. M., Choy, L., Ermita, B. V., Niranjan, B. V., and Mann, R. K. 2013. Efficacy and rice crop tolerance to mixtures of penoxsulam + cyhalofop as one-shot rice herbicide in ASEAN countries. In: *Weed Management and Utilization in the Tropics*. The 4th Tropical Weed Science Conference, Weed Science Society of Thailand, Chiang Mai, pp.41-47.

Loonis, W. E. 1958. Basic studies in botany, ecology and plant physiology. In: *Proceedings of the North Central Weed Conference.* Philippines, pp.15-81.

Lubigan, R. T. and Vega, M. R. 1971. The effect on yield of the competition of rice with *Echinochloa crus-galli* (L.) Beauv. and *Monochoria vaginalis* (Burm. F.) Presl. *Philipp. Agric.* 15: 210-215.

Lupwayi, N. Z., Harker, K. N., Clayton, G. W., Turkington, T. K., Rice, W. A., and O'Donovan, J. T. 2004. Soil microbial biomass and diversity after herbicide application. *Can. J. Plant Sci.* 84(2): 677-685.

Mabbayad, M. O. and Moody, K. 1984. Effect of time of application of herbicides on crop damage and weed control in wet seeded rice. *Int. Rice Res. Inst. Newsl.* 9(3): 22.

Madhavi, M., Ravikumar, A., Pratibha, G., and Ramprakash, T. 2018. Impact of different methods of rice establishment and weed management options on crop productivity and profitability. In: *Weeds and Society: Challenges and Opportunities.* Proceedings of ISWS Golden Jubilee International Conference, 21-24 November 2018, Jabalpur, India, ICAR - Directorate of Weed Research, 87p.

Mahajan, G., Chauhan, B. S., and Johnson, D. E. 2009. Weed management in aerobic rice in Northwestern Indo-Gangetic plains. *J. Crop Improv.* 23(4): 366-382.

Mahbub, M. M., Bhuiyan, M. K. A., and Kabir. M. M. 2017. Performance of metsulfuron methyl 10 % + chlorimuron ethyl 2 % WP against annual weed inhibition in transplanted rice. *Haya Saudi J. Life Sci*. 2(8): 298-305.

Mani, V. S., Malla, M. L., and Gautam, K. C. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* 22: 17-18.

Mann, R. A., Ahmad, S., Hassan, G., and Baloch, M. S. 2007. Weed management in direct seeded rice crop. *Pak. J. Weed Sci. Res*. 13(3&4): 219-226.

Mathiyalagan, S. and Arthanari, P. 2015. Sequential application of herbicides for weed control in transplanted rice. *Int. J. Farm Sci.* 5(2): 27-33.

Menon, S. S. 2012. Efficacy of new post-emergence herbicides for rice. Doctoral dissertation, Kerala Agricultural University, Thrissur, 132p.

Menon, S. S. and Prameela, P. 2015. Promising post-emergence herbicides for effective weed management in direct seeded rice. *Int. J. Trop. Agric.* 33(2 (Part I)): 327-331.

Metzger, B. A., Soltani, N., Raeder, A. J., Hooker, D. C., Robinson, D. E., and Sikkema, P. H. 2019. Influence of application timing and herbicide rate on the efficacy of tolpyralate plus atrazine. *Weed Technol.* 33(3): 448-458.

Miller, M. R. and Norsworthy, J. K. 2018. Florpyrauxifen-benzyl weed control spectrum and tank-mix compatibility with other commonly applied herbicides in rice. *Weed Technol.* 32(3): 319-325.

Mishra, J. S., Dixit, A., and Varshney, J. G. 2007. Efficacy of penoxsulam on weeds and yield of transplanted rice. *Indian J. Weed Sci*. 39(1&2): 24-27.

Moorthy, B. T. S. and Dubey, A. N. 1978. Weed control in puddle seeded rice (Rabi). In: *Annual Report-1978*, CRRI, Cuttack, pp.131-132.

Moorthy, B. T. S. and Saha, S. 2002. Bio-efficacy of certain new herbicide formulations in puddle-seeded rice. *Indian J. Weed Sci*. 34: 46-49.

Mukherjee, D. and Singh, R. P. 2005. Effect of low doses of herbicides on weeds, nutrient uptake and yield of transplanted rice (*Oryza sativa*). *Indian J. Agron.* 50(3): 194-196.

Mukherjee, D. and Singh, R. P. 2005. Effect of micro-herbicides on weed dynamics, yield and economics of transplanted rice (*Oryza sativa*). *Indian J. Agron.* 50(4): 292-295.

Mukherjee, D. and Singh, R. P. 2006. Studies on phytotoxic effect of sulfonylurea herbicide on different rice cultivars. *Indian J. Weed Sci*. 38(1&2): 129-130.

Mukherjee, P. K. and Malty, S. K. 2011. Weed control in transplanted and wet-seeded rainy season rice (*Oryza sativa*). *Indian J. Weed Sci*. 81(2): 134-139.

Nadeem, M. A., Tanveer, A., Maqbool, R., Abbas, T., and Farooq, N. 2018. Efficacy evaluation of fertilizers and weed control practices to mitigate wheat nutrient and yield losses. *Planta Daninha* [e-journal] *36*: e018169013. Available: https://doi.org/10.1590/s0100-83582018 360100029 [10 June 2020].

Nair, R. R., Vidyadharan, K. K., Pisharody, P. N., and Gopalakrishnan, R. 1974. Comparative efficiency of new herbicides for direct seeded rice fields. *Agric. Res. J. Kerala* 12(1): 24-27.

Nakatani, A. S., Fernandes, M. F., de Souza, R. A., da Silva, A. P., dos Reis-Junior, F. B., Mendes, I. C., and Hungria, M. 2014. Effects of the glyphosate-resistance gene and of herbicides applied to the soybean crop on soil microbial biomass and enzymes. *Field Crops Res.* 1 29.

Nanjappa, H. V. and Krishnamurthy, K. 1980. Nutrient losses due to weed competition in tall and dwarf varieties of rice. *Indian J. Agron.* 25(2): 273-278.

Narolia, R. S., Singh, P., Prakash, C., and Meena, H. 2014. Effect of irrigation schedule and weed-management practices on productivity and profitability of direct-seeded rice (*Oryza sativa*) in South-eastern Rajasthan. *Indian J. Agron.* 59(3): 398-403.

Nath, C. P., Saha, M., Pandey, P. C., Das, T. K., Meena, R. K., and Paul, T. 2014. Bio-efficacy evaluation of different herbicides on weed population, grain yield and nutrient uptake in direct seeded puddled rice (*Oryza sativa* L.). *Ann. Agric. Res.* 35(2).

Nayak, B. R. and Nanjappa, K. 2010. Topo-sequential variations in enzyme activity in rice growing soils in hilly region. *Karnataka J. Agric. Sci.* 23(4): 640-641.

Netam, C. R., Pandey, P., Thakur, A. K., and Netam, A. K. 2018. Influence of various crop establishment methods and weed management approaches on weed dynamics in rice crop. *Int. J. Curr. Microbiol. App. Sci*. 7(12): 2564-2574. doi: https://doi.org/10.20546/ijcmas.2018.712.291.

Noda, K. 1973. Competition effects of barnyard grass (*Echinochloa crus-galli*) on rice. In: Proceedings of the 4th Asian-Pacific Weed Science Society Conference, Rotorua, New Zealand, pp.145-150.

Ogborn, J. 1969. The potential use of herbicides in tropical peasant agriculture. *PANS Pest Articles News Summ.* 15(1): 9-11.

Ottis, B. V., Talbert, R. E., Scherder, E. F., Lovelace, M. L., Malik, M. S., Lassiter, R. B., and Gardisser, D. R. 2003. Early post emergence tank-mix programs with cyhalofop (Clincher) for residual grass control in rice. In: *Proc. South. Weed Sci. Soc. 56,* p.53.

Pal, D., Ghosh, R. K., Sounda, G., Dolai, A. K., and Mallick, S. 2009. Bio-efficacy of some promising herbicides in transplanted *Kharif* rice and their influence on soil microflora. *Indian Agric.* 53(3&4): 193-198.

Pal, S. and Banerjee, H. 2007. Efficacy of penoxsulam against weeds in transplanted kharif rice (*Oryza sativa* L.) *Indian J. Weed Sci.* 39(3&4): 172-175.

Parthipan, T. and Ravi, V. 2014. Productivity of transplanted rice as influenced by weed control methods. *Afr. J. Agric. Re*[illegible]: 2250-2254.

Parthipan, T., Ravi, V., and Subramanian. E. 2013. Integrated weed management practices on growth and yield of direct-seeded lowland rice. *Indian J. Weed Sci.* 45(1): 7-11.

Patil, S., Kumar, A., Kumar, M., Choubey, A. K., and Hans, H. 2016. Efficacy of herbicides and their combination of herbicides in *Cyperus* dominated rabi maize (*Zea mays* L.). *Bioscan* 12(1):533-537.

Patil, V. B. 2014. Studies on bio-efficacy and phytotoxicity of penoxsulam + cyhalofop-butyl 6% OD in direct dry seeded rice (*Oryza sativa* L.). Doctoral dissertation, University of Agricultural Sciences, Raichur, 116p.

Patra, A. K., Haldar, J., and Tripathy. S. K. 2006. Chemical weed control in transplanted rice in Hirakud command area. *Ann. Agric. Res. New Series* 27: 385-388.

Pavithra, M., Poonguzhalan, R., Narayanan, A. L., and Sundaravarathan, S. 2017. Bispyribac sodium – Early post-emergence herbicide for weed control in aerobic rice (*Oryza sativa* L.). *Agric. Update* 12(1): 270-276.

Payman, G. and Singh, S. 2008. Effect of seed rate, spacing and herbicide use on weed management in direct seeded upland rice (*Oryza sativa* L.). *Indian J. Weed Sci.* 40(1&2): 11-15.

Prabhakaran, N. K., Sakthivel, N., and Nithya, C. 2014. Effect of herbicide combinations on weed control efficacy and grain yield of direct seeded rice. *Trends Biosci.* 7(24): 4244-4247.

Prakash, C., Shivan R. K., and Koli. N. R. 2013. Bio-efficacy of penoxsulam against broad spectrum weed control in transplanted rice. *Adv. Res. J. Crop Improv.* 4(1): 51-53.

Prakash, C., Shivran, R. K., and Koli, N. R. 2011. Bio efficacy of new herbicides on weed dynamics, yield attributes, yield and weed control efficiency in transplanted rice. *Trends Biosci.* 4(2): 224-227.

Prakash, C., Shivran, R. K., and Koli, N.R. 2013. Bio-efficacy of new herbicides in transplanted rice. *Indian J. Weed Sci.* 45(4): 282-284.

Prasad, A., Singh, G., and Upadhyay, R. K. 2008. Integrated weed management in maize (*Zea mays* L.) and maize + blackgram. *Indian J. Weed Sci.* 40(3&4): 191-192.

Prasad, S. M., Mishra, S. S., and Singh, S. J. 2001. Effect of establishment methods, fertility levels and weed-management practices on rice (*Oryza sativa*). *Indian J. Agron.* 46(2): 216-221.

Prashanth, R., Murthy, K. N. K., Murali, M., Ramachandra, C., and Sunil, C. M. 2015. Growth and yield of transplanted rice as influenced by application of bispribac sodium 10 SC a post-emergence herbicide. *Int. J. Trop. Agric.* 33(1): 37-40.

Prashanth, R., Sunil, C. M., Murthy, K. N. K., Kumar, V. M., and Murali, M. 2016. Bispribac sodium influence on nutrient uptake by weeds and transplanted rice. *Indian J. Weed Sci.* 48(2): 217-219.

Priya, R. S., Chinnuswamy, C., Arthanari, P. M., and Janaki, P. 2017. Microbial and dehydrogenase activity of soil contaminated with herbicide combination in direct seeded rice (*Oryza sativa* L.). *J. Entomol. Zool. Stud.* 5(5): 1205-1212.

Puniya, R., Pandey, P. C., Bisht, P. S., and Singh, D. K. 2007b. Nutrient uptake by crop and weeds as influenced by trisulfuron, trisulfuron + pretilachlor and bensulfuron-methyl in transplanted rice (*Oryza sativa* L.). *Indian J. Weed Sci.* 39(3&4): 239-240.

Quilchano, C. and Maranon, T. 2002. Dehydrogenase activity in Mediterranean forest soils. *Biol. Fert. Soils* 35(2): 102-107.

Raj, S. K. and Syriac, E. K. 2015. Bio-efficacy of penoxsulam + cyhalofop-butyl 6 % OD, a new pre-mix herbicide mixture for weed control in direct seeded puddled irrigated rice (*Oryza sativa* L.). *Res. Crops* 16(3): 406-415.

Raj, S. K. and Syriac, E. K. 2017. Weed management in direct seeded rice: a review. *Agric. Rev.* 38(1): 41-50.

Raj, S. K., Jose, N., Mathew, R., and Leenakumary, S. 2013. Chemical management of non-grassy weeds in direct-seeded rice. *Indian J. Weed Sci.* 45(3): 159-162.

Rajasekar, N. 2015. Evaluation of new herbicides formulations in transplanted rice (*Oryza sativa* L.). M.Sc. (Ag) thesis, Dept. of Agronomy, Annamalai University.

Ramachandran, K., Balasubramanian, R., and Babu, R. 2010. Efficacy of new herbicide molecules for controlling weeds in aerobic rice. In: *Proceedings of Annual Weed Science Conference,* 30th November and 1st December, TNAU, Coimbatore, 149p.

Ramana, A. V., Naidu, G. J., and Murthy, K. V. 2007. Integrated weed management in rainfed upland rice (*Oryza sativa*). *Indian J. Agron.* 52(4): 311-314.

Rao, A. N. and Moody, K. 1987. Weed seedlings transplanted with rice seedlings reduce grain yield [Philippines]. *Int. Rice Res. Newsl.* 12(3): 51.

Rao, A. N., Wani, S. P., Ahmed, S., Ali, H. H., and Marambe, B. 2017. An overview of weeds and weed management in rice of South Asia. In: *Weed management in rice in the Asian-Pacific region.* Asian-Pacific Weed Science Society (APWSS), Hyderabad, pp.247-281.

Rao, A. S. and Ratnam, M. 2010. Evaluation of post emergence herbicides on weed control in rice nursery. *Pak. J. weed sci. Res* 16(4): 387-392.

Rao, A. S., Ratnam, M., and Reddy, T. Y. 2008. Weed management in direct-seeded semi dry rice. *Indian J. Weed Sci.* 40(3&4): 153-156.

Rao, U. R., Murthy, K. M. D., and Reddy, C. V. 2009. Efficacy of Bispribac sodium 10% SC - an early post emergence herbicide on rice. In: *Proceedings of the National Symposium on weed threat to environment, biodiversity and agriculture productivity*, TNAU, Coimbatore, pp.2-3.

Rathod, B. G. S. and Somasundaram, E. 2017. Nutrient uptake by weeds and rice under different organic weed management practices. *Int. J. Chem. Stud.* 5(4): 2050-2052.

Ravisankar, N., Chandrasekaran, B., Raja, R., Din, M., and Chaudhuri, S. G. 2008. Influence of integrated weed management practices on productivity and profitability of wet-seeded rice (*Oryza sativa*). *Indian J. Agron.* 53(1): 57-61.

Rekha, K. B., Raju, M. S., and Reddy, M. D. 2003. Effect of herbicides on weed growth, grain yield and nutrient uptake in rainfed lowland rice. *Indian J. Weed Sci.* 35(1&2): 121-122.

Rice, P. M., Toney, J. C., Bedunah, D. J., and Carlson, C. E. 1997. Plant community diversity and growth form responses to herbicide applications for control of *Centaurea maculosa*. *J. Appl. Ecol.* 34(6): 1397-1412.

Saeki, M. and Toyota, K. 2004. Effect of bensulfuron-methyl (a sulfonyurea herbicide) on the soil bacterial community of a paddy soil microcosm. *Biol. Fertil. Soils* 40(2): 110-118.

Saha, A., Bhaduri, D., Pipariya, A., and Jain, N. K. 2016. Influence of imazethapyr and quizalofop-p-ethyl application on microbial biomass and enzymatic activity in peanut grown soil. *Environ. Sci. Pollut. Res.* 23(23): 23758-23771.

Saha, S. 2005. Efficacy of certain new herbicide formulations in transplanted rice under rainfed shallow lowland. *Indian J. Weed Sci.* 37(1&2): 109-110.

Saha, S. 2006. Efficacy of herbicides in wet direct sown summer rice. *Indian J. Weed Sci*. 38(1&2): 45-48.

Sandeep, N., Singh, S., Panwar, K. S., Malik, R. K., Narwal, S., and Singh, S. 2002. Performance of acetachlor and anilofos + ethoxysulfuron for weed control in transplanted rice (*Oryza sativa*). *Indian J. Agron.* 47(1): 67-71.

Sangeetha, C., Chinnusamy, C., Kalaichelvi, K., and Muthukrishnan, P. 2010. Resistance of *Echinochloa colona* against post emergence application of azimsulfuron. In: *Bienniel Conference of ISWS on Recent Advances in Weed Science Research,* 25-26th Feb. 2010, Indira Gandhi Krishi Vishwavidyalaya, Raipur, 39p.

Sanjay, M. T., Setty, T. K. P., and Nanjappa, H. V. 2008. Investigation of crop establishment methods and weed management practices on productivity and economics in rice. *Mysore J. Agric. Sci*. 42: 60-66.

Sanjoy, S. 2009. Efficacy of bensulfuron-methyl for controlling sedges and non-grassy weeds in transplanted rice (*Oryza sativa*). *Indian J. Agric. Sci.* 79(4): 313-316.

Sankaran, S. and Mani, V. S. 1974. Comparative efficiency of physical, chemical and combination methods of weed control in grain sorghum. *Madras Agric. J.* 61(8): 344-352.

Sansa, S., Syriac, K. E., and Raj, S. K. 2016. Penoxsulam as post-emergence herbicide for weed control in transplanted rice. *Indian J. Weed Sci.* 48(2): 215-216.

Saranraj, T., Devasenapathy, P., and Lokanadhan, S. 2017. Penoxsulam evaluation for weed control efficacy and increased rice yield. *Indian J. Weed Sci.* 49(1): 1-4.

Sebiomo, A., Ogundero, V. W., and Bankole, S. A. 2011. Effect of four herbicides on microbial population, soil organic matter and dehydrogenase activity. *Afr. J. Biotechnol.* 10(5): 770-778.

Sharma, P., Singh, M. K., Verma, K., and Prasad, S. K. 2020. Changes in the weed seed bank in long term establishment methods trials under rice-wheat cropping system. *Agron.* 10(2): 292-306.

Sharma, S. D., Punia, S. S., Malik, R. K., and Narwal, S. 2004. Efficacy of cyhalofop-butyl against weeds in rice nursery. *Indian J. Weed Sci*. 36(3&4): 181-183.

Shukla, A. K. 1997. Effect of herbicides butachlor, fluchloralin, 2, 4-D and oxyfluorfen on microbial population and enzyme activities of rice field soil. *Indian J. Ecol.* 24(2): 189-192.

Sindhu, P. V. 2008. Ecofriendly management of weeds in rice [Doctoral dissertation]. Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur, 362p.

Singh, A. K., Singh, M. K., Prasad, S. K., and Sakarwar, P. 2014. Sequential herbicide application and nitrogen rates effects on weeds on direct seeded rice (*Oryza sativa* L.). *Ecoscan* 8(3&4): 249-252.

Singh, B., Malik, R. K., Yadav, A., and Nandal, D. P. 2009. Herbicide efficacy in seeded rice with different methods under wet and dry conditions. *Indian J. Weed Sci.* 41(1&2): 37-40.

Singh, D. K., Tewari, A. N., and Tripathi, A. K. 2007. Effect of herbicides on weed dynamics and yield of direct seeded puddled rice under varying water regimes. *Indian J. Agric. Sci.* 77(7): 415-419.

Singh, G. 2012. Efficacy of different formulations of penoxsulum on weeds and yield of transplanted rice. *Oryza Int. J. Rice* 49(3): 195-199.

Singh, G., Singh, V. P., and Singh, M. 2004. Effect of Almix and butachlor alone and in combinations on transplanted rice and associated weeds. *Indian J. Weed Sci.* 36: 64-67.

Singh, I., Ram, M., and Nandal, D. P. 2007. Efficacy of new herbicides for weed control in transplanted rice under rice-wheat system. *Indian J. Weed Sci.* 39(1&2): 28-31.

Singh, K. and Tripathi, H. P. 2007. Effect of nitrogen and weed-control practices on performance of irrigated direct-seeded rice (*Oryza sativa*). *Indian J. Agron.* 52(3): 231-234.

Singh, P., Singh, P., Singh, R., and Singh, K. N. 2006. Efficacy of new herbicides in transplanted rice under temperate conditions of Kashmir. *Indian J. Weed Sci.* 39(3&4): 167-171.

Singh, R. K., De, R., and Turkhede, B. B. 1986. Time of application of farmyard manure and fertilizer nitrogen on the growth, yield and nutrient uptake of dryland wheat. *J. Agric. Sci.* 106(1): 7-15.

Singh, S. 2016. Herbicide mixture and sequential application for weed control in Direct Seeded Rice in India. In: *Proceedings of the 56th annual meeting of Weed Science Society of America and 69th meeting of Southern Weed Science Society,* 8 to 11th February 2016, San Juan, Puerto Rico, Abstract No.403.

Singh, S. P. and Kumar, R. M. 1999. Efficacy of single and sequential application of herbicides on weed control in transplanted rice. *Indian J. Weed Sci.* 31(3&4): 222-224.

Singh, S., Ladha, J. K., Gupta, R. K., Bhushan, L., and Rao, A. N. 2008. Weed management in aerobic rice systems under varying establishment methods. *Crop Prot*. 27(3-5): 660-671.

Singh, S., Singh, H., Narwal, S., and Malik, R. K. 2003. Performance of herbicides in transplanted rice. *Indian J. Weed Sci.* 35(1&2): 114-116.

Singh, V. P., Singh, G., Singh, R. K., Singh, S. P., Kumar, A., Dhyani, V. C., Kumar, M., and Sharma, G. 2005. Effect of herbicides alone and in combination on direct seeded rice. *Indian J. Weed Sci*. 37(3&4): 197-201.

Singh, V. P., Singh, G., Singh, R. K., Singh, S. P., Kumar, A., Sharma, G., Singh, M. K., Mortimer, M., and Johnson, D. E. 2005. Effect of weed management and crop establishment methods on weed dynamics and grain yield of rice. *Indian J. Weed Sci*. 37(3&4): 188-192.

Singh, V. P., Singh, S. P., Banga, A., Kuma, A., Tripathi, N., and Bisht, N. 2015. Compatibility of penoxsulam + cyhalofop with insecticide, fungicide and urea 2% in direct seeded rice. *J. Ecofriendly Agric*. 10(1): 74-76.

Singh, V., Jat, M. L., Ganie, Z. A., Chauhan, B. S., and Gupta, R. K. 2016. Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic plains. *Crop Prot.* 81: 168-176.

Smith Jr, R. J. 1983. Weeds of major economic importance in rice and yield losses due to weed competition. In: *Proceedings of the Conference on Weed Control in Rice 31,* pp.19-36.

Smith, R. J. 1961. 3,4-Dichloropropionanilide for control of barnyard grass in rice. *Weeds* 9(2): 318-322.

Soren, C., Bera, S., Mukhopadhyay, S. K., and Saren, D. 2017. Bio-efficacy and phytotoxicity studies of bispribac sodium 10% SC in direct seeded rice. *J. Crop Weed* 13(3): 165-167.

Sreedevi, B., Kumar, R. M., Singh, A., Tuti, M. D., Saha, S., and Voleti, S. R. 2018. Assessing the efficacy of new low dose herbicide molecule in puddled direct seeded rice. *J. Rice Res.* 11(2): 45-49.

Sreedevi, B., Singh, A., Thakur, C., Kumar, M. P., Mehra, V., Mahenderkumar, R., and Srivastava, G. K. 2020. Weed control by single post-emergence combination herbicide florpyrauxifen-benzyl plus cyhalofop-butyl in aerobic rice. *Curr. J. Appl. Sci. Technol.* 39(3): 109-122.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for the determination of available nitrogen in soil. *Curr. Sci*. 25: 259-260.

Subhalakshmi, C. and Venkataramana, M. 2009. Growth and nutrient uptake of transplanted rabi rice, weeds as influenced by different weed management practices. In: *National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity*, TNAU, Coimbatore, 63p.

Subramanian, E., Martin, G. J., and Balasubramanian, R. 2006. Effect of integrated weed-management practices on growth and yield of wet-seeded rice (*Oryza sativa*) and their residual effect on succeeding pulse crop. *Indian J. Agron.* 51(2): 93-96.

Suganthi, M., Kandasamy. O. S., Subbian, P., and Jayakumar, R. 2005. Relative efficacy of pretilachlor 50 EC for weed control in lowland transplanted rice-rice cropping system. *Indian J. Weed Sci*. 37(1&2): 105-106.

Sureshkumar, R., Reddy, Y. A., and Ravichandran, S. 2016. Effect of weeds and their management in transplanted rice–a review. *Int. J. Res. Appl. Nat. Social Sci.* 4(11): 165-180.

Suria, A. J., Juraimi, A. S., Rahman, M., Man, A. B., and Selamat, A. 2011. Efficacy and economics of different herbicides in aerobic rice system. *Afr. J. Biotechnol.* 10(41): 8007-8022.

Teja, K. C., Duary, B., and Bhowmick, M. K. 2015. Efficacy of herbicides on weed management in wet season transplanted rice. *J. Crop Weed* 11(Special Issue): 224-227.

Thakur, A. K., Rath, S., Patil, D. U., and Kumar, A. 2011. Effects on rice plant morphology and physiology of water and associated management practices of the system of rice intensification and their implications for crop performance. *Paddy Water Environ.* 9(1): 13-24.

Thomas, C. G. and Abraham, C. T. 1998. *Common weeds in rice ecosystems of Kerala and their management*. Kerala Agricultural University, 80p.

Thomas, C. G. and Abraham, C. T. 2007. *Methods in weed science*. AICRP on weed control, College of Horticulture, Vellanikkara, 108p.

Uddin, M. K., Juraimi, A. S., Anwar, M. P., Mohamed, M. T. M., Ismail, M. R., and Man, A. 2013. Sustainable weed management in direct seeded rice culture: a review. *Aust. J. Crop Sci.* 7(7): 989-1002.

Uma, G., Ramana, M. V., Reddy, A. P. K., and Prakash, T. R. 2014. Evaluation of low dose herbicides in transplanted rice (*Oryza sativa* L.). *Int. J. Appl. Biol. Pharm. Technol.* 5(4): 96-101.

Uraon, M. 2016. Studies on efficacy of pre-mix penoxsulam + pendimethalin on weed growth, yield and economics of direct seeded rice [Doctoral dissertation]. Indira Gandhi Krishi Vishwavidyalaya, Raipur, 144p.

Uraon, M. 2019. Studies on efficacy of pre-mix penoxsulam + pendimethalin on weed growth of direct seeded rice. *J. Pharmacogn. Phytochem.* 8(3): 1020-1025.

Uraon, M. and Shrivastava, G. K. 2018. Studies on efficacy of pre-mix penoxsulam + pendimathalin on economics of direct seeded rice. *J. Pharmacogn. Phytochem.* 7(4): 3054-3055.

Vandana, L. J., Rao, P. C., and Padmaja, G. 2012. Effect of herbicides and nutrient management on soil enzyme activity. *J. Rice Res*. 5(1): 50-56.

Veeraputhiran, R. and Balasubramanian, R. 2010. Evaluation of new post emergence herbicide for transplanted rice. In: *Proceedings of the annual weed science conference,* 30th November and 1st December 2010, TNAU, Coimbatore, p.175

Veeraputhiran, R. and Balasubramanian, R. 2013. Evaluation of bispribac sodium in transplanted rice. *Indian J. Weed Sci.* 45(1): 12-15.

Verma, D. K., Jaiswal, L. M., Brijlal, and Singh, G. 2004. Effect of herbicides on direct seeded rice under puddled condition. *Oryza* 41(1&2): 55-56.

Walia, U. S., Bhullar, M. S., Nayyar, S., and Sidhu, A. S. 2009. Role of seed rate and herbicides on the growth and development of direct dry seeded rice. *Indian J. Weed Sci*. 41(1&2): 33-36.

Watanabe, F. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphate in water and $NaHCO_3$ extracts from soil. In: *Proc. Soil Sci. Am.* 29(6): 677-678

Weimer, M. R., Yerkes, C. N., Schmitzer, P. R., and Mann, R. K. 2015. Introduction to a new arylpicolinate herbicide from Dow AgroSciences with utility in rice and other crops. In: *Proc. Weed Sci. Soc. Am*. Lexington, Abstract. 55: 201. [March 19, 2019].

Wells, G. S. 2004. Cyhalofop - hard on barnyard and silvertop grasses but soft on rice. In: *Weed management: balancing people, planet, profit.* 14th Australian Weeds Conference, Wagga Wagga, New South Wales, Australia, 6-9 September 2004, Weed Society of New South Wales, pp.287-289.

Wells, G. S. and Taylor, M. 2016. Rinskor™ active–a new herbicide for rice weed control in Australia. In: *Proceedings of the 20th Australasian Weeds Conference,* pp.269-271.

Xia, X., Zhao, M., Wang, H., and Ma, H. 2012. Influence of butachlor on soil enzymes and microbial growth. *J. Food Agri. Environ.* 9(2): 753-756.

Yadav, D. B., Yadav, A., and Punia, S. S. 2008. Efficacy of penoxsulam against weeds in transplanted Rice. *Indian J. Weed Sci.* 40(3&4): 142-146.

Yadav, D. B., Yadav, A., and Punia, S. S. 2009. Evaluation of bispribac sodium for weed control in transplanted rice. *Indian J. Weed Sci.* 41(1&2): 23-27.

Yadav, N., Kishore, R., Dwivedi, A., Singh, R., Naresh, R. K., Kumar, V., Bankoti, P., and Sharma, D. K. 2017. Integrated effect of population and weed management regimes on weed dynamics, performance, and productivity of basmati rice (*Oryza sativa* L.). *Paddy Water Environ.* 15(1): 49-58.

Yun, M. S., Yogo, Y., Miura, R., Yamasue, Y., and Fischer, A. J. 2005. Cytochrome p-450 monooxygenase activity in herbicide resistant and susceptible late watergrasss (*Echinochloa phyllopogen*). *Pesticide Biochem. Physiol*. 83(2&3):107-114.

Appendices

Appendix - 1

Monthly weather data during the crop period

Month	Temperature (℃)		Relative humidity (%)	Mean rainfall (mm)	Rainy days	Mean evaporation (mm)	Sunshine (hrs)	Wind speed (km/h)
	Maximum	Minimum						
October	32.4	21.4	80	418.4	16	84	170.2	1.8
November	32.9	21.7	71	205	5	101.5	224.9	4
December	32.3	22.1	63	4.4	1	140.7	208.8	8.7
January	34.1	22.4	60	0	0	151	290.2	5.9

Appendix - 2

Details of the pre-mix herbicide combinations used

Sl. No.	Particulars	Quantity/ha	Amount (Rs.)
1	Pendimethalin + penoxsulam 25 SE	625 g/ha	800/- per L
2	Cyhalofop-butyl + penoxsulam 6 OD	135 g/ha	1,300/- per L
3	*Florpyrauxifen-benzyl + cyhalofop-butyl 12 EC	150 g/ha	1,875/- per L
4	Cyhalofop-butyl 10 EC *fb* (Chlorimuron ethyl 10% + metsulfuron methyl 10%)	80 g/ha + 8 g/ha	2,160/- per L + 177/- per 8g
5	Bispyribac sodium 10 SC	25 g/ha	8,260/- per L

*approximate price - as the product yet to be registered

Appendix – 3

Nutrient content of weeds (%) at 30 DAS

Treatments	N	P	K
Pendimethalin + penoxsulam, 5 DAS	2.98	0.49	1.84
Pendimethalin + penoxsulam, 10 DAS	3.68	0.53	1.75
Cyhalofop-butyl + penoxsulam, 12 DAS	4.03	0.42	1.81
Cyhalofop-butyl + penoxsulam, 18 DAS	2.98	0.57	1.88
Florpyrauxifen-benzyl + cyhalofopbutyl, 12 DAS	4.14	0.48	2.02
Florpyrauxifen-benzyl + cyhalofopbutyl, 18 DAS	4.43	0.56	2.92
Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 and 19 DAS	3.96	0.50	2.79
Bispyribac sodium, 18 DAS	3.97	0.37	2.28
Hand weeding, 20 DAS and 40 DAS	1.65	0.38	1.09
Unweeded control	4.67	0.40	2.38

Appendix – 4

Nutrient content of weeds (%) at 60 DAS

Treatments	N	P	K
Pendimethalin + penoxsulam, 5 DAS	1.63	0.41	1.31
Pendimethalin + penoxsulam, 10 DAS	1.98	0.47	1.25
Cyhalofop-butyl + penoxsulam, 12 DAS	1.52	0.38	1.27
Cyhalofop-butyl + penoxsulam, 18 DAS	1.17	0.37	1.28
Florpyrauxifen-benzyl + cyhalofopbutyl, 12 DAS	1.58	0.41	1.27
Florpyrauxifen-benzyl + cyhalofopbutyl, 18 DAS	1.47	0.36	1.16
Cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %), 18 and 19 DAS	1.75	0.40	1.23
Bispyribac sodium, 18 DAS	1.63	0.35	1.72
Hand weeding, 20 DAS and 40 DAS	1.75	0.38	1.24
Unweeded control	1.98	0.33	1.20

Abstract

BIO-EFFICACY OF PRE-MIX HERBICIDE COMBINATIONS FOR BROAD SPECTRUM WEED CONTROL IN WET SEEDED RICE

By

MOUNISHA J.

(2018-11-135)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

(AGRONOMY)

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2020

ABSTRACT

Most of the herbicides used in wet seeded rice are selective and weed specific, and thus control only a small portion of the diverse weed flora. Several new pre-mix herbicide products having broad spectrum activity are now available in the markets which could exclude the labour of tank mixing as well as the possibility of non-compatibility. However, information on the effectiveness of these new herbicides in the wetlands of Kerala is lacking. The present study entitled "Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice" was carried out to test the effectiveness of three new pre-mix herbicides in the *Kole* area of Thrisuur in Kerala.

The experiment was conducted from October 2019 to January 2020 in a farmer's field in *Kole* area of Alappad, Thrissur district with the objective to study the efficacy of different pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice. The rice variety used was Manuratna. The experiment was laid out in RBD with 10 treatments and 3 replications. Three pre-mix herbicide combinations at two different times of application viz., pendimethalin + penoxsulam at 5 and 10 DAS (T_1 and T_2), cyhalofop-butyl + penoxsulam at 12 and 18 DAS (T_3 and T_4), and florpyrauxifen-benzyl + cyhalofop-butyl at 12 and 18 DAS (T_5 and T_6) were evaluated along with the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10% + metsulfuron methyl 10%) at 18 and 19 DAS (T_7), bispribac sodium at 18 DAS (T_8), hand weeded control (at 20 and 40 DAS) (T_9), and unweeded control (T_{10}).

Major weed species observed in the experimental field were grasses consisting of weedy rice (*Oryza sativa* f. *spontanea*), *Echinochloa stagnina* and *Leptochloa chinensis*, and sedges consisting of *Cyperus* spp and *Fimbristylis miliacea*. Broad leaf weeds were comparatively very low, such that at 60 DAS, grasses, sedges and broad leaf weeds constituted 92 per cent, 7 per cent and 1 per cent of the total weed population.

The lowest weed dry matter production was recorded in hand weeded control (T_9) at both 30 and 60 DAS. Among the herbicide treatments, pendimethalin + penoxsulam applied at 5 and 10 DAS (T_1 and T_2) and florpyrauxifen-benzyl +

cyhalofop-butyl applied at 12 DAS and 18 DAS (T_5 and T_6) were on par with hand weeded control at 30 DAS with regard to weed dry matter production. Weed control efficiency at 30 DAS was also highest in these herbicide treatments. The nutrient removal by weeds at different growth stages followed the same trend as that of weed dry matter production.

Among the various herbicide combinations and herbicides, only pendimethalin + penoxsulam applied at 5 and 10 DAS (T_1 and T_2) caused slight injury on rice at three days after spraying; however, the crop completely recovered within seven days. At 30 DAS, there was no significant difference in tiller count per sq. m between the treatments. By 60 DAS the highest tiller count per sq. m was observed in hand weeded control (T_9), which was found to be on par with pendimethalin + penoxsulam sprayed at 10 DAS (T_2).

The highest number of productive tillers per sq. m, number of grains per panicle, percentage of filled grains per panicle, and grain and straw yield were recorded in hand weeded control (T_9). Among the herbicide treatments, the highest grain yield was recorded in florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5), due to the high weed control efficiency of 82.96 per cent and the lowest yield reduction to the tune of 2.61 per cent. This treatment was found to be statistically on par with hand weeded control (T_9), and pendimethalin + penoxsulam sprayed at 5 DAS (T_1) with respect to grain and straw yield.

On herbicide application, the microbial biomass carbon and the dehydrogenase activity of the soil were affected at earlier stages of crop growth, but at harvest both were found to be restored and the balance was almost attained. Thus, none of the herbicides showed pronounced adverse effect on the soil microbial properties.

The herbicidal combination florpyrauxifen-benzyl + cyhalofop-butyl applied at 12 DAS (T_5) fetched highest gross returns, net returns, and B:C ratio, followed by pendimethalin + penoxsulam applied at 5 DAS (T_1). These treatments also recorded the lowest weed indices. All the herbicide combinations from T_1 to T_6 performed significantly better than the sequential application of cyhalofop-butyl *fb* (chlorimuron ethyl 10 % + metsulfuron methyl 10 %) (T_7), bispribac sodium (T_8), and unweeded control (T_{10}). Although hand weeded control (T_9) recorded highest gross returns, net returns and B:C ratio were lowest due to high cost of cultivation.

Among the herbicidal combinations sprayed at different times of application, all the treatments at earlier time of application i.e., pendimethalin + penoxsulam at 5 DAS (T_1), cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both at 12 DAS (T_3 and T_5), were observed to perform better in terms of both growth and yield parameters than the later applied sprays.

All the herbicide combination treatments performed well in terms of yield attributes and crop yields, and thus fetched higher net returns and B:C ratio. Pre-mix herbicide combinations were as good as hand weeding twice in rice with respect to grain and straw yield, and gave higher monetary returns. Florpyrauxifen-benzyl + cyhalofop-butyl when sprayed at 12 DAS (T_5) recorded the lowest weed dry matter production, highest WCE and highest crop yield, which in turn gave highest economic benefit, and thus can be regarded as the best pre-mix herbicide combination. All the herbicide combinations tested can be recommended to effectively control mixed weed flora in wet seeded rice in the *Kole* lands of Kerala.

സംഗ്രഹം

ചേറ്റുവിതയിൽ എല്ലാത്തരം കളകൾക്കും എതിരെ ഉപയോഗിക്കാവുന്ന പല പ്രീമിക്സ് കളനാശിനികളുടെ കാര്യ ക്ഷമതയെ കുറിച്ചു മനസിലാക്കുക എന്ന ലക്ഷ്യത്തോടു കൂടി ഒക്ടോബർ 2019 മുതൽ ജനുവരി 2020 വരെ ഉള്ള കാലയളവിൽ തൃശൂരിലെ ആലപ്പാട് പഞ്ചായത്തിലെ കോൾ പാടത്ത് പഠനം നടത്തുകയുണ്ടായി.

മനുരത്ന എന്ന നെല്ലിനം ഉപയോഗിച്ച് നടത്തിയ പഠനത്തിൽ പത്തു വ്യത്യസ്ത കളനിയന്ത്രണ മാർഗ്ഗങ്ങളുടെ നിയന്ത്രണ മികവ് പരീക്ഷിച്ചു. മൂന്നു പ്രീമിക്സ് കളനാശിനികൾ രണ്ടു സമയങ്ങളിലായി പ്രയോഗിച്ചു. അതായത്,പെന്റിമെത്താലിൻ+പെനോക്സുലം വിതച്ച് 5 ദിവസങ്ങൾക്കും 10 ദിവസങ്ങൾക്കും ശേഷം (T_1&T_2), സൈഹാലോഫോപ് ബ്യൂട്ടൈൽ+ പെനോക്സുലം വിതച്ച് 12 ദിവസങ്ങൾക്കും 18 ദിവസങ്ങൾക്കും ശേഷം(T_3&T_4), ഫ്ലോർപൈറോക്സിഫെൻ ബെൻസൈൽ+സൈഹാലോഫോപ് ബ്യൂട്ടൈൽ വിതച്ച് 12 ദിവസങ്ങൾക്കും 18 ദിവസങ്ങൾക്കും ശേഷം(T_5&T_6), സൈഹാലോഫോപ് ബ്യൂട്ടൈലിനു ശേഷം ക്ളോറിമ്യൂറോൺ ഈതൈൽ 10%+ മെറ്റ്സൽഫ്യൂറോൺ മീതൈൽ 10% പ്രയോഗം വിതച്ച് 18 ,19 ദിവസങ്ങൾ കഴിഞ്ഞ് (T_7), ബിസ്പയറിബാക്ക് സോഡിയം പ്രയോഗം വിതച്ച് 18 ദിവസങ്ങൾ കഴിഞ്ഞ് (T_8) പരീക്ഷിച്ചു. വിതച്ച് ഇരുപതാം ദിവസവും നാല്പതാം ദിവസവും കൈ കൊണ്ട് കള പറിച്ചു നീക്കുന്ന രീതിയും കളകൾ ഒട്ടും തന്നെ നീക്കം ചെയ്യാതെയുള്ള ഒരു പ്ലോട്ടും ഉൾപ്പെടുത്തിയിരുന്നു (T_9&T_{10}).

വരിനെല്ല്, കവട, കുതിരവാലി, മഞ്ഞ്, മുത്തങ്ങ വിഭാഗത്തിൽ പെട്ടവ എന്നിവ ആയിരുന്നു കൃഷിയിടത്തിലെ പ്രധാന കളകൾ. എന്നിരുന്നാലും 92 ശതമാനം കളകളും പുല്ല് വിഭാഗത്തിൽപ്പെട്ടവ ആയിരുന്നു.

ഫ്ലോർപൈറോക്സിഫെൻ ബെൻസൈൽ+സൈഹാലോഫോപ് ബ്യൂട്ടൈൽ വിതച്ച് 12-15 ദിവസങ്ങൾക്കുള്ളിൽ പ്രയോഗിക്കുന്നത് മികച്ച കളനിയന്ത്രണവും,വിളവും, സാമ്പത്തിക ലാഭവും തരുന്നതായും കണ്ടെത്തി. എന്നത് മാത്രമല്ല, എല്ലാ പ്രീമിക്സ് കളനാശിനികളും മികച്ച കളനിയന്ത്രണത്തിന് നല്ലതാണെന്ന് കണ്ടെത്തി. അതിനാൽ പരീക്ഷിച്ച എല്ലാ കളനാശിനി സങ്കലനങ്ങളും കോൾ പാടങ്ങളിലെ കള നിയന്ത്രണത്തിനായി ചേറ്റുവിതയിൽ ശുപാർശ ചെയ്യാവുന്നതാണ്.