Bio-efficacy of tank mixed herbicides and urea in wet seeded rice

By

THUMU VENKATESWARA REDDY

(2018-21-052)

Department of Agronomy

COLLEGE OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

Bio-efficacy of tank mixed herbicides and urea in wet seeded rice

By

THUMU VENKATESWARA REDDY

(2018-21-052)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Doctor of Philosophy in Agriculture

(AGRONOMY)

Faculty of Agriculture

Kerala Agricultural University

Department of Agronomy

COLLEGE OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

DECLARATION

I hereby declare that this thesis entitled **"Bio-efficacy of tank mixed herbicides and urea 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: 01-09-2021

T. Venkateswara Reddy

Thumu Venkateswara Reddy

(2018-21-052)

CERTIFICATE

Certified that this thesis entitled **"Bio-efficacy of tank mixed herbicides and urea in wet seeded rice"** is a bonafide record of research work done independently by **Mr. Thumu Venkateswara Reddy (2018-21-052)** 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 him.

Meera Menon

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

Vellanikkara
Date: 1-09-2021

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Mr. Thumu Venkateswara Reddy (2018-21-052)**, a candidate for the degree of **Doctor of Philosophy in Agriculture** with major field in **Agronomy**, agree that this thesis entitled **"Bio-efficacy of tank mixed herbicides and urea in wet seeded rice"** may be submitted by **Mr. Thumu Venkateswara Reddy** in partial fulfillment of the requirement for the degree.

1-09-21

Dr. Meera V. Menon

(Chairperson, Advisory Committee)
Professor (Agronomy)
Cashew Research Station, Madakkathara

Dr. P. Prameela

(Member, Advisory Committee)
Professor and Head
Department of Agronomy
College of Agriculture, Vellanikkara

Dr. Anitha S. 01/09/2021

(Member, Advisory Committee)
Professor and Head
Instructional Farm
College of Agriculture, Vellanikkara

Dr. P. V. Sindhu 01.09.2021

(Member, Advisory Committee)
Assistant Professor (Agronomy)
AICRP (MAP & B)
College of Agriculture, Vellanikkara

01.09.21

Dr. Anita Cherian K.

(Member, Advisory Committee)
Professor (Plant Pathology)
Department of Plant Pathology
College of Agriculture, Vellanikkara

EXTERNAL EXAMINER

01 09 2021

Dr. M. Mohamed Yassin

Professor of Agronomy
Department of Agronomy
Tamil Nadu Agricultural University, Coimbatore

ACKNOWLEDGEMENT

First and foremost, it is with great respect and devotion I place on record my deep sense of gratitude and indebtedness to my chairperson **Dr. Meera V. Menon**, Professor (Agronomy), Cashew Research Station, Madakkathara for her sustained and valuable guidance, constant support, encouragement, motivation, constructive suggestions, unfailing patience, meticulous care and friendly approach throughout the course of study. I gratefully remember her knowledge and wisdom which nurtured this project in the right direction, without which fulfilment of this endeavour could not have been possible. I consider myself being very fortunate in having the privilege of being guided by madam and I will never let down myself or her name wherever I will be in future.

I extremely delighted to place on record my profound sense of gratitude to **Dr. P. Prameela**, Professor and Head (Department of Agronomy), and member of my advisory committee for the generous and timely help, valuable suggestions and critical comments accorded to me during the course of this study.

I am deeply indebted to **Dr. P.V. Sindhu**, Assistant Professor (Agronomy) and member of my advisory committee for her ever-willing help, constructive suggestions, and wholehearted support at times when I indeed moral support and cooperation.

I am thankful to **Dr. S. Anitha**, Professor and Head (Instructional Farm) for her sincere help during my research programme, and economic support in times of need.

I gratefully express my wholehearted thanks to **Dr. Anita Cherian K,** Professor (Plant Pathology) and member of my advisory committee for her constant support, valuable suggestions and kindly support during my lab work as well as for field disease diagnosis and recommendations.

My heartfelt thanks to my beloved teachers, **Dr. C. George Thomas, Dr. Syama S. Menon, Dr. K. Sreelakshmi** and **Dr. Savitha Antony** for their encouragement, valuable help and advice throughout my doctoral degree programme.

*My sincere thanks to **Dr. Jayasree Sankar**, Professor (Soil Science and Agricultural Chemistry) for timely help by letting me use chemicals and glassware for my laboratory analyses of soil and plant samples.*

*I am thankful to **Dr. T. Girija**, Professor (Plant Physiology) and **Dr. Parvathi Sreekumar,** Assistant Professor (Plant Physiology) for sincere help and suggestions for soil microbial studies.*

*I express my heartiest gratitude to **Dr. Haseena Bhaskar**, Professor (Entomology) for her wholehearted support during my study period.*

*I wish to express my sincere gratitude to **Mr. Sijith** and **Ms. Athira** (Farm Officers, Dept. of Agronomy), **Mr. George Joseph** (Farm Manager, AICRP on Weed Management)**, Mrs. Sreela, Mrs. Syamala, Mrs. Subha** and **Mr. Shameer,** for the sincere help, encouragement and mental support during the research period.*

I am deeply indebted to the labourers of Department of Agronomy for the timely help and cooperation during my field experiments.

I place on record my gratitude to the teachers and research staff of the College of Agriculture, Vellanikkara who helped me immensely during the course of my research programme.

*I am happy to express my sincere thanks to my senior **Dr. Pujari Shobha Rani**, my dear friends **Mrs. Durga C., Ms. Aparna G., Ms. Ajayasree T.S., Mr. Akash R.C., Mr. Sharanabasappa, Mr. Shivaji L., Mr. Purender E., Mrs. Akhila C.T., Mrs. Anusree T., Mrs. Amrutha** and **Mr. Sooraj,** my seniors and juniors of the Department of Agronomy **Dr. Saravana Kumar, Ms. Mounisha, Mr. Ajmal F., Ms. Anjaly, Ms. Jeen Shaji** and **Mrs. Teresa Alex.** I thank my seniors who helped me during this time, **Mr. M. Chakravarthy, Dr. Surendra Babu, Mr. Manohar Lal,** and my dearest juniors **Mr. M. Akhil Reddy, Mr. Abhishek, Mr. Mahesh, Mr. Suhas, Mr. Sunny, Mr. Aditya, Mr. Arjun** and 2017, 2018, 2019 PG and PhD students of Agronomy for their love, sincere help, suggestions, support and encouragement.*

I thankfully remember the services rendered by all the staff members of Students' Computer Club, Library, office of COA and Central Library, KAU.

I am extremely thankful to Sri. Keshava Raj, Alappad, Thrissur, his family and farm labourers for letting me use their field for experimentation and for their co-operation and support during the study period.

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

Even though thanks are taboo in friendship, my heartful thanks will always be there for my best friends of a life time, **Suresh, Devi, Brijal, Grishma** *and* **Daly** *for their constant moral support, encouragement, blessings and inspiration at every stage of my study without which this piece of work could not have been a reality.*

I am always grateful to my dearest seniors and part of my family, **Mr. V. Harish, Dr. P. Vinaya Lakshmi** *and* **Dr. K. Vykhaneswari,** *who were always there for me at all crucial moments of my life.*

I am in dearth of words to express my love towards my beloved parents, **Amma (Nagalakshmamma)** *and* **Nanna (T.V. Subba Reddy),** *my brother* **Dr. T. Satyanarayana Reddy** *and his wife* **Priyanka,** *my sisters* **Smt. T. Siva Parvati** *and her husband* **Mr. B. Sreeekanth Reddy**, *and* **Smt. T. Nagamalleswari** *and her husband* **Mr. K. Sudharkar Reddy** *for their boundless affection, moral support, eternal love, deep concern, prayers and personal sacrifices which sustains the peace in my life. I cannot find words to express my cordial appreciation to my nieces* **Deva Asritha, Nivika Siri and Dhriti Praghna** *whose smiles paved a way full of roses for me and who will go on motivating me in my future endeavours.*

I bow my head before God Almighty for enlightening and making me confident and optimistic throughout, enabling me to successfully complete my thesis work on a happy note.

T. Venkateswara Reddy

Thumu Venkateswara Reddy

CONTENTS

LIST OF TABLES

LIST OF TABLES (Contd.)

LIST OF TABLES (Contd.)

LIST OF TABLES (Contd.)

LIST OF TABLES (Contd.)

LIST OF FIGURES

LIST OF FIGURES (Contd.)

LIST OF FIGURES (Contd.)

LIST OF PLATES

LIST OF PLATES (Contd.)

Introduction

1. INTRODUCTION

Now-a-days the use of herbicides has become indispensable in agriculture, particularly in rice cultivation. Weeds are the most harmful of the biotic constraints to production. Potential yield losses in direct-seeded rice in India were estimated to vary from 15-66% (Gharde *et al*., 2018), and could sometimes go up to 100% (Singh *et al.,* 2015). Actual yield losses due to weeds however, would depend on the location (Swanton *et al.,* 2015; Jha *et al.,* 2017). High labour costs and shortage of labour have led to dominance of herbicides for weed control. Hence the use of herbicides has been escalating in the past few decades.

The loss due to weeds is caused by a complex of weeds with widely varying competitive ability. The response of different species to different herbicides also varies. Hence it is always advisable to use a combination of herbicides to control a group of different weed species. Moreover, when the population of a single weed is exposed to two or more herbicides with different modes of action, a more concerted control or suppression could be expected. While several herbicides are commonly applied in sequence to control different groups of weeds, their application in mixtures needs to be done more carefully. The compatibility of herbicides in such mixtures and the probable synergistic or antagonistic interactions has to be taken into consideration.

The use of herbicides has evolved from the use of a single herbicide at a high dose to two, three or four herbicide mixtures at low doses depending on the weed spectrum. Farmers are exposed to a wide choice of herbicides as well as to complex mixtures. Herbicide mixtures are often the best method to improve weed control. However, when two or more herbicides are active in a plant, the joint effect of the herbicides has to be considered. The mechanism of joint action of herbicides may be biochemical, competitive, physiological or chemical.

A usual practice among rice farmers is the tank mixing of herbicides, with the objectives of a broader spectrum of weed control, enhanced weed control efficiency and reduction in cost of application. This is true in the *Kole* lands of Kerala, located in Thrissur district where the present research programme was conducted. The area boasts of high productivity, mainly due to the inherent fertility of the soil. However, mixing of herbicides is done without any knowledge of the potential synergistic or antagonistic effect of the herbicides in the mixtures on weed flora. It thus becomes essential to scientifically validate such practices, and assess the effect on dominant weeds as well as different species of weeds. Identification of compatible herbicides with synergistic action would lead to increased bio-efficacy and enhanced weed control.

Mixing of other agrochemicals like fertilizers, fungicides and pesticides is also frequently practiced by farmers to reduce labour costs. Application of urea with herbicides like 2,4-D and propanil has been advocated as early as the 1980's. The effect could be due to synergism or better utilization of the fertilizer applied by the crop. Tank mixing of herbicides with urea is adopted to a large extent in the *Kole* fields, under the popular belief that the herbicide efficacy would be enhanced. Scientific information on the compatibility of urea with herbicides is scarce, and the effect on bio-efficacy and weed control needs to be evaluated.

The effect of widespread use of herbicides on microorganisms existing in the rice ecosystem is an area which is less explored. In addition to plant pathogens of various kinds, the rice fields are home to an array of microbial bioagents which occur naturally and play a significant role in integrated pest management. They also stimulate plant growth, resulting in better yield. It thus becomes necessary to assess the impact of commonly used herbicides on both plant pathogens and microbial bioagents.

With the above considerations in view, the present research programme entitled "Bio-efficacy of tank mixed herbicides and urea in wet seeded rice" was conducted with the following objectives:

1. To assess the additive, synergistic or antagonistic effect of tank mixing of commonly used rice herbicides on major weeds
2. To investigate the efficiency of these herbicides on mixing with urea, and
3. To assess the effect of commonly used herbicides on beneficial and disease causing organisms

Review of literature

2. REVIEW OF LITERATURE

Tank mixing of agrochemicals to control pests and weeds, and for additional supply of nutrients to crops is a common practice followed by farmers to save time and labour. However, in most of the cases, mixing is done without any knowledge of the interactions of various chemicals. Though synergistic effects could occur, the possibility of antagonistic interactions cannot be ignored.

Broad spectrum herbicides like bispyribac-sodium and pre mix herbicide (cyhalofop-butyl + penoxsulam) are extremely popular among farmers. However, bispyribac-sodium does not control *Leptochloa chinensis*, and (cyhalofop-butyl + penoxsulam) is less efficient against dicot weeds like *Ludwigia perennis*. Mixing these herbicides with other herbicides is reported to give good results.

In the main rice bowls of Kuttanad and *Kole*, farmers are educated and highly aware of developments in pesticide use. Mixing of various pesticides, and pesticides with fertilizers like urea is a common practice, and methods for increasing herbicide efficiency are arrived at by trial and error.

Microbial bioagents occurring naturally in nature play an important role in integrated pest management. They also have plant growth promoting effects which results in better yield. Application of chemical herbicides may affect the bio agents adversely and information on the compatibility of herbicides used in rice cultivation with bioagents is essential. At the same time, it is also necessary to assess the effect of these chemicals on disease causing organisms. New generation herbicides have different chemical compositions with very low residue build-up and low mammalian toxicity.

In this background a brief review on synergistic or antagonistic effect of tank mixing of commonly used rice herbicides on major weeds and the efficiency of these herbicides on mixing with urea is presented below. Literature on plant pathogens and biocontrol agents affected by herbicides has also been documented. In addition to this, the effect of herbicide combinations on economics of cultivation and nutrient uptake, and the visual phytoxicity symptoms of herbicide combinations have been reviewed in this chapter.

2.1 WEED SPECTRUM IN DIRECT SEEDED RICE

Major weeds in wet seeded rice fields of Kerala were *Echinochloa crus-galli, Cyperus* sp.*, Fimbristylis miliacea* and *Monochoria vaginalis* as reported by Nair *et al.* (1974). Moorthy and Dubey (1978) observed that sedges were the major weed species contributing to 90 per cent of the population in wet seeded rice. Joseph (1986) observed higher density of *Cyperus iria and C. difformis* in wet seeded rice in Kerala. Joy *et al.* (1991) reported that the weed population in wet seeded rice was composed majorly predominantly of sedges (40%), broad leaf weeds (32%) and grasses (22%) in Kerala.

In wet seeded rice, higher densities of *Echinochloa colona, Eleusine indica* and *Leptochloa chinensis* were observed (Singh *et al*., 2005). Similarly, Mann *et al.* (2007) recorded weed species *Echinochloa crus-galli, Trianthema* portulacastrum, *Paspalum distichum, Eclipta prostata, Cyperus difformis,* and *C. iria*.

Sanjoy (2009) observed *Echinochloa crus-galli, Cyperus iria, Fimbristylis miliacea, Ludwigia parviflora, Sphenochlea zeylanica,* and *Commelina benghalensis* as major weeds in rice ecosystem. *Monochoria hastate* and *Nymphoides indicum* were present in tillering stage and *Ludwigia perennis*, *Cyperus flavidus*, *Cyperus difformis* and *Cynodon dactylon* were present in the entire crop season in rice (Mukherjee and Malty, 2011).

Chaudhary *et al.* (2011) found *Echinochloa colona, E. crus-galli, Cyperus iria, C. rotundus, Eleusine indica, Fimbristylis miliacea, Ammania baccifera*, *Caesulia axillaris* and *Amaranthus viridis* to be the major weed species in direct wet seeded rice. *Echinochloa colona, E. crus-galli, Commelina benghalensis, Caesulia axillaris, Cynotis axillaris, Ammania baccifera* and *Cyperus* spp were found in rice fields of Uttar Pradesh by Singh (2012). Pratap *et al.* (2016a) reported that *Echinochloa crus-galli*, *E. colona*, *Leptochloa chinensis*, *Cyperus iria*, *Ammania baccifera*, *Alternanthera sessilis* and *Caesulia axillaris* were the major weeds in transplanted rice.

Paspalum distichium and *Echinochloa colona*, *Cyperus iria* and *Ludwigia parviflora* were dominant in transplanted *Kharif* (wet) rice (Teja *et al.,* 2016). The predominant weeds in fields of direct seeded rice were *Cynodon dactylon, Echinochloa* sp., *Bracharia mutica, Digitarias anguinalis*, *Panicum repens*, *Leptochloa chinensis*, *Cyperus* sp., *Commelina communis*, *Ludwigia parviflora* and *Eclipta alba* as observed by Ramesha *et al.* (2017).

In wet seeded rice, *Echinochloa crus-galli*, *E. colona, Cynodon dactylon*, *Cyperus rotundus*, *C. difformis*, *Marsilea quadrifolia*, *Eclipta alba, Sphaeranthus indicus* were predominant (Chinnamani *et al.,* 2018). Singh *et al.* (2019) revealed the dominant weed speciesto be *Echinochloa glabrescens*, *Dactyloctenium aegyptium, Eragrostis japonica* and *Leptochloa chinensis* at CCS Haryana Agricultural University, Hisar.

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 iria*, *Cyperus difformis, Cyperus rotundus* and *Fimbristylis maliacea*. *Phyllanthus niruri*, *Caesulia axillaris* and *Anagallis arvensis* were the common broad-leaf weeds. The major weed species found in wet seeded rice of *Kole* lands were grasses like *Echinochloa* spp and *Leptochloa chinensis. Cyperus* spp and *Fimbristylis miliacea* were the main sedges, and *Limnophila heterophyll, Ludwigia perennis*, and *Eichhornia crassipes* were the chief broad leaf weeds (Mounisha and Menon, 2020).

2.2 TANK MIX HERBICIDE COMBINATIONS ON WEEDS

2.2.1 Additive/synergistic effects

Chopra and Chopra (2005) observed higher weed control efficiency (88-90%) and seed yield (3367 kg/ha) with clodinafop and fenoxaprop over sole application in wheat. Effective control of weeds (76-87%) was achieved with tank mix application of triasulfuron (25 g/ha) + c1odinafop (50 g/ha), fenoxaprop (100 g/ha) or sulfosulfuron (20 g/ha) in wheat (Malik *et al.,* 2005).

Experimental results of Singh *et al.* (2005) brought out that application of pendimethalin (1.0 kg/ha) with 2, 4-D (0.5 kg/ha) recorded highest weed control efficiency and grain yield over the other treatments. A study conducted by Singh and Singh (2005) revealed that the success of tank mix application of clodinafop-propargyl with metsulfuron-methyl and carfentrazone-ethyl for the control of *Phalaris minor* and *Chenopodium album* in wheat, whereas clodinafop and fenoxaprop had no compatibility with 2,4-D.

Buehring (2006) conducted field experiments for the control of weeds species Amazon sprangletop and barnyard grass and achieved control by tank mix application of fenoxaprop + isoxadifen. Tank mix application of saflufenacil + imazethapyr in an experiment conducted to control red rice affected the weed adversely. However, although rice injured with higher doses of saflufenacil tank mixing, yield was not affected as reported by Camargo *et al.* (2012).

Chauhan and Abugho (2012) observed good control of barnyard grass, sprangletop, and jungle rice with tank mix application of fenoxaprop + ethoxysulfuron (>97%), and penoxsulam + cyhalofop controlled 89-100 per cent of the weeds, but control of southern crabgrass was only 54 per cent. Tank mixture of herbicides bispyribac-sodium + ethoxysulfuron resulted in higher control of weeds (both density and dry weight) and higher kernel quality attributes and rice yield over control (Khaliq *et al.,* 2012).

Lap *et al.* (2013) reported that combination of penoxsulam + cyhalofop-butyl tank mix application at 7 to 18 days after sowing controlled more than 90 per cent of common weeds and resulted in increase of 20-50 per cent yield over control.

A field experiment was conducted by Hossain and Mondal (2014) in transplanted rice at Visva-Bharati, Sriniketan during *Kharif* seasons of 2012 and 2013. Effective control of weeds and higher grain yield were achieved with bispyribac

+ (metsulfuron-methyl + chlorimuron-ethyl) and it was at par with bispyribac + ethoxysulfuron applied as post-emergence, as compared to sole application. Higher weed control efficiency with bispyribac-sodium was comparable to cyhalofop-butyl/fenoxaprop-p-ethyl/metamifop with follow up spray of (chlorimuron-ethyl + metsulfuron-methyl) as observed by Prameela *et al.* (2014) in wet seeded rice.

Revathi and Annadura (2014) conducted field experiments at Tiruchirappalli, Tamil Nadu, during *Rabi* 2011-12 and 2012-13. Results showed that application of pre-emergence pyrazosulfuron-ethyl (30 g/ha) + post emergence bispyribac-sodium (20 g/ha) realized higher weed control efficiency and productivity and it was comparable with hand weeding twice at 20 and 40 DAS.

A field study was conducted in 2012 and 2013 at IRRI, Philippines, to evaluate the performance of sole and sequential applications in DSR. Reports showed that application of thiobencarb + 2,4-D *fb* fenoxaprop + ethoxysulfuron, and oxadiazon *fb* fenoxaprop + ethoxysulfuron were effective control measures and reduced weed density and biomass and resulted in higher yield (5.83 t/ha) compared to the non-treated plots (Awana *et al.,* 2015).

Chauhan *et al.* (2015) conducted a field experiment during the dry seasons of 2013 and 2014 at the IRRI, Philippines to evaluate the performance of herbicides combined with mechanical weeding in DSR and observed that lowest weed density, biomass and higher grain yield (5.3-5.8 t/ha) were found in the treatment oxadiazon followed by (*fb*) fenoxaprop + ethoxysulfuron *fb* 2,4-D *fb* mechanical weeding (MW) at 42 days after sowing (DAS).

Mahajan and Chauhan (2015) conducted field experiments in the wet seasons of 2013 and 2014 to study weed control in response to tank mixtures of herbicides currently applied in DSR in South Asia. Results revealed that highest weed control efficiency (98%) was recorded with the tank mixture of azimsulfuron + bispyribac + fenoxaprop during both the years. This treatment also produced highest grain yield (7.2 t/ha in 2013 and 7.9 t/ha in 2014), which was similar to the grain yield in the plots treated with tank mix of azimsulfuron + fenoxaprop, and pendimethalin (applied as pre-emergence).

Singh *et al.* (2015) conducted field experiments during winter seasons of 2010-12 at Banaras Hindu University, Varanasi and observed that herbicidal application of sulfosulfuron + metsulfuron (32 g/ha) at 30 DAS had lower density and dry weight of weeds and led to enhanced the production of grain yield of wheat.

Bhullar *et al.* (2016) assessed the efficacy and compatibility of tank mixtures of different herbicides for the control of diverse weed flora in dry-seeded rice during the summer seasons of 2012 and 2013 and stated that the tank mixture of fenoxaprop with ethoxysulfuron improved the control of *Echinochloa* spp by 43-69 per cent as compared to fenoxaprop alone. It also improved the grain yield (5.6-6.2 t/ha).

Kaur *et al.* (2016) conducted field experiment to study the bio-efficacy of herbicide combinations on mixed weed flora and productivity in puddled transplanted rice. Post-emergence, tank-mix application of bispyribac-sodium with either ethoxysulfuron or chlorimuron + metsulfuron (pre-mix) recorded comparable WCE and yield to that obtained with sequential application of pendimethalin and bispyribac-sodium or pretilachlor with either ethoxysulfuron or chlorimuron + metsulfuron (pre-mix).

An experiment was conducted at Alappad *Kole* to evaluate the bio-efficacy of herbicide combinations by Menon *et al.* (2016) and results revealed that lower weed DMP, higher weed control efficiency and grain yield were achieved by triafamone + ethoxysulfuron, and bispyribac-sodium + (chlorimuron-ethyl + metsulfuron-methyl). Pratap *et al.* (2016) documented that application of penoxsulam + cyahalofop-butyl, hand weeding twice at 25 and 45 DAT, pendimethalin *fb* bispyribac-sodium and pretilachlor *fb* ethoxysulfuron recorded lower weed density, higher weed control efficiency and grain yield with over rest of the herbicidal treatments.

Pratap *et al.* (2016a) observed that significantly lower total weed density, dry matter accumulation and highest weed control efficiency with the application of bispyribac-sodium + ethoxysulfuron (25 + 18.75 g/ha) and it was at par with pretilachlor 750 g/ha *fb* chlorimuron-ethyl + metsulfuron-methyl (4 g/ha) and bispyribac-sodium + (chlorimuron-ethyl + metsulfuron-methyl (20 + 4 g/ha).

Field experiments conducted by Raj and Syriac (2016) for two seasons to assess the bio-efficacy of bispyribac-sodium + metamifop for broad spectrum weed control in DSR revealed that application of bispyribac-sodium + metamifop (90 g/ha) registered the highest weed control efficiency (96.62%) and grain yield (8.05t/ha).

Rana *et al.* (2016) evaluated various weed management practices during *Kharif* 2013, 2014 and 2015 at Palampur results shown that application ofpendimethalin *fb* bispyribac *fb* manual weeding found highest crop resistance index and efficiency index and lowest weed index.

In a field experiment on tank mixtures and sequential application of herbicides, tank mixture of bispyribac-sodium + (metsulfuron-methyl + chlorimuron-ethyl) recorded the lowest weed count and weed dry matter, and highest WCE, yield attributes and grain yield of rice (Sreelakshmi *et al.,* 2016). Results of a field experiment conducted by Sudha *et al.* (2016) revealed that lower weed density, weed DMP and higher weed control efficiency were recorded with sulfosulfuron + metsulfuron (25 + 4 g/ha) as compared to unweeded control.

Sarkar *et al.* (2016) showed that higher grain yield were observed under pre-emeregence application of bensulfuron-methyl + pretilachlor (10 DAT) *fb* hand weeding (40 DAT) and bispyribac-sodium as over other treatments. Field experiments conducted by Teja *et al.* (2016) in wet season transplanted rice revealed that combined application of azimsulfuron (35 g) + 2,4-D (500 g/ha) at 25 DAT registered lower weed density and total weed DMP and higher yield over sole application.

Efficient weed control and higher grain yield were observed by Yakadri *et al.* (2016) on the application of pretilachlor (750 g/ha) *fb* ethoxysulfuron (18.75 kg/ha) and it was at par with pretilachlor (750 g/ha) *fb* (metsulfuron-methyl + chlorimuron-ethyl) (4 g/ha) or pyrazosulfuron (20 g/ha) *fb* manual weeding in transplanted rice.

In a field experiment conducted by Barla *et al.* (2017) higher total and effective tillers and grain yield (3.08 t/ha) were obtained with the application of pendimethalin + metribuzin (1.0 kg/ha + 0.175 kg/ha) *fb* clodinafop (0.06 kg/ha). Bhatt *et al.* (2017) conducted field experiment and secured higher grain yield with the application of pyrazosulfuron-ethyl (20 g/ha) at 3 DAT *fb* manual weeding at 25 DAT (6.8 t/ha), pretilachlor (750 g/ha) at 3 DAT *fb* (metsulfuron-methyl + chlorimuron-ethyl) (4 g/ha) at 25 DAT (6.6 t/ha) and bispyribac-sodium (20 g/ha) + (metsulfuron-methyl + chlorimuron-ethyl) (4 g/ha) at 25 DAT (6.3 t/ha).

Hossain and Malik (2017) reported that effective control of total weeds and highest number of effective tillers/m^2, number of grains/panicle and grain yield were obtained with the application of ready mix of penoxsulam + cyhalofop in transplanted rice. Hemalatha *et al.* (2017) revealed that application of pendimethalin (0.75 kg/ha at 3-5 DAS) *fb* metsulfuronmethyl + chlorimuron-ethyl (4 g/ha at 20-25 DAS) resulted in lower weed index, higher weed control efficiency and grain yield.

Mohapatra and Tripathy (2017) recorded lowest total weed density (8 no./m^2), weed DMP (3.5 g/m^2), and enhanced weed control efficiency (84.6%), and rice grain yield (5.23 t/ha) as well as low dead hearts (0.59%) and white ears (3.5%) incidence with tank mixture of (cyhalofop-butyl + penoxsulam) + fipronil (135 + 50 g/ha) when compared with sole application of fipronil.

Kaur *et al.* (2017), in field experiments of wheat, applied tank mix of pendimethalin + metribuzin and got control of *P. minor* (78-85%), *Medicago denticulata* (77-92%), *Rumex dentatus* (98-100%) and *Chenpodium album* (98-100%). Pendimethalin *fb* sulfosulfuron as sequential application recorded the highest weed control efficiency (96%) and grain yield (4.8 t/ha) and was at par with pendimethalin + metribuzin tank mixture.

A field experiment conducted by Prakash *et al.* (2017) during *Kharif* 2014 and 2015 at the Crop Research Centre, Meerut to develop weed management practice in rice showed that pendimethalin *fb* bispyribac significantly lowered total weed density, whereas tank mix of bispyribac + (chlorimuron-ethyl + metsulfuron-methyl) at 60 DAT lowered total weed dry matter and weed density, and increased weed control efficiency and grain yield of rice.

Rana *et al.* (2017) reported that clodinafop + metsulfuron, pinoxaden + metsulfuron and pendimethalin *fb* metsulfuron herbicide combimations were effective in reducing weed count and dry weight, and increasing plant growth and yield attributes and yield (28.6, 22.5 and 23.1% higher grain yield over two hand weedings) in wheat.

An in-depth field study on the effect of various herbicides on weed controls in irrigated dry-seeded rice was carried out during *Kharif* 2015 and summer of 2016 at Raichur, Karnataka, Agricultural Research Station. The application of BAS 9548 H (penoxsulam 10 g/l + bentazone 360 g/l SC), 3000 ml/ha, followed by BAS 9548 (penoxsulam 10 g/l + bentazone 360 g/l SC), 2500 ml/ha, and hand weeding twice at 15 and 30 DAS, resulted in considerably greater rice grain production (Ramesha *et al.,* 2017).

According to Rakes *et al.* (2017), application of tank mixed Clincher®+ Ricer®, Clincher® + Kifix®, Clincher® + imazethapyr + Nortox®, Clincher® + Ricer®+ Kifix®, Clincher® + Ricer® + Sirius®, imazethapyr + Nortox® + Basagran® did not present any physicochemical change in the spray mix and were therefore, compatible to be used as herbicide mixtures for rice.

Experimental testing of Verma *et al.* (2017) showed that the most effective way of controlling any weed type in transplanted *Kharif* rice was with the various herbicidal formulation of flucetosulfuron + bispyribac-sodium @ 20 + 25 g/ha at 2-3 DAT, and then at 15 to 20 DAT.

Yogananda *et al.* (2017) conducted experiments in wet direct-seeded rice in the Cauvery command area of Karnataka during the rainy seasons of 2014 and 2015 and revealed that pre-emergence application of bensulfuron-methyl + pretilachlor GR (Londax Power) at 660 g/ha *fb* bispyribac-sodium at 25 g/ha at 20 days after sowing

(DAS) significantly reduced weed growth and increased seed yield (4.80 t/ha), and it was comparable to other sequential application treatments, such as pre-emergence application of pendimethalin (Stomp-1.0 kg/ha) *fb* bispyribac-sodium post-emergence application.

Choudhary and Anil (2018) investigated the effects of herbicide combinations and concluded that pyrazosulfuron + pretilachlor offered broad-spectrum weed control at 15 + 600 g/ha to 30 + 1200 g/ha (61.6-81.5%), which was comparable to two hand weedings at 15 and 30 days after sowing. Grain yield and crop growth and yield features (panicle length, panicle weight, and filled grains/panicle) were higher with pyrazosulfuron + pretilachlor at 15 + 600, 16.88 + 675, and 30 + 1200 g/ha, respectively. According to Ghosh *et al.* (2018), tank mix treatment of bispyribac-sodium + 2,4-D reduced weed growth at an early stage and increased rice grain yield.

Kaur and Dhillon (2018) reported that effective weed control efficiency and highest output in wheat were recorded with mesosulfuron + iododosulfuron (5.1 t/ha) and it was statistically equivalent to pendimethalin (5.06 t/ha), fenoxaprop + metribizin (5.01 t/ha) or sulfosulfuron (4.98 t/ha).

The density and dry weight of weeds was reduced by pretilachlor 1000 g/ha PE or 25 g/ha of pyrazosulfuron-ethyl *fb* bispyribac-sodium salt by 50 g/ha at 30 DAS. These combinations were also associated with improved growth and yield attributes, namely plant height, no. of tillers, no. of panicles/length of panicles and no. of grains/panicle, grain and straw yields (Patel *et al.,* 2018).

A field experiment was conducted by Singh *et al.* (2018) at Agricultural Research Farm, Banaras Hindu University, Varanasi to study effect of nitrogen level and weed management in direct-seeded rice. Two hand weedings recorded significantly lower weed biomass and density and better performance of crop growth and higher yield attributes and yield followed by bispyribac-sodium 25 g/ha *fb* cono-weeding.

During *Kharif* 2010-2011, Yadav *et al.* (2018) examined the efficiency of penoxsulam + cyhalofop-butyl in transplanted rice at Regional Research Station, Karnal. They reported that when compared to other treatments, the herbicide reduced the density and dry weight of *Echinochloa crus-galli* and other aerobic grassland and broad leaf weeds, nearly totally controlled sedges, and boosted grain output.

During the *Kharif* season of 2018, a field experiment was undertaken in Tirupati, Andhra Pradesh, to determine the effect of sequential application of pre- and post-emergence herbicides on weed growth and yield of rainfed lowland rice. Pre-emergence applications of pendimethalin (1000 g/ha) *fb* florpyrauxifen-benzyl (25 g/ha) or halosulfuron-methyl (65.7 g/ha) applied at 20 DAS resulted in maximum grain yield and broad-spectrum weed control in rainfed lowland rice (Gangireddy *et al.,* 2019).

Menon (2019) found that triafamone + ethoxysulfuron and cyhalofop-butyl + penoxsulam, as well as bispyribac-sodium and manual weeding at 60 DAS, significantly reduced weed biomass. The treatments triafamone + ethoxysulfuron and manual weeding, followed by cyhalofop-butyl + penoxsulam, all enhanced yield parameters such as number of panicles/m^2 and grain and straw yields.

Singh *et al.* (2019), evaluating the efficency of pendimethalin and cyhalofop-butyl+ penoxsulam, found that pendimethalin could be used in the management of *E. glabrescens, L. chinensis*, *E. japonica* and *D. aegyptium*. However, in fields dominated by *E. glabrescens* and *L. chinensis*, cyhalofop-butyl + penoxsulam could be used as PoE.

According to Yadav *et al.* (2019), penoxsulam + butachlor (41% SE @ 820 g/ha) provided nearly perfect control (98.1-98.5% WCE) of complex weed flora, the maximum number of effective tillers, and highest grain production (5.43-6.06 t/ha).

Yogananda *et al.* (2019) found that at 20 days after sowing (DAS), pre-emergence application of bensulfuron-methyl + pretilachlor (10 kg/ha) *fb* post-emergence application of bispyribac-sodium (25 g/ha) resulted in significantly lower total weed population (39.4 and 43.1/m^2) and weed dry weight (8.2 and 9.0 g/m^2), and higher grain production (4.60 and 4.42 t/ha) in dry direct-seeded rice with high weed control efficacy (77.8 and 77.2%).

Pendimethalin + metribuzin (2000 g/ha) *fb* mesosulfuron + iodosulfuron (14.4 g/ha) and pendimethalin + metribuzin (2000 g/ha) *fb* sulfosulfuron + metsulfuron (32 g/ha) and pinoxaden (50 g/ha) were shown to be the most effective in controlling resistant *P. minor* and producing higher grain yield (Abdull *et al,* 2020).

Mounisha and Menon (2020) revealed that hand weeding had the lowest weed dry matter, highest weed control efficiency, yield characteristics and yield values in rice, followed by florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS and pendimethalin + penoxsulam (625 g/ha) at 5 DAS in wet seeded rice.

In field experiments conducted by Mukherjee (2020) it was found that metsulfuron + carfentrazone (4 + 20 g/ha), halauxifen-methyl ester + florasulam + carfentrazone (10.21 + 20 g/ha) and 2,4-D E + carfentrazone (400 + 20 g/ha) lowered total weed density and dry matter, and produced higher grain yields in wheat.

Mohapatra *et al.* (2020) showed that the use of triafamone + ethoxysulfurone (ready-mix 67.5 g/ha) at 20 DAT recorded 81.7 per cent WCE, enhanced crop growth and yields as well as increased grain yield (6.0 t/ha) in transplanted rice. When compared to unweeded control, Sekhar *et al.* (2020) found that tank mix application of bispyribac-sodium with fenoxaprop-p-ethyl (at 25 + 60 g/ha) or cyhalofop-butyl (at 25 + 80 g/ha) resulted in the lowest total dry matter production of weeds and increased grain yield.

Singh (2020) found that clodinafop + metsulfuron (60 + 2 g/ha) caused significant reductions in total weed counts (28.6 and 40.8/m^2), weed dry weight (3.5 and 4.2 g/m^2), highest weed control efficiency (83 and 82.6%), and higher grain yield of wheat (4.10 and 4.71 t/ha) when compared to sulfosulfuron + metsulfuron (30 + 2 g/ha) and farmers' practice.

Vasudev *et al.* (2020) conducted a field experiment in Udaipur, in 2015-16 and 2016-17 with the objective of determining the bio-efficacy of ready-mix herbicides against complex weed flora in wheat. The results showed that ready-mix applications of sulfosulfuron + metsulfuron (32.0 g/ha) and mesosulfuron + iodosulfuron (14.4 g/ha) resulted in a significant reduction in weed population and growth, a higher value of weed control index (WCI) with maximum reduction of weed density and dry matter, and higher grain yield (34.3 and 20.5% more) than the unweeded control.

Saravanane (2020) conducted field trials at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, and Puducherry UT in 2015-16 and 2016-17. Pendimethalin and bispyribac-sodium (1000 *fb* 25 g/ha) were applied sequentially with manual weeding at 40 days after sowing (DAS), resulting in lower total weed density (14.4/m^2) and dry matter (37 g/m^2), as well as improved rice growth (plant height and tillers/m^2), yield parameters (panicle weight and 1000 grain weight), and higher rice grain yield (3.86 t/ha).

Sen *et al.* (2020) found that sequential pre-emergence applications of pendimethalin (1.0 kg/ha) and a ready-mixture of penoxsulam + cyhalofop-butyl (130 g/ha) at 25 DAS significantly decreased weed dry weight at harvest, and was superior to other treatments. In comparison to the unweeded control, this treatment increased rice grain yield (3.92 t/ha) by 378.9 per cent.

Soni *et al.* (2021) revealed good control of *P. minor*, broad-leaved weeds and total weeds with sequential application of pendimethalin + pyroxasulfone (1500 + 102 g/ha- tank-mix) *fb* mesosulfuron + iodosulfuron (14.4 g/ha - ready-mix, RM), and pendimethalin + metribuzin (1000 + 175 g/ha- TM) *fb* mesosulfuron + iodosulfuron (14.4 g/ha- RM). When compared to the unweeded control, this resulted in greater crop development, higher yield attributes, and higher grain yield (37.6-51.9% higher).

2.2.2 Antagonistic effects

A study conducted in 2000 and 2001 found that carfentrazone and halosulfuron consistently antagonized the activity of fenoxaprop at two rates of application on barnyard grass. Bensulfuron at 10 and 20 DAT and triclopyr at 20

DAT were antagonistic to fenoxaprop (Zhang *et al.*, 2005). Similarly, fenoxaprop-p-ethyl in association with imazethapyr, penoxsulam, halosulfuron-methyl, bensulfuron or bispyribac-sodium decreased control of barnyard grass, while with imazethapyr, penoxsulam and bispyribac-sodium reduced control of *Urochloa platyphylla*, (Blouin *et al.,* 2010).

Yadav *et al.* (2009) found that fenoxaprop + carfentrazone at 120 g/ha was superior to 100 g/ha in terms of *P. minor* density and dry weight, as well as weed control efficiency and grain yield. When used as a tank mixture with fenoxaprop, metsulfuron + 2,4-D ester and Na salt had an antagonistic effect on its efficacy.

Matzenbacher *et al.* (2015) evaluated the effects of different herbicide mixtures used in irrigated rice in order to establish the suitable combinations for the prevention and management of herbicide resistance in barnyard grass. Barnyard grass resistant and susceptible to imidazolinone herbicides were applied with doses of 50 or 75 per cent of the label rates and the occurrence of additive, synergistic and antagonistic effects were identified as 18, 18 and 64 per cent, respectively. Rice grain yield varied according to the efficiency of weed control.

Bhullar *et al.* (2016) conducted field trials of tank mixture of azimsulfuron with fenoxaprop and found that the mixture was antagonistic and reduced the control of *Leptochloa chinensis* by 86 per cent as compared to fenoxaprop alone. Similarly, bispyribac and fenoxaprop mixture was antagonistic for the control of *Dactyloctenum aegyptium*, *Acrachne racemose* and *L. chinensis*.

According to Atheena *et al.* (2017), tank mixing of cyhalofop-butyl (80 g/ha) with pyrazosulfuron-ethyl (30 g/ha) at 18 DAS provided effective control of mixed weed flora in wet-seeded rice. Tank mixing of cyhalofop-butyl with (chlorimuron-ethyl + mesulfuron-methyl) had to be avoided as the activity of cyhalophop-butyl would be lost altogether, whereas pre-emergence herbicide mixing was found to be less effective than their sequential application. The result was the total loss of cyhalophop -butyl activity.

Miller *et al.* (2018) conducting field trials to assess florpyrauxifen-benzyl efficacy and tank mixing compatibility, found a high Palmer amaranth control level of 96 and 99 per cent respectively with florpyrauxifen-benzyl (30 and 40 g/ha).

2.3 EFFECT OF TANK MIX OF HERBICIDES AND UREA ON WEEDS

2.3.1 Additive/synergistic effect

Tank mixing and foliar application of urea fertilizer and selective herbicides was evaluated during 1999 to 2001 at Weed Research Station of Plant Pest and Diseases Research Institute, Karaj, and their results indicated that urea + tribenuron-methyl + clodinafop-propargile was the best combination for controlling weeds and increasing grain yield of wheat (Moeini *et al.*, 2006).

Soliman *et al.* (2011) indicated that under severe annual infestation with weeds, herbicides (isoproturon + diflufenic), tribenuron-methyl and clodinafop-propargyl could be used at a moderate rate with one per cent urea to control annual weeds, broad leaf weeds and grassy weeds respectively, to increase wheat yield and its components.

According to Singh *et al.* (2015), tank mix combination of (penoxsulam + cyhalofop-butyl) + carbendazim (150 + 125 g/ha) and urea was more successful at reducing *E. colona* and *P. maxicum* density and weed total dry weight. Similarly, there was an increase in the number of panicles/m^2, grains/panicle, and yield.

2.4 ECONOMICS OF RICE PRODUCTION

Spraying herbicide mixtures for broad range weed control resulted in better production and B:C ratio (Jacob *et al.,* 2014). According to Hossain and Mondal (2014), tank mix application of bispyribac + (metsulfuron-methyl + chlorimuron-ethyl) produced the highest net returns and B:C ratio.

Raj and Syriac (2016) revealed that when compared to sole application of bispyribac-sodium, the application of bispyribac-sodium + metamifop achieved the highest net returns (Rs. 86,238/ha). The maximum net returns were achieved with pendimethalin *fb* bispyribac-sodium followed by manual weeding 45 days after sowing, with a greater B:C ratio as recorded by Madhavi *et al.* (2016).

Rana *et al.* (2016) secured higher net returns in oxadiargyl *fb* bispyribac application in direct seeded rice. Compared to the other treatments, sulfosulfuron + metsulfuron (25 + 4 g/ha) had the highest gross returns, net returns, and benefit:cost ratio (Sudha *et al.,* 2016).

Higher value of benefit:cost ratio (1.92) was obtained with the application of bensulfuron-methyl + pretilachlor as PE along with (metsulfuron-methyl + chlorimuron-ethyl) as POE as reported by Sarkar *et al.* (2016). Pretilachlor (750 g/ha) *fb* ethoxysulfuron (18.75 kg/ha), or pretilachlor (750 g/ha) *fb* (metsulfuron-methyl + chlorimuron-ethyl) (4 g/ha) or pyrazosulfuron (20 g/ha) resulted in a greater B:C ratio, according to Yakadri *et al.* (2016).

In comparison to other herbicides, application of pendimethalin + metribuzin (1.0 kg/ha + 0.175 kg/ha) *fb* clodinafop (0.06 kg/ha) resulted in net returns (Rs. 32,019/ha) and a B:C ratio (1.33) (Barla *et al.* 2017). Pyrazosulfuron-ethyl (20 g/ha at 3 DAT) *fb* manual weeding (25 DAT- Rs. 69,788, B:C 2.79), pretilachlor 750 g/ha (at 3 DAT) *fb* metsulfuron-methyl + chlorimuron-ethyl (4 g/ha at 25 DAT- Rs. 67,646, B:C 2.77) had higher net returns (Rs./ha) (Bhatt *et al.,* 2017).

According to Rana *et al.* (2017), clodinafop + metsulfuron produced the highest net returns and marginal benefit: cost ratio (MBCR) in wheat. The tank mixture of (cyhalofop-butyl + penoxsulam) + fipronil (135 + 50 g/ha) secured highest net returns (40.44 x 103 t/ha) and B:C ratio (2.02) (Mohapatra and Tripathy, 2017). Ramesha *et al.* (2017) realised that plots treated with BAS 9548 H (penoxsulam 10 g/L + bentazone 360 g/L SC) had the highest B:C ratio. Pre-emergence application of bensulfuron-methyl + pretilachlor GR (Londax Power) at 660 g/ha *fb* bispyribac-sodium at 25 g/ha at 20 days after sowing (DAS) resulted in greater net monetary returns (Rs. 25,631/ha) and a B:C ratio of 1.62 compared to other sequential treatments (Yogananda *et al.,* 2017).

Patel *et al.* (2018) found that the use of pretilachlor (1250 g/ha) or pyrazosulfuron-ethyl (25 g/ha) *fb* bispyribac-sodium (50 g/ha at 30 DAS) and pendimethalin (1.0 kg/ha) *fb* bispyribac-sodium (0.04 kg/ha) resulted in greater net returns. According to Yadav *et al.* (2018), net returns and B:C ratio were higher when penoxsulam + cyhalofop-butyl was used compared to other treatments.

According to Gangireddy *et al.* (2019), application of pendimethalin (1000 g/ha) *fb* florpyrauxifen-benzyl (25 g/ha) or halosulfuron-methyl (65.7 g/ha) at 20 DAS yielded the best economic returns. Dhakal *et al.* (2019) secured higher economic returns with pendimethalin *fb* 2,4-D, bispyribac-sodium and oxadiargyl in rice.

In dry direct-seeded rice, Yogananda *et al.* (2019) found that using bensulfuron-methyl + pretilachlor (10 kg/ha) *fb* bispyribac-sodium (25 g/ha at 20 DAS) resulted in greater net monetary returns (Rs. 39,340 and 36,710/ha) and B:C ratio (2.32 and 2.23).

Abdull *et al.* (2020) secured higher profitability with sequential application of PE pendimethalin + metribuzin *fb* mesosulfuron + iodosulfuron. The B: C ratio was greater when pre-emergence pendimethalin (1.0 kg/ha) was combined with manual weeding with or without bispyribac-sodium treatment and manual weeding three times (Saravanane, 2020).

Higher net returns (Rs. 69,360/ha) were realized with triafamone + ethoxysulfuron (67.5 g/ha at 20 DAT) application in rice (Mohapatra *et al.*, 2020). Pendimethalin (1.0 kg/ha) *fb* (penoxsulam + cyhalofop-butyl) (130 g/ha at 25 DAS) was found to be superior to other treatments with greater gross benefit:cost ratio of 2.30 reported by Sen *et al.* (2020). Clodinafop + metsulfuron (60 + 2 g/ha) secured the highest net returns (Rs. 51,003 and 65,267/ha) and B:C ratio (2.78 and 3.45) as reported by Singh (2020).

Vasudev *et al.* (2020) found that ready-mix applications of sulfosulfuron + metsulfuron (32.0 g/ha) and mesosulfuron + iodosulfuron (14.4 g/ha) produced 49.1 and 47.7 per cent higher net returns and a B:C ratio (2.34 and 2.32) than the unweeded control. Soni *et al.* (2021) found that pendimethalin + pyroxasulfone *fb* mesosulfuron + iodosulfuron, and pendimethalin + metribuzin *fb* mesosulfuron + iodosulfuron produced better net returns over other treatments.

2.5 EFFECT OF HERBICIDES ON NUTRIENT UPTAKE BY WEEDS AND RICE

Nanjappa and Krishnamurthy (1980) reported that the lowest nutrient removal by weeds was in hand weeding (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).

Kumar *et al.* (2010) found that nutrient uptake by weeds in direct seeded rice could be reduced with HW *fb* pendimethalin + anilophos. 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 + metsulfuron-methyl) 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).

The application of pre-mix herbicide combination of cyhalofop-butyl + penoxsulam effectively 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). Significantly higher dry matter accumulation at harvest (1352 g/m^2) was achieved with application of bispyribac + (chlorimuron-ethyl + metsulfuron-methyl) (Prakash *et al.,* 2017).

Pendimethalin (0.75 kg/ha at 3-5 DAS) *fb* (metsulfuronmethyl + chlorimuron-ethyl) (4 g/ha at 20-25 DAS) resulted in higher nutrient uptake in crops and lower nutrient uptake in weeds (Hemalatha *et al.,* 2017). Devi and Singh (2018) reported that application of bispyribac + azimsulfuron at 15-20 DAS established their superiority in minimizing the nitrogen removable by weeds, after hand weeding twice at 20 and 40 DAS. Higher total nutrient uptake found with metsulfuron +

carfentrazone and it was significantly better than other treatments as reported by Mukherjee (2020).

2.6 TANK MIX OF HERBICIDE COMBINATIONS AND UREA ON SOIL MICROBIAL ACTIVITY

2.6.1 Soil dehydrogenase

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. Dehydrogenase activity is used as an indicator of biological redox systems and as measure of microbial activity in soil. The microbiological activity of a soil has a direct impact on ecosystem stability and fertility, and it is widely understood that sustaining soil quality requires a high degree of microbiological activity (Dick *et al.,* 1993). Soil enzyme activities are more sensitive to both natural and anthropogenic disturbances and show a quick response to the induced changes (Dick, 1997). Dehydrogenase activity is considered as the most sensitive indicator of soil microbial activity due its association with viable microbial populations (Mijangos *et al.,* 2006). Most of the herbicides applied to the soil had inhibitory effect on the enzyme dehydrogenase (Sebiomo *et al.,* 2011). Therefore, the assay of microbial biomass carbon and dehydrogenase activity in the soil will be useful to understand the potential adverse effect of herbicides on soil health and to predict the persistence of herbicide residues in the soil system under rice.

In puddled soil of rice fields, dehydrogenase activity of the herbicide treated soil increased just after the application and peaked on the 4th day but dropped rapidly during subsequent weeks (Shukla, 1997). The amount of rainfall received and the topography determined the water stagnation period in rice fields, as well as the enzyme activity of soils, which influenced rice growth and nutrition (Tsubo *et al*., 2005).

The dehydrogenase activity of rice soils in low rainfall areas ranged from 18.47 g TPF/g soil/day in the lowlands to 19.30 g TPF/g soil/day in the uplands, according to Nayak and Manjappa (2010). It ranged from 17.45 g TPF/g soil/day in the lowlands to 19.02 g TPF/g soil/day in the uplands due to heavy rain.

When compared to other herbicides used for treatment, Sebiomo *et al.* (2011) found that soils treated with Primextra® had the lowest dehydrogenase activity of 16.09 g (g/min) after the sixth week of treatment, while soils treated with glyphosate had the highest dehydrogenase activity of 20.16 g (g/min). From the second to the sixth week of treatment, dehydrogenase activity increased, indicating a significant response of soil microbial activity to herbicide treatment and increased adaptation of the microbial community to the stress caused by increased herbicide concentrations over weeks of treatment.

Vandana *et al.* (2012) investigated the effect of herbicides on dehydrogenase activity in flooded rice soil and found a significant increase in all treatments between 20 and 40 DAT, which corresponded to the rice crop's most active growth period, and which could be due to the proliferation of anaerobic micro-flora in the rhizosphere. At 120 DAT, dehydrogenase activity was stabilised at lower levels, possibly due to the soil reaching a moisture content between field capacity and permanent wilting point, which showed the effect of soil drying on dehydrogenase activity.

Das *et al.* (2015) evaluated the activity of dehydrogenase enzyme in both *Kharif* (wet) and *Rabi* (dry) seasons and highest activity was noticed in *Kharif*, ranging 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. Highest activity was observed at panicle initiation stage during both seasons followed by maximum tillering, active tillering and heading stages (PI> MT> AT> H).

An increase in dehydrogenase activity was observed by Raj *et al.* (2015) in all herbicide treated plots at 15 days after application. The same trend was observed at 45 days after herbicide application. With regard to phosphatase activity, irrespective of treatments, decline in activity was observed at 15 days after herbicide application. On 15 and 45 days after herbicide application, bispyribac-sodium applied at 70, 80 and 90 g/ha was on par with weedy check.

According to Islam and Borthakur (2016), soil dehydrogenase activity ranged from 315.10 mg TPF kg/soil/d to 572.95 mg TPF kg/soil/d in 0-10 cm depth and from 124.25 mg TPF kg/soil/d to 332.56 mg TPF kg/soil/d in 10-20 cm depth, with a progressive decrease in dehydrogenase activity from 90 DAT to 150 DAT.

Amritha and Devi (2017) documented that effects of herbicide application on dehydrogenase activity increased up to 60 days after herbicide application (DAHA) with slight variations and declined thereafter, registering a peak at 60 DAHA. Dehydrogenase activity at 15 DAHA was comparatively lower than activity at seven days after pendimethalin treatment. Soil dehydrogenase activity at 15 DAHA was studied by Priya *et al*. (2017) with different herbicides in DSR. Soils treated with bispyribac-sodium + metamifop at 140 g/ha recorded lower dehydrogenase activity of 56.79 µg TPF released/g soil over other treatments, whereas unsprayed control and hand weeding registered maximum dehydrogenase activity (122.70 and 114.68 µg TPF released/g soil).

The experiment carried out with flucetosulfuron applied at different rates (20, 25 and 30 g/ha) and days after sowing (2-3, 10-12 and 18-20) indicated that dehydrogenase enzyme activity and organic carbon content at 15 and 30 days after herbicide application was the highest when the herbicide was applied @ 25g/ha at 10-12 and 18-20 DAS compared to 2-3 DAS (Arya *et al*., 2018).

Pertile *et al.* (2020) revealed that with the exception of soil without previous application of the herbicide fumioxazin in soil, dehydrogenase activity (DHA) increased significantly after herbicide application compared to the control, while DHA increased at 15 days after herbicide application and decreased at 30 and 60 days during the incubation.

Mahapatra *et al.* (2021) revealed that at 4 days after application of herbicides, the DHA content of weed-free (8.421 mg TPF/g of dry soil/h), weedy check (8.392 mg TPF/g of dry soil/h) and bispyribac-sodium@ 30 g/ha (8.777 mg TPF/g of dry soil/h) remained almost unaffected whereas the highest decrease occurred in florpyrauxifen-benzyl + cyhalofop-butyl @ 360 g/ha (3.370 mg TPF/g of dry soil/h) *fb* florpyrauxifen-benzyl + cyhalofop-butyl @ 180 g/ha (4.961 mg TPF/g of dry soil/h), florpyrauxifen-benzyl + cyhalofop-butyl @ 150 g/ha (5.093 mg TPF/g of dry soil/h) and florpyrauxifen-benzyl + cyhalofop-butyl @ 120 g/ha (5.765 mg TPF/g of dry soil/h).

2.6.2 Soil microbial biomass carbon

The live component of soil organic matter is microbial biomass. Organic matter is the preferred energy source for microbes, hence soils with a lot of organic matter have a lot of microbial biomass. In most soils, the surface horizon had the most microbial activity relative to the deeper horizons (Januszek, 2011). Microbial biomass performed the majority of enzymatic transformations in soil, resulting in the stabilisation of a portion of the organic components as humus and the utilisation of the remaining carbon and other nutrients by bacteria for their own growth (Anderson and Domsch, 1989). Seasonal variations in soil moisture, temperature, and accessible residue had a significant impact on microbial biomass and activity in the soil (Diaz-Ravina *et al.* 1995).

According to Haney *et al.* (2000), an increase in C mineralization rate occurred the first day after glyphosate application and lasted for 14 days. Microbes observed to breakdown glyphosate directly and quickly, even at high application rates, without reducing microbial activity. Similar results by Subhani *et al*. (2000) showed no impact of recommended doses on microbial population growth and application of herbicides whereas higher dose adversely affected growth.

Lupwayi *et al*. (2003) conducted an experiment to study the effect of different herbicides on soil microbial biomass carbon and results showed that none of the herbicides had a significant overall effect on soil microbial C, but weekly analysis of the data showed that glufosinate ammonium and metribuzin decreased microbial C at four weeks after herbicide application, whereas microbial C tended to decrease with increasing incubation period, particularly in the first two to three weeks after herbicide spray of imazethapyr in soils.

Das *et al*. (2003) revealed that application of oxyfluorfen and oxadiazone did not show any inhibitory effect on phosphate solubilizing microorganisms in rice field and application of herbicides accelerated the microbial population up to 30 days while herbicide treatments at both recommended and 1.5 times of recommended rates resulted in decreases in microbial counts. Similarly, higher concentrations of herbicide treatments resulted in much lower microbial counts compared to soils treated with recommended dose (Ayansina and Oso, 2006).

Gupta and Joshi (2009) found that the application of all the concentrations of 2, 4-D showed statistically significant decreases in biomass C and greater response (430 μg/g) was in ¼ EC_{50} treatments while the treatments ½ EC_{50} and EC_{50} showed relatively lower values with respect to the control treatment.

As per Mondal *et al*. (2011) herbicides (butachlor, pyrozosulfuron, paraquat and glyphosate) have been known to have negative consequences on soil organic carbon and microbial biomass-C over a period of four weeks, showed a declining trend from 7th day to 28th day of incubation in all herbicide treated soils.

To investigate the impact of herbicides on soil microbial biomass carbon, Amritha and Devi (2017) used a pot culture experiment. At harvest, the extent of microbial biomass carbon decrease was greatest, followed by 30 DAHA. The reduction in microbial biomass carbon at thirty days following herbicide treatment and at harvest ranged from 0.84 to 21.22 per cent and 8.44 to 32.59 per cent, respectively. The herbicides' toxicity (oral LD_{50}) and soil persistence were also in the same order: pendimethalin> bispyribac-sodium> oxyfluorfen> cyhalofop-butyl.

The microbial population was reduced immediately after the application of herbicides due to toxicity in the soil environment, according to a study conducted by Priya *et al.* (2017). The herbicides bispyribac-sodium, metamifop, (chlorimuron-ethyl + metsulfuron-methyl), cyhalofop-butyl, and wetter were used in the experiment at various concentrations, and it was discovered that herbicide treatment had no suppressive effect on the soil microbial population. The microbial population was less immediately after the application of herbicides due to herbicidal toxicity and it recovered to the normal level after a few days of herbicide application.

Ramalakshmi *et al.* (2017) opined that application of herbicides pyrasosulfuron ethyl, bensulfuron methyl, pretilachlor and bispyribac-sodium at recommended rates in rice decreased the soil microbial population initially, and later increased the population due to degradation of herbicide, which acted as a nutrient source for the growth of microorganisms.

Dubey *et al.* (2018) studied the effect of herbicides on soil microbial population in direct seeded rice at Bihar Agricultural University in India, and found that application of bispyribac-sodium and pendimethalin stimulated the growth of actinomycetes while having no effect on the soil bacterial population. In comparison to the weedy check and weed-free plots, the herbicide treated plot had a higher population of actinomycetes.

Pertile *et al.* (2020) assessed the effect of the herbicides imazethapyr, fumioxazin, and their mixture on soil microbial biomass and enzyme activity in soil and the results showed that soil microbial biomass C (MBC) decreased significantly after the application of the herbicides as compared to the control in both areas with and without previous application of the herbicides. During the incubation, MBC decreased at 15 days after herbicides application and increased at 30 and 60 days and in contrast, MBC increased from 0 to 60 days in the control.

Mahapatra *et al.* (2021) observed a reduction in MBC content at four days after treatment (DAT) of the herbicides except in bispyribac-sodium where the MBC content was higher than initial status. Among the herbicide treatments, under florpyrauxifen-benzyl + cyhalofop-butyl highest MBC was observed, while under florpyrauxifen-benzyl + cyhalofop-butyl lowest value was obtained. Similar trend was also observed at 10 and 20 DAT whereas while the MBC contents of all treatments decreased at 30 DAT.

2.7 VISUAL PHYTOTOXICITY OF HERBICIDES

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 + metsulfuron-methyl) + butachlor (4 + 1250 g/ha) and ready mix of (chlorimuron-ethyl + metsulfuron-methyl) + 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 + metsulfuron-methyl) when applied on rice produced no phytotoxic symptoms. However, Mukherjee and Singh (2006) reported that chlorimuron-ethyl + metsulfuron-methyl @ 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 penoxsulamon 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.

Bhullar *et al.* (2012) reported that fenoxaprop-p-ethyl + metribuzin was phototoxic to wheat plants and wheat grain yield was at par to weedy check. Fenoxaprop may cause injury on rice plants (Chauhan and Abugho, 2012). Carfentrazone-ethyl, both at 20 and 25 g/ha did not exhibit any phytotoxic effect in rice plant (Raj *et al*., 2013). Rice seedlings were not affected by a post-emergence application of bispyribac-sodium (20 to 25 g/ha) in rice nurseries (Channabasavanna *et al.,* 2017).

A post-harvest investigation on a subsequent maize crop revealed that fenoxaprop-p-ethyl tested in onion had no residual phytotoxic effect (Singh *et al.,* 2017). No phytotoxicity effect was observed in any of the doses of the tested carfentrozone ethyl 40% DF in direct seeded rice crop (Shinde *et al.,* 2018). Yellowing of rice leaves occurred due to tank-mix application of fenoxaprop-p-ethyl + ethoxysulfuron, but it disappeared after 20 days (Mohapatra *et al.,* 2020).

2.8 EFFECT OF HERBICIDES ON PLANT PATHOGENS

Harikrishnan and Yang (2001) conducted an experiment to see how glyphosate, imazethapyr, and pendimethalin affected mycelial development, sclerotial formation, and viability of *R. solani* isolates (AG-1, AG-2-2, and AG-4). The results showed that pendimethalin inhibited mycelial growth in all isolates, whereas the herbicides imazethapyr and glyphosate had no effect on mycelial growth.

Hua *et al.* (2002) investigated the effects of the herbicides oxyfluorfen, butachlor, acetochlor, cinmethylin, and oxadiazon on *R. solani* mycelial growth and sclerotial germination in PSA medium (with IC_{50} of 2.01, 4.16, 8.12, 11.97, and 22.01 mg/L, respectively). *In vitro* testing of various herbicide formulations (paraquat dichloride, quizalofop, butachlor, alachlor, and oxyflourfen) against *R. solani* indicated that paraquat and butachlor inhibited the pathogen the most (88.23%) (Mishra *et al.,* 2005).

Various fungicides, insecticides, nematicides and herbicides were tested against *R. solani* and it was seen that herbicides affected mycelia growth adversely (Kumar and Tripathi, 2007). Rai *et al.* (2007) used poisoned food technique to study the effects of pendimethalin, anilofos, paraquat, butachlor, isoproturon, alachlor, and 2, 4-D at 25, 50, 100, or 500 ppm each on the growth of *R. solani*. Paraquat inhibited fungal growth by 99.5 and 78.6 per cent when applied at 500 and 25 ppm, respectively and alachlor reduced fungal growth by 92.2 per cent at 500 ppm.

Madhuri *et al.* (2013) investigated the effect of herbicides on *R. solani* growth. Atrazine inhibited the mycelial dry weight. Inhibition of the pathogen also became more pronounced as the concentration of paraquat was increased from 6.25 ppm to 100 ppm. According to Raj *et al.* (2017), the inhibitory effects of bispyribac-sodium + metamifop and (penoxsulam + cyhalofop-butyl) on *R. solani* growth could be successfully used in an integrated pest and disease management programme.

Sandhya *et al.* (2018) reported that among treatments, butachlor and pretilachlor showed inhibition (100%) of sclerotial germination of *R. solani* at all the incubation periods. Glyphosate showed 100 per cent inhibition at 18 and 24 h of incubation followed by 93.43 per cent at 6 h but however, was ineffective in inhibiting the sclerotial germination at 5 min (6.66 per cent) and 30 min (20 per cent) incubation, whereas cyhalofop-butyl showed 100 per cent inhibition at 24 h incubation followed by 89.43 per cent inhibition at 18 h incubation however was ineffective in inhibiting at 5 min (56.66%), 30 min (0%) and 6 h (26.67%) incubation.

2.9 EFFECT OF HERBICIDES ON BIOCONTROL AGENTS

2.9.1 Fungi

Trichoderma viride is a possible biocontrol agent for a variety of diseases found in soil and seeds (Papavizas, 1983). It is one of the most effective agents for biological control of diseases due to its antagonistic action on inimical organisms. (Gupta, 2004). Furthermore, pesticides administered as a foliar spray or as soil drench eventually reached the soil, where they damaged beneficial non-target mycoflora, such as fungus. As a result, understanding *T. viride*'s compatibility with common pesticides might aid in the selection of more effective plant-protection measures. Tolerance to regularly used pesticides improved the efficacy of biocontrol agents like *T. viride* and enhanced their application range.

At low concentrations, primisulfuron and triasulfuron + fluoroglycofen enhanced the mycelial development of *Trichoderma longibrachiatum*, according to Macek and Lesnik (1994). Sulfonylurea-based herbicides had no substantial detrimental effect on antagonistic fungus *Trichoderma* spp, according to Ciraj (1996), and in some cases, they promoted fungi growth. Treatment with 50 ppm butachlor resulted in an increase in *T. viride* CFU 24 hours after treatment, according to Rao and Divakar (2002). Milicic *et al.* (2003) found that *T. viride* in the soil had the highest level of atrazine inactivation and was capable of inactivating-detoxicating simazine.

Desai and Kulkarni (2004) conducted an *in vitro* evaluation with 13 agrochemicals comprising six weedicides, five fungicides and two insecticides (each

@ 500, 1000 and 2000 ppm) against native *T. harzianum* and reported cent per cent growth inhibition with alachlor, carbendazim, chlorpyrifos, glyphosate and thiram whereas lowest inhibition was with per cent of acephate (8.45), atrazine (27.50), captan (32.45) and metalaxyl MZ (33.13).

Chattannavar *et al.* (2006) conducted an experiment on herbicide evaluation under *in vitro* conditions against *Trichoderma harzianum* and found that alachlor (100%), followed by paraquat (84.58), glyophosate (73.81) and pendimethalin (63.73) per cent were suppressive to its growth.

In vitro compatibility of biocontrol agents *T. harzianum a*nd *T. viride* was evaluated with 10 chemicals by Lal and Maharshi (2007) to reveal that carbendazim and thiophanate methyl each @ 500 µg/ml completely inhibited mycelia growth of both of the test bioagents, but thiram and streptocycline showed less toxicity and better compatibility while imidacloprid, endosulfan and chlorpyriphos were less compatibile and pendimethalin, fluchloralin and oxyflourfen reduced the growth of both bioagents, but pendimethalin was highly toxic.

A study on compatibility of stable mutants of *T. viride* (TvM1) and (ThM1) with agrochemicals found that TvM1 was more compatibile with captan (0.25), copper oxychloride (0.15), phosalone (0.1) and butachlor (0.2) per cent; while ThM1 was compatible with mancozeb (0.125) and phosalone (0.1). However, mancozeb (0.25), copper oxychloride (0.3), dicofol (0.5), pendimethalin (0.66) and alachlor (0.4) per cent significantly inhibited mycelial growth of both the mutants and were incompatible (Madhavi *et al.,* 2008).

Sushir *et al.* (2008) studied tolerance of *T. harzianum* against weedicides (diuron and atrazine) at different concentrations and reported higher tolerance in the bioagent to diuron and atrazine (each @ 0.2 per cent). Madhavi *et al.* (2011) evaluated *in vitro* compatibility of *T. viride* with herbicides and observed that the bioagent was highly compatible with imazathafir (9.0 cm) followed by 2,4-D sodium salt (8.9 cm) and oxyfluorfen (6.5cm). Pendimethalin, alachlor, glyphosate, and 2, 4-D were found to be harmful to *Trichoderma* spp. by Ranganathaswamy *et al.* (2012).

Compatibility of fenoxaprop-p-ethyl, bispyribac-sodium, and 2,4-D concentrations of 1D and 10D against three strains (T.17, T.75 and T.78) of *T. asperellum* showed that the fenoxaprop-p-ethyl products and 2,4-D amine salt at concentrations of 10D showed residual effects on the strains T.17 and T.75 while bispyribac-sodium turned out to be compatible with the three strains of *T. asperellum* (Reyes *et al.*, 2012).

Saravanan *et al.* (2014) studied *in vitro* compatibility of *T. viride* with agrochemicals (14 insecticides, 2 fungicides and one herbicide) at their recommended and double the recommended dosages and reported that among the insecticides tested phorate, imidacloprid, fipronil and cypermethrin at the recommended concentration did not show any inhibition of mycelial growth, while carbendazim, quinalphos, chlorpyriphos, profenophos, buprofezin, L-cyhalothrin, triazophos, thiamethoxam and acetamiprid were highly incompatible with *T. viride*.

On testing herbicides each at 500 ppm and 1000 ppm, the strain Ts6 at 500 ppm showed maximum tolerance of about 68.33 (57.36%) and Ts10 showed tolerance of about 78.15 (62.16%), and at 1000 ppm butachlor, pendimethalin and imazethapyr were less toxic to the strains of test bioagent (Karumuri and Singh, 2015).

Sharma (2015) found that the herbicides imazethapyr and pendimethalin were compatible against soil borne pathogens and so both of them could be safely used along with antagonist, while quizalofop was found highly inhibitory to both the pathogen and antagonist. Shrivastava (2015) reported that fluchloralin and metribuzin slightly reduced the sporulation of bioagent whereas it was slightly stimulated by pendimethalin.

According to Aswathi *et al.* (2016) *T. harzianum* and *T. viride* were highly sensitive to carbendazim, but insensitive and compatible with imidacloprid @ 0.02 per cent, causing maximum mycelial growth of 84.66 and 79.66 mm, respectively, whereas pendimethalin @ 0.2 per cent caused mycelial growth of 72.66 and 84.66 mm, respectively. Weedicides diuron and atrazine increased tolerance from 500 to 2000 g/ml in the test bioagent, according to Sushir *et al.* (2016).

The compatibility study of bispyribac sodium + metamifop with antagonistic fungi *T. viride* showed that doses of 60-90 g/ha were harmless and safe for *T. viride,* as a growth inhibition of 8.25 to 22.95 per cent decreased in class I category of toxicity, whereas the highest tested doses (100 and 10 g/ha) showed an inhibition of growth of 31.48 and 37.04 per cent respectively and fell in Class II toxicity category and were slightly harmful (Raj *et al.,* 2017).

2.9.2 Bacteria

Reddy *et al.* (2007) studied the compatibility of bacterial bioagent with herbicides and found that anilofos, showing mean inhibition zone of 0.8 mm, could be considered as compatible with *P. fluorescens* isolate 83, whereas butachlor and pendimethalin showed compatibility with *P. fluorescens* at lower concentrations (500 and 250 ppm) as well as at higher concentrations (2000 and 1000 ppm) and mean inhibition zone was exhibited only at lower concentrations.

All the 10 weedicides tested were highly compatible with *P. fluorescens* (PF 43) in the report of Surendran *et al.* (2012). *P. fluorescens* showed compatibility with 2,4 D sodium and 50 EC pretilachlor indicating that the majority of herbicides tested were *P. fluorescens* compatible and could be recommended for farmers.

Gangwar (2013) documented the compatibility in higher doses of 1000 and 2000 µl/l of *P. fluorescens* with herbicides butachlor and pendimethalin. The study on tolerance of herbicides imazethapyr, 2,4-D and pendimethalin on *Pseudomonas fluorescens* showed that *P. fluorescens* strain IM-4 was capable of degrading imazethapyr, and *P. fluorescens* SMF1 strain was found resistant to 2,4-D due to efficiency of *P. fluorescens* to utilize these herbicides as a carbon source for their growth (Kurhade *et al.,* 2016).

Parime *et al.* (2017) concluded that quizalfop-ethyl at 0.1 per cent inhibited PSB-2 (inhibition zone of 10.33 mm) while at 0.2 per cent PSB-9 recorded growth of 11.66 mm inhibition zone, and at 0.3 per cent PSB-2 growth of 13.33 mm inhibition zone was observed. However, *In vitro* sensitivity studies conducted by Raj *et al.*

(2017) found that bispyribac-sodium + metamifop at varied tested concentrations of 100, 120, 140, 160, 180, 200, and 220 L/L corresponding to field dosages of 50, 60, 70, 80, 90, 100, and 120 g/ha had no effect on *P. fluorescens* growth.

The strain *P. fluorescens* was found to be compatible with all of the herbicides tested, including quizalopop ethyl, pyrithiobac sodium, oxyfluorfen, cyhalofop butyl, glyphosate + ammonium sulphate, pendimethalin, 2,4-D sodium salt, imazethapyr, atrazine, and glyphosate, at all three concentrations (100, 500 and 1000 ppm) (Hanuman and Madhavi, 2018).

Materials and methods

3. MATERIAL AND METHODS

The research programme entitled "Bio-efficacy of tank mixed herbicides and urea in wet seeded rice" was conducted in 2019-20 and 2020-21 at Alappad *padasekharam* in the *Kole* lands of Thrissur district. The entire research programme consisted of three parts:-

Experiment I- Bio-efficacy of tank mixed herbicide combinations in wet seeded rice. The experiment was conducted from October to January in 2019-20 and 2020-21 at Alappad *padasekharam* in the *Kole* lands of Thrissur.

Experiment II- Bio-efficacy of tank mixing of herbicides and urea in wet seeded rice. This trial was also conducted was conducted from October to January in 2019-20 and 2020-21 at Alappad *padasekharam* in the *Kole* lands of Thrissur.

Experiment III- *In vitro* evaluation of herbicides on beneficial and pathogenic microorganisms. This experiment was conducted in the laboratory of the Department of Plant Pathology of the College of Agriculture, Vellanikkara.

3.1 GENERAL DETAILS

Location

The field experiments i.e., Experiments I and II, were conducted in a farmer's field (Mr. Kesavaraj, Kulappully House, Alappad P.O., Thrissur Dt.) Geographically, the area is located between 10˚20' and 10˚43' North latitudes and 76˚58' and 76˚17' East longitudes, at an altitude of 0.5 to 1 metre below sea level.

Climate

The study area enjoys humid tropical climate with an annual average rainfall of 3107 mm distributed mainly through southwest and northeast monsoons. During the months from October to January 2019-20 and 2020-21, the area received rainfall of 627.8and 419.8 mm from the two monsoons. The mean monthly data of the important meteorological parameters recorded during the experimental period in 2019-20 and 2020-21 are given in Appendix I and Fig. 1, 2 and 3.

Soil

Kole soils are clayey in texture with the pH in surface layers ranging from 4.5 to 6.3, and belong 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 nine 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 which can be harvested in 95-105 days 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 to January in both 2019-20 and 2020-21 (*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).

3.2 DETAILS OF THE EXPERIMENTS

The two field experiments conducted were (Plate 1-4):

Experiment I. Bio-efficacy of tank mixed herbicide combinations in wet seeded rice

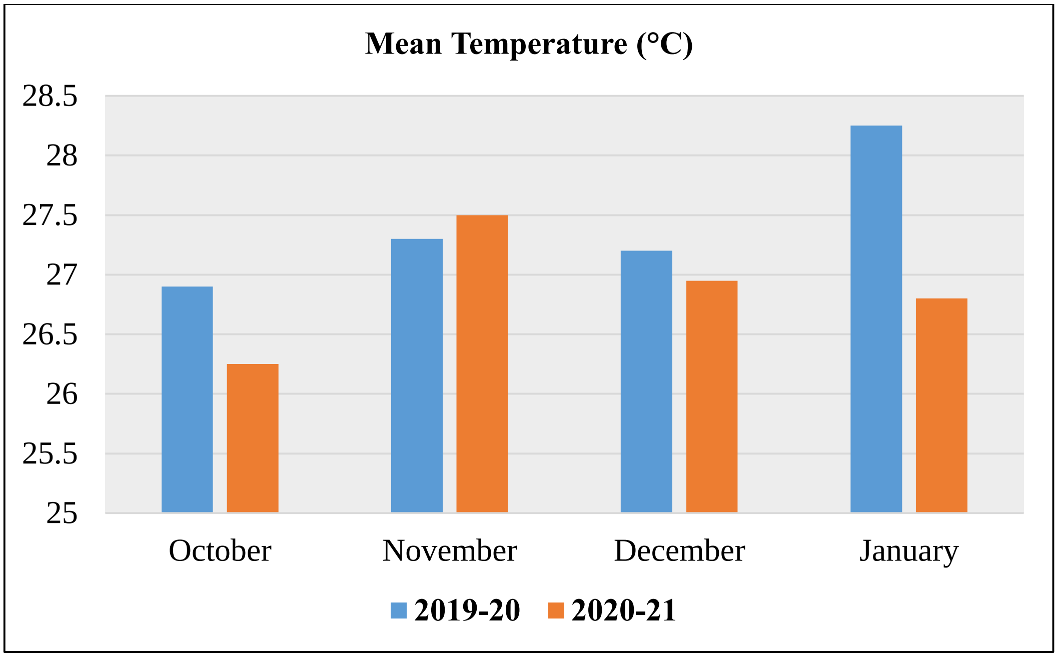


Fig. 1. Mean temperatures during the experimental period (2019-20 and 2020-21)

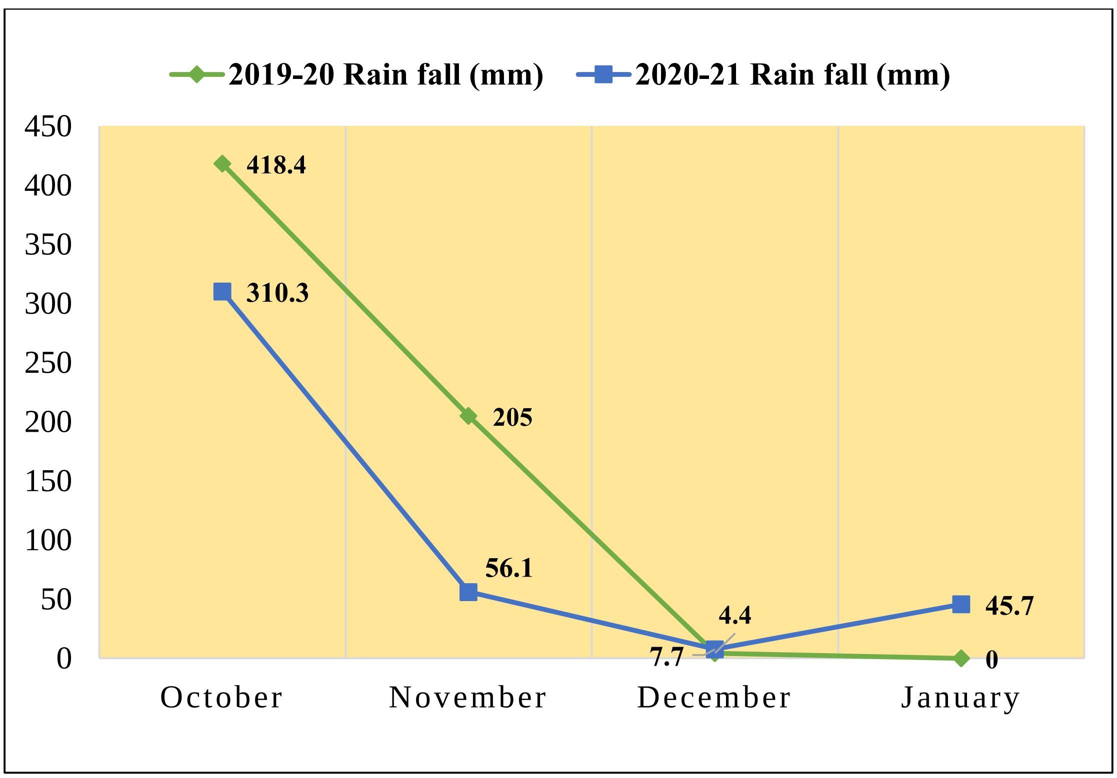


Fig.2. Mean rainfall during the experimental period (2019-20 and 2020-21)

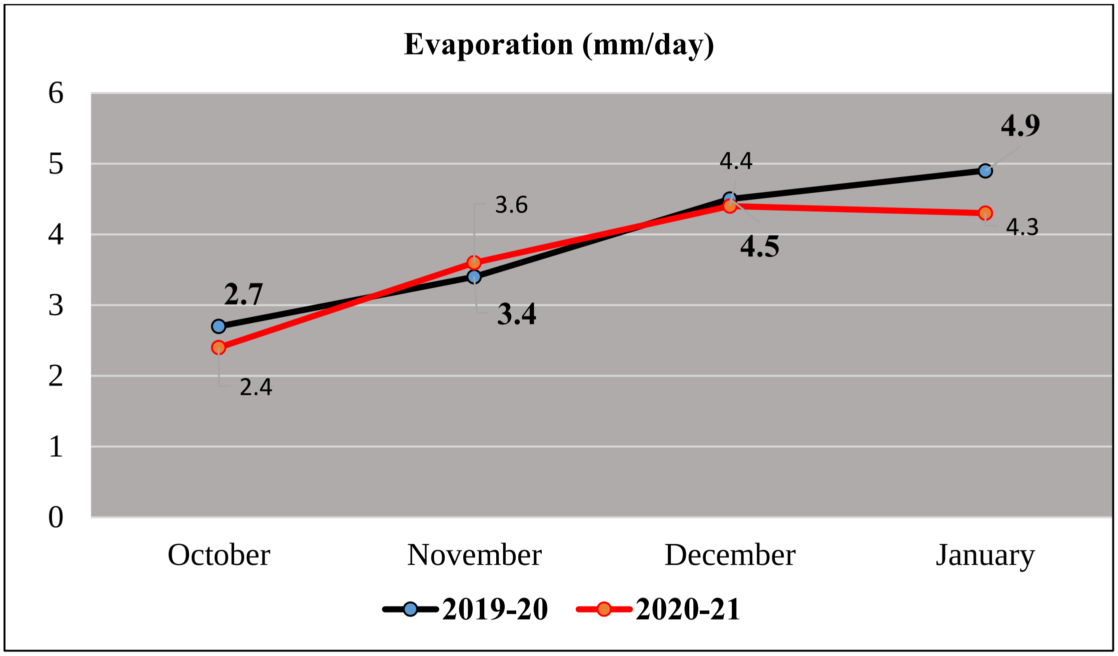


Fig.3. Mean evaporation during the experimental period (2019-20 and 2020-21)

Experiment II. Bio-efficacy of tank mixing of herbicides and urea in wet seeded rice

a) Treatments

In experiment I and experiment II, twelve and fourteen herbicide treatments with three replications each were used in Randomized Block Design (RBD). Details of treatments are provided in Table 2 and 3.

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

Sl. No.	Particulars	Experiment I		Experiment II		Method adopted
		2019-20	2020-21	2019-20	2020-21	
1	pH	4.6	4.7	4.6	4.5	1: 2.5 (soil: water) suspension - pH meter (Jackson, 1958)
2	EC (dS/m)	2.3	2.2	2.25	2.3	1: 2.5 (soil: water) suspension - EC meter (Jackson, 1958)
3	Organic C (%)	1.2	1.1	1.3	1.1	Walkley and Black method (Jackson, 1958)
4	Available N (kg/ ha)	188.3	179.5	182.4	186.5	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg/ ha)	21.5	19.8	20.6	21.3	Bray-1 extractant - ascorbic acid reductant method (Watanabe and Olsen, 1965)
6	Available K (kg/ ha)	152.4	156.5	158.5	153.8	Neutral normal ammonium acetate extractant - Flame photometry (Jackson, 1958)

b) Land preparation and sowing

The experimental field was ploughed, puddled and levelled. Individual plots of size 20 sq. m (5m x 4m) were formed by constructing bunds of 10 cm height and 15 cm width, leaving channels of 30 cm width between plots. Pre-germinated seeds were broadcasted at a rate of 200 g/plot throughout the field, with a seed rate of 100 kg/ha. Layout plan of field experiments I and II are given in Fig. 4 and 5 respectively.

c) Fertilizer application

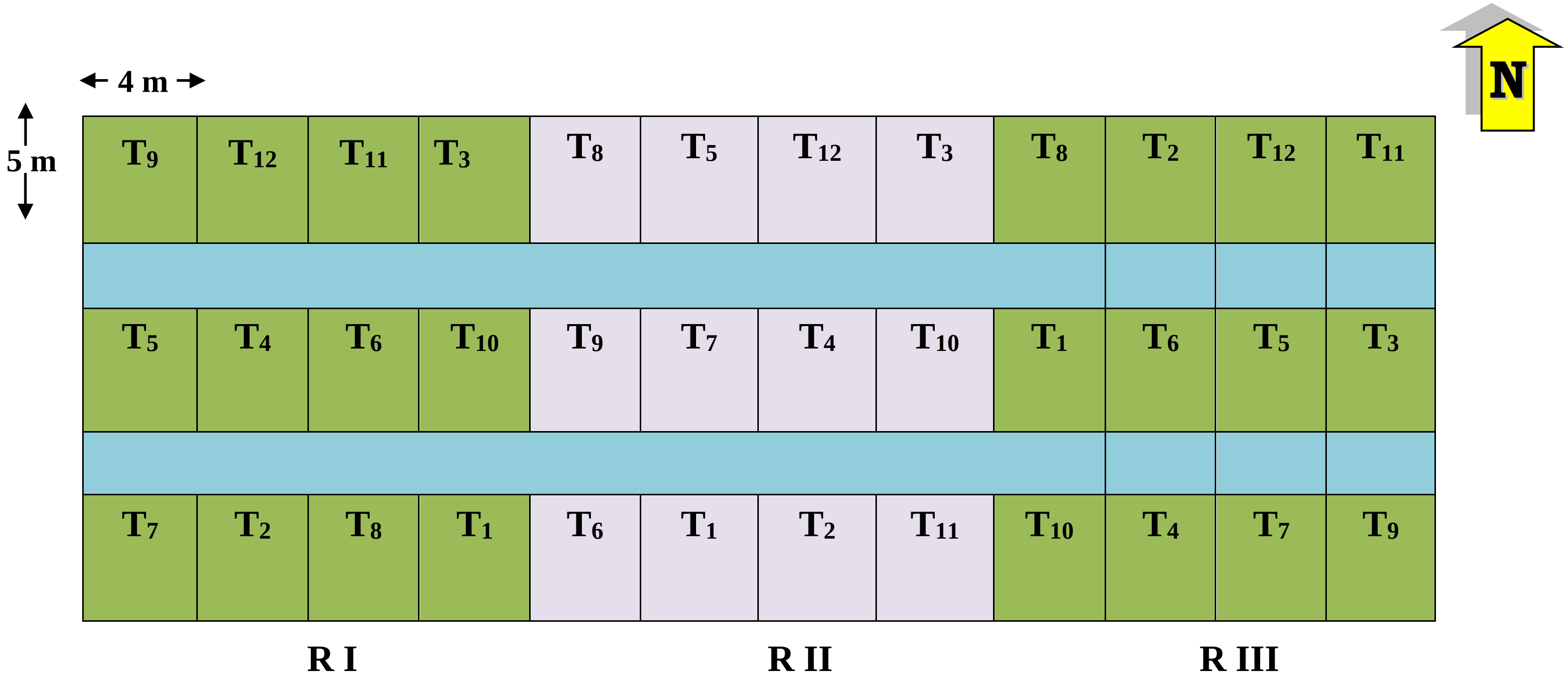
Fertilizer was applied in accordance with the Package of Practices for rice in *Kole* fields (KAU, 2016). Nitrogen, phosphorus and potassium @ 90:35:45 kg/ha were supplied through urea, factamphos and muriate of potash. Full dose of P was applied basally. Potassium was applied in two equal split doses at land preparation and active tillering. N was applied in three equal doses at land preparation, tillering and panicle initiation stages.

d) Removal of weedy rice

Weedy rice was present in all the plots of the experimental area. As herbicides have no effect against this weed, all the plants of weedy rice were removed from the area as and when identified. So, the density and dry weight of weedy rice were not included in the weed observations.

e) Plant protection measures

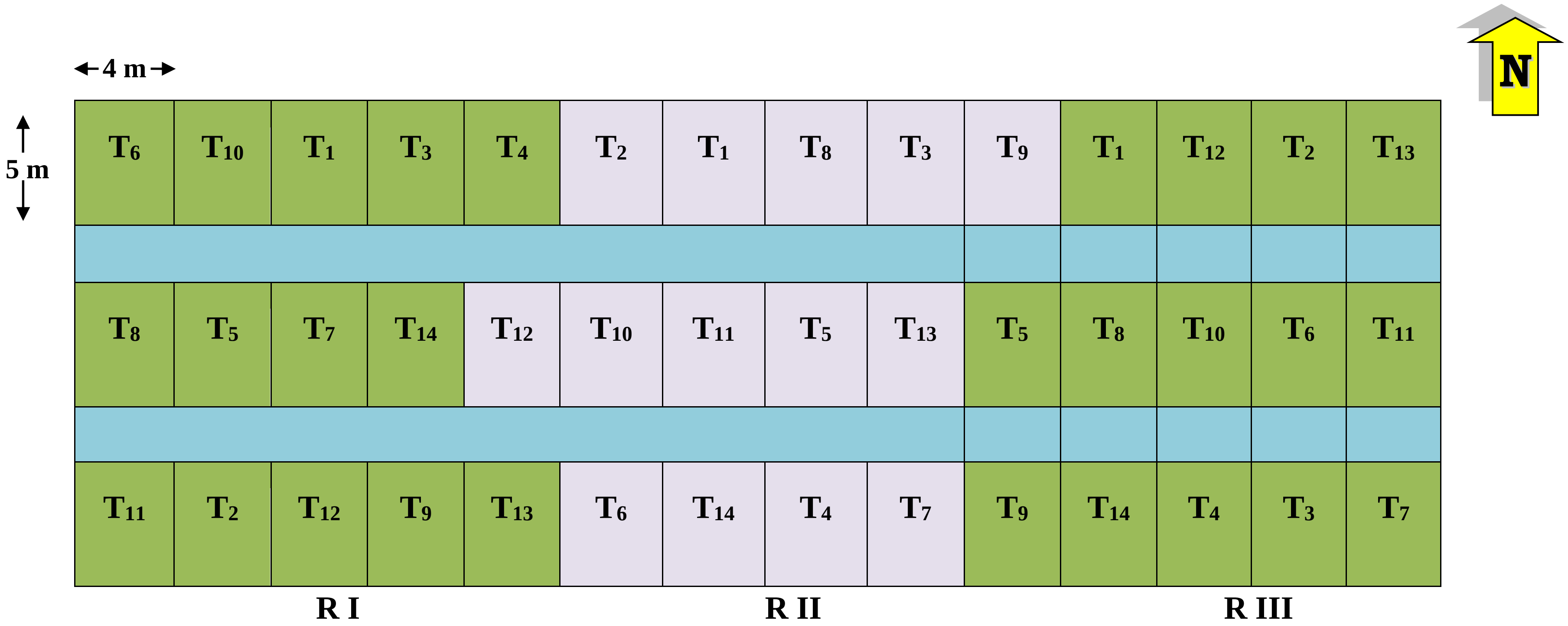
The experimental fields were regularly monitored for pest infestation, and timely organic plant protection measures were adopted. In the early stage, dead heart symptoms indicated the attack of rice stem borer and so surveillance and removal of egg masses was done to control the pest. Application of *Pseudomonas fluorescens* @ 2.5 kg/ha reduced the incidence of bacterial leaf blight.



Treatments: **T_1** = Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)**;** **T_2** = Fenoxaprop-p-ethyl + carfentrazone-ethyl**;** **T_3** = Fenoxaprop-p-ethyl+ bispyribac-sodium**;** **T_4** = (Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)**;** **T_5** = Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)**;** **T_6** = Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl**;** **T_7** = Fenoxaprop-p-ethyl *fb* bispyribac sodium**;** **T_8** = (Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl); **T_9** = Bispyribac-sodium**;** **T_{10}** = (Cyhalofop-butyl + penoxsulam)**;** **T_{11}** = Hand weeded control**;** **T_{12}** = Unweeded control

Design: Randomized Block Design; Plot Size: Gross plot: - 5.0 m × 4.0 m

Fig. 4 Layout experiment-I



Treatments: $\mathbf{T_1}$ = Cyhalofop-butyl + urea 1%; $\mathbf{T_2}$ = (Cyhalofop-butyl + penoxsulam) + urea 1%; $\mathbf{T_3}$ = Bispyribac-sodium + urea 1%; $\mathbf{T_4}$ = Fenoxaprop-p ethyl + urea 1%; $\mathbf{T_5}$ = Carfentrazone-ethyl + urea 1%; $\mathbf{T_6}$ = (Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%; $\mathbf{T_7}$ = Cyhalofop-butyl; $\mathbf{T_8}$ = (Cyhalofop-butyl + penoxsulam); $\mathbf{T_9}$ = Bispyribac-sodium; $\mathbf{T_{10}}$ = Fenoxaprop-p-ethyl; $\mathbf{T_{11}}$ = Carfentrazone-ethyl; $\mathbf{T_{12}}$ = (Chlorimuron-ethyl + metsulfuron-methyl); $\mathbf{T_{13}}$ = Hand weeded control; $\mathbf{T_{14}}$ = Unweeded control

Design: Randomized Block Design; Plot Size: Gross plot: - 5.0 m × 4.0 m

Fig. 5 Layout of experiment-II

f) Phytotoxicity scoring

On the 3rd and 7th day after each herbicidal spray, visual symptoms for phytotoxicity on weeds and crops were recorded in both seasons. The injury symptoms were graded on a toxicity scale from 0 to 5 as described by Thomas and Abraham (2007) (Table 4).

g) 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.

Experiment III - *In vitro* evaluation of herbicides on beneficial and pathogenic microorganisms

The experiment consisted of two parts as detailed below.

A. *In vitro* evaluation of herbicides against fungal (beneficial and pathogenic) microorganisms

In vitro evaluation of selected herbicides against fungal beneficial microorganism *Trichoderma viride* (KAU reference culture) and fungal pathogens *viz., Rhizoctonia solani* and *Pyricularia oryzae* (KAU reference culture) was carried out by poison food technique (Zentmeyer, 1955) at three different doses *viz*., lower, recommended and higher doses (Table 5). For this chemicals were mixed separately in 100 ml sterilized PDA media and poured into sterilized petri plates @ 20 ml/plate and eight mm mycelial discs of pathogens were placed at the center of poisoned media. Plates without herbicide served as control.

B. *In vitro* evaluation of herbicides against beneficial and pathogenic bacteria

In vitro evaluation of biocontrol agents *viz., Pseudomonas fluorescens* and *Xanthomonas oryzae* pv. *oryzae* (KAU reference culture) was carried out by filter paper disc method (Pauli and Schilcher, 2010). The solutions of the desired concentrations of the herbicides were prepared separately. Filter paper discs (Whatman No. 42) of 1-2 cm diameter were soaked in the respective chemical solutions for 5 to 10 minutes and transferred onto the centre of the solidified bacterium seeded NA medium (for *Xanthomonas*) and King's B medium (for *Pseudomonas*) in petri plates. The inoculated plates were kept in the refrigerator at 4^0C for 4 hours to allow diffusion of the chemical into medium. Untreated control plate containing the test bacterium seeded NA and KB inoculated with filter paper disc soaked in distilled water was also maintained. Then the plates were incubated at 28°C for 48 hours and observed for the production of inhibition zone around filter paper discs.

Factorial Completely Randomized Block Design was adopted with 18 treatments and three replications each.

Table 2. Herbicide combinations, dosages and time of application in experiment-I

Treatment	Herbicide combinations	Dose (kg/ha)	Time of application (DAS)
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	0.06 + 0.004	15-20
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	0.06 + 0.02	15-20
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	0.06 + 0.025	15-20
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0.15 + 0.004	15-20
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	0.06, 0.004	15, 18
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	0.06, 0.02	15, 18
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.06, 0.025	15, 18
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	0.15, 0.004	15, 18
T_9	Bispyribac-sodium	0.025	15-20
T_{10}	(Cyhalofop-butyl + penoxsulam)	0.15	15-20
T_{11}	Hand weeded control	-	20 & 40
T_{12}	Unweeded control	-	-

- *fb*-followed by; DAS-Days after sowing

Table 3. Herbicide and urea dosages and time of application in experiment-II

Treatment	Herbicide (with and without urea)	Dose (kg/ha)	Time of application (DAS)
T_1	Cyhalofop-butyl + urea 1%	0.080	15-20
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	0.15	15-20
T_3	Bispyribac-sodium + urea 1%	0.025	15-20
T_4	Fenoxaprop-p-ethyl + urea 1%	0.06	15-20
T_5	Carfentrazone ethyl + urea 1%	0.02	15-20
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	0.004	15-20
T_7	Cyhalofop-butyl	0.080	15-20
T_8	(Cyhalofop-butyl + penoxsulam)	0.15	15-20
T_9	Bispyribac-sodium	0.025	15-20
T_{10}	Fenoxaprop-p-ethyl	0.06	15-20
T_{11}	Carfentrazone-ethyl	0.02	15-20
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	0.004	15-20
T_{13}	Hand weeded control	-	20 & 40
T_{14}	Unweeded control	-	-

- DAS - Days after sowing

In both experiments the volume of water utilized for spraying was 500 L/ha. Spraying was done with a knapsack sprayer fitted with a flood jet nozzle.

Table 4. 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

The third experiment was a laboratory study as detailed below.

Table 5. Herbicides and concentrations in experiment-III

Sl. No.	Herbicide	Recommended dose (kg/ha)	Under *in vitro* conditions (ppm)		
			Higher dose	Recommended dose	Lower dose
1.	Cyhalofop-butyl	0.08	240	160	80
2.	(Cyhalofop-butyl + penoxsulam)	0.15	450	300	150
3.	Bispyribac-sodium	0.025	75	50	25
4.	Fenoxaprop-p-ethyl	0.06	180	120	60
5	Carfentrazone-ethyl	0.02	60	40	20
6.	(Chlorimuron-ethyl + metsulfuron-methyl)	0.004	12	8	4

3.3 Observations recorded

1) Observations recorded for Experiment I and II were as follows:

A. Biometric observations on weeds

a) Weed count

Species-wise counts of weeds were recorded using a quadrat of size 50cm x 50cm (0.25 m^2). Samples were collected by placing the quadrat randomly at 2 places in each plot. In experiment I, samples were collected at 15, 30 and 60 days after application of the herbicides, and in experiment II at 15 and 30 days after herbicide application. All the weeds coming within the quadrat were uprooted and the weed counts were expressed as numbers/m^2.

b) Dry matter production of weeds

The weeds which were uprooted from the quadrat as detailed above 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

Removal of N, P and K by weeds in plots of experiment I and experiment II were estimated by standard procedures given by Jackson (1958) and expressed in

Plate 1. Various field operations carried out in experimental fields

Plate 2. Various field operations carried out in experimental fields

Plate 3. General view of field experiments at harvest stage 1st year

Plate 4. General view of field experiments at harvest stage 2nd year

kg/ha. Nutrient removal was worked out by multiplying percentage of nutrient with total dry matter production and expressed in kg/ha.

d) Weed Control Efficiency (WCE)

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

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

* WDMP = Weed Dry Matter Production

e) Weed Index (WI)

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

$$\text{WI} = \frac{\text{Grain yield in hand weeded plot - Grain yield in treatment}}{\text{Grain yield in hand weeded plot}} \times 100$$

B. Biometric observations on rice

a) Plant height

Plant height (in cm) was recorded at 30 days after sowing (DAS), 60 DAS and at harvest in both experiments. 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 was counted from one square metre area in each plot using quadrat of size 1m x 1m at 30 DAS, 60 DAS and at harvest in both experiments, and expressed as numbers per m^2.

c) Number of panicles per square metre

The number of panicles or productive tillers was recorded from each plot at harvest in both experiments using quadrat of 1 m^2 size, and expressed in numbers per m^2.

d) Nutrient uptake by rice

Nutrient uptake by rice at 60 days after sowing in both experiments were estimated by standard procedures given by Jackson (1958) and expressed in kg/ha. Nutrient uptake was worked out by multiplying percentage of nutrient with grain and straw yield.

e) Number of grains per panicle

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

f) Percentage of filled grains

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

g) Thousand grain weight

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

h) Grain yield

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

i) Straw yield

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

j) 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, and 60 days after herbicide application and at harvest from all the plots of both experiments and analysed for the biological characteristics dehydrogenase activity (DHA) and soil microbial biomass carbon (SMBC).

a) 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 triphenyl tetrazolium chloride (TTC-0.2 ml of 3%) solution was added to make the soil saturated. Then glucose (0.5 ml of 1%) 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°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 six 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/h.

b) 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 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 were added. Distilled water of 10 ml was used as blank. These flasks were kept on hot plate at 100ºC 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:

$$\text{MBC } (\mu g/g \text{ soil}) = \frac{EC_f - EC_{nf}}{K_{EC}}$$

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.

2) Observations recorded in the laboratory experiment were as follows:

A. *In vitro* evaluation of herbicides against fungal (beneficial and pathogenic) microorganisms

Observations were recorded till the control plate attained full growth of the pathogen. Radial growth (cm) of fungal colonies and per cent inhibition of the pathogen with the herbicide was calculated using the formula given by Vincent (1927).

$$\text{Per cent inhibition of pathogen} = \frac{C - T}{C} \times 100$$

C – Growth of the pathogen in the control

T – Growth of the pathogen in treatment

B. *In vitro* evaluation of herbicides against bacterial (beneficial and pathogenic) microorganisms

Observations were recorded till the control plates attained full growth of the pathogen. Radial growth (cm) of bacterial colonies and per cent inhibition of the pathogen with the herbicide was calculated using the formula given by Vincent (1927).

$$\text{Per cent inhibition of pathogen} = \frac{C - T}{C} \times 100$$

C – Growth of the pathogen in the control

T – Growth of the pathogen in treatment

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 Rs./ha (Appendix II and III). The benefit:cost ratio (BCR) was calculated as ratio of gross returns to total cost of cultivation.

3.5 Statistical analysis

The statistical software 'WASP 2.0' was used for the analysis (Freed, 1986). Data on density and biomass of weeds which showed wide variation were subjected to square root transformation, $\sqrt{(x+0.5)}$, to make the analysis of variance valid (Gomez and Gomez, 1984) and then analyzed following ANOVA, and the means were compared based on the critical differences (least significant difference) at 0.05 level of significance.

Pooled analysis of the data obtained from two years of experimentation was done (Panse and Sukhatme, 1976, and Nigam and Gupta, 1979).

Results

4. RESULTS

The research programme entitled "Bio-efficacy of tank mixed herbicides and urea in wet seeded rice" consisted of three parts, the results of each of which are presented separately in this chapter.

4.1 Experiment-I Bio-efficacy of tank mixed herbicide combinations in wet seeded rice

The field trial of the research programme on "Bio-efficacy of tank mixed combinations in wet seeded rice" was conducted from October to January in 2019-20 and 2020-21 (*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 below.

4.1.1 Studies on weeds

Weed spectrum

The *Kole* area is infested with grasses, sedges and broad leaf weeds, but grasses and sedges dominate. The main grass species in the experimental area included *Echinochloa colona*, *Echinochloa stagnina*, *Oryza sativa* f. *spontanea* (weedy rice), and *Leptochloa chinensis*. *Cyperus iria* and *Fimbristylis miliacea* were the main sedges, though several other species also occurred sporadically. *Ludwigia perennis* and *Monochoria vaginalis* were the chief broad leaf weeds, though *Sphenoclea zeylanic*a and *Limnocharis flava* were also observed in the second season of experimentation (Plates 5-14).

Phytotoxicity rating

Phytotoxicity scoring of both weeds as well as crop was done at third and seventh day after spraying (Table 6). Injury symptoms were graded from 0 to 5 using the toxicity scale described by Thomas and Abraham (2007).

The data showed that the scoring was similar for both years of experimentation. (Cyhalofop-butyl + penoxsulam) whether tank mixed with or applied in sequence to (chlorimuron-ethyl + metsulfuron-methyl) produced no injury on rice at both stages of observation. Slight injury was noticed on rice on the 3rd day after treatment application in the plots where fenoxaprop-p-ethyl was tank mixed with (chlorimuron-ethyl + metsulfuron-methyl) and bispyribac-sodium. The injury persisted on the 7th day after application for the tank mixed treatments but disappeared for bispyribac-sodium. Moderate injury was observed on the 3rd day, and persisted on the 7th day after applicationin the case of fenoxaprop-p-ethyl + carfentrazone, fenoxaprop-p-ethyl followed by (*fb*) (chlorimuron-ethyl + metsulfuron-methyl), fenoxaprop-p-ethyl *fb* carfentrazone, and fenoxaprop-p-ethyl *fb* bispyribac-sodium. Chlorosis of mid rib, yellowing of leaves, and white and brown spots (like rust spots) as well as necrotic spots on leaves of crop were noted. However, the crop recovered within a week after spraying and no phytotoxic symptoms were further seen (Plates 15-18).

Very good control of weeds was obtained with fenoxaprop-p-ethyl + carfentrazone and [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] three days after treatment application (Table 6). Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) and fenoxaprop-p-ethyl *fb* bispyribac-sodium gave moderate control of weeds at this stage, while all other treatments gave good control. The effect on weeds was intensified on the 7th day after treatment application. (Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl) completely controlled the weeds, while all other treatments except fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) and fenoxaprop-p-ethyl *fb* bispyribac-sodium gave very good control. The latter two treatments achieved only good control.

Weed density

An analysis of data on species-wise count of weeds after the application of various herbicidal combinations and individual herbicides revealed that there was

Plate 5. ***Echinochloa colona*** **Plate 6.** ***Echinochloa stagnina***

Plate 7. ***Echinochloa crus-galli***

Plate 8. ***Leptochloa chinensis***

Plate 9. ***Cyperus iria***

Plate 10. ***Fimbristylis miliacea***

Plate 11. ***Ludwigia perennis***

Plate 12. ***Sphenoclea zeylanica***

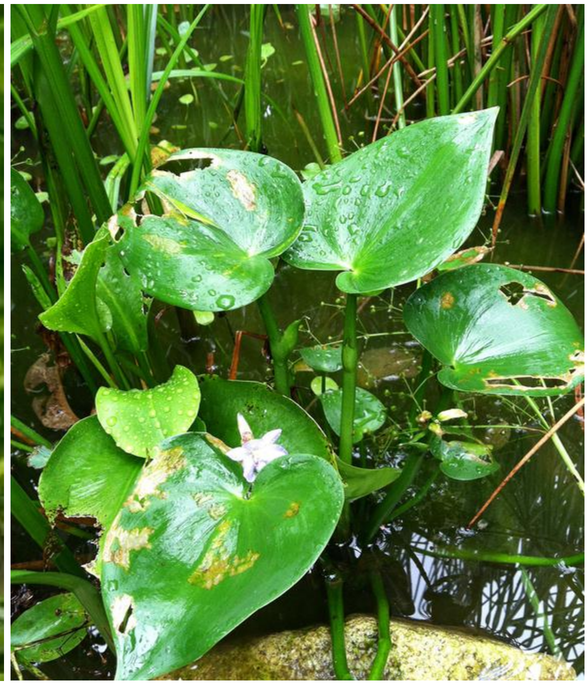


Plate 13. ***Monochoria vaginalis***

Plate 14. ***Limnocharis flava***

Plate 15. Phytotoxicity symptoms on 3rd day of rice- tank mixing application

Plate 16. Phytotoxicity symptoms on 3rd day of rice- sequential application

Plate 17. Phytotoxicity symptoms on 7th day of rice- tank mixing application

Plate 18. Phytotoxicity symptoms on 7th day of rice- sequential application

significant reduction in weed population due to treatments at 15, 30 and 60 days after application. The data on the total weed density of grasses, sedges and broad leaf weeds at 15, 30 and 60 days after application (DAA) also showed significant effect of herbicide application.

In both 2019-20 and 2020-21, *Echinochloa colona*, *E. stagnina*, and *Leptochloa chinensis* were observed in the experimental field. *E. crus-galli* was seen in 2020-21 but the effect of treatments on this weed was not significant. *Cyperus iria* and *Fimbristylis miliacea* were the main sedges in the field. *Ludwigia perennis* and *Monochoria vaginalis* were the main broad leaf weed species, and *Sphenoclea zeylanica* and *Limnocharis flava* were observed in 2020-21 alone. Among the weeds, *E. colona*, *E. stagnina*, *Leptochloa chinensis*, *Oryza sativa* f. *spontanea* (weedy rice), *Cyperus iria* and *Fimbristylis miliacea* were found to be the most dominant at 15, 30 and 60 DAA.

The density of *E. colona* in 2019-20 at 15 days after application (DAA) (Table 7) was lower in the treatment fenoxaprop-p-ethyl *fb* bispyribac-sodium (T_7), followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and T_3, T_2 and T_1 [fenoxaprop-p-ethyl tank mixed with bispyribac-sodium, carfentrazone and (chlorimuron-ethyl + metsulfuron-methyl) respectively]. Weed density was higher in unweeded control.

At 30 DAA lower density of *E. colona* was seen in the hand weeded plot and T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] followed by T_2 (fenoxaprop-p-ethyl + carfentrazone), T_4 (cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) (Table 7). At 60 DAA density of the weed was lower in the handweeded plot and in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (Table 7). Unweeded control (T_{12}) had higher density of 3, 3, and 8 nos./m^2 at 15, 30 and 60 DAA respectively.

The density of *E. colona* at 15 DAA in 2020-21 (Table 9) was lower in the treatment fenoxaprop-p-ethyl + carfentrazone (T_2), and was at par with fenoxaprop-p-ethyl *fb* bispyribac-sodium (T_7). Higher density was in T_{12} (unweeded control). At 30 and 60 DAA (Table 9), lower density was in hand weeded plot. Unweeded control (T_{12}) had highest density of 4, 6, 11 nos./m^2 at 15, 30 and 60 DAA respectively.

The density of *E. stagnina* in 2019-20 was lower in T_{11} (hand weeding), T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)], T_2 (fenoxaprop-p-ethyl + carfentrazone), and T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)] at 15 DAA (Table 7), in T_5 (fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) at 30 DAA (Table 7) and in T_{11} (hand weeded control), T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)] and T_4 [(cyhalofop butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] at 60 DAA (Table 7). Higher density of the weed was in T_{10} (cyhalofop-butyl+ penoxsulam) and T_9 (bispyribac-sodium) at 15 and 30 DAA, and in T_{10} (cyhalofop-butyl + penoxsulam) at 60 DAA. Unweeded control was also at par at both 15 and 30 DAA.

The population of *E. stagnina* in 2020-21 was lower in T_{11} (hand weeding) and T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)] at 15 DAA, and in the hand weeded plot at 30 DAA and at 60 DAA (Table 9). Higher density of weed was in unweeded control (T_{12}) and T_1 [fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] at 15 DAA, while at 30 and 60 DAA, highest density of the weed was observed unweeded control (T_{12}).

The population of *Leptochloa chinensis* at 15 DAA in 2019-20 was lower in T_{11} (hand weeding), and T_{10} (cyhalofop-butyl + penoxsulam), T_6 (fenoxaprop-p-ethyl *fb* carfentrazone), and T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)] were at par (Table 7). T_{11} (hand weeding) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) recorded lower density at 30 DAA) whereas T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) had the lower density at 60 DAA. Highest density of the weed was recorded in T_1 (fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl) and T_9 (bispyribac-sodium), along with unweeded control (T_{12}) at 15 DAA. At 30 DAA unweeded control registered higher density of *L. chinensis*, while at 60 DAA it was in fenoxaprop-p-ethyl *fb* bispyribac-sodium (T_7).

Lower population of *Leptochloa chinensis* in 2020-21 was in T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)], T_6 (fenoxaprop-p-ethyl *fb* carfentrazone), T_{11} (hand weeding), T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], and T_{10} (cyhalofop-butyl + penoxsulam), whereas higher density of weed was in T_{12} (unweeded control) at 15 DAA (Table 9). T_{11} (hand weeding) and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) registered lower weed density, and T_{12} (unweeded control), higher density of *L. chinensis* at 30 DAA. At 60 DAA lower density of the weed was recorded in T_{11} (hand weeding) and T_2 (fenoxaprop-p-ethyl + carfentrazone), while highest density was again observed in unweeded control (T_{12}).

Effect of treatments on *Echinochloa crus-galli* at 15, 30 and 60 days after application of herbicides was not significant in 2020-21 (Table 9), whereas in 2019-20 the weed was absent.

Next to grass weeds, sedges dominated in the experimental field and a reduction in weed density was attained in almost all the treatments. The population of *Cyperus iria* in 2019-20 was lower in T_{11} (hand weeded plot) followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) at 15, 30 and 60 DAA. Unweeded control (T_{12}) had the highest density at all three stages (Table 8).

The density of *Cyperus iria* in 2020-21 was lower in T_{11} (hand weeded plot) at all three stages of observation. At 15 DAA, the next best treatments were T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), while at 30 DAA it was T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and at 60 DAA, it was T_9 (bispyribac-sodium). Unweeded control (T_{12}) had the highest density at 15, 30 and 60 DAA respectively (Table 10).

In 2019-20 lower density of the sedge *Fimbristylis miliacea* was noticed in plots treated with T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) at 15, 30 and 60 DAA (Table 8). Hand weeded control also had lower density at 30 DAA. At 60 DAA the higher density was in unweeded control (T_{12}). T_9 (bispyribac-sodium) and T_{12} (unweeded control) had higher density at 30 DAA, while T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) registered higher count of the weed per sq. m at 15 DAA.

Lower density of *Fimbristylis miliacea* at all three stages of observation in 2020-21 was recorded in the treatments T_2 (fenoxaprop-p-ethyl + carfentrazone), T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) and T_{10} (cyhalofop-butyl + penoxsulam) (Table 10). The highest density was in the unweeded control (T_{12}) at all three stages of observation.

The main broad leaf weed was *Ludwigia perennis* in 2019-20. However, at 15 and 30 DAA weed infestation was seen only in T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)], T_{11} (hand weeding) and T_{12} (unweeded control) (Table 8). At 60 DAA in addition to T_1 and T_{12}, *L. perennis* was also observed in T_9 (bispyribac-sodium). In 2020-21, at 15 DAA higher density of the weed was observed in unweeded control (4 nos./m^2). At 30 DAA, density was very low and the highest was recorded in unweeded control (3 nos./m^2). This trend continued at 60 DAA, with a density of 3 nos./m^2 recorded in unweeded control and T_9 (bispyribac-sodium).

In 2020-21, density of *Ludwigia perennis* at 15 DAA was highest in unweeded control followed by T_{10} (cyhalofop-butyl + penoxsulam) and T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] (Table 10). The weed was absent in T_2 (fenoxaprop-p-ethyl + carfentrazone), T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) and T_9 (bispyribac-sodium). Highest density was observed in unweeded control followed by hand weeded control at 30 DAA, while the weed did not occur in T_2, T_3, T_4, T_9 and T_{10}. At 60 DAA T_9

(bispyribac-sodium) followed by unweeded control and T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] recorded higher density while all other treatments were inferior and at par.

Very low infestation of *Monochoria vaginalis* was observed in experimental plots in 2019-20 (Table 8). The unweeded control registered the highest weed density of 4, 4 and 2 nos./m^2 at 15, 30 and 60 DAA respectively. The trend was similar in 2020-21 (Table 11).

Sphenoclea zeylanica and *Limnocharis flava* were observed in experimental plots in 2020-21. However the density was too low to record any significant effect of treatments (Table 11).

Two years data on densities of grasses, sedges, broad leaf weeds and total weeds were pooled and the results are presented in Tables 12 to 16. Unweeded control registered the highest density of grasses at all three stages of observation. Grass density was lower in the hand weeded plot (T_{11}), T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] at 15 DAA. T_{11} and T_4 continued to be the best treatments at 30 and 60 DAA. Lower density of sedges was recorded in the hand weeded plot (T_{11}) followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] at all three stages of observation, while unweeded control had the highest density. At 15 DAA, density of broad leaf weeds was lower in T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] were at par. At 30 DAA, T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) registered lower density of broad leaf weeds. At 60 DAA there was a change in the trend and lower density was noticed in T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium). At all three stages unweeded control recorded highest weed density.

Analysis of data on total weed density revealed that it was lower in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and the hand weeded plot (T_{11}) at 15 DAA. At 30 DAA in addition to these two treatments, T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) also recorded equally low value for weed density. However, at 60 DAA, lower total weed density was seen in hand weeding (T_{11}), followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)].

Table 6. Effect of tank mixed herbicide combinations on phytotoxicity scoring on crop and weeds

Treatments		1st year				2nd year			
		3rd Day		7th Day		3rd Day		7th Day	
		Score on crop	Score on weed	Score on crop	Score on weed	Score on crop	Score on weed	Score on crop	Score on weed
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	1	3	1	4	1	3	1	4
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	2	4	1	4	2	4	1	4
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	1	3	1	4	1	3	1	4
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0	4	0	5	0	4	0	5
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2	2	1	3	2	2	1	3
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2	3	1	4	2	3	1	4
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	1	2	1	3	1	2	1	3
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	0	3	0	4	0	3	0	4
T_9	Bispyribac-sodium	0	3	0	4	0	3	0	4
T_{10}	(Cyhalofop-butyl + penoxsulam)	0	3	0	4	0	3	0	4

Table 7. Effect of tank mixed herbicide combinations on species-wise weed density (no./m^2) in 2019-20

Treatments		*Echinochloa colona*			*Leptochloa chinensis*			*Echinochloa stagnina*		
		15 DAA†	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	1.34^{abc} (1)*	1.86^{a} (3)	1.93^{b} (3)	1.56^{a} (2)	1.23^{abcd} (1)	1.34^{abcd} (1)	1.29^{ab} (1)	1.46^{abcd} (2)	1.56^{ab} (2)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	1.00^{bc} (1)	1.34^{bc} (1)	1.44^{bc} (2)	1.34^{ab} (1)	0.88^{cd} (0)	0.88^{cd} (0)	0.71^{c} (0)	1.17^{bcd} (1)	1.39^{ab} (2)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	1.00^{bc} (1)	1.46^{abc} (2)	1.52^{bc} (2)	1.23^{abc} (1)	1.46^{abc} (2)	1.56^{ab} (2)	1.34^{ab} (1)	1.34^{abcd} (1)	1.46^{ab} (2)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.00^{bc} (1)	1.34^{bc} (1)	1.34^{c} (1)	0.88^{cd} (0)	1.00^{bcd} (1)	1.00^{bcd} (1)	0.71^{c} (0)	1.00^{cd} (1)	1.10^{b} (1)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.58^{ab} (2)	1.68^{ab} (2)	1.77^{bc} (3)	0.71^{d} (0)	1.27^{abcd} (1)	1.39^{abc} (2)	0.71^{c} (0)	0.88^{d} (0)	1.05^{b} (1)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.34^{abc} (1)	1.76^{ab} (3)	1.56^{bc} (2)	0.71^{d} (0)	0.71^{d} (0)	0.71^{d} (0)	1.29^{ab} (1)	1.74^{ab} (3)	1.86^{a} (3)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.71^{c} (0)	1.34^{bc} (1)	1.39^{bc} (2)	1.00^{bcd} (1)	1.60^{ab} (2)	1.90^{a} (3)	1.44^{ab} (2)	1.72^{abc} (3)	1.88^{a} (3)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.17^{abc} (1)	1.17^{c} (1)	1.39^{bc} (2)	1.23^{abc} (1)	1.46^{abc} (2)	1.17^{bcd} (1)	0.71^{c} (0)	1.39^{abcd} (2)	1.56^{ab} (2)
T_9	Bispyribac-sodium	1.82^{a} (3)	1.86^{a} (3)	1.77^{bc} (3)	1.46^{a} (2)	1.17^{abcd} (1)	1.46^{abc} (2)	1.56^{a} (2)	1.97^{a} (4)	1.64^{ab} (2)
T_{10}	(Cyhalofop-butyl + penoxsulam)	1.34^{abc} (1)	1.56^{abc} (2)	1.77^{bc} (3)	0.71^{d} (0)	0.88^{cd} (0)	0.88^{cd} (0)	1.74^{a} (3)	2.02^{a} (4)	1.95^{a} (3)
T_{11}	Hand weeded control	1.17^{abc} (1)	1.17^{c} (1)	1.34^{c} (1)	0.71^{d} (0)	0.71^{d} (0)	0.88^{cd} (0)	0.71^{c} (0)	1.00^{cd} (1)	1.00^{b} (1)
T_{12}	Unweeded control	1.82^{a} (3)	1.86^{a} (3)	2.91^{a} (8)	1.56^{a} (2)	1.64^{a} (2)	1.56^{ab} (2)	1.00^{bc} (1)	1.93^{a} (3)	2.04^{a} (4)
SEm		0.10	0.08	0.13	0.10	0.10	0.10	0.11	0.12	0.10
CD (0.05)		0.66	0.50	0.58	0.37	0.63	0.67	0.47	0.73	0.66

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
†days after application

Table 8. Effect of tank mixed herbicide combinations on species-wise weed density (no./m^2) in 2019-20

Treatments		*Cyperus iria*			*Fimbristylis miliacea*			*Ludwigia perennis*			*Monochoria vaginalis*		
		15 DAA†	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	4.07^{ef} (17) *	3.83^{cd} (15)	2.70^{cd} (7)	2.06^{bc} (4)	1.82^{bcd} (3)	1.34^{ef} (1)	1.23^{b} (1)	1.56^{b} (2)	1.34^{b} (1)	1.34^{ab} (1)	1.17^{b} (1)	1.46^{b} (2)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	5.02^{cd} (25)	4.46^{bc} (20)	3.15^{bc} (10)	0.71^{d} (0)	1.14^{d} (1)	0.71^{f} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.62^{fg} (13)	3.27^{de} (11)	2.28^{de} (5)	2.04^{bc} (4)	1.24^{cd} (2)	1.23^{ef} (1)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	2.97^{g} (9)	2.81^{e} (8)	1.88^{e} (4)	1.86^{c} (3)	1.28^{cd} (2)	1.46^{de} (2)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.88^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.15^{def} (17)	3.93^{cd} (16)	2.80^{cd} (8)	3.33^{a} (11)	2.10^{bc} (5)	2.20^{bc} (4)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	5.74^{bc} (33)	4.93^{b} (25)	3.82^{b} (15)	0.71^{d} (0)	1.14^{d} (1)	0.71^{f} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	1.00^{bc} (1)	1.17^{b} (1)	1.34^{b} (1)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	4.92^{cde} (25)	3.88^{cd} (15)	2.82^{cd} (8)	1.61^{c} (3)	1.55^{bcd} (3)	2.21^{bc} (5)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	3.46^{fg} (12)	3.39^{de} (12)	2.55^{cde} (7)	1.93^{c} (3)	2.37^{b} (6)	2.85^{ab} (8)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_9	Bispyribac-sodium	6.50^{b} (43)	4.42^{bc} (20)	3.26^{bc} (11)	2.78^{ab} (7)	3.29^{a} (11)	2.04^{cd} (4)	0.71^{c} (0)	0.71^{c} (0)	1.56^{a} (2)	1.00^{bc} (1)	1.64^{a} (2)	2.02^{a} (6)
T_{10}	(Cyhalofop-butyl + penoxsulam)	5.21^{c} (27)	4.20^{bcd} (18)	3.16^{bc} (10)	1.46^{cd} (2)	1.38^{cd} (2)	1.34^{ef} (1)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{c} (0)
T_{11}	Hand weeded control	1.61^{h} (3)	1.82^{f} (3)	1.14^{f} (1)	2.00^{bc} (4)	1.14^{d} (1)	1.34^{ef} (1)	1.56^{a} (2)	1.94^{a} (3)	0.71^{c} (0)	1.00^{bc} (1)	0.71^{c} (0)	0.71^{c} (0)
T_{12}	Unweeded control	9.07^{a} (83)	8.07^{a} (65)	5.46^{a} (30)	2.06^{bc} (4)	3.72^{a} (14)	3.23^{a} (10)	1.44^{ab} (2)	1.64^{b} (2)	1.34^{b} (1)	1.91^{a} (4)	1.74^{a} (3)	1.84^{a} (4)
SEm		0.55	0.43	0.31	0.21	0.25	0.23	0.09	0.13	0.09	0.10	0.11	0.14
CD (0.05)		0.94	0.96	0.73	0.84	0.88	0.66	0.23	0.30	0.22	0.61	0.41	0.30

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

†days after application

Table 9. Effect of tank mixed herbicide combinations on species-wise weed density no./m^2) in 2020-21

Treatments		*Echinochloa colona*			*Leptochloa chinensis*			*Echinochloa stagnina*			*Echinochloa crus-galli*		
		15 DAA†	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	1.76^{abc} (3)*	2.04^{ab} (4)	2.27^{b} (5)	0.71^{c} (0)	1.34^{bcd} (1)	1.23^{bcde} (1)	1.56^{a} (2)	1.23^{bcd} (1)	1.46^{b} (2)	1.05 (1)	1.17 (1)	1.17 (1)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	1.00^{d} (1)	1.64^{bcd} (2)	2.37^{b} (6)	1.23^{abc} (1)	1.34^{bcd} (1)	0.71^{e} (0)	0.88^{bc} (0)	1.00^{bcd} (1)	1.56^{b} (2)	0.88 (0)	1.10 (1)	1.27 (1)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	1.27^{cd} (1)	1.86^{abc} (3)	2.06^{b} (4)	1.56^{ab} (2)	1.52^{abc} (2)	1.44^{abcd} (2)	1.17^{abc} (1)	1.27^{bcd} (1)	1.39^{b} (2)	0.71 (0)	0.71 (0)	1.17 (1)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.34^{cd} (1)	1.47^{bcd} (2)	1.58^{bc} (3)	0.88^{c} (0)	1.17^{bcd} (1)	1.23^{bcde} (1)	0.88^{bc} (0)	0.88^{cd} (0)	1.17^{bc} (1)	0.88 (0)	1.00 (1)	1.00 (1)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.66^{abcd} (2)	1.82^{abc} (3)	2.41^{b} (6)	1.05^{bc} (1)	1.39^{bcd} (2)	1.05^{cde} (1)	0.71^{c} (0)	1.23^{bcd} (1)	1.56^{b} (2)	0.71 (0)	0.71 (0)	1.17 (1)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.77^{abc} (3)	2.04^{ab} (4)	2.03^{b} (4)	0.71^{c} (0)	1.00^{cd} (1)	0.88^{de} (0)	1.17^{abc} (1)	1.17^{bcd} (1)	1.56^{b} (2)	0.88 (0)	1.10 (1)	1.56 (2)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	1.05^{d} (1)	1.27^{cd} (1)	1.88^{bc} (4)	1.10^{abc} (1)	0.71^{d} (0)	1.18^{bcde} (1)	1.56^{a} (2)	1.56^{ab} (2)	1.56^{b} (2)	0.71 (0)	0.71 (0)	1.27 (1)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.27^{cd} (1)	1.47^{bcd} (2)	1.72^{bc} (3)	1.17^{abc} (1)	1.27^{bcd} (1)	1.68^{ab} (2)	0.88^{bc} (0)	0.88^{cd} (0)	1.00^{bc} (1)	0.88 (0)	1.00 (1)	1.00 (1)
T_9	Bispyribac-sodium	2.02^{ab} (4)	2.10^{ab} (4)	2.19^{b} (5)	1.64^{ab} (2)	1.81^{ab} (3)	1.56^{abc} (2)	1.34^{ab} (1)	1.17^{bcd} (1)	1.56^{b} (2)	0.71 (0)	0.71 (0)	1.17 (1)
T_{10}	(Cyhalofop-butyl + penoxsulam)	1.46^{bcd} (2)	1.94^{abc} (3)	2.14^{b} (5)	0.88^{c} (0)	1.17^{bcd} (1)	1.05^{cde} (1)	1.66^{a} (2)	1.52^{abc} (2)	1.64^{ab} (2)	1.05 (1)	1.39 (2)	1.17 (1)
T_{11}	Hand weeded control	1.27^{cd} (1)	1.05^{d} (1)	1.14^{c} (1)	0.71^{c} (0)	0.71^{d} (0)	0.71^{e} (0)	0.71^{c} (0)	0.71^{d} (0)	0.71^{c} (0)	1.00 (1)	1.00 (1)	1.05 (1)
T_{12}	Unweeded control	2.19^{a} (4)	2.53^{a} (6)	3.33^{a} (11)	1.72^{a} (3)	2.11^{a} (4)	1.93^{a} (3)	1.64^{a} (2)	2.02^{a} (4)	2.26^{a} (5)	1.05 (1)	1.39 (2)	1.17 (1)
SEm		0.11	0.12	0.15	0.11	0.12	0.11	0.11	0.10	0.11	0.04	0.07	0.04
CD (0.05)		0.66	0.75	0.85	0.63	0.73	0.59	0.56	0.66	0.65	NS	NS	NS

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

†days after application

Table 10. Effect of tank mixed herbicide combinations on species-wise weed count (no./m^2) in 2020-21

Treatments		*Cyperus iria*			*Fimbristylis miliacea*			*Ludwigia perennis*		
		15 DAA	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	4.28^{bc} (19)	3.82^{bcd} (15)	3.26^{b} (11)	2.11^{abc} (4)	1.64^{abc} (2)	1.56^{abc} (2)	1.52^{ab} (2)	1.46^{abc} (2)	1.23^{bc} (0)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	5.17^{bc} (27)	4.31^{bc} (19)	3.76^{b} (14)	0.71^{d} (0)	0.71^{c} (0)	0.88^{cd} (0)	0.71^{c} (0)	0.71^{d} (0)	1.23^{bc} (0)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.26^{cd} (14)	3.50^{cd} (12)	3.11^{bc} (10)	1.87^{abc} (4)	1.47^{bc} (2)	1.39^{abcd} (2)	0.71^{c} (0)	0.71^{d} (0)	1.27^{bc} (1)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	3.55^{cd} (13)	2.81^{de} (8)	3.03^{bc} (9)	1.27^{bcd} (1)	1.17^{bc} (1)	1.56^{abc} (2)	0.71^{c} (0)	0.88^{cd} (0)	1.56^{b} (2)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.57^{bc} (21)	4.03^{bcd} (16)	3.46^{b} (12)	2.31^{ab} (5)	1.88^{ab} (3)	1.56^{abc} (2)	1.10^{bc} (1)	1.17^{abcd} (1)	1.17^{bc} (1)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	4.92^{bc} (24)	4.29^{bc} (19)	3.91^{b} (15)	0.71^{d} (0)	0.71^{c} (0)	0.71^{d} (0)	0.88^{bc} (0)	1.64^{ab} (2)	1.10^{bc} (1)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	4.03^{bc} (21)	4.31^{bc} (19)	3.24^{b} (11)	2.89^{a} (8)	1.32^{bc} (2)	1.10^{bcd} (1)	0.71^{c} (0)	1.00^{cd} (1)	0.88^{bc} (0)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.06^{bc} (17)	3.54^{cd} (13)	3.19^{bc} (10)	1.56^{bcd} (2)	1.27^{bc} (1)	1.17^{bcd} (1)	1.18^{bc} (1)	1.10^{bcd} (1)	1.46^{bc} (2)
T_9	Bispyribac-sodium	6.27^{b} (40)	4.63^{bc} (23)	2.23^{cd} (5)	1.68^{bcd} (2)	1.05^{bc} (1)	1.64^{ab} (2)	0.71^{c} (0)	0.71^{d} (0)	1.44^{bc} (3)
T_{10}	(Cyhalofop-butyl + penoxsulam)	5.92^{b} (35)	5.02^{b} (25)	3.72^{b} (14)	1.23^{cd} (1)	0.71^{c} (0)	0.71^{d} (0)	1.64^{ab} (3)	0.71^{d} (0)	0.71^{c} (0)
T_{11}	Hand weeded control	1.39^{d} (2)	1.87^{e} (4)	1.75^{d} (3)	1.68^{bcd} (2)	1.46^{bc} (2)	1.44^{abcd} (2)	1.29^{abc} (1)	1.68^{ab} (2)	1.56^{b} (2)
T_{12}	Unweeded control	10.00^{a} (100)	8.59^{a} (75)	6.71^{a} (45)	2.77^{a} (8)	2.58^{a} (7)	1.97^{a} (4)	2.03^{a} (4)	1.74^{a} (3)	2.47^{a} (3)
SEm		0.60	0.47	0.35	0.20	0.16	0.11	0.13	0.12	0.13
CD (0.05)		2.30	1.27	0.97	1.05	0.98	0.76	0.80	0.60	0.82

*√x + 0.5 transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.

†days after application

Table 11. Effect of tank mixed herbicide combinations on species wise weed count (no./m^2) in 2020-21

Treatments		*Sphenoclea zeylanica*			*Monochoria vaginalis*			*Limnocharis flava*		
		15 DAA†	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	1.34^{ab} (1)*	1.17^{ab} (1)	1.00 (1)	1.18^{b} (1)	1.23^{b} (1)	1.23^{bc} (1)	1.23^{ab} (1)	1.00 (1)	1.23^{bc} (1)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	0.71^{c} (0)	0.71^{b} (0)	0.71 (0)	0.71^{b} (0)	1.00^{b} (1)	0.71^{c} (0)	0.71^{c} (0)	0.71 (0)	0.71^{d} (0)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	0.71^{c} (0)	0.71^{b} (0)	1.44 (2)	0.71^{b} (0)	0.88^{b} (0)	1.46^{b} (2)	0.88^{bc} (0)	1.00 (1)	1.17^{bc} (1)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0.71^{c} (0)	0.71^{b} (0)	1.56 (2)	0.71^{b} (0)	1.17^{b} (1)	1.34^{bc} (1)	0.88^{bc} (0)	1.17 (1)	1.46^{ab} (2)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.00^{bc} (1)	1.17^{ab} (1)	1.00 (1)	0.71^{b} (0)	0.71^{b} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71 (0)	0.71^{d} (0)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.17^{abc} (1)	1.27^{a} (1)	1.10 (1)	1.18^{b} (1)	0.71^{b} (0)	1.18^{bc} (1)	0.71^{c} (0)	0.71 (0)	0.71^{d} (0)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.71^{c} (0)	0.71^{b} (0)	0.71 (0)	0.71^{b} (0)	0.71^{b} (0)	0.71^{c} (0)	0.88^{bc} (0)	0.88 (0)	0.88^{cd} (0)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.00^{bc} (1)	1.17^{ab} (1)	1.00 (1)	0.71^{b} (0)	1.25^{b} (2)	1.34^{bc} (1)	0.71^{c} (0)	0.71 (0)	1.17^{bc} (1)
T_9	Bispyribac-sodium	0.71^{c} (0)	0.71^{b} (0)	0.71 (0)	0.71^{b} (0)	1.10^{b} (1)	1.18^{bc} (1)	0.71^{c} (0)	0.71 (0)	0.71^{d} (0)
T_{10}	(Cyhalofop-butyl + penoxsulam)	1.56^{a} (2)	1.46^{a} (2)	1.34 (1)	1.18^{b} (1)	1.27^{b} (1)	0.71^{c} (0)	1.17^{ab} (1)	1.17 (1)	1.17^{bc} (1)
T_{11}	Hand weeded control	1.17^{abc} (1)	1.34^{a} (1)	1.64 (2)	0.88^{b} (0)	1.46^{ab} (2)	1.74^{ab} (3)	1.00^{bc} (1)	1.17 (1)	1.68^{a} (2)
T_{12}	Unweeded control	1.44^{ab} (2)	1.34^{a} (1)	1.44 (2)	2.18^{a} (5)	2.18^{a} (4)	2.34^{a} (5)	1.56^{a} (2)	1.05 (1)	1.68^{a} (2)
SEm		0.09	0.09	0.10	0.13	0.12	0.14	0.08	0.06	0.11
CD (0.05)		0.55	0.51	NS	0.83	0.78	0.64	0.45	NS	0.44

*$\sqrt{x+0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
†days after application

Table 12. Effect of tank mixed herbicide combinations on weed density (no./m^2) at 15 days after herbicide application

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.45^{bc*} (6)**	2.51^{bcde} (7)	2.48^{bcd} (6)	4.54^{def} (21)	4.69^{cd} (23)	5.35^{cde} (22)	1.56^{bc} (2)	2.45^{abc} (6)	2.63^{b} (4)	5.32^{de} (28)	5.86^{bc} (35)	5.62^{de} (32)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	1.94^{cd} (3)	1.62^{e} (3)	1.73^{ef} (3)	5.02^{cde} (25)	5.12^{bcd} (27)	5.87^{cd} (26)	0.71^{d} (0)	0.71^{d} (0)	0.71^{d} (0)	5.34^{cde} (29)	5.42^{cd} (30)	5.39^{def} (29)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	2.04^{cd} (4)	2.30^{bcde} (5)	2.12^{cde} (5)	4.16^{efg} (17)	3.97^{d} (17)	4.80^{de} (17)	0.71^{d} (0)	0.88^{d} (0)	0.83^{d} (0)	4.58^{ef} (21)	4.65^{cd} (23)	4.65^{fg} (22)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.39^{d} (2)	1.82^{de} (3)	1.56^{f} (3)	3.44^{gh} (12)	3.71^{d} (14)	4.14^{e} (13)	0.88^{d} (0)	0.88^{d} (0)	1.01^{d} (0)	3.75^{fg} (14)	4.18^{de} (18)	3.99^{gh} (16)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.04^{cd} (4)	2.17^{bcde} (5)	2.05^{def} (4)	5.29^{cd} (28)	5.10^{bcd} (26)	6.05^{c} (27)	0.71^{d} (0)	1.25^{cd} (2)	1.13^{cd} (1)	5.63^{cd} (32)	5.71^{c} (33)	5.67^{cde} (32)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2.32^{bc} (5)	2.65^{bcd} (7)	2.44^{bcd} (6)	5.74^{c} (33)	4.86^{bcd} (24)	6.29^{c} (29)	1.00^{cd} (1)	1.61^{bcd} (3)	1.59^{bcd} (2)	6.23^{c} (39)	5.79^{c} (34)	6.02^{cd} (36)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.00^{cd} (4)	2.27^{bcde} (5)	2.16^{cde} (5)	5.16^{cde} (27)	5.33^{bcd} (30)	6.05^{c} (29)	0.71^{d} (0)	0.88^{d} (0)	0.83^{d} (0)	5.52^{cd} (31)	5.86^{bc} (35)	5.70^{cd} (33)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.22^{bc} (5)	2.03^{cde} (5)	2.09^{cdef} (5)	3.90^{fg} (15)	4.25^{d} (19)	4.70^{de} (17)	0.71^{d} (0)	1.32^{cd} (2)	1.18^{cd} (1)	4.47^{ef} (20)	5.03^{cd} (25)	4.76^{efg} (23)
T_9	Bispyribac-sodium	2.80^{b} (7)	3.03^{b} (9)	2.88^{b} (8)	7.04^{b} (50)	6.41^{b} (42)	7.90^{b} (46)	1.00^{cd} (1)	0.71^{d} (0)	1.07^{cd} (0)	7.59^{b} (58)	7.12^{b} (51)	7.36^{b} (55)
T_{10}	(Cyhalofop-butyl + penoxsulam)	2.49^{bc} (6)	2.76^{bc} (8)	2.61^{bc} (7)	5.37^{cd} (29)	5.97^{bc} (36)	6.50^{c} (33)	0.71^{d} (0)	2.65^{ab} (7)	2.22^{bc} (4)	5.91^{cd} (35)	7.13^{b} (51)	6.55^{bc} (43)
T_{11}	Hand weeded control	1.44^{d} (2)	1.75^{de} (3)	1.58^{f} (3)	2.51^{h} (6)	1.96^{e} (4)	2.71^{f} (5)	1.74^{ab} (3)	1.80^{bcd} (3)	2.43^{b} (3)	3.26^{g} (11)	3.23^{e} (11)	3.26^{h} (11)
T_{12}	Unweeded control	4.17^{a} (17)	4.80^{a} (23)	4.47^{a} (20)	9.28^{a} (87)	10.35^{a} (108)	11.24^{a} (97)	2.28^{a} (5)	3.52^{a} (13)	3.93^{a} (9)	10.43^{a} (109)	11.99^{a} (144)	11.24^{a} (127)
SEm		0.20	0.24	0.22	0.51	0.58	0.61	0.15	0.26	0.28	0.54	0.63	0.58
CD (0.05)		0.67	0.92	0.55	1.01	1.67	1.24	0.61	1.25	1.21	0.92	1.30	0.91

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

** Original values before combined analysis in parentheses

Table 13. Effect of tank mixed herbicide combinations on weed density (no./m^2) at 30 days after application

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.60^{bc*} (7)**	3.37^{bcde} (11)	4.10^{bcde} (9)	4.24^{cd} (18)	4.12^{bcd} (17)	4.18^{cd} (18)	1.86^{ab} (3)	2.20^{bc} (4)	3.24^{bc} (4)	5.29^{cd} (28)	5.71^{bcd} (33)	5.51^{cd} (30)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	2.43^{bc} (6)	3.13^{bcde} (10)	3.86^{def} (8)	4.61^{bc} (21)	4.31^{bc} (19)	4.48^{bc} (20)	0.71^{d} (0)	1.00^{e} (1)	1.00^{g} (0)	5.22^{cd} (27)	5.48^{cd} (30)	5.35^{d} (29)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	2.37^{bc} (6)	2.90^{cd}e (9)	3.64^{ef} (7)	3.50^{de} (13)	3.75^{cd} (14)	3.63^{de} (14)	0.71^{d} (0)	1.17^{de} (1)	1.17^{fg} (1)	4.26^{ef} (18)	4.87^{de} (24)	4.58^{e} (21)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.93^{cd} (4)	2.44^{ef} (6)	3.03^{fg} (5)	3.10^{ef} (10)	2.99^{de} (9)	3.05^{e} (9)	0.71^{d} (0)	1.64^{cdce} (2)	1.65^{defg} (1)	3.68^{fg} (14)	4.16^{e} (17)	3.93^{f} (16)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.37^{bc} (6)	3.20^{bcde} (11)	3.83^{def} (8)	4.47^{cd} (20)	4.43^{bc} (20)	4.46^{bc} (20)	0.71^{d} (0)	1.56^{cde} (2)	1.56^{efg} (1)	5.07^{de} (26)	5.70^{bcd} (33)	5.41^{cd} (29)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2.93^{b} (9)	3.68^{bcd} (14)	4.53^{bcd} (11)	5.06^{bc} (26)	4.29^{bc} (19)	4.71^{bc} (23)	1.17^{c} (1)	2.04^{bc} (4)	2.43^{cd} (2)	5.95^{bc} (36)	6.04^{bc} (37)	6.00^{bc} (36)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.83^{b} (8)	2.81^{def} (8)	3.97^{cde} (8)	4.20^{cd} (18)	4.51^{bc} (21)	4.39^{cd} (19)	0.71^{d} (0)	1.17^{de} (1)	1.17^{fg} (1)	5.07^{de} (26)	5.42^{cd} (30)	5.29^{d} (28)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.57^{bc} (7)	2.44^{ef} (7)	3.55^{ef} (7)	4.18^{cd} (18)	3.71^{cd} (14)	4.00^{cd} (16)	0.71^{d} (0)	1.91^{bcd} (4)	1.91^{def} (2)	4.98^{de} (25)	4.88^{de} (25)	4.96^{de} (25)
T_9	Bispyribac-sodium	2.91^{b} (9)	3.96^{bc} (16)	4.73^{bc} (12)	5.56^{b} (31)	4.71^{bc} (23)	5.19^{b} (27)	1.64^{b} (2)	1.10^{de} (1)	2.42^{cde} (2)	6.48^{b} (42)	6.26^{bc} (40)	6.41^{b} (41)
T_{10}	(Cyhalofop-butyl + penoxsulam)	2.98^{b} (9)	4.12^{f} (17)	4.86^{b} (13)	4.44^{cd} (20)	5.02^{b} (25)	4.76^{bc} (23)	0.71^{d} (0)	2.08^{bc} (4)	2.09^{de} (2)	5.38^{cd} (29)	6.80^{b} (46)	6.14^{b} (38)
T_{11}	Hand weeded control	1.63^{d} (3)	1.72^{b} (3)	2.33^{g} (2)	2.16^{f} (5)	2.29^{e} (5)	2.23^{f} (5)	1.94^{ab} (3)	2.59^{ab} (6)	3.60^{ab} (5)	3.26^{g} (11)	3.81^{e} (15)	3.55^{f} (13)
T_{12}	Unweeded control	4.69^{a} (22)	5.79^{a} (34)	7.19^{a} (28)	8.89^{a} (79)	8.99^{a} (81)	8.96^{a} (80)	2.28^{a} (5)	3.06^{a} (9)	4.36^{a} (7)	10.31^{a} (106)	11.12^{a} (124)	10.73^{a} (115)
SEm		0.22	0.30	0.34	0.47	0.47	0.47	0.17	0.19	0.30	0.51	0.54	0.52
CD (0.05)		0.71	1.12	0.85	1.03	1.26	0.77	0.45	0.84	0.87	0.85	1.16	0.61

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** Original values before combined analysis in parentheses

Table 14. Effect of tank mixed herbicide combinations on weed density (no./m^2) at 60 days after application

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	3.90^{bc*} (15)**	3.99^{bc} (16)	3.96^{bcd} (16)	2.94^{bcd} (9)	3.56^{bc} (13)	3.27^{bcd} (11)	1.86^{b} (3)	1.76^{cdef} (3)	3.19^{b} (3)	5.19^{cd} (27)	5.60^{b} (31)	5.40^{bc} (29)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	4.26^{bc} (18)	4.32^{bc} (19)	4.29^{bcd} (19)	3.15^{bcd} (10)	3.81^{b} (15)	3.50^{bcd} (12)	0.71^{d} (0)	0.71^{f} (0)	0.71^{f} (0)	5.30^{cd} (28)	5.77^{b} (33)	5.55^{bc} (31)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.72^{c} (14)	3.90^{bcd} (15)	3.81^{cd} (15)	2.49^{cde} (6)	3.36^{bc} (11)	2.96^{cd} (9)	0.71^{d} (0)	2.45^{abcd} (6)	2.09^{cde} (3)	4.47^{d} (20)	5.68^{b} (32)	5.12^{cd} (26)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	2.58^{d} (7)	2.99^{d} (9)	2.82^{e} (8)	2.30^{de} (5)	3.33^{bc} (11)	2.88^{d} (8)	0.71^{d} (0)	2.73^{abc} (7)	2.32^{bcd} (4)	3.52^{e} (13)	5.20^{bc} (27)	4.44^{d} (20)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.22^{bc} (18)	4.18^{bc} (18)	4.20^{bcd} (18)	3.49^{b} (12)	3.73^{b} (14)	3.63^{bc} (13)	0.71^{d} (0)	1.39^{def} (2)	1.24^{ef} (1)	5.48^{c} (30)	5.79^{b} (34)	5.64^{bc} (32)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	4.50^{bc} (20)	4.40^{bc} (19)	4.45^{bc} (20)	3.82^{b} (15)	3.91^{b} (15)	3.86^{b} (15)	1.34^{c} (1)	1.55^{cdef} (3)	2.37^{bc} (2)	6.01^{bc} (36)	6.16^{b} (38)	6.10^{b} (37)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	4.68^{b} (22)	3.97^{bc} (16)	4.34^{bcd} (19)	3.53^{b} (13)	3.37^{bc} (12)	3.49^{bcd} (13)	0.71^{d} (0)	1.05^{ef} (1)	0.97^{f} (0)	5.88^{bc} (35)	5.38^{b} (29)	5.64^{bc} (32)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	3.70^{c} (14)	3.67^{cd} (14)	3.69^{d} (14)	3.76^{b} (15)	3.35^{bc} (11)	3.57^{bcd} (13)	0.71^{d} (0)	2.21^{bcde} (5)	1.89^{cde} (2)	5.32^{cd} (29)	5.40^{b} (30)	5.37^{bc} (29)
T_9	Bispyribac-sodium	4.58^{b} (21)	4.67^{b} (22)	4.63^{b} (22)	3.78^{b} (14)	2.69^{cd} (8)	3.30^{bcd} (11)	2.45^{a} (6)	1.65^{cdef} (4)	4.17^{a} (5)	6.40^{b} (41)	5.78^{b} (34)	6.10^{b} (37)
T_{10}	(Cyhalofop-butyl + penoxsulam)	4.75^{ab} (23)	4.28^{bc} (19)	4.53^{bc} (21)	3.36^{bc} (12)	3.72^{bc} (14)	3.58^{bcd} (13)	0.71^{d} (0)	1.68^{cdef} (2)	1.46^{def} (1)	5.86^{bc} (34)	5.89^{b} (35)	5.88^{bc} (35)
T_{11}	Hand weeded control	2.21^{d} (5)	1.99^{e} (4)	2.12^{e} (5)	1.61^{e} (3)	2.17^{d} (5)	1.92^{e} (4)	0.71^{d} (0)	3.12^{ab} (9)	2.65^{bc} (5)	2.73^{e} (8)	4.26^{c} (18)	3.59^{e} (13)
T_{12}	Unweeded control	5.60^{a} (31)	6.41^{a} (42)	6.03^{a} (37)	6.32^{a} (40)	6.97^{a} (49)	6.66^{a} (45)	2.18^{ab} (4)	3.48^{a} (12)	4.48^{a} (8)	8.70^{a} (76)	10.08^{a} (102)	9.42^{a} (89)
Em		0.27	0.30	0.28	0.33	0.33	0.32	0.19	0.24	0.34	0.43	0.40	0.40
CD (0.05)		0.86	0.95	0.75	0.88	1.04	0.75	0.32	1.20	0.87	0.88	1.04	0.81

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

**Original values before combined analysis in parentheses

4.1.2 Weed dry matter production

Species-wise dry matter production at three stages of observation in 2019-20 and 2020-21 has been tabulated in Tables 15, 16, 17, 18, and 19.

In 2019-20, dry matter production of *Echinochloa colona* at 15 DAA was lower in T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) in which there was no weed infestation, followed by the treatments T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (0.58 kg/ha), T_{11} (hand weeding) (1.12 kg/ha) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) (1.21 kg/ha). At 30 DAA the treatments T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] and T_{11} (hand weeding) were seen to record lower dry matter of the weed (9.84 and 10.78 kg/ha respectively). At 60 DAA, in addition to these two treatments, T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) was also seen to be superior in controlling the weed. At all three stages, unweeded control registered highest dry matter production of *E. colona* (8.03, 36.85 and 95.53 kg/ha respectively) (Table 15).

In the next year, T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) was again found to reduce dry matter production significantly at 15 DAA (1.99 kg/ha). This treatment, along with T_{11} (hand weeding) continued to be superior at 30 DAA, while at 60 DAA, T_{11} (hand weeding) was found to be the best treatment (6.46 kg/ha), followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (19.08 kg/ha). Highest weed dry matter was observed in the unweeded treatment (Table 17).

Dry matter production of *E. stagnina* was relatively low at 15 DAA in 2019-20. There was no infestation in several treatments (Table 15). Higher dry matter production was in T_{10} (cyhalofop-butyl + penoxsulam) (9.97 kg/ha), followed by T_9 (bispyribac-sodium) (9.04 kg/ha). The same treatments recorded higher dry matter at 30 DAA, while lower dry matter was in the treatments T_{11} (hand weeding) and T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)]. Hand weeding treatment was superior in reducing weed dry matter at 60 DAA (3.98 kg/ha), followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (10.54 kg/ha). Highest weed dry matter was in the unweeded control (41.32 kg/ha).

Infestation of *E. stagnina* was comparatively higher in 2020-21. At 15 DAA, hand weeded control registered lower dry matter of the weed (0 kg/ha), while higher dry matter production was in T_{12} (unweeded control) (6.25 kg/ha) and T_{10} (cyhalofop-butyl + penoxsulam) (6.97 kg/ha). At 30 and 60 DAA, hand weeding resulted in lower weed dry matter and unweeded control, the highest (Table 17).

E. crus-galli was observed in the field in 2020-21, but the effect of treatments on weed dry matter was non significant at all three stages of observation (Table 17).

Leptochloa chinensis is a problematic weed in the *Kole* lands. In 2019-20, unweeded control registered the highest dry matter production of the weed (6.22 kg/ha) at 15 DAA, while in several treatments viz., T_{11} (hand weeding), T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), there was no infestation of the weed (Table 15). There was no weed infestation even at 30 DAA in T_{11} (hand weeding) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone). Highest dry matter was recorded in unweeded control (12.84 kg/ha). This trend continued at 60 DAA with lower dry matter recorded in T_{11} (hand weeding) (1.87 kg/ha) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) (0 kg/ha).

The same trend was seen in 2020-21 also at 15 DAA. Lower dry matter production of *L. chinensis* was recorded in T_{11} and T_6, and highest in unweeded control (Table 17). At 30 DAA there no infestation of the weed in T_{11} (hand weeding) and T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium), while unweeded control again recorded highest dry matter of the weed (14.77 kg/ha). The highest dry matter of 28.35 kg/ha was produced in unweeded control at 60 DAA, while hand weeding and application of fenoxaprop-p-ethyl + carfentrazone resulted in complete control of the weed.

Weedy rice was present in all the experimental plots in both years of the study. All the plants were removed by hand weeding.

Cyperus iria was the predominant sedge in the experimental area. At all three stages of observation in 2019-20 the best control and lower dry matter of the sedge was seen in the hand weeded control, followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (Table 16). At 30 DAA, T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] was on par with T_4. At all stages, unweeded control recorded the lowest dry matter production of the weed.

The same trend was seen in 2020-21. After hand weeding the best treatment for controlling *C. iria* was T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)]. At 15 DAA, T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) was at par with T_4, while at 30 DAA T_4 was on par with T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)]. At 60 DAA T_9 (bispyribac-sodium) was on par with T_4 and T_3 in recording lower dry matter of *C. iria* (Table 18).

The sedge *Fimbristylis miliacea* was best controlled by the treatments T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) at all three stages of observation in 2019-20 (Table 16). Hand weeding was also at par with these treatments at 30 DAA. At 15 DAA highest weed dry mtter production was observed in T_9 (bispyribac-sodium) (6.31 kg/ha), while at 30 and 60 DAA it was in the unweeded control (28.93 and 31.97 kg/ha respectively).

Almost the same trend was noticed in 2020-21. Total control of the weed was obtained with the treatments T_2 (fenoxaprop-p-ethyl + carfentrazone) and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) at 15 and 30 DAA, while at 60 DAA it was obtained with the treatments T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) and T_{10} (cyhalofop-butyl + penoxsulam). T_{10} was at par with the best treatments at 30 DAA also. Unweeded control recorded the highest weed dry matter production at all three stages (Table 18).

Ludwigia perennis was the main broad leaf weed in the experimental area. However, in 2019-20 at 15, 30 and 60 DAA, the weed dry matter production was nil in most treatments (Table 16). Low dry matter was produced in the hand weeded and unweeded plots. In 2020-21, although the weed was absent in several treatments at 15 DAA, dry matter of 6.59 kg/ha was produced in T_{10} (cyhalofop-butyl + penoxsulam), followed by 4.90 kg/ha in the unweeded control and 2.06 kg/ha in T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] (Table 18). Unweeded control and T_1 had highest dry matter production at 30 DAA also, followed by T_6 (fenoxaprop-p-ethyl *fb* carfentrazone). However, by 60 DAA only the unweeded control produced significant amount of dry matter (25.34 kg/ha) while all other treatments were inferior and at par.

Unweeded control was significantly superior to all other treatments in dry matter production of *Monochoria vaginalis* at 15 DAA in 2019-20 (Table 16). At 30 DAA, along with unweeded control, in treatments T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) and T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] also weed dry matter production was superior to all other treatments. At 60 DAA, there was a change in the trend and higher dry matter was produced in T_9 (bispyribac-sodium) followed by unweeded control. In 2020-21, at both 15 and 30 DAA, dry matter of *M. vaginalis* was produced only in unweeded control (Table 19). However at 60 DAA, while unweeded control had highest dry matter production, dry matter was produced in lower quantities in treatments T_{11} (hand weeding), T_9 (bispyribac-sodium), T_6 (fenoxaprop-p-ethyl *fb* carfentrazone), T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)], T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)].

Dry weights of *Sphenoclea zeylanica* and *Limnocharis flava* were very low in the experimental area in 2020-21 and higher dry weight was observed in unweeded control plots at all stages of observation (Table 19).

Table 15. Effect of tank mixed herbicide combinations on species-wise weed dry matter production (weed DMP) (kg/ha) in 2019-20

Treatments		*Echinochloa colona*			*Leptochloa chinensis*			*Echinochloa stagnina*		
		15 DAA	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.67^{ab*} $(6.99)^{**}$	5.62^{ab} (31.67)	6.07^{b} (37.57)	1.28^{b} (1.14)	2.28^{ab} (4.72)	2.96^{abcd} (8.30)	1.95^{bc} (4.06)	4.32^{abc} (18.44)	4.48^{abcd} (20.99)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	1.75^{abcd} (3.11)	3.57^{cde} (12.77)	4.69^{bc} (22.84)	1.28^{b} (1.17)	1.33^{bc} (2.05)	1.51^{cde} (3.04)	0.71^{d} (0.00)	2.86^{bcd} (10.37)	3.57^{bcde} (16.47)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	1.92^{abcd} (4.19)	3.92^{bcde} (15.21)	4.82^{bc} (24.66)	1.06^{bc} (0.63)	2.39^{ab} (5.36)	3.26^{abcd} (10.50)	1.77^{bcd} (2.69)	3.56^{abcd} (12.53)	4.29^{abcd} (18.26)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0.97^{cd} (0.58)	3.48^{cde} (11.98)	4.24^{bc} (17.88)	0.89^{bc} (0.37)	1.47^{bc} (2.80)	1.63^{bcde} (3.85)	0.71^{d} (0.00)	1.77^{cd} (4.87)	2.36^{de} (10.54)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.29^{bcd} (1.85)	4.82^{abcd} (23.11)	5.41^{bc} (28.91)	0.71^{c} (0.00)	2.37^{ab} (5.36)	2.46^{abcde} (7.20)	0.71^{d} (0.00)	1.67^{d} (4.17)	2.56^{cde} (7.76)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.15^{cd} (1.21)	5.23^{abc} (27.42)	5.03^{bc} (26.54)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{e} (0.00)	2.08^{abc} (4.75)	4.96^{ab} (26.20)	5.63^{ab} (32.09)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.71^{d} (0.00)	3.46^{cde} (11.97)	3.55^{c} (16.22)	1.16^{bc} (1.25)	2.62^{ab} (6.48)	3.82^{a} (14.12)	2.12^{abc} (4.65)	4.75^{ab} (24.53)	5.10^{ab} (28.63)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.68^{abcd} (2.93)	2.82^{e} (9.84)	3.71^{c} (18.73)	1.02^{bc} (0.56)	2.33^{ab} (5.09)	3.58^{abc} (17.08)	0.71^{d} (0.00)	3.42^{abcd} (15.25)	4.55^{abcd} (20.53)
T_9	Bispyribac-sodium	2.98^{a} (9.04)	5.36^{abc} (28.57)	5.12^{bc} (25.93)	1.42^{b} (1.56)	2.19^{ab} (5.50)	3.70^{ab} (13.07)	2.67^{ab} (7.05)	5.49^{a} (33.06)	5.02^{abc} (28.29)
T_{10}	(Cyhalofop-butyl + penoxsulam)	2.31^{abc} (5.01)	4.22^{abcde} (18.05)	5.23^{bc} (27.23)	0.71^{c} (0.00)	1.22^{bc} (1.53)	1.50^{cde} (3.00)	3.13^{a} (9.97)	5.98^{a} (35.95)	5.45^{ab} (29.26)
T_{11}	Hand weeded control	1.22^{cd} (1.12)	2.95^{de} (10.78)	3.41^{c} (11.63)	0.71^{c} (0.00)	0.71^{c} (0.00)	1.30^{de} (1.87)	0.71^{d} (0.00)	1.57^{d} (3.44)	1.65^{e} (3.98)
T_{12}	Unweeded control	2.84^{a} (8.03)	6.04^{a} (36.85)	9.76^{a} (95.53)	2.54^{a} (6.22)	3.47^{a} (12.84)	4.06^{a} (16.70)	1.49^{cd} (2.97)	5.32^{ab} (28.41)	6.46^{a} (41.32)
SEm		0.22	0.31	0.48	0.15	0.24	0.34	0.25	0.45	0.42
CD (0.05)		1.39	1.95	2.31	0.53	1.45	2.14	1.11	2.62	2.54

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

** Original values before combined analysis in parentheses

Table 16. Effect of tank mixed herbicide combinations on species-wise weed DMP (kg/ha) in 2019-20

Treatments		*Cyperus iria*			*Fimbristylis miliacea*			*Ludwigia perennis*			*Monochoria vaginalis*		
		15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	3.54^{def*} (12.56)**	3.59^{gh} (19.58)	4.49^{cdef} (20.60)	1.61^{bcd} (2.18)	1.77^{de} (3.18)	1.86^{c} (3.05)	0.75^{b} (0.07)	1.07^{b} (0.67)	1.55^{b} (1.91)	0.83^{b} (0.19)	1.13^{a} (0.86)	1.64^{c} (2.20)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	4.01^{cde} (16.15)	8.44^{c} (72.46)	5.52^{bc} (30.60)	0.71^{e} (0.00)	1.18^{e} (1.44)	0.71^{d} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.24^{def} (10.67)	7.03^{cd} (49.96)	4.01^{def} (16.47)	1.61^{bcd} (2.32)	1.27^{de} (1.70)	1.65^{c} (2.23)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	2.52^{fg} (6.39)	4.05^{fgh} (16.98)	3.48^{f} (13.20)	1.38^{cde} (1.47)	1.44^{de} (2.08)	2.17^{c} (4.26)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.75^{b} (0.07)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	3.57^{def} (12.79)	4.50^{efgh} (21.09)	4.98^{cde} (25.27)	2.03^{abc} (3.70)	2.06^{cd} (4.46)	3.93^{b} (15.04)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	4.97^{bc} (25.23)	10.97^{b} (121.61)	6.60^{b} (44.33)	0.71^{e} (0.00)	1.22^{e} (1.51)	0.71^{d} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.82^{b} (0.19)	1.26^{a} (1.26)	1.84^{bc} (3.20)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	4.16^{cde} (17.56)	6.09^{cdef} (36.84)	4.34^{cdef} (18.93)	1.26^{de} (1.33)	1.65^{de} (2.86)	3.86^{b} (15.35)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.93^{ef} (8.62)	5.27^{defg} (27.57)	3.82^{ef} (14.63)	2.19^{ab} (4.33)	2.78^{c} (8.37)	3.58^{b} (12.43)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_9	Bispyribac-sodium	5.52^{b} (30.83)	6.78^{cde} (45.87)	5.15^{cde} (26.67)	2.52^{a} (6.31)	3.64^{b} (13.45)	3.33^{b} (10.67)	0.71^{b} (0.00)	0.71^{c} (0.00)	2.20^{a} (4.50)	0.92^{b} (0.43)	1.34^{a} (1.36)	3.16^{a} (10.13)
T_{10}	(Cyhalofop-butyl + penoxsulam)	4.40^{bcd} (19.42)	6.24^{cdef} (39.22)	5.31^{bcd} (28.67)	1.14^{de} (0.82)	1.49^{de} (2.24)	2.19^{c} (4.51)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_{11}	Hand weeded control	1.53^{g} (2.60)	2.60^{h} (6.36)	1.89^{g} (3.70)	1.49^{bcd} (1.77)	1.16^{e} (1.46)	2.20^{c} (4.55)	0.85^{a} (0.23)	1.40^{a} (1.50)	0.71^{c} (0.00)	0.81^{b} (0.17)	0.71^{b} (0.00)	0.71^{d} (0.00)
T_{12}	Unweeded control	9.89^{a} (100.82)	13.58^{a} (184.48)	10.32^{a} (107.80)	1.16^{de} (0.88)	5.32^{a} (28.93)	5.69^{a} (31.97)	0.89^{a} (0.31)	1.16^{b} (0.88)	1.89^{a} (3.17)	1.28^{a} (1.26)	1.39^{a} (1.48)	2.42^{b} (6.14)
SEm		0.60	0.91	0.59	0.16	0.36	0.42	0.02	0.07	0.16	0.05	0.08	0.24
CD (0.05)		1.31	2.48	1.44	0.70	0.83	0.81	0.10	0.20	0.34	0.29	0.35	0.70

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

** Original values before combined analysis in parentheses

Table 17. Effect of tank mixed herbicide combinations on species wise weed DMP (kg/ha) in 2020-21

Treatments		*Echinochloa colona*			*Leptochloa chinensis*			*Echinochloa stagnina*			*Echinochloa crus-galli*		
		15 DAA	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	3.01^{ab*} $(8.74)^{**}$	5.49^{abc} (29.71)	7.79^{abc} (62.75)	0.71^{c} (0.00)	1.69^{bcd} (2.39)	2.79^{bcd} (7.31)	2.33^{ab} (5.43)	3.19^{bcd} (9.69)	4.83^{bc} (23.28)	1.64 (2.63)	2.65 (8.67)	3.42 (15.21)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	2.77^{abc} (7.84)	5.00^{bc} (27.16)	8.66^{ab} (75.37)	1.77^{abc} (2.62)	2.63^{abc} (6.78)	0.71^{d} (0.00)	1.16^{cd} (1.27)	1.99^{bcd} (6.73)	5.02^{bc} (26.34)	1.31 (1.93)	1.99 (6.73)	3.69 (19.13)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.09^{ab} (9.22)	4.80^{bc} (22.75)	6.51^{bcd} (43.27)	2.30^{ab} (5.08)	3.14^{abc} (9.80)	2.42^{bcd} (7.03)	1.28^{bcd} (1.29)	3.44^{abc} (11.94)	3.37^{bcd} (14.75)	0.71 (0.00)	0.71 (0.00)	2.78 (9.41)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.89^{bc} (3.18)	3.27^{cd} (13.57)	4.29^{de} (19.08)	1.10^{bc} (1.00)	2.05^{abcd} (4.77)	2.51^{bcd} (7.61)	1.06^{cd} (0.87)	1.64^{cd} (3.93)	3.17^{bcd} (12.60)	1.09 (0.96)	1.67 (4.11)	1.71 (4.43)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.60^{bc} (3.65)	5.25^{bc} (30.01)	7.69^{abc} (66.23)	1.50^{abc} (2.07)	2.45^{abcd} (7.07)	2.48^{bcd} (7.40)	0.71^{d} (0.00)	3.85^{abc} (15.10)	5.21^{abc} (28.08)	0.71 (0.00)	0.71 (0.00)	3.01 (11.47)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.81^{bc} (3.53)	6.81^{ab} (46.34)	7.13^{abcd} (54.08)	0.71^{c} (0.00)	1.53^{cd} (3.20)	1.97^{cd} (6.54)	1.66^{abcd} (2.77)	2.94^{bcd} (10.72)	5.21^{abc} (27.69)	1.13 (1.15)	2.17 (8.49)	4.99 (25.96)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	1.48^{c} (1.99)	3.46^{cd} (16.33)	6.19^{bcd} (41.11)	1.47^{bc} (2.83)	0.71^{d} (0.00)	2.46^{bcd} (11.70)	2.48^{a} (6.16)	4.43^{ab} (20.19)	5.62^{ab} (32.07)	0.71 (0.00)	0.71 (0.00)	3.30 (14.53)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.91^{bc} (4.03)	3.94^{bcd} (21.00)	5.24^{cde} (28.03)	1.68^{abc} (2.88)	2.37^{abcd} (6.97)	4.52^{ab} (20.32)	1.02^{cd} (0.73)	1.94^{bcd} (6.28)	2.37^{cd} (10.60)	1.05 (0.83)	1.94 (6.28)	2.05 (7.27)
T_9	Bispyribac-sodium	3.05^{ab} (9.06)	6.09^{abc} (37.92)	7.43^{abc} (58.35)	2.37^{ab} (5.43)	3.48^{ab} (12.92)	4.29^{abc} (17.92)	2.08^{abc} (3.91)	2.85^{bcd} (10.24)	5.27^{ab} (28.47)	0.71 (0.00)	0.71 (0.00)	3.32 (14.01)
T_{10}	(Cyhalofop-butyl + penoxsulam)	2.24^{bc} (4.60)	5.75^{abc} (33.12)	7.14^{abcd} (51.83)	1.13^{bc} (1.15)	2.03^{abcd} (4.67)	2.18^{bcd} (5.34)	2.68^{a} (6.97)	4.02^{abc} (15.99)	5.16^{bc} (28.05)	1.63 (2.59)	3.45 (15.48)	3.12 (12.25)
T_{11}	Hand weeded control	1.98^{bc} (4.76)	1.61^{d} (2.50)	2.54^{e} (6.46)	0.71^{c} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	0.71^{d} (0.00)	1.26 (1.70)	0.71 (0.00)	2.06 (4.68)
T_{12}	Unweeded control	4.03^{a} (15.81)	8.34^{a} (69.97)	10.10^{a} (103.99)	2.78^{a} (8.06)	3.89^{a} (14.77)	5.36^{a} (28.35)	2.52^{a} (6.25)	5.85^{a} (34.87)	8.06^{a} (65.24)	1.61 (2.53)	3.34 (14.43)	3.44 (15.31)
SEm		0.22	0.51	0.58	0.20	0.29	0.41	0.21	0.40	0.54	0.11	0.30	0.25
CD (0.05)		1.50	2.87	3.01	1.28	1.87	2.48	1.14	2.57	2.90	NS	NS	NS

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** Original values before combined analysis in parentheses

Table 18. Effect of tank mixed herbicide combinations on species-wise weed DMP (kg/ha) in 2020-21

Treatments		*Cyperus iria*			*Fimbristylis miliacea*			*Ludwigia perennis*		
		15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA	15 DAA	30 DAA	60 DAA
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	3.85^{bcd} (14.92)	4.09^{cd} (17.01)	4.27^{bcd} (18.35)	1.03^{abc} (0.57)	1.33^{bc} (1.33)	1.72^{ab} (2.57)	1.52^{abc} (2.06)	2.08^{ab} (3.97)	1.65^{b} (2.24)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	4.77^{bcd} (22.44)	4.30^{bc} (19.63)	4.60^{bc} (21.29)	0.71^{d} (0.00)	0.71^{c} (0.00)	0.94^{bc} (0.49)	0.71^{c} (0.00)	0.71^{c} (0.00)	2.04^{b} (3.85)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.06^{de} (9.15)	3.90^{cd} (15.19)	3.34^{de} (11.19)	0.91^{bcd} (0.35)	1.22^{bc} (1.14)	1.27^{bc} (1.32)	0.71^{c} (0.00)	0.71^{c} (0.00)	1.85^{b} (3.65)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	2.79^{de} (9.52)	2.65^{de} (7.13)	2.93^{e} (8.75)	0.78^{cd} (0.11)	0.92^{bc} (0.38)	1.34^{bc} (1.36)	0.71^{c} (0.00)	0.94^{c} (0.49)	2.14^{b} (4.30)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.04^{bcd} (16.02)	4.33^{bc} (18.99)	4.52^{bc} (20.62)	1.07^{ab} (0.67)	1.52^{ab} (1.98)	1.59^{b} (2.13)	1.30^{bc} (1.88)	1.47^{bc} (2.03)	1.92^{b} (4.07)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	4.47^{bcd} (19.84)	4.49^{bc} (21.95)	5.06^{b} (25.61)	0.71^{d} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.92^{c} (0.44)	1.69^{abc} (2.77)	1.75^{b} (4.70)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	3.95^{bcd} (20.41)	4.47^{bc} (20.01)	4.00^{cd} (17.01)	0.86^{bcd} (0.25)	1.15^{bc} (1.23)	1.31^{bc} (1.96)	0.71^{c} (0.00)	1.30^{bc} (1.88)	1.25^{b} (1.63)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	3.67^{cd} (13.62)	3.73^{cde} (14.09)	4.07^{bcd} (16.68)	0.84^{bcd} (0.21)	1.12^{bc} (0.87)	1.24^{bc} (1.21)	1.26^{bc} (1.68)	1.39^{bc} (2.37)	2.33^{b} (5.11)
T_9	Bispyribac-sodium	5.80^{b} (33.63)	4.97^{bc} (26.07)	2.92^{e} (9.07)	0.95^{abcd} (0.40)	1.11^{bc} (0.82)	1.76^{ab} (2.74)	0.71^{c} (0.00)	0.71^{c} (0.00)	2.42^{b} (11.24)
T_{10}	(Cyhalofop-butyl + penoxsulam)	5.49^{bc} (30.31)	5.73^{b} (32.89)	4.64^{bc} (21.56)	0.82^{bcd} (0.17)	0.71^{c} (0.00)	0.71^{c} (0.00)	2.38^{a} (6.59)	0.71^{c} (0.00)	0.71^{b} (0.00)
T_{11}	Hand weeded control	1.53^{e} (2.39)	2.31^{e} (5.61)	1.66^{f} (2.95)	0.89^{bcd} (0.30)	1.06^{bc} (0.62)	1.34^{bc} (1.34)	1.07^{c} (0.72)	1.65^{bc} (2.65)	1.80^{b} (2.87)
T_{12}	Unweeded control	9.42^{a} (88.52)	9.42^{a} (89.63)	8.51^{a} (73.01)	1.20^{a} (1.02)	2.08^{a} (4.04)	2.44^{a} (5.62)	2.31^{ab} (4.90)	2.70^{ab} (7.07)	5.02^{a} (25.34)
SEm		0.57	0.52	0.48	0.04	0.11	0.14	0.18	0.18	0.30
CD (0.05)		2.10	1.57	1.05	0.26	0.69	0.84	1.08	1.03	1.98

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

** Original values before combined analysis in parentheses

Table 19. Effect of tank mixed herbicide combinations on species-wise weed DMP (kg/ha) in 2020-21

Treatments		*Sphenoclea zeylanica*			*Monochoria vaginalis*			*Limnocharis flava*		
		15 DAA	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**	**15 DAA**	**30 DAA**	**60 DAA**
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	1.21^{abc} (0.98)	1.60^{abc} (2.46)	1.51 (3.05)	0.80^{b} (0.16)	1.12^{b} (0.75)	1.13^{bc} (0.77)	0.97^{b} (0.44)	0.91 (0.42)	1.40^{ab} (1.47)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{b} (0.00)	1.01^{b} (0.71)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{c} (0.00)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	0.71^{c} (0.00)	0.71^{c} (0.00)	2.47 (5.97)	0.71^{b} (0.00)	0.89^{b} (0.36)	1.52^{bc} (1.85)	0.78^{bc} (0.12)	0.98 (0.61)	1.22^{abc} (1.12)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0.71^{c} (0.00)	0.71^{c} (0.00)	1.99 (4.00)	0.71^{b} (0.00)	1.06^{b} (0.74)	1.20^{bc} (0.94)	0.77^{bc} (0.10)	1.14 (0.90)	1.37^{ab} (1.39)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.06^{bc} (0.88)	1.70^{abc} (2.99)	1.50 (3.02)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{c} (0.00)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	1.12^{abc} (1.11)	1.99^{ab} (4.59)	1.78 (4.97)	0.90^{b} (0.39)	0.71^{b} (0.00)	1.48^{bc} (2.89)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{c} (0.00)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.77^{bc} (0.10)	0.91 (0.41)	0.96^{bc} (0.54)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.10^{abc} (1.01)	1.63^{abc} (2.63)	1.48 (2.91)	0.71^{b} (0.00)	1.23^{b} (1.56)	1.73^{bc} (2.53)	0.71^{c} (0.00)	0.71 (0.00)	1.34^{ab} (1.51)
T_9	Bispyribac-sodium	0.71^{c} (0.00)	0.71^{c} (0.00)	0.71 (0.00)	0.71^{b} (0.00)	1.20^{b} (1.41)	1.59^{bc} (3.61)	0.71^{c} (0.00)	1.61 (3.75)	0.71^{c} (0.00)
T_{10}	(Cyhalofop-butyl + penoxsulam)	1.67^{ab} (2.30)	2.57^{a} (6.30)	2.55 (6.21)	1.17^{b} (1.28)	1.40^{b} (1.90)	0.71^{c} (0.00)	0.96^{b} (0.45)	1.20 (1.07)	1.27^{ab} (1.31)
T_{11}	Hand weeded control	1.03^{bc} (0.63)	1.48^{bc} (1.76)	2.28 (5.20)	0.89^{b} (0.35)	1.23^{b} (1.02)	2.01^{b} (3.86)	0.83^{bc} (0.21)	1.06 (0.69)	1.42^{ab} (1.54)
T_{12}	Unweeded control	1.72^{a} (2.56)	2.43^{ab} (5.63)	2.79 (7.75)	2.30^{a} (6.08)	2.43^{a} (5.40)	3.53^{a} (12.00)	1.27^{a} (1.17)	1.17 (0.97)	1.74^{a} (2.53)
SEm		0.10	0.20	0.21	0.13	0.13	0.23	0.05	0.08	0.10
CD (0.05)		0.66	1.08	NS	0.76	0.85	1.07	0.24	NS	0.53

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

** Original values before combined analysis in parentheses

Analysis of pooled data on dry matter production of grasses revealed that at 15 DAA, the treatments hand weeded control, T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and T_5 [fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)] were most effective in controlling grasses (5.73, 5.85 and 7.85 kg/ha respectively) (Table 20). At 30 DAA and 60 DAA, hand weeding and application of [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] were most effective (Tables 21 and 22). At all three stages, unweeded control registered higher weed dry matter.

Considering dry matter production of sedges, hand weeding, followed by T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] were consistently better in reducing dry matter at all three stages (Tables 20, 21 and 22). Unweeded control registered higher dry matter production throughout.

Dry matter production of broad leaf weeds did not register a constant trend. At 15 DAA highest dry matter was recorded in unweeded control (8.14 kg/ha), while T_2 (fenoxaprop-p-ethyl + carfentrazone) had no infestation of the weed (Table 20). At 30 DAA, unweeded control recorded higher dry matter (10.72 kg/ha), followed by T_1 [(fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)] (4.56 kg/ha), and lower dry matter was produced in T_2 (fenoxaprop-p-ethyl + carfentrazone) (0.36 kg/ha) and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) (0.48 kg/ha) (Table 21). Highest dry matter continued to be recorded in unweeded control at 60 DAA (28.47 kg/ha) and was on par with T_9 (bispyribac-sodium) (14.74 kg/ha) (Table 22).

Highest total weed dry matter pooled over the two years at 15 DAA was in unweeded control (161.05 kg/ha), while the most effective treatments for reducing dry matter production were T_{11} (hand weeding) (10.42 kg/ha) and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (14.68 kg/ha) (Table 20). At 30 DAA, unweeded control continued to produce highest dry matter (432.97 kg/ha), and hand weeding was the most effective treatment having a dry matter production of 28.88 kg/ha, followed by T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] with 88.22 kg/ha, and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] with 50.50 kg/ha (Table 21). Hand weeding and T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] remained the best treatments at 60 DAA (Table 22) producing dry matter of 41.53 and 88.95 kg/ha respectively, while unweeded control with 518.45 kg/ha was the least effective treatment.

Table 20. Effect of tank mixed herbicide combinations on weed DMP (kg/ha) at 15 DAA (days after application)

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	3.53^{bc*} (12.90)**	4.74^{bc} (22.47)	4.20^{bcd} (17.69)	3.84^{cde} (14.74)	3.93^{bcd} (15.49)	3.99^{cdef} (15.12)	0.87^{b} (0.25)	1.99^{bc} (3.63)	1.83^{bc} (1.94)	5.26^{cde} (27.90)	6.42^{c} (41.59)	5.89^{c} (34.74)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	2.77^{cd} (7.24)	3.85^{bcde} (15.46)	3.33^{defg} (11.35)	4.01^{cde} (16.15)	4.71^{bcd} (22.44)	4.45^{cde} (19.29)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{d} (0.00)	4.83^{de} (23.39)	6.14^{c} (37.90)	5.53^{cd} (30.65)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	2.95^{cd} (8.40)	4.43^{bcde} (19.87)	3.73^{cde} (14.14)	3.60^{de} (12.99)	3.11^{de} (9.50)	3.53^{ef} (11.25)	0.71^{b} (0.00)	0.78^{c} (0.12)	0.75^{cd} (0.06)	4.61^{de} (21.39)	5.42^{cd} (29.49)	5.04^{cd} (25.44)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.52^{e} (2.13)	3.09^{de} (9.58)	2.41^{fg} (5.85)	2.80^{ef} (7.87)	2.81^{de} (9.63)	3.00^{fg} (8.75)	0.75^{b} (0.07)	0.77^{c} (0.10)	0.85^{cd} (0.09)	3.17^{fg} (10.07)	4.31^{de} (19.30)	3.80^{e} (14.68)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.78^{de} (3.64)	3.24^{cde} (12.06)	2.62^{fg} (7.85)	4.05^{cde} (16.49)	4.13^{bcd} (16.69)	4.20^{cdef} (16.59)	0.71^{b} (0.00)	1.46^{c} (2.76)	1.26^{cd} (1.38)	4.48^{de} (20.13)	5.61^{c} (31.51)	5.08^{cd} (25.82)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2.77^{cd} (7.50)	3.97^{bcde} (16.48)	3.39^{defg} (11.99)	4.97^{bc} (25.23)	4.47^{bcd} (19.84)	4.92^{bcd} (22.53)	0.82^{b} (0.19)	1.31^{c} (1.93)	1.27^{cd} (1.06)	5.71^{cd} (32.92)	6.17^{c} (38.26)	5.95^{c} (35.59)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.73^{cd} (8.11)	3.89^{bcde} (15.72)	3.45^{def} (11.92)	4.31^{cd} (18.89)	4.05^{bcd} (20.67)	4.43^{cde} (19.78)	0.71^{b} (0.00)	0.77^{c} (0.10)	0.75^{cd} (0.05)	5.12^{cde} (27.01)	5.89^{c} (36.49)	5.54^{cd} (31.75)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.53^{cde} (6.58)	3.11^{cde} (11.02)	2.84^{efg} (8.80)	3.59^{de} (12.94)	3.70^{cd} (13.82)	3.75^{def} (13.38)	0.71^{b} (0.00)	1.45^{c} (2.69)	1.25^{cd} (1.35)	4.40^{ef} (19.52)	5.21^{cd} (27.53)	4.83^{d} (23.53)
T_9	Bispyribac-sodium	4.35^{ab} (20.12)	5.19^{b} (27.54)	4.85^{b} (23.83)	6.04^{b} (37.14)	5.83^{b} (34.03)	6.16^{b} (35.59)	0.92^{b} (0.43)	0.71^{c} (0.00)	1.15^{cd} (0.22)	7.56^{b} (57.69)	7.83^{b} (61.57)	7.70^{b} (59.63)
T_{10}	(Cyhalofop-butyl + penoxsulam)	4.27^{b} (18.20)	4.71^{bcd} (22.43)	4.51^{bc} (20.31)	4.49^{cd} (20.24)	5.50^{bc} (30.48)	5.07^{bc} (25.36)	0.71^{b} (0.00)	3.20^{ab} (10.62)	2.54^{b} (5.31)	6.19^{c} (38.43)	7.95^{b} (63.53)	7.14^{b} (50.98)
T_{11}	Hand weeded control	1.59^{e} (2.20)	2.92^{e} (9.50)	2.35^{g} (5.73)	2.07^{f} (4.37)	1.62^{e} (2.69)	1.98^{g} (3.53)	0.94^{b} (0.40)	1.45^{c} (1.91)	1.60^{bcd} (1.16)	2.56^{g} (6.74)	3.69^{g} (14.10)	3.22^{e} (10.42)
T_{12}	Unweeded control	5.63^{a} (31.59)	9.11^{a} (82.99)	7.56^{a} (57.29)	9.93^{a} (101.70)	9.48^{a} (89.54)	10.10^{a} (95.62)	1.38^{a} (1.57)	3.80^{a} (14.71)	3.66^{a} (8.14)	11.55^{a} (134.86)	13.68^{a} (187.24)	12.68^{a} (161.05)
SEm		0.36	0.49	0.42	0.57	0.57	0.58	0.06	0.29	0.25	0.67	0.74	0.71
CD (0.05)		1.18	1.63	1.04	1.29	2.05	1.29	0.30	1.39	1.12	1.27	1.28	0.94

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

** Original values before combined analysis in parentheses

Table 21. Effect of tank mixed herbicide combinations on weed DMP (kg/ha) at 30 DAA

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	8.12^{bc} (68.25)**	9.49^{bc} (90.22)	8.88^{bcd} (79.23)	$4.13f^{g}$ (22.76)	4.26^{bc} (18.34)	4.32^{ef} (20.55)	1.40^{ab} (1.52)	2.84^{ab} (7.60)	2.83^{b} (4.56)	9.59^{de} (92.53)	10.76^{cd} (116.16)	10.20^{de} (104.34)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethylv	7.17^{bcd} (52.23)	9.34^{bcd} (93.90)	8.44^{cd} (73.06)	8.50^{c} (73.90)	4.30^{bc} (19.63)	6.77^{c} (46.76)	0.71^{c} (0.00)	1.01^{c} (0.71)	0.90^{e} (0.36)	11.20^{cd} (126.13)	10.51^{cd} (114.24)	10.94^{cd} (120.18)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	6.57^{cde} (44.17)	7.78^{cd} (61.12)	7.23^{de} (52.64)	7.11^{cde} (51.66)	4.04^{cd} (16.33)	5.79^{cd} (34.40)	0.71^{c} (0.00)	1.16^{c} (0.97)	0.99^{e} (0.48)	9.70^{de} (95.83)	8.83^{de} (78.42)	9.29^{de} (87.12)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	5.57^{de} (32.81)	6.24^{de} (39.48)	5.98^{ef} (36.15)	4.24^{fg} (19.06)	2.72^{de} (7.50)	3.61^{fg} (13.28)	0.71^{c} (0.00)	1.54^{bc} (2.13)	1.24^{de} (1.07)	7.18^{fg} (51.88)	6.99^{ef} (49.12)	7.09^{f} (50.50)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	7.07^{bcd} (50.19)	9.84^{bc} (100.45)	8.63^{cd} (75.32)	4.96^{efg} (25.54)	4.56^{bc} (20.96)	4.81^{def} (23.25)	0.71^{c} (0.00)	2.31^{bc} (5.02)	1.76^{cde} (2.51)	8.70^{ef} (75.74)	11.16^{bcd} (126.43)	10.02^{de} (101.09)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	9.11^{b} (84.51)	11.51^{b} (132.76)	10.39bc (108.63)	11.01^{b} (123.12)	4.49^{bc} (21.95)	8.44^{b} (72.53)	1.26^{b} (1.26)	2.53^{bc} (7.36)	2.59^{bc} (4.31)	14.39^{b} (208.89)	12.72^{bc} (162.06)	13.59^{b} (185.48)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	7.82^{bcd} (63.34)	9.02^{bcd} (81.98)	8.49cd (72.66)	6.29^{cdef} (39.70)	4.59^{bc} (21.24)	5.52^{cde} (30.47)	0.71^{c} (0.00)	1.50^{bc} (2.29)	1.22^{de} (1.14)	10.07^{cde} (103.05)	10.26^{cd} (105.51)	10.19^{de} (104.28)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	7.02^{bcde} (53.54)	7.41^{cd} (65.33)	7.27^{de} (59.44)	5.95^{def} (35.94)	3.84^{cde} (15.06)	$5.04d^{e}$ (25.50)	0.71^{c} (0.00)	2.56^{bc} (6.56)	1.94^{bcd} (3.28)	9.39^{de} (89.48)	8.91^{de} (86.95)	9.20^{e} (88.22)
T_9	Bispyribac-sodium	8.69^{bc} (76.97)	11.59^{b} (136.73)	10.32^{bc} (106.85)	7.69^{cd} (59.32)	5.07^{bc} (26.88)	6.54^{c} (43.10)	1.34^{ab} (1.36)	1.80^{bc} (5.16)	2.46^{bc} (3.26)	11.69^{c} (137.65)	12.88^{bc} (168.78)	12.37^{bc} (153.21)
T_{10}	(Cyhalofop-butyl + penoxsulam)	8.98^{b} (81.94)	12.01^{b} (144.76)	10.64^{b} (113.35)	6.38^{cdef} (41.46)	5.73^{b} (32.89)	6.09^{cd} (37.18)	0.71^{c} (0.00)	3.05^{ab} (9.27)	2.29^{bc} (4.64)	11.10^{cd} (123.40)	13.66^{b} (186.93)	12.45^{bc} (155.17)
T_{11}	Hand weeded control	4.76^{e} (23.96)	3.48e (12.12)	4.20^{f} (18.04)	2.79^{g} (7.82)	2.44^{e} (6.23)	2.64^{g} (7.03)	1.40^{ab} (1.50)	2.55^{bc} (6.13)	2.66^{bc} (3.82)	5.67^{g} (33.28)	4.94^{f} (24.48)	5.34^{g} (28.88)
T_{12}	Unweeded control	14.18^{a} (202.52)	18.25^{a} (334.89)	16.36^{a} (268.70)	14.59^{a} (213.41)	9.64^{a} (93.66)	12.38^{a} (153.54)	1.66^{a} (2.37)	4.40^{a} (19.08)	4.01^{a} (10.72)	20.43^{a} (418.30)	21.12^{a} (447.63)	20.80^{a} (432.97)
SEm		0.68	1.05	0.87	0.94	0.52	0.73	0.11	0.27	0.26	1.09	1.16	1.11
CD (0.05)		2.28	3.19	1.99	2.27	1.52	1.43	0.38	1.57	0.91	1.87	2.72	1.66

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

** Original values mentioned in brackets were before combined analysis in parenthesis

Table 22. Effect of tank mixed herbicide combinations on weed DMP (kg/ha) at 60 DAA

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	12.90^{bc} (168.53)**	13.19^{bc} (174.99)	13.10^{bc} (171.76)	4.83^{def} (23.65)	4.57^{bc} (20.91)	4.71^{cd} (22.28)	2.14^{c} (4.11)	2.73 (7.53)	2.82^{b} (5.82)	13.96^{bcd} (196.29)	14.24^{bc} (203.43)	14.13^{bcd} (199.86)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	13.24^{bc} (176.28)	14.51^{c} (210.68)	13.89^{b} (193.48)	5.52^{bcde} (30.60)	4.66^{b} (21.78)	5.11^{bc} (26.19)	0.71^{d} (0.00)	2.04 (3.65)	1.28^{d} (1.83)	14.34^{bcd} (206.88)	15.36^{b} (236.12)	14.87^{b} (221.50)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	11.76^{c} (139.09)	10.94^{bc} (120.09)	11.36^{c} (129.59)	4.29^{ef} (18.70)	3.54^{cd} (12.51)	3.94^{de} (15.60)	0.71^{d} (0.00)	3.51 (12.79)	2.05^{bcd} (6.39)	12.52^{d} (157.79)	12.05^{c} (145.39)	12.30^{d} (151.59)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	8.44^{d} (76.20)	7.97^{bc} (63.50)	8.28^{d} (69.85)	4.10^{fg} (17.46)	3.14^{de} (10.11)	3.70^{e} (13.79)	0.71^{d} (0.00)	3.26 (10.63)	1.91^{bcd} (5.32)	9.52^{e} (93.66)	9.17^{d} (84.24)	9.37^{e} (88.95)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	12.87^{bc} (168.33)	13.24^{c} (181.44)	13.07^{bc} (174.89)	6.31^{bc} (40.30)	4.74^{b} (22.75)	5.61^{bc} (31.53)	0.71^{d} (0.00)	2.45 (7.09)	1.53^{cd} (3.55)	14.34^{bcd} (208.63)	14.35^{bc} (211.28)	14.35^{bc} (209.96)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	14.31^{b} (205.17)	14.54^{bc} (211.60)	14.43^{b} (208.38)	6.60^{b} (44.33)	5.06^{b} (25.61)	5.88^{b} (34.97)	1.84^{bc} (3.01)	2.53 (12.57)	2.61^{bc} (7.79)	15.87^{b} (252.51)	15.79^{b} (249.78)	15.85^{b} (251.15)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	13.11^{bc} (172.91)	13.12^{c} (174.87)	13.13^{bc} (173.89)	5.82^{bcd} (34.28)	4.21^{bcd} (18.98)	5.11^{bc} (26.63)	0.71^{d} (0.00)	1.49 (2.17)	1.04^{d} (1.08)	14.36^{bcd} (207.19)	13.94^{bc} (196.02)	14.17^{bcd} (201.60)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	11.96^{bc} (144.61)	10.94^{bc} (121.01)	11.49^{c} (132.81)	5.20^{cdef} (27.07)	4.22^{bcd} (17.89)	4.74^{cd} (22.48)	0.71^{d} (0.00)	3.42 (12.05)	2.00^{bcd} (6.03)	13.05^{cd} (171.68)	12.21^{c} (150.96)	12.67^{cd} (161.32)
T_9	Bispyribac-sodium	13.88^{bc} (192.79)	14.56^{bc} (213.40)	14.24^{b} (203.10)	6.10^{bcd} (37.33)	3.34^{d} (11.81)	4.95^{c} (24.57)	3.78^{a} (14.62)	2.71 (14.85)	4.72^{a} (14.74)	15.64^{b} (244.75)	15.41^{b} (240.06)	15.55^{b} (242.41)
T_{10}	(Cyhalofop-butyl + penoxsulam)	14.01^{bc} (196.49)	13.18^{c} (176.29)	13.62^{b} (186.39)	5.71^{bcd} (33.18)	4.64^{bc} (21.56)	5.22^{bc} (27.37)	0.71^{d} (0.00)	2.82 (7.52)	1.68^{bcd} (3.76)	15.14^{bc} (229.67)	14.25^{bc} (205.37)	14.72^{b} (217.52)
T_{11}	Hand weeded control	5.95^{d} (36.28)	4.53^{b} (20.77)	5.32^{e} (28.53)	2.81^{g} (8.25)	2.03^{e} (4.28)	2.46^{f} (6.27)	0.71^{d} (0.00)	3.68 (13.57)	2.14^{bcd} (6.74)	6.59^{f} (44.53)	6.20^{e} (38.52)	6.41^{f} (41.53)
T_{12}	Unweeded control	18.65^{a} (374.82)	20.30^{a} (413.74)	19.50^{a} (380.78)	11.79^{a} (139.77)	8.84^{a} (78.64)	10.44^{a} (109.20)	3.07^{b} (9.32)	6.89 (47.62)	5.19^{a} (28.47)	22.29^{a} (496.91)	23.19^{a} (540.00)	22.76^{a} (518.45)
SEm		0.90	1.11	1.00	0.63	0.47	0.55	0.31	0.39	0.37	1.08	1.18	1.13
CD (0.05)		2.50	2.61	2.06	1.40	1.11	0.91	0.66	NS	1.23	2.38	2.61	1.99

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

** Original values mentioned in brackets were before combined analysis in parenthesis.

4.1.3 Nutrient removal by weeds

Data on pooled analysis of nutrient removal by weeds at 15 days after sowing of rice (Table 23) revealed that commensurate with the higher weed dry matter production, removal of N, P and K was highest in the unweeded control (4.92, 0.78 and 3.49 kg/ha respectively). Lowest values of removal were recorded in the hand weeded control (0.29, 0.03 and 0.17 kg/ha respectively). Low removal was registered in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] for N and K (0.40 and 0.26 kg/ha respectively), while P removal was low in T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] (0.07 kg/ha).

Removal of N, P and K was highest in unweeded control and lowest in hand weeded control at 30 days after sowing also (Table 24). At this stage also comparably low values of removal were recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)]. The trend of nutrient removal was the same at 60 days after sowing (Table 25).

4.1.4 Weed Control Efficiency (WCE) and Weed Index (WI)

Weed Control Efficiency

The results of pooled analysis of data on weed control efficiency and weed index are presented in Table 26. At all three stages of observation, hand weed control registered highest WCE (93.5, 93.3 and 91.9%), and was followed by the treatments T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) and T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)]. At 15 DAS, the WCE in these three treatments ranged between 84 and 91 per cent, at 30 DAS between 80 and 88 per cent and at 60 DAS between 69 and 83 per cent. Lowest values for WCE were recorded in the treatments T_{10} (cyhalofop-butyl + penoxsulam) and T_9 (bispyribac-sodium).

It was seen that tank mixing of herbicides led to invariably higher values for WCE than their sequential application.

Weed Index was lowest for the treatment T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (-0.51%). The next best treatments were T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) (7.51%) and T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] (11.39%). Here too, tank mixed combinations were seen to have lower WI than their sequential applications.

Table 23. Effect of tank mixed herbicide combinations on nutrient removal by weeds at 15 days after application

Treatments		Nutrient removal (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.17^{cd*} $(0.82)^{**}$	4.99^{c} (1.21)	3.58^{cd} (1.02)	1.87^{cdce} (0.10)	4.38^{c} (0.14)	3.12^{cd} (0.12)	1.86^{bc} (0.49)	4.86^{c} (0.83)	3.35^{cd} (0.66)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	1.77^{cd} (0.67)	4.44^{cd} (1.08)	3.10^{cde} (0.87)	1.68^{cde} (0.09)	4.37^{c} (0.14)	3.03^{cde} (0.12)	1.76^{bc} (0.47)	4.52^{cd} (0.77)	3.14^{cde} (0.62)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	1.60^{cd} (0.60)	3.37^{cde} (0.82)	2.48^{def} (0.71)	1.23^{de} (0.07)	2.72^{de} (0.09)	1.98^{efg} (0.08)	1.40^{bc} (0.37)	3.20^{cde} (0.54)	2.30^{def} (0.46)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	0.73^{d} (0.28)	2.18^{ef} (0.53)	1.46^{fg} (0.40)	0.50^{e} (0.03)	1.81^{ef} (0.06)	1.15^{gh} (0.04)	0.64^{bc} (0.17)	2.10^{ef} (0.36)	1.37^{fg} (0.26)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.60^{cd} (0.60)	3.85^{cde} (0.93)	2.72^{cde} (0.77)	1.40^{de} (0.08)	3.46^{cd} (0.11)	2.43^{def} (0.09)	1.41^{bc} (0.37)	3.61^{cde} (0.62)	2.52^{de} (0.49)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2.70^{c} (1.02)	4.75^{cd} (1.15)	3.73^{c} (1.09)	2.55^{cd} (0.14)	4.76^{c} (0.15)	3.65^{c} (0.15)	2.63^{bc} (0.70)	4.70^{cd} (0.80)	3.67^{c} (0.75)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.06^{cd} (0.78)	4.35^{cd} (1.06)	3.21^{cde} (0.92)	1.64^{de} (0.09)	3.69^{cd} (0.12)	2.67^{cdef} (0.10)	1.82^{bc} (0.48)	4.18^{cd} (0.71)	3.00^{cde} (0.60)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	1.49^{cd} (0.56)	3.19^{def} (0.77)	2.34^{ef} (0.67)	1.17^{de} (0.06)	2.52^{def} (0.08)	1.84^{fg} (0.07)	1.32^{bc} (0.35)	3.08^{de} (0.52)	2.20^{ef} (0.44)
T_9	Bispyribac-sodium	4.68^{b} (1.77)	7.70^{b} (1.87)	6.19^{b} (1.82)	4.57^{b} (0.25)	7.35^{b} (0.23)	5.96^{b} (0.24)	4.34^{b} (1.15)	7.31^{b} (1.25)	5.83^{b} (1.20)
T_{10}	(Cyhalofop-butyl + penoxsulam)	3.06^{bc} (1.16)	7.79^{b} (1.89)	5.42^{b} (1.52)	3.43^{bc} (0.19)	8.48^{b} (0.27)	5.95^{b} (0.23)	2.91^{bc} (0.77)	7.66^{b} (1.30)	5.28^{b} (1.04)
T_{11}	Hand weeded control	0.51^{d} (0.19)	1.58^{f} (0.38)	1.04^{g} (0.29)	0.37^{e} (0.02)	1.02^{f} (0.03)	0.70^{h} (0.03)	0.43^{c} (0.11)	1.36^{f} (0.23)	0.89^{g} (0.17)
T_{12}	Unweeded control	10.97^{a} (4.15)	23.47^{a} (5.70)	17.22^{a} (4.92)	12.02^{a} (0.66)	28.37^{a} (0.90)	20.20^{a} (0.78)	8.22^{a} (2.98)	23.46^{a} (3.99)	17.37^{a} (3.49)
SEm		0.81	1.68	1.24	0.91	2.12	1.51	0.61	1.69	1.26
CD (0.05)		1.70	1.69	1.12	1.78	1.61	1.06	3.73	1.69	1.10

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

** Original values before combined analysis in parentheses

Table 24. Effect of tank mixed herbicide combinations on nutrient removal by weeds at 30 days after application

Treatments		Nutrient removal (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T$_1$	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.61^{def*}	3.22^{cde}	2.92^{c}	0.32^{de}	0.47^{cd}	0.40^{de}	1.76^{de}	2.44^{cd}	2.11^{ef}
T$_2$	Fenoxaprop-p-ethyl + carfentrazone-ethyl	3.43^{cde}	3.13^{cde}	3.28^{c}	0.39^{cd}	0.51^{cd}	0.45^{d}	2.53^{cd}	2.47^{cd}	2.50^{de}
T$_3$	Fenoxaprop-p-ethyl + bispyribac-sodium	2.56^{def}	2.05^{efg}	2.30^{c}	0.29^{de}	0.27^{de}	0.28^{ef}	1.76^{de}	1.53^{def}	1.65^{fg}
T$_4$	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	1.35^{fg}	1.26^{fg}	1.31^{d}	0.13^{ef}	0.15^{e}	0.14^{fg}	0.95^{ef}	0.96^{ef}	0.95^{gh}
T$_5$	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.17^{efg}	3.53^{cde}	2.85^{c}	0.30^{de}	0.53^{cd}	0.41^{de}	1.48^{ef}	2.65^{cd}	2.07^{ef}
T$_6$	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	5.81^{b}	4.48^{bcd}	5.14^{b}	0.98^{b}	0.73^{bc}	0.85^{b}	4.60^{b}	3.62^{bc}	4.11^{b}
T$_7$	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.78^{cde}	2.85^{def}	2.82^{c}	0.34^{d}	0.45^{d}	0.39^{de}	1.93^{cde}	2.21^{de}	2.07^{ef}
T$_8$	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.43^{de}f	2.29^{efg}	2.36^{c}	0.27^{de}	0.35^{de}	0.31^{de}	1.64^{de}	1.73^{def}	1.68^{fg}
T$_9$	Bispyribac-sodium	3.97^{c}	4.77^{bc}	4.37^{b}	0.55^{c}	0.73^{bc}	0.64^{c}	2.81^{c}	3.61^{bc}	3.21^{cd}
T$_{10}$	(Cyhalofop-butyl + penoxsulam)	3.63^{cd}	5.43^{b}	4.53^{b}	0.57^{c}	0.84^{b}	0.71^{bc}	2.58^{cd}	4.14^{b}	3.36^{c}
T$_{11}$	Hand weeded control	0.88^{g}	0.64^{g}	0.76^{d}	0.06^{f}	0.08^{e}	0.07^{g}	0.55^{f}	0.45^{f}	0.50^{h}
T$_{12}$	Unweeded control	11.75^{a}	12.37^{a}	12.06^{a}	2.03^{a}	2.23^{a}	2.13^{a}	9.65^{a}	11.01^{a}	10.33^{a}
SEm		0.83	0.87	0.84	0.15	0.16	0.16	0.70	0.79	0.74
CD (0.05)		1.29	1.74	0.98	0.20	0.27	0.15	0.99	1.32	0.74

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

Table 25. Effect of tank mixed herbicide combinations on nutrient removal weeds at 60 days after application

Treatments		Nutrient removal (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	5.68^bc*	5.88^bcd	5.78^bc	0.61^def	0.81^bcd	0.71^d	3.57^de	3.54^cde	3.56^de
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	5.82^bc	6.59^bc	6.20^b	0.86^cd	0.98^bc	0.92^cd	3.91^cde	4.66^bc	4.28^cd
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	4.39^cd	3.94^de	4.17^c	0.38^fg	0.40^ef	0.39^ef	2.71^ef	2.15^ef	2.43^fg
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	2.59^de	2.25^ef	2.42^d	0.21^gh	0.21^ef	0.22^fg	1.62^fg	1.19^fg	1.41^gh
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	6.23^bc	6.27^bcd	6.25^b	0.81^cd	0.89^bc	0.85^cd	3.88^cde	3.75^bcd	3.82^cd
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	7.34^b	7.15^b	7.24^b	1.27^b	1.15^b	1.22^b	5.50^b	5.25^b	5.37^b
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	5.84^bc	5.53^bcd	5.68^bc	0.64^de	0.77^cd	0.71^d	3.75^cde	3.20^cde	3.48^def
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	4.84^c	4.14^cde	4.49^c	0.41^efg	0.52^de	0.47^e	2.96^e	2.31^def	2.63^ef
T_9	Bispyribac-sodium	7.29^b	6.86^b	7.08^b	0.89^c	1.05^bc	0.97^c	4.98^bc	4.67^bc	4.83^bc
T_{10}	(Cyhalofop-butyl + penoxsulam)	6.97^b	6.01^bcd	6.49^b	0.96^c	0.95^bc	0.95^c	4.71^bcd	4.12^bc	4.42^bcd
T_{11}	Hand weeded control	1.22^e	1.06^f	1.14^d	0.09^h	0.10^f	0.09^g	0.76^g	0.54^g	0.65^h
T_{12}	Unweeded control	14.42^a	15.49^a	14.95^a	2.59^a	2.62^a	2.60^a	11.41^a	12.05^a	11.73^a
SEm		0.93	1.03	0.97	0.19	0.19	0.19	0.77	0.85	0.80
CD (0.05)		1.95	2.58	1.68	0.25	0.36	0.24	1.26	1.57	1.08

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

Table 26. Effect of tank mixed herbicide combinations on weed control efficiency and weed index

Treatments		WCE (%)									WI (%)		
		1st year			2nd year			Pooled			1st year	2nd year	Pooled
		15 DAS	30 DAS	60 DAS	15 DAS	30 DAS	60 DAS	15 DAS	30 DAS	60 DAS			
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	79.31	77.88	60.50	77.79	74.05	62.33	78.43	75.90	61.42	16.95	14.98	15.86
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	82.66	69.85	58.37	79.76	74.48	56.27	80.97	72.24	57.24	27.68	27.83	27.76
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	84.14	77.09	68.25	84.25	82.48	73.08	84.20	79.88	70.74	7.34	7.65	7.51
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	92.54	87.60	81.15	89.69	89.03	84.40	90.88	88.34	82.83	-4.90	3.06	-0.51
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	85.07	81.89	58.01	83.17	71.75	60.87	83.97	76.65	59.47	18.64	17.13	17.81
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	75.59	50.06	49.18	79.57	63.80	53.74	77.90	57.16	51.52	39.55	40.06	39.83
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	79.97	75.37	58.30	80.51	76.43	63.70	80.29	75.92	61.08	25.05	26.61	25.91
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	85.52	78.61	65.45	85.30	80.58	72.05	85.39	79.63	68.86	13.37	9.79	11.39
T_9	Bispyribac-sodium	57.22	67.09	50.75	67.12	62.30	55.54	62.97	64.61	53.20	31.45	34.56	33.16
T_{10}	(Cyhalofop-butyl + penoxsulam)	71.50	70.50	53.78	66.07	58.24	61.97	68.34	64.16	58.01	29.38	33.33	31.56
T_{11}	Hand weeded control	95.00	92.04	91.04	92.47	94.53	92.87	93.53	93.33	91.98	-	-	-
T_{12}	Unweeded control		-	-	-		-	-	-	-	46.14	53.21	50.04

4.1.5 Studies on rice

4.1.5.1 Plant height

There was no significant effect of treatments on rice plant height and the average plant heights were 61.93, 95.23 and 99.51 cm at 30 DAS, 60 DAS and harvest respectively (Table 27).

4.1.5.2 Number of tillers

Significant effect of treatments on number of tillers per sq. m of rice was seen at 30 and 60 DAS and at harvest (Table 28). At 30 DAS higher number of tillers per sq. m was recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (481 tillers/m^2) and T_{11} (hand weeding) (469 tillers/m^2), followed by T_3 (fenoxaprop-p-ethyl + bispyribac-sodium), with 424 tillers per sq. m. At 60 DAS, T_{11} and T_4 again had higher tiller number of 654 and 621 per sq. m. At harvest, T_4 had the higher tiller number of 411 per sq. m and T_{11} was at par with 380 tillers per sq. m. At all three stages of observation unweeded control had the lowest tiller number per sq. m.

4.1.5.3 Yield attributes

Number of panicles

There was significant difference in the effect of herbicides applied on tank mixing or in sequence on number of panicles per sq. m (Table 29). In both years, highest number of panicles per sq. m of 301 and 275 were recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], which was on par with hand weeding having 261 and 239 panicles per sq. m. After pooled analysis, the higher value of 288 was recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], followed by hand weeding with 250. Lowest number of panicles per sq. m was recorded in unweeded control (130), followed by T_9 (bispyribac-sodium) with 166 panicles per sq. m.

Number of grains per panicle, % filled grains per panicle and test weight

Number of grains per panicle was also highest in tank mixed application of [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (T_4) in both years (97 and 108). On par with this treatment were hand weeding with 97 and 104, and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) with 93 and 96 grains per panicle. Pooled analysis of data of two years showed that tank mixed application of [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (T_4) resulted in higher number (103) of grains per panicle (Table 29). This was followed by hand weeding with 100 and (fenoxaprop-p-ethyl + bispyribac-sodium) with 95 grains per panicle. Lowest number of 78 grains per panicle was recorded in the unweeded control.

In the first year percentage of filled grain was highest in hand weeding (88.8%) and almost all treatments were on par with this treatment except unweeded control, bispyribac-sodium and (cyhalofop-butyl + penoxsulam). However, in the second year highest filling percentage was recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] with 93.5 per cent and treatments hand weeding (90.3%), T_3 (88.5%), T_8 (88%), T_1 (87.8%) and T_5 (87.5%) were on par with T_4. Pooled analysis of data revealed that percentage of filled grain followed the same trend as number of grains per panicle, with 91.62, 89.59 and 87.67 per cent of filling recorded in T_4, T_{11} and T_3 respectively (Table 29). Lowest percentage of 78 was recorded in the unweeded control, with T_9 (bispyribac-sodium) and T_{10} (cyhalofop-butyl + penoxsulam) at par.

The test weight or 1000 grain weight of paddy was not significantly affected by treatments and was in the range of 30.32 to 31.30 g (Table 29).

4.1.5.4 Grain yield, straw yield and harvest index

In the first year highest grain yield was recorded in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] with 3.71 t/ha, while in the second year, hand weeding T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] recorded highest yield of 4.36 t/ha. However, these two treatments were on par with each other and also with T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) and T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] in both years. Pooling the data, it was seen that tank mixed application of herbicides resulted in higher yield than their sequential application (Table 30). Higher grain and straw yields were obtained in the treatment T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (3.97 and 4.73 t/ha respectively). This was followed by the treatments hand weeded control (3.95 and 4.50 t/ha) and T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) (3.65 and 4.45 t/ha respectively). Lowest grain and straw yields were obtained in the unweeded control (1.97 and 2.89 t/ha respectively).

The harvest index was not significantly affected by treatments and ranged from 0.41 to 0.47.

4.1.5.5 Nutrient uptake by rice

Analysis of pooled data on nutrient uptake by rice at 60 DAS (Table 31) revealed that highest N, P and K uptake was in hand weeded treatment with 107.53, 13.43 and 72.82 kg/ha. At par with this was T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] with 105.06, 14.32 and 74.28 kg/ha of N, P and K respectively, and T_3 (fenoxaprop with bispyribac) with 99.50, 12.74 and 66.84 kg/ha of N, P and K respectively. The treatments that showed lowest N and K uptake values were in unweeded control which had values of 58.04 and 36.83 kg/ha of N and K, and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) with 69.33 and 43.68 kg/ha of N and K respectively. Phosphorus uptake was lower in unweeded control (7.17

kg/ha), and T_6 (fenoxaprop-p-ethyl *fb* carfentrazone) with 8.56 kg/ha and T_{10} (cyhalofop-butyl + penoxsulam) with 8.97 kg/ha which were statistically at par.

4.1.5.6 Economics of cultivation

Details of economics of cultivation are presented in Table 32. Income from grain and straw as well as gross income were highest in the treatment T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], the values being Rs. 1,08,247, Rs. 20,120 and Rs. 1,28,366 per hectare respectively. This was followed by the hand weeding treatment with Rs. 1,07,740, Rs. 19,125 and Rs. 1,26,865 respectively. Treatments T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) and T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] were the next best treatments. Lowest income from grain and straw and total gross income was registered in the unweeded control (Rs. 53,790, Rs. 12,291 and Rs. 66,081 respectively).

Net returns and benefit:cost ratio were highest in T_4 [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], the values being Rs. 71,406 and 2.25 respectively. This was followed by T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) which had a net return of Rs. 62,234 and a B:C ratio of 2.10. Hand weeded control had a net return of Rs. 58,644 but the B:C ratio was only 1.86, while T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] with a net return of only Rs. 56,845 had a B:C ratio of 1.99.

All tank mixed herbicide combinations had higher net returns and B:C ratios than the sequential application of herbicides.

Table 27. Effect of tank mixed herbicide combinations on plant height of rice

Treatments		Plant height (cm)								
		30 DAS			60 DAS			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	58.63	66.40	62.52	89.53	102.80	96.16	91.73	105.60	98.67
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	62.37	64.80	63.59	93.80	101.70	97.75	96.40	107.87	102.13
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	57.97	60.13	59.04	86.20	100.03	93.13	89.70	103.73	96.72
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	57.93	57.33	57.63	83.03	97.53	90.29	85.77	102.40	94.09
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	60.87	61.40	61.14	95.43	98.93	97.18	93.90	101.87	97.88
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	63.60	63.67	63.63	98.67	98.60	98.63	100.47	106.73	103.60
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	59.20	64.60	61.90	91.23	97.10	94.17	93.87	108.27	101.07
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	58.40	62.67	60.53	87.07	96.50	91.78	90.67	112.67	101.67
T_9	Bispyribac-sodium	63.53	64.27	63.91	96.33	100.63	98.49	99.47	103.60	101.53
T_{10}	(Cyhalofop-butyl + penoxsulam)	63.03	62.67	62.85	94.50	97.63	96.07	97.33	102.07	99.70
T_{11}	Hand weeded control	56.30	62.60	59.45	82.13	95.90	89.02	85.43	100.33	92.88
T_{12}	Unweeded control	63.87	70.07	66.97	95.20	104.93	100.07	100.43	107.93	104.18
SEm		0.78	0.92	0.74	1.57	0.79	1.02	1.52	1.03	1.03
CD (0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 28. Effect of tank mixed herbicide combinations on tiller number of rice

Treatments		No. of tillers / m^2								
		30 DAS			60 DAS			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	359^{bcd*}	347^{bcd}	353^{bc}	453^{cde}	513^{abc}	483^{bc}	309^{bcd}	254^{cd}	282^{cd}
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	339^{cd}	325^{bcd}	332^{cd}	318^{fgh}	404^{cde}	361^{de}	224^{def}	237^{cde}	230^{def}
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	439^{ab}	409^{ab}	424^{ab}	549^{bc}	507^{abcd}	528^{b}	389^{ab}	316^{bc}	353^{ab}
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	488^{a}	474^{a}	481^{a}	629^{ab}	612^{a}	621^{a}	419^{a}	403^{a}	411^{a}
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	357^{bcd}	336^{bcd}	347^{bc}	410^{ef}	451^{bcde}	431^{cd}	281^{cde}	247^{cde}	264^{cde}
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	270^{de}	245^{de}	257^{de}	301^{gh}	330^{ef}	315^{ef}	221^{ef}	170^{ef}	195^{fg}
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	358^{bcd}	322^{bcd}	340^{c}	515^{cd}	549^{ab}	532^{b}	308^{bcd}	234^{cde}	271^{cde}
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	369^{bc}	384^{abc}	376^{bc}	537^{bc}	489^{abcd}	513^{b}	359^{abc}	282^{bcd}	320^{bc}
T_9	Bispyribac-sodium	329^{cd}	280^{cde}	305^{cd}	393^{efg}	365^{def}	379^{de}	224^{def}	207^{def}	215^{efg}
T_{10}	(Cyhalofop-butyl + penoxsulam)	294^{cd}	298^{cde}	296^{cd}	422^{de}	403^{cde}	413^{cd}	26^{def}	214^{de}	241^{def}
T_{11}	Hand weeded control	479^{a}	458^{a}	469^{a}	730^{a}	578^{ab}	654^{a}	401^{a}	358^{ab}	380^{ab}
T_{12}	Unweeded control	192^{e}	201^{e}	196^{e}	267^{h}	249^{f}	258^{f}	193^{f}	126^{f}	159^{g}
SEm		24.43	23.53	23.83	39.85	31.10	34.58	22.49	22.36	22.06
CD (0.05)		95.68	108.88	80.87	103.60	144.41	76.98	86.34	83.74	60.12

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

Table 29. Effect of tank mixed herbicide combinations on yield attributes of rice

Treatments		Yield attributes of rice											
		No. of panicles per m^2			No. of grains per panicle			% filled grains per panicle			Test weight (g)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	205^{cd}	208^{bc}	207^{cd}	84.20^{bc}	91.80^{bcde}	88.00^{cde}	85.98^{ab}	87.80^{abcd}	86.89^{abcd}	31.30	31.14	31.22
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	193^{cd}	188^{bcd}	190^{cde}	83.73^{bc}	77.60^{f}	80.67^{e}	83.59^{abc}	79.26^{de}	81.42^{de}	30.81	30.68	30.75
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	227^{bc}	228^{abc}	227^{bc}	93.33^{ab}	96.00^{abc}	94.67^{abc}	86.84^{a}	88.49^{abc}	87.67^{ab}	30.32	30.65	30.48
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	301^{a}	275^{a}	288^{a}	97.00^{a}	108.20^{a}	102.60^{a}	89.73^{a}	93.51^{a}	91.62^{a}	30.82	31.15	30.99
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	197^{cd}	201^{bcd}	199^{cde}	82.80^{bc}	91.23^{bcdef}	87.00^{cde}	86.71^{abc}	87.46^{abcd}	87.08^{abcd}	30.54	30.61	30.57
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	175^{cd}	152de	163^{ef}	84.67^{bc}	83.60^{cdef}	84.13^{de}	83.81^{abc}	79.95^{cde}	81.88^{cde}	31.53	31.03	31.28
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	195^{cd}	196^{bcd}	196^{cde}	87.87^{abc}	78.40^{ef}	83.13^{de}	83.25^{abc}	81.09^{cde}	82.17^{bcde}	30.76	30.69	30.72
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	208^{cd}	227^{abc}	217^{bcd}	90.40^{ab}	93.37^{bcd}	91.90^{bcd}	86.88^{a}	87.99^{abcd}	87.43^{abc}	31.11	31.04	31.07
T_9	Bispyribac-sodium	179^{cd}	153de	166^{ef}	82.87^{bc}	86.20^{cdef}	84.53^{de}	79.28^{bc}	80.91^{cde}	80.10^{e}	30.78	30.78	30.78
T_{10}	(Cyhalofop-butyl + penoxsulam)	181^{cd}	183^{cd}	182de	81.60^{bc}	89.60^{cdef}	85.60^{cde}	79.06^{c}	81.92^{bcde}	80.48^{e}	30.74	30.74	30.74
T_{11}	Hand weeded control	261^{ab}	239^{ab}	250^{ab}	96.80^{a}	103.80^{ab}	100.30^{ab}	88.81^{a}	90.37^{ab}	89.59^{a}	31.19	31.33	31.26
T_{12}	Unweeded control	157^{d}	103^{e}	130^{f}	75.93^{c}	81.03^{def}	78.47^{e}	77.60^{c}	78.45^{e}	78.03^{e}	31.10	30.77	30.94
SEm		11.52	13.16	12.02	1.86	2.75	2.17	1.14	1.45	1.25	0.10	0.07	0.08
CD (0.05)		53.08	52.45	39.30	12.06	14.20	10.01	6.91	8.85	5.77	NS	NS	NS

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

Table 30. Effect of tank mixed herbicide combinations on grain yield, straw yield and harvest index

Treatments		Grain yield (t/ha)			Straw yield (t/ha)			Harvest index		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	2.94^{bcd*}	3.71^{bc}	3.32^{cd}	4.00^{abc}	4.15^{ab}	4.07^{abcd}	0.43	0.48	0.45
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	2.56^{cdef}	3.15^{cd}	2.85^{ef}	3.76^{abcd}	3.98^{ab}	3.87^{bcd}	0.40	0.45	0.42
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	3.28^{abc}	4.03^{ab}	3.65^{abc}	4.34^{ab}	4.55^{ab}	4.45^{ab}	0.43	0.47	0.45
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	3.71^{a}	4.23^{ab}	3.97^{a}	4.55^{a}	4.91^{a}	4.73^{a}	0.45	0.46	0.46
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	2.88^{bcde}	3.61^{bc}	3.25^{cde}	3.79^{abcd}	4.10^{ab}	3.95^{abcd}	0.44	0.47	0.46
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	2.14^{ef}	2.61^{de}	2.38^{gh}	3.26^{cd}	3.50^{bc}	3.38^{de}	0.40	0.43	0.41
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.65^{cde}	3.20^{cd}	2.93^{def}	3.94^{abc}	4.06^{ab}	4.00^{abcd}	0.41	0.44	0.42
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	3.07^{abcd}	3.93^{ab}	3.50^{bc}	4.19^{abc}	4.43^{ab}	4.31^{abc}	0.43	0.47	0.45
T_9	Bispyribac-sodium	2.43^{def}	2.85^{d}	2.64^{fg}	3.49^{bcd}	3.50^{bc}	3.50^{cde}	0.41	0.45	0.43
T_{10}	(Cyhalofop-butyl + penoxsulam)	2.50^{def}	2.91^{d}	2.70^{fg}	3.61^{bcd}	3.56^{bc}	3.59^{cde}	0.41	0.45	0.43
T_{11}	Hand weeded control	3.54^{ab}	4.36^{a}	3.95^{ab}	4.41^{ab}	4.59^{ab}	4.50^{ab}	0.44	0.49	0.47
T_{12}	Unweeded control	1.91^{f}	2.04^{e}	1.97^{h}	2.97^{d}	2.81^{c}	2.89^{e}	0.39	0.42	0.41
SEm		0.16	0.20	0.18	0.14	0.17	0.15	0.01	0.01	0.01
CD (0.05)		0.74	0.65	0.46	0.93	1.14	0.86	NS	NS	NS

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

Table 31. Effect of tank mixed herbicide combinations on nutrient uptake by rice at 60 DAS

Treatments		Nutrient uptake (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	86.60^{abc}*	103.83^{abc}	95.21^{abc}	10.60^{bcde}	12.02^{abcd}	11.31^{bcd}	53.92^{bcde}	65.40^{abc}	59.66^{cde}
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	73.67^{bcd}	86.04^{bcd}	79.86^{cd}	8.75^{ef}	10.21^{de}	9.48^{def}	45.49^{def}	53.29^{cd}	49.39^{fg}
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	91.98^{ab}	107.02^{ab}	99.50^{a}	12.44^{abc}	13.04^{abc}	12.74^{ab}	62.62^{abc}	71.07^{ab}	66.84^{abc}
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	101.04^{a}	109.09^{a}	105.06^{a}	14.02^{a}	14.63^{a}	14.32^{a}	70.62^{a}	77.94^{a}	74.28^{a}
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	87.12^{ab}	103.80^{abc}	95.46^{ab}	9.87^{cdef}	11.72^{bcd}	10.79^{cde}	54.27^{bcde}	66.48^{abc}	60.38^{cd}
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	65.96^{cd}	72.69^{de}	69.33^{de}	8.11^{ef}	9.01^{ef}	8.56^{fg}	40.56^{ef}	46.81^{de}	43.68^{gh}
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	76.98^{bcd}	87.27^{bcd}	82.13^{bcd}	8.92^{ef}	11.10^{cde}	10.01^{def}	49.11^{cdef}	60.72^{bcd}	54.92^{def}
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	88.09^{ab}	107.58^{ab}	97.83^{a}	11.63^{abcd}	13.68^{abc}	12.65^{abc}	55.74^{bcd}	72.50^{ab}	64.12^{bcd}
T_9	Bispyribac-sodium	74.66^{bcd}	82.02^{d}	78.34^{d}	9.18^{def}	9.92^{de}	9.55^{def}	45.58^{def}	54.66^{cd}	50.12^{efg}
T_{10}	(Cyhalofop-butyl + penoxsulam)	75.21^{bcd}	85.39^{cd}	80.30^{bcd}	8.52^{ef}	9.41^{def}	8.97^{efg}	46.09^{def}	52.65^{cd}	49.37^{fg}
T_{11}	Hand weeded control	98.35^{a}	116.72^{a}	107.53^{a}	12.64^{ab}	14.22^{ab}	13.43^{a}	67.02^{ab}	78.62^{a}	72.82^{ab}
T_{12}	Unweeded control	58.79^{d}	57.30^{e}	58.04^{e}	7.23^{f}	7.10^{f}	7.17^{g}	36.54^{f}	37.13^{e}	36.83^{h}
SEm		3.69	5.08	4.36	0.61	0.67	0.63	3.02	3.71	3.33
CD (0.05)		21.14	21.57	15.47	2.65	2.64	1.90	13.84	14.29	10.07

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

Table 32. Effect of tank mixed herbicide combinations on economics of cultivation of rice

Treatments		Grain income (Rs./ha)			Straw income (Rs./ha)			Gross income (Rs./ha)			Cost of cultivation (Rs./ha)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	79380	101933	90657	16983	17621	17302	96363	119554	107958	53568	55804	54686
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	69120	86533	77827	15989	16907	16448	85109	103440	94274	53605	55841	54723
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	88560	110733	99647	18462	19329	18896	107022	130062	118542	55190	57426	56308
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	100260	116233	108247	19355	20885	20120	119615	137118	128366	55843	58079	56961
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	77760	99367	88563	16091	17442	16766	93851	116809	105330	53568	55804	54686
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	57780	71867	64823	13847	14867	14357	71627	86733	79180	53605	55841	54723
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	71640	88000	79820	16754	17264	17009	88394	105264	96829	55190	57426	56308
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	82800	108167	95483	17799	18845	18322	100599	127011	113805	55843	58079	56961
T_9	Bispyribac-sodium	65520	78467	71993	14816	14892	14854	80336	93359	86847	53190	55426	54308
T_{10}	(Cyhalofop-butyl + penoxsulam)	67500	79933	73717	15351	15147	15249	82851	95080	88966	55400	57636	56518
T_{11}	Hand weeded control	95580	119900	107740	18743	19508	19125	114323	139408	126865	66125	70317	68221
T_{12}	Unweeded control	51480	56100	53790	12623	11960	12291	64103	68060	66081	51125	53361	52243

Table 33. Effect of tank mixed herbicide combinations on rice economics

Treatments		Net income (Rs./ha)			Benefit:cost ratio			Additional Cost due to weed management (Rs./ha)			Additional returns due to weed management (Rs./ha)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	42796	63750	53273	1.80	2.14	1.97	2443	2443	2443	29818	49052	39435
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	31504	47599	39551	1.59	1.85	1.72	2480	2480	2480	18526	32900	25713
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	51832	72636	62234	1.94	2.26	2.10	4065	4065	4065	38855	57938	48396
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	63772	79039	71406	2.14	2.36	2.25	4718	4718	4718	50795	64341	57568
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	40283	61005	50644	1.75	2.09	1.92	2443	2443	2443	27306	46307	36806
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	18022	30892	24457	1.34	1.55	1.44	2480	2480	2480	5044	16194	10619
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	33204	47838	40521	1.60	1.83	1.72	4065	4065	4065	20226	33139	26683
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	44757	68933	56845	1.80	2.19	1.99	4718	4718	4718	31779	54234	43007
T_9	Bispyribac-sodium	27146	37933	32539	1.51	1.68	1.60	2065	2065	2065	14168	23234	18701
T_{10}	(Cyhalofop-butyl + penoxsulam)	27451	37444	32448	1.50	1.65	1.57	4275	4275	4275	14474	22746	18610
T_{11}	Hand weeded control	48198	69091	58644	1.73	1.98	1.86	15000	16956	15978	35220	54392	44806
T_{12}	Unweeded control	12978	14699	13838	1.25	1.28	1.26	-	-	-	-	-	-

4.1.6 Studies on soil microbial activity

Results on the effect of herbicides on soil microbial population are presented below.

4.1.6.1 Dehydrogenase activity (DHA)

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

The initial observations before the application of herbicidal treatments at 15 days after sowing did not vary significantly, the mean dehydrogenase activity observed ranging between 62.28 and 67.00 μg TPF/g soil/h (Table 34).

From the pooled data at 30 DAS it was seen that the higher dehydrogenase activity was recorded in unweeded control (83.12 μg TPF/g soil/h), which was on par with the hand weeded control (81.04) whereas the lowest activity was in T_3 (67.81 μg TPF/g soil/h) followed by T_7 (68.83 μg TPF/g soil/h).

At harvest dehydrogenase activity ranged from 53.05 to 61.70 μg TPF/g soil/h (Table 34). Higher dehydrogenase activity was recorded in unweeded control (61.70 μg TPF/g soil/h) followed by hand weeded control (61.16 μg TPF/g soil/h).The lower dehydrogenase activity of 53.05 μg TPF/g soil/h was recorded in the treatment T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) followed by T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) with 53.81 μg TPF/g soil/h and T_9 (bispyribac-sodium) with 56.80 μg TPF/g soil/h.

4.1.6.2 Soil microbial biomass carbon (SMBC)

The initial observations before the application of herbicidal treatments at 15 days after sowing did not vary significantly, and the mean soil microbial biomass carbon was observed in the range 163.99 to 168.50 μg/g soil (Table 35).

As per the pooled data, at 30 DAS higher soil microbial biomass carbon was recorded in unweeded control (150.35 µg/g soil) which was on par with hand weeded control (T_{11}) with 147.36 µg/g soil, whereas the lower values were recorded in T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) with 122.25 µg/g soil, T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) with 124.30 µg/g soil and T_9 (bispyribac-sodium) with 127.46 µg/g soil.

At harvest soil microbial biomass carbon ranged from 94.26 to 125.33 µg/g soil. Highest soil microbial biomass carbon was recorded in unweeded control (124.37 µg/g soil) which however, was on par with hand weeded control (T_{11}) with 122.13 µg/g soil, T_{10} (cyhalofop-butyl + penoxsulam) with 119.35 µg/g soil, T_8 [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)] with 118.36 µg/g soil and T_4 (cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] with 117.39 µg/g soil. The lowest soil microbial biomass carbon was recorded in the treatment T_3 (fenoxaprop-p-ethyl + bispyribac-sodium) with 96.54 µg/g soil which was at par with T_7 (fenoxaprop-p-ethyl *fb* bispyribac-sodium) with 98.90 µg/g soil and T_9 (bispyribac-sodium) with 102.74 µg/g soil.

Table 34. Effect of tank mixed herbicide combinations on soil dehydrogenase activity

Treatments		Dehydrogenase activity (µg TPF/g soil/h)								
		15 DAS			30 DAT			Harvest		
		1^{st} year	2^{nd} year	Pooled	1^{st} year	2^{nd} year	Pooled	1^{st} year	2^{nd} year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	62.70	65.93	64.32	77.20^{ab}	74.39^{bcdef*}	75.79^{bcd}	13.42^{ab*} (56.88)**	37.61^{abcd} (59.33)	25.52^{abcd} (58.30)
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	62.60	63.82	63.20	74.75^{abc}	73.06^{cdef}	73.90^{cdef}	13.23^{abc} (56.06)	36.93^{bcde} (58.64)	25.08^{cde} (57.35)
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	63.41	67.00	65.20	65.35^{d}	70.28^{f}	67.81^{f}	11.60^{c} (49.15)	35.86^{e} (56.94)	23.73^{f} (53.05)
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	62.91	65.96	64.43	78.46^{ab}	77.98^{abcde}	78.22^{abc}	13.70^{a} (58.06)	37.72^{abcd} (59.89)	25.71^{abcd} (58.98)
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	63.72	66.94	65.33	77.98^{ab}	76.68^{bcdef}	77.33^{abcd}	13.53^{a} (57.33)	37.80^{abcd} (60.01)	25.66^{abcd} (58.67)
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	63.34	64.81	64.08	76.50^{ab}	73.47^{cdef}	74.99^{bcde}	13.31^{ab} (56.41)	37.25^{abcde} (59.14)	25.28^{bcd} (57.68)
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	62.81	64.94	63.87	67.04^{cd}	70.63^{ef}	68.83^{ef}	11.77^{bc} (49.88)	36.37^{de} (57.75)	24.07^{ef} (53.81)
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	63.99	65.38	64.69	79.89^{a}	78.73^{abcd}	79.31^{abc}	13.80^{a} (58.46)	38.24^{abc} (60.71)	26.02^{abcd} (59.59)
T_9	Bispyribac-sodium	62.28	64.76	63.52	70.58^{bcd}	71.33^{def}	70.96^{def}	13.09^{abc} (55.48)	36.61^{cde} (58.12)	24.85^{def} (56.80)
T_{10}	(Cyhalofop-butyl + penoxsulam)	63.30	63.96	63.63	80.16^{a}	79.66^{abc}	79.91^{abc}	13.85^{a} (58.70)	38.45^{ab} (61.06)	26.16^{abc} (59.88)
T_{11}	Hand weeded control	63.98	66.08	65.03	81.00^{a}	81.08^{ab}	81.04^{ab}	14.45^{a} (61.22)	38.48^{ab} (61.10)	26.46^{ab} (61.16)
T_{12}	Unweeded control	64.33	65.64	64.99	81.66^{a}	84.58^{a}	83.12^{a}	14.63^{a} (62.00)	38.67^{a} (61.41)	26.65^{a} (61.70)
SEm		0.18	0.30	0.20	1.57	1.31	1.40	0.26	0.26	0.26
CD (0.05)		NS	NS	NS	8.45	7.42	6.74	1.69	1.69	1.19

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

** Original values before combined analysis in parentheses

Table 35. Effect of tank mixed herbicide combinations on soil microbial biomass carbon

Treatments		Soil microbial biomass carbon (µg/g soil)								
		15 DAS			30 DAT			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Fenoxaprop-p-ethyl + (chlorimuron-ethyl + metsulfuron-methyl)	164.	167.43	165.90	137.98^{abc*}	133.30^{cde}	135.64^{cde}	114.22^{abcd}	109.14^{abcde}	111.68^{cdef}
T_2	Fenoxaprop-p-ethyl + carfentrazone-ethyl	164.36	165.32	164.79	134.75^{bcde}	127.81^{def}	131.28^{def}	108.06^{cdef}	104.96^{bcde}	106.51^{efg}
T_3	Fenoxaprop-p-ethyl + bispyribac-sodium	166.74	168.50	167.62	122.68^{e}	122.25^{f}	122.47^{g}	98.82^{f}	94.26^{e}	96.54^{h}
T_4	(Cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)	164.58	167.46	166.02	139.89^{abc}	136.76^{cd}	138.32^{cd}	119.79^{abc}	114.98^{abc}	117.39^{abcd}
T_5	Fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl)	166.72	166.44	166.58	138.46^{abc}	134.48^{cde}	136.47^{cd}	117.33^{abc}	110.58^{abcd}	113.95^{bcde}
T_6	Fenoxaprop-p-ethyl *fb* carfentrazone-ethyl	166.68	166.37	166.50	136.50^{abcd}	129.85^{def}	133.17^{cde}	112.41^{bcde}	105.39^{bcde}	108.90^{def}
T_7	Fenoxaprop-p-ethyl *fb* bispyribac-sodium	166.47	165.77	166.12	123.71^{de}	124.90^{ef}	124.30^{fg}	102.15^{ef}	95.67^{de}	98.90^{gh}
T_8	(Cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)	163.99	165.21	164.60	140.53^{abc}	137.58^{cd}	139.06^{bcd}	120.72^{ab}	115.99^{abc}	118.36^{abcd}
T_9	Bispyribac-sodium	163.94	165.92	164.93	129.24^{cde}	125.69^{ef}	127.46^{efg}	104.87^{def}	100.61^{cde}	102.74^{fgh}
T_{10}	(Cyhalofop-butyl + penoxsulam)	164.96	165.46	165.21	139.16^{abc}	140.37^{bc}	139.77^{bc}	122.03^{ab}	116.68^{ab}	119.35^{ab}c
T_{11}	Hand weeded control	166.31	167.58	166.95	146.00^{ab}	148.72^{ab}	147.36^{ab}	124.22^{ab}	120.03^{ab}	122.13^{ab}
T_{12}	Unweeded control	167.33	167.15	167.24	149.99^{a}	150.71^{a}	150.35^{a}	125.33^{a}	123.41^{a}	124.37^{a}
SEm		0.06	0.02	0.04	2.34	2.61	2.44	2.58	2.71	2.64
CD (0.05)		NS	NS	NS	13.71	10.33	8.40	11.87	15.99	9.50

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

4.2 Experiment II - Bio-efficacy of tank mixing of herbicides and urea in wet seeded rice

4.2.1 Weed density

Weed spectrum

A wide spectrum of weeds dominated in the experimental field, located in the the *Kole* area of Thrissur district. The major grass species included *Echinochloa colona*, *E. stagnina*, *Leptochloa chinensis* and *Oryza sativa* f. *spontanea* (weedy rice). *Cyperus iria* and *Fimbristylis miliacea* were the main sedges. Broad leaf weeds were few, and consisted of *Ludwigia perennis* and *Monochoria vaginalis*, and rare occurrence of *Limnocharis flava* in the second year.

Phytotoxicity rating of herbicides

Herbicide phytotoxicity scoring was done on both rice and weeds on the third and seventh day after spraying, following the guidelines of Thomas and Abraham (2007). Data are presented in Table 36. Injuries caused on rice and weeds were almost the same in both the years of study as per the scores.

In the rice crop, injury due to herbicide combinations was low on the 3rd day after application, except in the case of carfentrazone-ethyl + urea (T_5), where moderate injury was observed. In all other treatments, the effect ranged from none to slight (0 to 1). On the seventh day after spraying, the phytotoxic effect was further reduced, with slight injury noticed in the treatments where fenoxaprop-p-ethyl and carfentrazone-ethyl were applied, both without and with urea mixing. The symptoms disappeared by 10 days after application.

In the case of weeds, moderate control was observed in most of the treatments on the 3rd day after herbicide application (Table 36). Treatments in which bispyribac-sodium, (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) were mixed with urea (T_2, T_3 and T_6) registered very good control which progressed to complete control by the 7th day after application. Carfentrazone-ethyl +

urea showed only moderate control of weeds on the 3rd day. On the 7th day after spraying, good control of weeds (score 3) was with urea, while all other treatments registered very good control (Plates 19-22).

Species-wise density

i) Grasses

Species-wise density was significantly affected by treatments at both 15 and 30 after application (Tables 37, 38, 39 and 40). In 2019-20 at 15 DAA, the density of *E. colona* was lowest when tank mixed application of (cyhalofop-butyl + penoxsulam) and bispyribac-sodium with urea was done and was on par with hand weeding (T_{13}). This was followed by treatments T_4 (fenoxaprop-p-ethyl + urea) and T_9 (bispyribac-sodium), both of which recorded a density of 2 nos./m^2. (Cyhalofop-butyl + penoxsulam) was on par with these treatments. In 2020-21, at the same stage, hand weeding was the best treatment, while unweeded recorded the highest density of the weed.

At 30 DAA in 2019-20, hand weeding (T_{13}) and bispyribac-sodium + urea (T_9) registered lowest density of the weed, while in 2020-21, hand weeding was superior to all other treatments. Highest density of *E. colona* was seen in unweeded control in both years.

The density of *E. stagnina* was comparatively low in both years. The herbicides (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl tank mixed with (1%) urea, and cyhalofop-butyl and (cyhalofop-butyl + penoxsulam) applied unmixed with urea were equally effective in reducing the density of *E. stagnina* at 15 DAA in both 2019-20 and 2020-21. At 30 DAA, hand weeding was the best treatment, while unweeded control recorded highest density of the weed in both years.

Highest density of *Leptochloa chinensis* in 2019-20 was seen in unweeded control at both 15 and 30 DAA in both years of experimentation. At 15 DAA, the best

Plate 19. Phytotoxicity symptoms on 3rd day of rice- tank mixing with urea

Plate 20. Phytotoxicity symptoms on 3rd day of rice- without urea

Plate 21. Phytotoxicity symptoms on 7th day of rice- tank mixing with urea

Plate 22. Phytotoxicity symptoms on 7th day of rice- without urea

treatments for controlling the weed were application of (cyhalofop-butyl + penoxsulam), fenoxaprop-p-ethyl and cyhalofop-butyl both with and without urea. Hand weeding was also on par in 2020-21. In 2019-20, at 30 DAA, the treatments fenoxaprop-p-ethyl and (cyhalofop-butyl + penoxsulam) with and without urea mixing completely controlled *L. chinensis*, while in 2020-21, hand weeding had a similar effect. Cyhalofop-butyl was also effective in reducing density of the weed in 2019-20, irrespective of urea mixing.

ii) Sedges

Cyperus iria was the dominant and most problematic sedge in both years of the study. At 15 and 30 DAA, in both years, highest density was recorded in the unweeded control and lowest in the hand weeded plot. In 2019-20, at 15 DAA the treatments (chlorimuron-ethyl + metsulfuron-methyl) with and without urea mixing and cafentrazone-ethyl were on par with hand weeding, while in 2020-21, cafentrazone-ethyl + urea was comparable with hand weeding. At 30 DAA, in 2019-20, (chlorimuron-ethyl + metsulfuron-methyl) mixed with urea, and in 2020-21, (chlorimuron-ethyl + metsulfuron-methyl) applied alone, were on par with hand weeding.

Highest density of *Fimbristylis miliacea* was recorded in unweeded control in both years at both stages of observation. In 2019-20, hand weeding was the best treatment to control the sedge at both 15 and 30 DAA, but in 2020-21, carfentrazone-ethyl completely killed the weed at both stages. (Chlorimuron-ethyl + metsulfuron-methyl) was also comparable at 15 DAA.

iii) Broad leaf weeds

The densities of *Ludwigia perennis* and *Monochoria vaginalis* were comparatively less compared to grasses and sedges in both the years of study. *Limnocharis flava*, which was noticed in the second year, was seen to be unaffected by the treatments. In 2019-20, *Ludwigia perennis* was best controlled by the treatments fenoxaprop-p-ethyl, cafentrazone-ethyl with and without urea at 15 DAA, while at 30 DAA, better control was obtained with cafentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl), both tank mixed with urea. In 2020-21, bispyribac-sodium was the best treatment at 15 DAA, while at 30 DAA, all treatments were equally effective.

In 2020-21, the effect of treatments on *Monochoria vaginalis* was non-significant at 15 DAA, while at 30 DAA, treatments (cyhalofop-butyl + penoxsulam) + urea and fenoxaprop-p-ethyl were superior in controlling the weed. In 2020-21, at 15 DAA, the treatments bispyribac-sodium, carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl), all mixed with urea, and carfentrazone-ethyl applied alone completely killed the emerged weed, while at 30 DAA the best treatments were (cyhalofop-butyl + penoxsulam), bispyribac-sodium, carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl), all tank mixed with urea.

Table 36. Phytotoxicity scoring of tank mixed herbicides along with urea

Treatments		1st year				2nd year			
		Score on 3rd Day		Score on 7th Day		Score on 3rd Day		Score on 7th Day	
		Crop	Weed	Crop	Weed	Crop	Weed	Crop	Weed
T_1	Cyhalofop-butyl + urea 1%	0	3	0	4	0	4	0	4
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	0	4	0	5	0	4	0	5
T_3	Bispyribac-sodium + urea 1%	0	4	0	5	0	4	0	5
T_4	Fenoxaprop-p-ethyl + urea 1%	1	3	1	4	1	3	1	4
T_5	Carfentrazone-ethyl + urea 1%	2	2	1	3	2	2	1	3
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	0	4	0	5	0	4	0	5
T_7	Cyhalofop-butyl	0	3	0	4	0	3	0	4
T_8	(Cyhalofop-butyl + penoxsulam)	0	3	0	4	0	3	0	4
T_9	Bispyribac-sodium	0	3	0	4	0	3	0	4
T_{10}	Fenoxaprop-p-ethyl	1	3	1	4	1	3	1	4
T_{11}	Carfentrazone-ethyl	1	3	1	4	1	3	1	4
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	0	3	0	4	0	3	0	4

Table 37. Effect of tank mixed herbicides along with urea on species-wise weed count (no./m^2) in 2019-20

Treatments		*E. colona*		*L. chinensis*		*E. stagnina*	
		15 DAA†	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA
T_1	Cyhalofop-butyl + urea 1%	1.46^{def} (2)*	1.64^{bcd} (2)	0.93^{cd} (0)	1.23^{cdef} (1)	1.23^{bc} (1)	1.52^{bc} (2)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	1.27^{f} (1)	1.56^{cd} (2)	0.71^{d} (0)	0.88^{ef} (0)	0.71^{c} (0)	1.46^{bc} (2)
T_3	Bispyribac-sodium + urea 1%	1.29^{f} (1)	1.27^{d} (1)	1.58^{b} (2)	1.93^{b} (3)	0.71^{c} (0)	1.29^{bc} (1)
T_4	Fenoxaprop-p-ethyl + urea 1%	1.58^{cdef} (2)	1.76^{bcd} (3)	0.71^{d} (0)	0.71^{f} (0)	1.00^{c} (1)	1.44^{bc} (2)
T_5	Carfentrazone-ethyl + urea 1%	2.35^{abc} (5)	2.26^{abc} (5)	1.34^{bc} (1)	1.44^{bcde} (2)	1.86^{a} (3)	1.94^{ab} (3)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	2.26^{abcd} (5)	2.38^{abc} (5)	1.56^{b} (2)	1.64^{bc} (2)	1.86^{a} (33)	1.86^{abc} (3)
T_7	Cyhalofop-butyl	1.74^{bcdef} (3)	1.64^{bcd} (2)	0.88^{cd} (0)	1.05^{def} (1)	1.23^{bc} (1)	1.56^{bc} (2)
T_8	(Cyhalofop-butyl + penoxsulam)	1.64^{bcdef} (2)	1.72^{bcd} (3)	0.71^{d} (0)	0.88^{ef} (0)	1.05^{c} (1)	1.44^{bc} (2)
T_9	Bispyribac-sodium	1.56^{cdef} (2)	1.58^{cd} (2)	1.66^{b} (2)	2.02^{b} (4)	1.05^{c} (1)	1.56^{bc} (2)
T_{10}	Fenoxaprop-p-ethyl	1.86^{abcdef} (3)	1.94^{abcd} (3)	0.71^{d} (0)	0.71^{f} (0)	1.27^{bc} (1)	1.35^{bc} (2)
T_{11}	Carfentrazone-ethyl	2.13^{abcde} (5)	1.97^{abcd} (4)	1.64^{b} (2)	1.46^{bcd} (2)	1.74^{ab} (3)	1.93^{ab} (3)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	2.41^{ab} (5)	2.46^{ab} (6)	1.35^{bc} (2)	1.64^{bc} (2)	2.02^{a} (4)	2.29^{a} (5)
T_{13}	Hand weeded control	1.34^{ef} (1)	1.17^{d} (1)	0.88^{cd} (0)	1.05^{def} (1)	1.05^{c} (1)	1.17^{c} (1)
T_{14}	Unweeded control	2.64^{a} (7)	2.76^{a} (7)	2.33^{a} (5)	2.64^{a} (7)	2.08^{a} (4)	2.53^{a} (6)
SEm		0.12	0.12	0.13	0.15	0.13	0.10
CD (0.05)		0.80	0.84	0.63	0.58	0.59	0.71

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

† DAA- days after application

Table 38. Effect of tank mixed herbicides along with urea on species-wise weed count (no./m^2) in 2019-20

Treatments		*Cyperus iria*		*Fimbristylis miliacea*		*Ludwigia perennis*		*Monochoria vaginalis*	
		15 DAA†	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA
T_1	Cyhalofop-butyl + urea 1%	6.12^{bc} (39)*	7.22^{a} (53)	2.31^{cde} (5)	3.05^{bc} (10)	1.23^{bc} (1)	1.34^{bc} (1)	1.23 (1)	1.34^{abc} (1)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	4.17^{de} (18)	4.67^{b} (22)	1.93^{de} (3)	2.02^{cd} (4)	0.88^{c} (0)	1.27^{bc} (1)	0.71 (0)	0.71^{d} (0)
T_3	Bispyribac-sodium + urea 1%	3.79^{de} (15)	4.29^{b} (19)	1.81^{de} (3)	1.96^{cd} (4)	1.05^{c} (1)	1.34^{bc} (1)	0.71 (0)	0.88^{cd} (0)
T_4	Fenoxaprop-p-ethyl + urea 1%	5.90^{bc} (35)	7.51^{a} (57)	3.00^{bcd} (9)	2.19^{cd} (5)	1.46^{bc} (2)	1.52^{bc} (2)	1.18 (1)	0.88^{cd} (0)
T_5	Carfentrazone-ethyl + urea 1%	3.65^{de} (15)	4.03^{b} (17)	2.08^{cde} (4)	2.09^{cd} (5)	0.88^{c} (0)	1.17^{c} (1)	0.71 (0)	1.17^{bcd} (1)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	2.92^{ef} (9)	3.35^{bc} (12)	1.90^{de} (3)	1.76^{d} (3)	0.88^{c} (0)	1.17^{c} (1)	1.00 (1)	1.46^{ab} (2)
T_7	Cyhalofop-butyl	6.70^{ab} (45)	7.74^{a} (61)	3.42^{bc} (11)	3.64^{b} (13)	1.52^{bc} (2)	1.74^{bc} (3)	1.00 (1)	1.00^{bcd} (1)
T_8	(Cyhalofop-butyl + penoxsulam)	4.61^{cd} (22)	5.10^{b} (26)	2.21^{cde} (5)	2.23^{cd} (5)	1.05^{c} (1)	1.34^{bc} (1)	1.00 (1)	1.00^{bcd} (1)
T_9	Bispyribac-sodium	4.59^{cd} (21)	4.68^{b} (23)	2.03^{de} (4)	2.23^{cd} (5)	1.17^{bc} (1)	1.46^{bc} (2)	1.05 (1)	1.17^{bcd} (1)
T_{10}	Fenoxaprop-p-ethyl	6.36^{ab} (41)	7.98^{a} (64)	3.90^{ab} (15)	2.64^{bcd} (7)	1.46^{bc} (2)	1.88^{ab} (3)	0.71 (0)	0.71^{d} (0)
T_{11}	Carfentrazone-ethyl	3.46^{def} (13)	3.89^{b} (16)	2.20^{cde} (5)	2.39^{bcd} (6)	1.00^{c} (1)	1.34^{bc} (1)	1.05 (1)	1.34^{abc} (1)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.13^{def} (10)	3.74^{b} (15)	2.21^{cde} (5)	2.19^{cd} (5)	1.00^{c} (1)	1.34^{bc} (1)	1.34 (1)	1.46^{ab} (2)
T_{13}	Hand weeded control	1.88^{f} (4)	1.61^{c} (3)	1.39^{e} (2)	1.47^{d} (2)	1.88^{ab} (3)	1.68^{bc} (2)	1.34 (1)	1.46^{ab} (2)
T_{14}	Unweeded control	7.82^{a} (63)	8.24^{a} (71)	4.86^{a} (26)	5.21^{a} (28)	2.31^{a} (5)	2.46^{a} (6)	1.44 (2)	1.86^{a} (3)
SEm		0.45	0.55	0.25	0.25	0.11	0.09	0.07	0.09
CD (0.05)		1.66	1.84	1.39	1.29	0.75	0.66	NS	0.53

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

† DAA days after application

Table 39. Effect of tank mixed herbicides along with urea on species-wise weed count (no./m^2 in 2020-21

Treatments		*E. colona*		*L. chinensis*		*E. stagnina*		*E. crus-galli*	
		15 DAA†	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA
T_1	Cyhalofop-butyl + urea 1%	1.46^{bc} (2)*	1.46^{bc} (2)	1.23^{bc} (1)	1.23^{bcde} (1)	1.23^{cd} (1)	1.44^{abcde} (2)	1.23^{abc} (1)	1.23^{abcde} (1)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	1.17^{bc} (1)	1.34^{bc} (1)	0.71^{d} (0)	0.88^{de} (0)	0.88^{d} (0)	1.23^{de} (1)	0.71^{d} (0)	0.88^{e} (0)
T_3	Bispyribac-sodium + urea 1%	1.10^{bc} (1)	1.34^{bc} (1)	1.56^{b} (2)	1.64^{b} (2)	0.88^{d} (0)	1.29^{cde} (1)	0.71^{d} (0)	0.88^{e} (0)
T_4	Fenoxaprop-p-ethyl + urea 1%	1.44^{bc} (2)	1.60^{bc} (2)	0.71^{d} (0)	0.71^{e} (0)	1.00^{cd} (1)	1.56^{abcde} (2)	0.88^{cd} (0)	1.05^{cde} (1)
T_5	Carfentrazone-ethyl + urea 1%	1.88^{ab} (3)	2.23^{ab} (5)	1.56^{b} (2)	1.56^{bc} (2)	1.56^{abc} (2)	2.02^{a} (4)	1.46^{ab} (2)	1.56^{abcd} (2)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	1.66^{bc} (2)	1.97^{bc} (4)	1.56^{b} (2)	1.64^{b} (2)	1.56^{abc} (2)	1.86^{abc} (3)	1.56^{a} (2)	1.68^{ab} (2)
T_7	Cyhalofop-butyl	1.52^{bc} (2)	1.58^{bc} (2)	1.00^{cd} (1)	0.88^{de} (0)	1.34^{bcd} (1)	1.56^{abcde} (2)	1.23^{abc} (1)	1.17^{bcde} (1)
T_8	(Cyhalofop-butyl + penoxsulam)	1.44^{bc} (2)	1.46^{bc} (2)	0.71^{d} (0)	1.00^{cde} (1)	1.05^{cd} (1)	1.34^{bcde} (1)	0.88^{cd} (0)	1.00^{de} (1)
T_9	Bispyribac-sodium	1.35^{bc} (2)	1.47^{bc} (2)	1.64^{b} (2)	1.76^{b} (3)	1.05^{cd} (1)	1.46^{abcde} (2)	0.88^{cd} (0)	1.00^{de} (1)
T_{10}	Fenoxaprop-p-ethyl	1.64^{bc} (2)	1.81bc (3)	0.71^{d} (0)	0.71^{e} (0)	1.27^{bcd} (1)	1.52^{abcde} (2)	1.05^{bcd} (1)	1.17^{bcde} (1)
T_{11}	Carfentrazone-ethyl	1.86^{ab} (3)	2.03^{abc} (4)	1.44^{bc} (2)	1.46^{bcd} (2)	1.56^{abc} (2)	1.74^{abcd} (3)	1.34^{ab} (1)	1.58^{abc} (2)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	1.72^{b} (3)	2.22^{ab} (5)	1.64^{b} (2)	1.76^{b} (3)	1.86^{ab} (3)	2.02^{a} (4)	1.64^{a} (2)	1.76^{a} (3)
T_{13}	Hand weeded control	0.88^{c} (0)	1.17^{c} (1)	0.71^{d} (0)	0.71^{e} (0)	1.23^{cd} (1)	1.05^{e} (4)	0.88^{cd} (0)	1.05^{cde} (1)
T_{14}	Unweeded control	2.65^{a} (7)	2.88^{a} (8)	2.18^{a} (4)	2.36^{a} (5)	2.06^{a} (4)	1.94^{ab} (3)	1.56^{a} (2)	1.76^{a} (3)
SEm		0.11	0.12	0.13	0.14	0.10	0.08	0.09	0.09
CD (0.05)		0.82	0.91	0.51	0.59	0.61	0.60	0.42	0.57

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
† DAA days after application

Table 40. Effect of tank mixed herbicides along with urea on species-wise weed count (no./m^2 in 2020-21

Treatments		*Cyperus iria*		*Fimbristylis miliacea*		*Ludwigia perennis*		*Monochoria vaginalis*		*Limnocharis flava*	
		15 DAA†	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA
T_1	Cyhalofop-butyl + urea 1%	5.13^{abcd} (26)*	5.83^{abc} (35)	1.95^{ab} (4)	1.74^{bc} (3)	1.23^{bc} (1)	1.23^{b} (1)	1.23^{abc} (1)	1.34^{bc} (1)	1.34 (1)	1.23 (1)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	3.95^{cdef} (16)	4.49^{cde} (20)	1.10^{bc} (1)	1.18^{cd} (1)	0.88^{bc} (0)	1.00^{b} (1)	0.88^{cd} (0)	0.88^{c} (0)	0.88 (0)	1.00 (1)
T_3	Bispyribac-sodium + urea 1%	3.53^{defg} (14)	3.88^{de} (17)	1.34^{bc} (1)	1.52^{bcd} (2)	1.25^{bc} (2)	1.27^{b} (1)	0.71^{d} (0)	0.88^{c} (0)	1.05 (1)	1.17 (1)
T_4	Fenoxaprop-p-ethyl + urea 1%	4.85^{bcde} (24)	6.05^{ab} (37)	1.35^{bc} (1)	1.43^{bcd} (2)	1.17^{bc} (1)	1.17^{b} (1)	1.05^{bcd} (1)	1.23^{bc} (1)	1.05 (1)	1.17 (1)
T_5	Carfentrazone-ethyl + urea 1%	2.46^{fg}h (6)	3.77^{de} (14)	1.10^{bc} (1)	1.23^{cd} (1)	1.47^{bc} (2)	1.39^{b} (2)	0.71^{d} (0)	0.88^{c} (0)	0.88 (0)	1.17 (1)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	2.11^{gh} (4)	3.33^{de} (11)	0.71^{c} (0)	1.39^{bcd} (2)	1.05^{b} (1)	1.00^{b} (1)	0.71^{d} (0)	0.88^{c} (0)	0.88 (0)	1.17 (1)
T_7	Cyhalofop-butyl	5.62^{ab} (32)	6.11^{ab} (37)	1.05^{bc} (1)	1.00^{cd} (1)	1.34^{bc} (1)	1.23^{b} (1)	1.34^{ab} (1)	1.46^{ab} (2)	1.17 (1)	1.27 (1)
T_8	(Cyhalofop-butyl + penoxsulam)	4.55^{bcde} (20)	4.72^{bcd} (22)	1.34^{bc} (1)	1.44^{bcd} (2)	0.88^{bc} (0)	0.88^{b} (0)	0.88^{cd} (0)	1.05^{bc} (1)	1.17 (1)	1.17 (1)
T_9	Bispyribac-sodium	4.61^{bcde} (21)	4.53^{cde} (21)	1.56^{bc} (2)	1.86^{abc} (3)	0.71^{c} (0)	1.27^{b} (1)	1.17^{abc} (1)	1.17^{bc} (1)	1.17 (1)	1.17 (1)
T_{10}	Fenoxaprop-p-ethyl	5.34^{abc} (28)	6.28^{a} (39)	1.35^{bc} (2)	2.26^{ab} (5)	1.17^{bc} (1)	1.00^{b} (1)	1.17^{abc} (1)	1.17^{bc} (1)	1.17 (1)	1.34 (1)
T_{11}	Carfentrazone-ethyl	3.47^{efg} (12)	3.39^{de} (11)	0.71^{c} (0)	0.71^{d} (0)	1.34^{bc} (1)	1.46^{b} (2)	0.71^{d} (0)	1.05^{bc} (1)	1.05 (1)	1.17 (1)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.31^{efg} (11)	3.05^{e} (9)	1.10^{bc} (1)	1.47^{bcd} (2)	1.27^{bc} (1)	1.27^{b} (1)	0.88^{cd} (0)	1.17^{bc} (1)	1.05 (1)	1.17 (1)
T_{13}	Hand weeded control	1.17^{h} (1)	1.29^{f} (1)	1.27^{bc} (1)	1.23^{cd} (1)	1.46^{bc} (2)	1.17^{b} (1)	1.05^{bcd} (1)	1.17^{bc} (1)	1.05 (1)	1.05 (1)
T_{14}	Unweeded control	6.53^{a} (43)	7.29^{a} (53)	2.57^{a} (6)	2.74^{a} (7)	2.53^{a} (6)	2.66^{a} (7)	1.56^{a} (2)	1.93^{a} (3)	1.86 (3)	1.86 (38)
S.Em		0.39	0.43	0.13	0.14	0.11	0.11	0.07	0.08	0.07	0.05
CD (0.05)		1.61	1.52	0.90	0.91	0.76	0.77	0.45	0.55	NS	NS

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

† DAA days after application

Density of grasses, sedges and broad leaf weeds

Data on the effect of treatments on density of grasses, sedges and broad leaf weeds are presented in the Tables 41 and 42. Pooled analysis of data revealed that at 15 DAA hand weeding resulted in lower density of weeds (3 nos./m^2) and was on par with tank mixed application of urea with (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl and (cyhalofop-butyl + penoxsulam) applied alone. At 30 DAA, (cyhalofop-butyl + penoxsulam) was on par with hand weeding, registering densities of 3 and 6 nos./m^2 respectively. At both stages, unweeded control had the highest density of grasses.

Mixing of urea with the the first four herbicides [cyhalofop-butyl, (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl], which were effective against grasses, was seen to bring about better control although the effect was not statistically significant.

At 15 DAA, as per pooled analysis of data, higher density of sedges was in the unweeded control (69 nos./m^2), and lower in the hand weeded plot (4 nos./m^2). At this stage, the density of sedges in the treatment (chorimuron-ethyl + metsulfuron-methyl) + urea was comparable to hand weeding (8 nos./m^2). At 30 DAA, all herbicide treatments were significantly inferior to hand weeding, which recorded lowest density (4 nos./m^2).

Density of broad leaf weeds was highest in unweeded control (9 nos./m^2) and lower (1 no./m^2) in the treatment (cyhalofop-butyl + penoxsulam) + urea. The treatment (chlorimuron-ethyl + metsulfuron-methyl) + urea was on par with this treatment. At 30 DAA, unweeded control again registered the highest density of broad leaf weeds (11 nos./m^2). The lowest density (2 nos./m^2) was seen in the treatment (cyhalofop-butyl + penoxsulam) + urea and bispyribac-sodium + urea was on par with this.

Of the four herbicides effective against sedges and broad leaf weeds, three [(cyhalofop-butyl + penoxsulam), bispyribac-sodium and (chorimuron-ethyl +

metsulfuron-methyl)] showed a numerical reduction in the number of sedges on mixing with urea although the effect was non significant. In the case of broad leaf weeds the same effect was seen with all four herbicides, i.e., the above three and carfentrazone-ethyl.

Following the trend of density of the three classes of weeds, total weed density was highest in unweeded control both at 15 and 30 DAA (102 and 119 nos./m^2), and lowest in the hand weeded plot at the two stages (10 nos./m^2). At 15 DAA, application of (chlorimuron-ethyl + metsulfuron-methyl) tank mixed with urea resulted in total weed density comparable to hand weeding.

Comparing the application of herbicides with and without urea mixing on total weed density, the mixing of urea was seen to synergistically enhance the action of cyhalofop-butyl, (cyhalofop-butyl + penoxsulam), bispyribac-sodium, fenoxaprop-p-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) and the effect was statistically significant.

Table 41. Effect of tank mixed herbicides on density of grasses, sedges and broad leaf weeds at 15 DAA (no./m^2)**

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	2.32^{d*} (5)†	2.58^{cd} (7)	2.46^{de} (6)	6.57^{b} (44)	5.46^{abc} (30)	6.02^{b} (37)	1.58^{bcd} (2)	1.95^{bc} (3)	1.78^{bcd} (3)	7.12^{b} (51)	6.29^{b} (40)	6.72^{bc} (46)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	1.87^{d} (4)	1.66^{e} (3)	1.78^{ef} (3)	4.54^{cd} (21)	4.06^{cde} (17)	4.34^{de} (19)	0.88^{d} (0)	1.17^{c} (1)	1.04^{f} (1)	4.95^{c} (25)	4.51^{cd} (21)	4.78^{ef} (23)
T_3	Bispyribac-sodium + urea 1%	2.38^{d} (6)	2.16^{de} (5)	2.29^{def} (5)	4.16^{cd} (18)	3.73^{de} (15)	4.05^{de} (17)	1.05^{cd} (1)	1.49^{bc} (2)	1.37^{def} (2)	4.87^{c} (24)	4.54^{cd} (23)	4.81^{ef} (23)
T_4	Fenoxaprop-p-ethyl + urea 1%	2.15^{d} (5)	2.10^{de} (5)	2.13^{def} (5)	6.58^{b} (44)	4.99^{bcd} (26)	5.85^{bc} (35)	1.79^{bc} (3)	1.64^{bc} (2)	1.73^{bcde} (3)	7.15^{b} (52)	5.67^{bc} (33)	6.47^{c} (42)
T_5	Carfentrazone-ethyl + urea 1%	3.63^{b} (14)	3.55^{b} (13)	3.61^{b} (13)	4.25^{cd} (19)	2.71^{efg} (7)	3.54^{ef} (13)	0.88^{d} (0)	1.64^{bc} (2)	1.34^{def} (1)	5.70^{c} (33)	4.68^{cd} (22)	5.22^{def} (27)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	3.64^{b} (13)	3.60^{b} (13)	3.63^{b} (13)	3.48^{de} (12)	2.11^{fg} (4)	2.84^{fg} (8)	1.17^{cd} (1)	1.17^{c} (1)	1.21^{ef} (1)	5.15^{c} (27)	4.24^{d} (18)	4.72^{f} (22)
T_7	Cyhalofop-butyl	2.52^{d} (7)	2.61^{cd} (7)	2.57^{d} (7)	7.51^{b} (57)	5.68^{ab} (32)	6.65^{b} (45)	1.74^{bc} (3)	2.02^{b} (4)	1.91^{bc} (3)	8.12^{b} (66)	6.54^{b} (43)	7.37^{b} (55)
T_8	(Cyhalofop-butyl + penoxsulam)	2.22^{d} (5)	2.17^{de} (5)	2.20^{def} (5)	5.13^{c} (27)	4.70^{bcd} (22)	4.91^{cd} (24)	1.27^{cd} (1)	1.39^{bc} (2)	1.41^{cdef} (2)	5.76^{c} (33)	5.31^{bcd} (28)	5.55^{d} (31)
T_9	Bispyribac-sodium	2.60^{d} (7)	2.57^{cd} (7)	2.59^{d} (7)	4.98^{c} (25)	4.81^{bcd} (23)	4.90^{cd} (24)	1.44^{bcd} (2)	1.47^{bc} (2)	1.52^{cdef} (2)	5.82^{c} (34)	5.65^{bc} (32)	5.74^{d} (33)
T_{10}	Fenoxaprop-p-ethyl	2.67^{cd} (7)	2.65^{cd} (7)	2.66^{cd} (7)	7.45^{b} (56)	5.51^{abc} (30)	6.54^{b} (43)	1.46^{bcd} (2)	1.87^{bc} (3)	1.68^{bcde} (2)	8.03^{b} (65)	6.34^{b} (40)	7.24^{b} (53)
T_{11}	Carfentrazone-ethyl	3.57^{bc} (13)	3.21^{bc} (10)	3.40^{bc} (12)	4.08^{cd} (18)	3.47^{def} (12)	3.82^{ef} (15)	1.27^{cd} (1)	1.56^{bc} (2)	1.44^{cdef} (2)	5.64^{c} (32)	4.93^{cd} (25)	5.31^{def} (28)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.77^{b} (14)	3.87^{b} (15)	3.82^{b} (15)	3.84^{cd} (15)	3.47^{def} (12)	3.65^{ef} (13)	1.52^{bcd} (2)	1.64^{bc} (2)	1.61^{bcde} (2)	5.58^{c} (31)	5.38^{bcd} (29)	5.49^{de} (30)
T_{13}	Hand weeded control	1.82^{d} (3)	1.38^{e} (2)	1.63^{f} (3)	2.29^{e} (5)	1.57^{g} (2)	1.92^{g} (4)	2.21^{ab} (5)	1.86^{bc} (3)	2.07^{b} (4)	3.64^{d} (13)	2.65^{e} (7)	3.21^{g} (10)
T_{14}	Unweeded control	4.86^{a} (24)	4.92^{a} (24)	4.91^{a} (24)	9.42^{a} (89)	7.02^{a} (49)	8.30^{a} (69)	2.69^{a} (7)	3.38^{a} (11)	3.06^{a} (9)	10.94^{a} (120)	9.17^{a} (84)	10.10^{a} (102)
SEm		0.24	0.25	0.24	0.52	0.40	0.46	0.13	0.14	0.13	0.49	0.40	0.44
CD (0.05)		0.93	0.83	0.74	1.30	1.57	0.99	0.82	0.80	0.52	1.01	1.30	0.73

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
† Original values before combined analysis in parentheses. ** DAA- Days after application

Table 42. Effect of tank mixed herbicides on density of grasses, sedges and broad leaf weeds at 30 DAA** (no./m^2)

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	2.79^{de*} (8)†	2.76^{de} (8)	2.78^{ef} (8)	7.86^{b} (63)	6.03^{bcd} (37)	7.00^{b} (50)	1.77^{bc} (3)	1.95^{bc} (3)	1.73^{bc} (3)	8.50^{b} (73)	6.89^{bcd} (48)	7.74^{b} (61)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	2.57^{ef} (7)	2.23^{ef} (5)	2.41^{fg} (6)	5.10^{c} (26)	4.58^{def} (21)	4.86^{cd} (24)	1.27^{c} (1)	1.35^{c} (2)	1.18^{c} (2)	5.84^{c} (34)	5.26^{e} (28)	5.56^{c} (31)
T_3	Bispyribac-sodium + urea 1%	2.94^{de} (9)	2.69^{de} (7)	2.82^{ef} (8)	4.73^{c} (23)	4.07^{ef} (19)	4.57^{cd} (21)	1.46^{bc} (2)	1.76^{bc} (3)	1.46^{bc} (2)	5.73^{c} (33)	5.30^{e} (29)	5.57^{c} (31)
T_4	Fenoxaprop-p-ethyl + urea 1%	2.60^{ef} (7)	2.62^{de} (7)	2.61^{ef} (7)	7.86^{b} (62)	6.15^{bc} (39)	7.07^{b} (50)	1.64^{bc} (2)	1.86^{bc} (3)	1.60^{bc} (3)	8.44^{b} (71)	6.97^{bc} (49)	7.74^{b} (60)
T_5	Carfentrazone-ethyl + urea 1%	3.86^{bc} (15)	3.97^{b} (16)	3.92^{bc} (16)	4.63^{c} (22)	3.84^{ef} (15)	4.25^{cd} (18)	1.48^{bc} (2)	1.84^{bc} (3)	1.53^{bc} (3)	6.20^{c} (39)	5.81^{de} (34)	6.01^{c} (36)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	3.74^{bc} (14)	3.88^{b} (15)	3.81^{bc} (15)	3.85^{cd} (15)	3.47^{ef} (13)	3.73^{d} (14)	1.76^{bc} (3)	1.48^{bc} (2)	1.48^{bc} (2)	5.65^{c} (32)	5.43^{e} (30)	5.55^{c} (31)
T_7	Cyhalofop-butyl	2.73^{de} (8)	2.79^{de} (8)	2.76^{ef} (8)	8.56^{ab} (75)	6.12^{bc} (38)	7.48^{b} (56)	1.95^{b} (3)	2.11^{b} (4)	1.91^{b} (4)	9.20^{b} (86)	7.03^{bc} (50)	8.22^{b} (68)
T_8	(Cyhalofop-butyl + penoxsulam)	2.65^{def} (7)	2.63^{de} (7)	2.64^{ef} (7)	5.62^{c} (32)	4.84^{cde} (24)	5.24^{c} (28)	1.56^{bc} (2)	1.56^{bc} (2)	1.38^{bc} (2)	6.37^{c} (41)	5.70^{e} (33)	6.05^{c} (37)
T_9	Bispyribac-sodium	3.10^{cde} (10)	3.04^{cd} (9)	3.07^{de} (10)	5.20^{c} (28)	4.82^{cde} (24)	5.02^{cd} (26)	1.74^{bc} (3)	1.95^{bc} (3)	1.72^{bc} (3)	6.32^{c} (41)	5.99^{cde} (36)	6.16^{c} (39)
T_{10}	Fenoxaprop-p-ethyl	2.80^{de} (8)	3.05^{cd} (9)	2.93^{def} (9)	8.42^{ab} (71)	6.61^{ab} (44)	7.59^{ab} (58)	1.88^{bc} (3)	1.82^{bc} (3)	1.74^{b} (3)	9.06^{b} (83)	7.50^{b} (56)	8.33^{b} (70)
T_{11}	Carfentrazone-ethyl	3.41^{bcd} (12)	3.60^{bc} (13)	3.51^{cd} (12)	4.62^{c} (22)	3.31^{f} (11)	4.04^{cd} (17)	1.76^{bc} (3)	1.95^{bc} (3)	1.72^{bc} (3)	5.99^{c} (36)	5.24^{e} (28)	5.64^{c} (32)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	4.18^{b} (18)	4.24^{b} (18)	4.23^{b} (18)	4.33^{c} (21)	3.29^{f} (11)	3.87^{d} (16)	1.86^{bc} (3)	1.94^{bc} (3)	1.78^{b} (3)	6.42^{c} (42)	5.70^{e} (33)	6.07^{c} (37)
T_{13}	Hand weeded control	1.91^{f} (4)	1.72^{f} (3)	1.82^{g} (3)	2.21^{d} (5)	1.49^{g} (2)	1.91^{e} (4)	2.12^{b} (4)	1.76^{bc} (3)	1.82^{b} (3)	3.55^{d} (13)	2.82^{f} (8)	3.21^{d} (10)
T_{14}	Unweeded control	5.22^{a} (27)	5.47^{a} (30)	5.35^{a} (29)	9.80^{a} (99)	7.76a (60)	8.86^{a} (80)	3.02^{a} (9)	3.65^{a} (13)	3.28^{a} (11)	11.54^{a} (135)	10.16^{a} (103)	10.90^{a} (119)
SEm		0.22	0.26	0.24	0.59	0.44	0.51	0.11	0.14	0.13	0.54	0.43	0.49
CD (0.05)		0.79	0.66	0.63	1.88	1.49	1.31	0.68	0.67	0.55	1.49	1.14	1.04

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
† Original values before combined analysis in parentheses. ** DAA- Days after application

Species-wise weed dry matter

Species-wise weed dry matter production was found to be highest in the unweeded treatment at both 15 and 30 DAA in both years of experimentation (Table 43, 44, 45 and 46).

i) Grasses

In the first year, dry weight of *E. colona* at 15 DAA was lowest on tank mixing of (cyhalofop-butyl + penoxsulam) and bispyribac-sodium with urea, and on application of cyhalofop-butyl alone. In 2020-21, lowest dry weight was recorded in the hand weeded plot, and bispyribac-sodium + urea produced comparable dry weight of the weed. At 30 DAA, in both years, the superior treatments were identified as hand weeding, combination of (cyhalofop-butyl + penoxsulam) and bispyribac-sodium with urea. In 2020-21 bispyribac-sodium, applied without urea produced comparable value of weed dry weight.

Mixing of urea with (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl was found to be more effective against *E. colona* at both 15 and 30 DAA. Although the effect was not statistically significant, there was a decrease in the dry weight of the weed when compared with the dry weight when the herbicides were applied without urea mixing.

Tank mixing of urea with (cyhalofop-butyl + penoxsulam) and bispyribac-sodium was found to be effective in reducing dry matter production of *E. stagnina* at both stages of observation in both years. However, hand weeding was the best treatment at 30 DAA in both years. Unweeded control recorded the highest weed dry matter production at both stages in both years. In 2019-20, at both 15 and 30 DAA, carfentrazine-ethyl + urea, (chlorimuron ethyl + metsulfuron methy) with without urea were equally ineffective in reducing weed dry matter production. Similar results were observed in 2020-21.

Comparing the effects of the herbicides effective against *E. stagnina*, application of (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl on mixing with urea was found to be more effective against the weed. However, as in the case of *E. colona*, the effect was not significant.

Weed dry matter of *Leptochloa chinensis* followed the same trend in 2019-20 and 2020-21. At both stages of observation, highest weed dry matter production was observed in hand weeding. Comparable values were observed at 30 DAA in 2020-21 in the treatments (chlorimuron-ethyl + metsulfuron-methyl) and bispyribac-sodium, with and without urea mixing. In both years, at both 15 and 30 DAA, hand weeding led to lower dry matter production of *L. chinensis*, and treatments on par with hand weeding were (cyhalofop-butyl + penoxsulam) and fenoxaprop-p-ethyl, with and without urea mixing. In 2019-20, cyhalofop-butyl with and without urea mixing was also effective in reducing dry matter production at 30 DAA.

There was no specific advantage in mixing urea with the herbicides against *L. chinensis*.

Echinochloa crus-galli is a grass weed which occurred in the experimental plots only in 2020-21. Highest values for weed dry weight was observed at both 15 and 30 DAA in the unweeded control, which was on par with the treatments carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) with and without urea mixing.

Mixing of cyhalofop-butyl, (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl with urea was seen to be more effective than their application without urea only at 15 DAA. A decrease in weed dry matter production was observed on mixing with urea, although the effect was non significant. Such an effect was not visible at 30 DAA.

ii) Sedges

Hand weeding resulted in lower dry matter production of *C. iria* at both 15 and 30 DAA in both years, while unweeded control had the highest values for dry matter. (Chlorimuron-ethyl + metsulfuron-methyl) irrespective of urea mixing was seen to be effective in reducing dry matter production and was next best to hand weeding treatment in both years. However, in 2019-20, cyhalofop-butyl, and in both years, fenoxaprop-p-ethyl, were seen to be ineffective in reducing dry matter production of *C. iria* at both 15 and 30 DAA.

Tank mixing of urea was found to be beneficial for reducing dry matter production of *C. iria* only with (chlorimuron-ethyl + metsulfuron-methyl) in 2019-20. The effect, however, was not significant. A similar effect was observed in 2020-21 with bispyribac-sodium, carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl).

Dry matter production of *Fimbristylis miliacea* in both years at both stages of observation was highest in the unweeded control. In 2019-20, lowest dry matter was produced in the hand weeded plot at both stages and in the treatment bispyribac-sodium + urea at 15 DAA. However, in 2020-21, a similar performance was seen in the treatment carfentrazone-ethyl, followed by hand weeding and carfentrazone-ethyl + urea.

A slight beneficial effect, though non significant, of tank mixing bispyribac-sodium with urea was noticed against *F. miliacea*.

iii) Broad leaf weeds

Growth and dry matter production of *Ludwigia perennis* was highest at both stages in both years in the unweeded control. However, the effect of other treatments was not so significant and all treatments recorded similar values of dry matter production.

Monochoria vaginalis produced higher dry matter in the unweeded control both 15 and 30 DAA in both 2019-20 and 2020-21, although the effect was not significant at 15 DAA in 2019-20. However in 2020-21, at 15 DAA, lower dry matter production was in the treatments bispyribac-sodium, carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) mixed with urea. At 30 DAA, in 2019-20, the lower production was in the treatments (cyhalofop-butyl + penoxsulam) + urea and fenoxaprop-p-ethyl while in 2020-21, it was in (cyhalofop-butyl+ penoxsulam) and bispyribac-sodium, both mixed with urea.

Comparing the application of herbicides with and without urea mixing, it was seen that the effect was non significant. However, a positive effect of mixing was noticed with (cyhalofop-butyl + penoxsulam) and bispyribac sodium. This was also observed with (chlorimuron-ethyl + metsulfuron-methyl) at 15 DAA and with carfentrazone-ethyl at 30 DAA.

Limnocharis flava was seen in plots only in 2020-21. While the effect of treatments on dry matter production of the weed at 30 DAA was non-significant, at 15 DAA, highest dry matter production was in the unweeded control, while all other treatments were inferior and on par.

Table 43. Effect of tank mixed herbicides with urea on species-wise weed DMP (kg/ha) in 2019-20

Treatments		*E. colona*		*L. chinensis*		*E. stagnina*	
		15 DAA†	**30 DAA**	**15 DAA**	**30 DAA**	**15 DAA**	**30 DAA**
T_1	Cyhalofop-butyl + urea 1%	2.78^{cd} (7.42)*	4.09^{de} (17.33)	0.96^{cd} (0.50)	1.55^{c} (1.90)	2.00^{cd} (3.53)	3.50^{bcdef} (13.08)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	2.11^{d} (5.54)	3.18^{e} (10.22)	0.71^{d} (0.00)	1.14^{c} (1.16)	0.71^{d} (0.00)	3.23^{bcdef} (10.54)
T_3	Bispyribac-sodium + urea 1%	2.09^{d} (4.83)	2.46^{e} (7.50)	2.21^{b} (4.38)	3.11^{b} (9.90)	0.71^{d} (0.00)	2.67^{ef} (8.57)
T_4	Fenoxaprop-p-ethyl + urea 1%	3.07^{bcd} (9.02)	4.69^{cde} (22.26)	0.71^{d} (0.00)	0.71^{c} (0.00)	1.35^{cd} (2.13)	3.03^{def} (9.38)
T_5	Carfentrazone-ethyl + urea 1%	4.92^{abc} (25.13)	7.33^{abc} (54.10)	1.82^{bc} (2.87)	2.92^{b} (8.74)	4.25^{a} (18.11)	5.57^{ab} (31.39)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	4.85^{abc} (23.17)	8.05^{ab} (66.67)	2.18^{b} (4.46)	3.09^{b} (9.44)	4.01^{a} (15.96)	5.51^{abc} (30.01)
T_7	Cyhalofop-butyl	1.93^{d} (6.19)	4.35^{de} (19.93)	0.98^{cd} (0.59)	1.29^{c} (1.34)	2.20^{bc} (4.34)	3.98^{bcde} (15.81)
T_8	(Cyhalofop-butyl + penoxsulam)	3.01^{bcd} (11.23)	4.14^{de} (17.83)	0.71^{d} (0.00)	1.14^{c} (1.17)	1.49^{cd} (2.01)	3.27^{bcdef} (10.83)
T_9	Bispyribac-sodium	3.88^{abcd} (16.55)	4.04^{de} (15.90)	2.41^{b} (5.64)	3.42^{ab} (11.58)	1.51^{cd} (2.11)	3.48^{bcdef} (12.88)
T_{10}	Fenoxaprop-p-ethyl	3.63^{abcd} (12.98)	6.22^{bcd} (39.58)	0.71^{d} (0.00)	0.71^{c} (0.00)	2.10^{bcd} (5.18)	3.19^{cdef} (14.40)
T_{11}	Carfentrazone-ethyl	4.73^{abc} (22.64)	6.62^{abcd} (48.07)	2.05^{b} (3.96)	2.87^{b} (7.95)	3.52^{ab} (12.99)	5.29^{abcd} (28.44)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	5.19^{ab} (26.78)	8.10^{ab} (71.82)	1.76^{bc} (3.53)	3.25^{b} (10.66)	4.23^{a} (18.38)	6.75^{a} (47.83)
T_{13}	Hand weeded control	2.66^{cd} (6.66)	2.02^{e} (4.64)	0.93^{cd} (0.47)	1.33^{c} (1.47)	1.48^{cd} (2.01)	1.56^{f} (2.32)
T_{14}	Unweeded control	5.41^{a} (31.07)	9.28^{a} (87.04)	3.46^{a} (12.47)	4.55^{a} (20.75)	4.20^{a} (18.09)	6.92^{a} (48.30)
SEm		0.33	0.61	0.23	0.33	0.36	0.43
CD (0.05)		2.26	2.81	1.00	1.23	1.48	2.34

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

† DAA- Days after application

Table 44. Effect of tank mixed herbicides with urea on species-wise weed DMP (kg/ha) in 2019-20

Treatments		*Cyperus iria*		*Fimbristylis miliacea*		*Ludwigia perennis*		*Monochoria vaginalis*	
		15 DAA†	**30 DAA**	**15 DAA**	**30 DAA**	**15 DAA**	**30 DAA**	**15 DAA**	**30 DAA**
T_1	Cyhalofop-butyl + urea 1%	6.85^{b} (48.83)*	9.79^{a} (97.28)	1.69^{cd} (2.60)	2.81^{bc} (8.32)	1.01^{b} (0.53)	1.37^{bc} (1.38)	0.95 (0.42)	1.37^{bc} (1.42)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	3.90^{cd} (15.40)	5.67^{bc} (32.45)	1.55^{cd} (1.92)	1.89^{cd} (3.90)	0.78^{b} (0.13)	1.22^{c} (1.16)	0.71 (0.00)	0.71^{d} (0.00)
T_3	Bispyribac-sodium + urea 1%	3.83^{cd} (15.08)	5.35^{bc} (29.10)	1.44^{d} (1.68)	1.83^{cd} (3.68)	0.91^{b} (0.34)	1.28^{bc} (1.16)	0.71 (0.00)	0.89^{cd} (0.36)
T_4	Fenoxaprop-p-ethyl + urea 1%	7.02^{ab} (49.97)	10.61^{a} (113.39)	2.24^{bc} (4.57)	2.34^{bcd} (6.07)	1.19^{b} (0.93)	1.46^{bc} (1.79)	1.09 (0.97)	0.94^{bcd} (0.50)
T_5	Carfentrazone-ethyl + urea 1%	3.59^{cd} (14.30)	4.74^{bc} (22.72)	1.54^{cd} (1.96)	1.96^{cd} (4.30)	0.80^{b} (0.15)	1.20^{c} (1.07)	0.71 (0.00)	1.20^{bcd} (1.09)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	2.86^{de} (8.48)	4.12^{c} (17.73)	1.50^{cd} (1.86)	1.64^{cd} (2.80)	0.82^{b} (0.20)	1.19^{c} (1.05)	0.86 (0.29)	1.55^{ab} (0.96)
T_7	Cyhalofop-butyl	7.81^{ab} (61.60)	10.92^{a} (120.80)	2.56^{b} (6.15)	3.36^{b} (11.44)	1.21^{b} (1.09)	1.73^{bc} (2.63)	0.92 (0.44)	1.08^{bcd} (0.95)
T_8	(Cyhalofop-butyl + penoxsulam)	4.74^{c} (22.95)	6.26^{b} (39.21)	1.70^{cd} (2.49)	2.09^{cd} (4.69)	0.91^{b} (0.36)	1.41^{bc} (1.56)	0.91 (0.40)	0.98^{bcd} (0.62)
T_9	Bispyribac-sodium	4.67^{c} (22.41)	5.84^{bc} (35.21)	1.49^{cd} (1.87)	2.03^{cd} (4.32)	1.00^{b} (0.56)	1.56^{bc} (1.98)	0.93 (0.40)	1.19^{bcd} (0.08)
T_{10}	Fenoxaprop-p-ethyl	7.36^{ab} (55.19)	11.03^{a} (121.93)	2.84^{ab} (7.66)	2.34^{bcd} (5.94)	1.20^{b} (0.96)	1.89^{ab} (3.35)	0.71 (0.00)	0.71^{d} (0.00)
T_{11}	Carfentrazone-ethyl	3.25^{cde} (11.00)	4.47^{bc} (20.54)	1.72^{cd} (2.87)	2.11^{cd} (4.74)	0.88^{b} (0.33)	1.41^{bc} (1.57)	0.84 (0.21)	1.32^{bc} (1.28)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.08^{cde} (9.70)	4.58^{bc} (22.35)	1.70^{cd} (2.66)	1.95^{cd} (4.18)	0.85^{b} (0.27)	1.42^{bc} (1.55)	1.14 (0.81)	1.49^{abc} (1.75)
T_{13}	Hand weeded control	1.63^{e} (2.73)	1.87^{d} (3.62)	1.25^{d} (1.21)	1.16^{d} (1.40)	1.09^{b} (0.76)	1.44^{bc} (1.60)	1.12 (0.78)	1.22^{bcd} (1.01)
T_{14}	Unweeded control	8.58^{a} (75.60)	11.22^{a} (127.81)	3.63^{a} (13.09)	4.75^{a} (22.97)	1.72^{a} (2.61)	2.49^{a} (5.80)	1.24 (1.08)	2.09^{a} (3.95)
SEm		0.58	0.84	0.18	0.23	0.07	0.09	0.05	0.10
CD (0.05)		1.71	1.79	0.80	1.20	0.46	0.67	NS	0.61

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

† DAA- Days after application

Table 45. Effect of tank mixed herbicides with urea on species-wise weed DMP (kg/ha) in 2020-21

Treatments		*E. colona*		*L. chinensis*		*E. stagnina*		*E. crus-galli*	
		15 DAA†	**30 DAA**	**15 DAA**	**30 DAA**	**15 DAA**	**30 DAA**	**15 DAA**	**30 DAA**
T_1	Cyhalofop-butyl + urea 1%	2.53^{bcde} (6.04)*	3.80^{bcd} (14.28)	1.23^{bcd} (1.01)	1.85^{cdef} (2.94)	2.07^{bcd} (3.77)	3.50^{cd} (12.42)	1.64^{cde} (2.21)	2.82^{bcde} (7.48)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	1.93^{cde} (4.15)	3.37^{cd} (11.22)	0.71^{d} (0.00)	1.14^{f} (1.16)	1.09^{d} (0.98)	2.92^{de} (8.00)	0.71^{e} (0.00)	1.42^{e} (2.53)
T_3	Bispyribac-sodium + urea 1%	1.55^{de} (3.29)	3.32^{cd} (10.83)	1.81^{bc} (3.08)	2.82^{abc} (8.18)	1.07^{d} (0.91)	2.86^{de} (7.71)	0.71^{e} (0.00)	1.34^{e} (2.11)
T_4	Fenoxaprop-p-ethyl + urea 1%	2.70^{bcde} (7.58)	4.13^{bcd} (19.07)	0.71^{d} (0.00)	0.71^{f} (0.00)	1.33^{cd} (2.06)	4.14^{abcd} (17.40)	1.14^{de} (1.14)	2.26^{de} (5.80)
T_5	Carfentrazone-ethyl + urea 1%	4.04^{ab} (17.42)	6.26^{abc} (43.75)	1.65^{bc} (2.31)	2.36^{bcde} (5.38)	3.00^{ab} (9.03)	5.53^{a} (30.80)	2.79^{ab} (7.46)	4.44^{abcd} (19.98)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	3.51^{abcd} (12.84)	5.60^{abc} (34.00)	1.64^{bc} (2.32)	2.72^{bc} (7.32)	3.00^{ab} (9.07)	5.09^{abc} (25.95)	2.82^{ab} (8.09)	4.66^{abc} (21.57)
T_7	Cyhalofop-butyl	2.99^{bcde} (9.38)	4.34^{bcd} (18.31)	1.16^{cd} (1.24)	1.19^{ef} (1.39)	2.50^{abc} (5.95)	3.94^{abcd} (15.55)	1.85^{bcd} (2.96)	2.54^{cde} (7.90)
T_8	(Cyhalofop-butyl + penoxsulam)	2.86^{bcde} (8.29)	4.07^{bcd} (16.73)	0.71^{d} (0.00)	1.36^{def} (2.17)	1.61^{bcd} (2.52)	3.44cd (11.68)	1.16^{de} (1.27)	1.88^{e} (5.77)
T_9	Bispyribac-sodium	2.50^{bcd}e (8.22)	3.42^{cd} (15.26)	1.90^{b} (3.38)	3.05^{ab} (9.04)	1.68^{bcd} (2.79)	3.63^{bcd} (12.87)	1.20^{de} (1.44)	1.83^{e} (5.40)
T_{10}	Fenoxaprop-p-ethyl	3.35^{abcd} (11.55)	5.02^{bc} (27.00)	0.71^{d} (0.00)	0.71^{f} (0.00)	1.96^{bcd} (4.43)	4.01^{abcd} (17.54)	1.76^{bcde} (3.13)	2.71^{bcde} (9.08)
T_{11}	Carfentrazone-ethyl	3.97^{abc} (15.31)	5.81^{abc} (37.08)	1.55^{bc} (1.99)	2.46^{bcd} (5.66)	2.69^{abc} (6.98)	4.72^{abc} (23.22)	2.67^{abc} (6.74)	4.32^{abcd} (18.13)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.57^{abcd} (13.78)	6.49^{ab} (45.15)	1.62^{bc} (2.28)	2.99^{abc} (8.62)	3.71^{a} (13.45)	5.29^{ab} (27.99)	3.13^{a} (9.95)	4.87^{ab} (23.85)
T_{13}	Hand weeded control	1.15^{e} (1.21)	1.67^{d} (2.95)	0.71^{d} (0.00)	0.71^{f} (0.00)	1.80^{bcd} (2.76)	1.55^{e} (2.32)	1.04^{de} (0.79)	1.55^{e} (2.32)
T_{14}	Unweeded control	5.35^{a} (29.10)	8.21^{a} (70.37)	2.69^{a} (6.89)	3.92^{a} (15.56)	3.84^{a} (15.38)	5.55^{a} (31.05)	3.13^{a} (9.96)	5.12^{a} (26.75)
SEm		0.29	0.45	0.16	0.28	0.24	0.31	0.24	0.37
CD (0.05)		2.06	3.02	0.70	1.17	1.41	1.66	1.11	2.21

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
† DAA- Days after application

Table 46. Effect of tank mixed herbicides with urea on species-wise weed DMP (kg/ha) in 2020-21

Treatments		*Cyperus iria*		*Fimbristylis miliacea*		*Ludwigia perennis*		*Monochoria vaginalis*		*Limnocharis flava*	
		15 DAA†	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA
T_1	Cyhalofop-butyl + urea 1%	5.62^{b} (32.16)*	7.92^{bc} (63.95)	1.26^{b} (1.18)	1.91^{abc} (3.35)	0.97^{bc} (0.44)	1.33^{b} (1.29)	1.03^{abc} (0.57)	1.36^{bc} (1.42)	1.06^{b} (0.62)	1.26 (1.09)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	3.94^{cde} (15.40)	5.59^{de} (30.92)	1.01^{b} (0.69)	1.27^{bcd} (1.76)	0.78^{bc} (0.12)	0.86^{b} (0.30)	0.80^{cd} (0.15)	0.87^{c} (0.32)	0.80^{b} (0.15)	0.89 (0.35)
T_3	Bispyribac-sodium + urea 1%	3.64^{cdef} (14.22)	5.25^{de} (30.10)	1.09^{b} (0.73)	1.45^{bcd} (1.65)	1.04^{bc} (0.80)	1.24^{b} (1.22)	0.71^{d} (0.00)	0.89^{c} (0.36)	0.87^{b} (0.28)	1.12 (0.85)
T_4	Fenoxaprop-p-ethyl + urea 1%	5.71^{b} (33.63)	8.15^{b} (66.72)	1.17^{b} (1.07)	1.44^{bcd} (2.10)	1.02^{bc} (0.60)	1.27^{b} (1.30)	0.95^{bcd} (0.44)	1.30^{bc} (1.19)	0.87^{b} (0.27)	1.17 (1.03)
T_5	Carfentrazone-ethyl + urea 1%	2.30^{fgh} (4.97)	4.48^{de} (20.39)	0.71^{b} (0.00)	1.15^{cd} (0.83)	1.24^{b} (1.23)	1.43^{b} (1.80)	0.71^{d} (0.00)	0.87^{c} (0.32)	0.81^{b} (0.17)	1.11 (0.82)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	1.84^{gh} (2.91)	3.91^{e} (15.52)	0.89^{b} (0.31)	1.43^{bcd} (1.84)	0.90^{bc} (0.33)	1.01^{b} (0.69)	0.71^{d} (0.00)	1.20^{bc} (1.10)	0.82^{b} (0.20)	1.16 (0.96)
T_7	Cyhalofop-butyl	5.89^{b} (34.93)	8.62^{ab} (74.13)	1.19^{b} (0.93)	1.07^{cd} (0.89)	1.09^{bc} (0.69)	1.20^{b} (0.95)	1.08^{ab} (0.69)	1.57^{b} (2.01)	1.05^{b} (0.66)	1.25 (1.27)
T_8	(Cyhalofop-butyl + penoxsulam)	4.70^{bc} (21.95)	6.10^{cd} (36.88)	1.20^{b} (0.98)	1.49^{bcd} (1.83)	0.78^{bc} (0.11)	0.84^{b} (0.25)	0.84^{bcd} (0.24)	1.17^{bc} (0.98)	1.01^{b} (0.58)	1.13 (0.91)
T_9	Bispyribac-sodium	4.56^{bcd} (20.41)	5.95^{d} (35.67)	1.30^{b} (1.26)	1.85^{abc} (2.93)	0.71^{c} (0.00)	1.27^{b} (1.40)	0.93^{bcd} (0.40)	1.19^{bc} (1.08)	1.00^{b} (0.55)	1.16 (0.97)
T_{10}	Fenoxaprop-p-ethyl	6.10^{ab} (36.86)	8.81^{ab} (78.59)	1.13^{b} (0.95)	2.24^{ab} (4.67)	0.99^{bc} (0.53)	1.04^{b} (0.81)	0.97^{bcd} (0.49)	1.23^{bc} (1.19)	0.94^{b} (0.43)	1.34 (1.35)
T_{11}	Carfentrazone-ethyl	3.07^{defg} (9.10)	4.27^{de} (18.23)	0.71^{b} (0.00)	0.71^{d} (0.00)	1.09^{bc} (0.71)	1.51^{b} (1.85)	0.71^{d} (0.00)	1.08^{bc} (0.75)	0.94^{b} (0.41)	1.06 (0.68)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	2.51^{efgh} (5.86)	4.10^{e} (17.37)	1.01^{b} (0.71)	1.59^{bcd} (2.50)	1.12^{bc} (0.90)	1.36^{b} (1.62)	0.80^{cd} (0.15)	1.21^{bc} (1.12)	0.90^{b} (0.33)	1.15 (0.96)
T_{13}	Hand weeded control	1.12^{h} (0.86)	1.51^{f} (2.11)	1.04^{b} (0.66)	1.13^{cd} (0.79)	1.13^{bc} (0.81)	1.07^{b} (0.73)	0.90^{bcd} (0.33)	1.00^{bc} (0.57)	0.81^{b} (0.16)	0.85 (0.23)
T_{14}	Unweeded control	7.51^{a} (56.94)	10.21^{a} (104.48)	3.21^{a} (10.09)	2.81^{a} (7.64)	1.91^{a} (3.23)	2.89^{a} (7.96)	1.29^{a} (1.21)	2.31^{a} (4.95)	1.52^{a} (1.83)	1.59 (2.11)
SEm		0.50	0.64	0.16	0.14	0.08	0.13	0.05	0.10	0.05	0.05
CD (0.05)		1.55	1.83	0.66	0.98	0.52	0.79	0.29	0.63	0.36	NS

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

† DAA- Days after application

Dry matter production of grasses, sedges and broad leaf weeds

Data on pooled analysis of dry matter of grasses, sedges and broad leaf weeds at 15 and 30 DAA are given in Tables 47 and 48.

Dry matter production of grasses at 15 DAA was highest in the unweeded control (89.86 kg/ha). At 15 DAA, lower dry weight was recorded in the hand weeded plot (8.12 kg/ha), which was on par with the treatment (cyhalofop-butyl + penoxsulam) + urea (11.09 kg/ha). This was followed by the treatment bispyribac-sodium + urea (13.70 kg/ha). Dry matter production was again highest in the unweeded plot at 30 DAA (218.79 kg/ha), and lower value was recorded in the hand weeded plot (12.11 kg/ha), which was comparable with the treatments (cyhalofop-butyl + penoxsulam) + urea (40.94 kg/ha) and bispyribac-sodium + urea (45.94 kg/ha).

The effect of tank mixing urea with herbicides on grass dry matter production was not significant. However, there was a reduction in dry matter when urea was mixed with cyhalofop-butyl, (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl as compared to the application of these herbicides without mixing with urea.

The highest value for dry matter of sedges of 77.86 kg/ha and 131.45 kg/ha was recorded in the unweeded control at 15 and 30 DAA respectively. At 15 DAA, lowest value of 2.73 kg/ha was recorded in the hand weeded control, while at 30 DAA the correspondingly value was 3.96 kg/ha. At both stages, the treatment (chlorimuron-ethyl + metsulfuron-methyl) tank mixed with urea was next best (6.78 and 18.95 kg/ha respectively).

Mixing of (cyhalofop-butyl + penoxsulam), bispyribac-sodium and (chlorimuron-ethyl + metsulfuron-methyl) was seen to reduce dry matter production as compared to their urea-free application, although the effect was non significant.

Broad leaf weeds produced the highest dry matter in the unweeded plots at both 15 and 30 DAA (4.98 and 15.02 kg/ha respectively). However, lower dry matter production at both stages was recorded in the treatment (cyhalofop-butyl + penoxsulam) + urea (0.27 and 1.07 kg/ha respectively).

The dry matter production in broad leaf weeds was less, though non significant, when (chlorimuron-ethyl + metsulfuron-methyl), (cyhalofop-butyl + penoxsulam) and bispyribac-sodium were applied tank mixed with urea as compared to their application without urea mixing.

Pooled analysis of data showed that total weed dry matter production at both stages of observation followed the trend of majority of the weed species and was highest in the unweeded control (172.70 and 362.63 kg/ha respectively) and lowest in the hand weeding treatment (12.27 and 18.14 kg/ha respectively). The next best treatment at 15 DAA were (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea. At 30 DAA, the superior treatments after hand weeding were the same two treatments along with (cyhalofop-butyl + penoxsulam).

The pooled data on total weed dry matter production revealed that application of herbicides (except carfentrazone-ethyl) on tank mixing with urea reduced weed dry matter to a greater extent than their application without urea. However, significant effect of mixing was seen only with bispyribac-sodium and fenoxaprop-p-ethyl.

Table 47. Effect of tank mixed herbicides on weed DMP (kg/ha) of grasses, sedges and broad leaf weeds at 15 days after application

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	4.40^{ef*} (19.37)**	4.43^{ef} (19.61)	4.41^{defg} (19.49)	7.07^{b} (51.43)	5.73^{b} (33.34)	6.41^{b} (42.39)	1.20^{bcd} (0.95)	1.46^{bc} (1.63)	1.34^{bcd} (1.29)	8.41^{bcd} (71.74)	7.35^{bc} (54.79)	7.90^{bcde} (63.16)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	3.34^{f} (12.30)	2.98^{fg} (9.88)	3.20^{fg} (11.09)	4.14^{cd} (17.32)	4.02^{cd} (16.09)	4.09^{cd} (16.71)	0.78^{d} (0.13)	0.94^{c} (0.42)	0.87^{e} (0.27)	5.36^{ef} (29.74)	5.13^{de} (26.39)	5.27^{f} (28.07)
T_3	Bispyribac-sodium + urea 1%	3.95^{ef} (15.66)	3.28^{fg} (11.73)	3.66^{efg} (13.70)	4.03^{cd} (16.76)	3.73^{cde} (14.95)	3.98^{cd} (15.86)	0.91^{cd} (0.34)	1.15^{bc} (1.08)	1.07^{cde} (0.71)	5.71^{e} (32.76)	5.07^{e} (27.76)	5.48^{f} (30.26)
T_4	Fenoxaprop-p-ethyl + urea 1%	4.20^{ef} (17.81)	4.18^{ef} (18.81)	4.24^{defg} (18.31)	7.33^{b} (54.53)	5.79^{b} (34.70)	6.61^{b} (44.62)	1.47^{b} (1.90)	1.31^{bc} (1.31)	1.40^{bc} (1.61)	8.57^{bcd} (74.25)	7.37^{bc} (54.82)	7.99^{bcde} (64.54)
T_5	Carfentrazone-ethyl + urea 1%	7.55^{b} (59.33)	7.10^{bc} (5.97)	7.40^{b} (55.25)	3.92^{cd} (16.26)	2.30^{efg} (4.97)	3.22^{de} (10.62)	0.80^{d} (0.15)	1.35^{bc} (1.40)	1.12^{bcde} (0.78)	8.63^{bc} (75.95)	7.54^{bc} (57.33)	8.15^{bcde} (66.64)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	7.41^{bc} (55.01)	6.93^{bc} (48.32)	7.18^{b} (51.67)	3.19^{de} (10.34)	1.92^{fg} (3.23)	2.59^{ef} (6.78)	0.98^{bcd} (0.50)	0.98^{c} (0.53)	1.00^{de} (0.51)	8.11^{bcd} (65.84)	7.19^{bc} (52.08)	7.67^{cde} (58.96)
T_7	Cyhalofop-butyl	4.30^{ef} (20.33)	5.10^{de} (26.98)	4.72^{def} (23.61)	8.21^{ab} (67.75)	5.97^{b} (35.87)	7.18^{b} (51.81)	1.39^{bc} (1.53)	1.57^{b} (2.05)	1.51^{b} (1.79)	9.46^{b} (89.52)	8.03^{bc} (64.89)	8.78^{bc} (77.21)
T_8	(Cyhalofop-butyl + penoxsulam)	4.36^{ef} (21.98)	4.51^{ef} (21.48)	4.46^{defg} (21.73)	5.01^{c} (25.43)	4.81^{b} (22.93)	4.91^{c} (24.18)	1.06^{bcd} (0.77)	1.15^{bc} (0.93)	1.16^{bcde} (0.85)	6.92^{de} (48.18)	6.65^{cd} (45.34)	6.80^{e} (46.76)
T_9	Bispyribac-sodium	5.44^{cde} (31.79)	4.65^{ef} (23.31)	5.10^{de} (27.55)	4.85^{c} (24.78)	4.69^{bc} (21.67)	4.76^{c} (22.97)	1.18^{bcd} (0.96)	1.15^{bc} (0.95)	1.20^{bcde} (0.96)	7.52^{cd} (57.03)	6.75^{c} (45.93)	7.15^{de} (51.48)
T_{10}	Fenoxaprop-p-ethyl	5.24^{def} (28.58)	5.43^{cde} (30.54)	5.34^{cd} (29.56)	7.86^{ab} (62.85)	6.18^{bc} (37.81)	7.07^{b} (50.33)	1.20^{bcd} (0.96)	1.39^{bc} (1.44)	1.30^{bcd} (1.20)	9.54^{b} (92.39)	8.34^{b} (69.80)	8.96^{b} (81.18)
T_{11}	Carfentrazone-ethyl	7.09^{bcd} (51.25)	6.45^{bcd} (41.67)	6.79^{bc} (46.46)	3.64^{cd} (13.87)	3.07^{def} (9.10)	3.35^{de} (11.49)	0.98^{bcd} (0.54)	1.26^{bc} (1.12)	1.14^{bcde} (0.83)	8.05^{bcd} (65.66)	7.20^{bc} (51.89)	7.66^{cde} (58.77)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	7.88^{ab} (62.58)	7.65^{ab} (58.68)	7.78^{b} (60.63)	3.50^{cde} (12.36)	2.66^{defg} (6.56)	3.07^{de} (9.46)	1.23^{bcd} (1.08)	1.33^{bc} (1.37)	1.30^{bcd} (1.23)	8.68^{bc} (76.02)	8.15^{bc} (66.62)	8.44^{bc} (71.32)
T_{13}	Hand weeded control	3.25^{f} (10.65)	2.32^{g} (5.59)	2.85^{g} (8.12)	1.93^{e} (3.93)	1.35^{g} (1.52)	1.58^{f} (2.73)	1.40^{bc} (1.54)	1.32^{bcb} (1.30)	1.38^{bcd} (1.42)	4.00^{f} (16.13)	2.88^{f} (8.41)	3.49^{g} (12.27)
T_{14}	Unweeded control	9.66^{a} (93.34)	9.25^{a} (86.37)	9.47^{a} (89.86)	9.35^{a} (88.68)	8.19^{a} (67.03)	8.81^{a} (77.86)	2.03^{a} (3.69)	2.60^{a} (6.28)	2.33^{a} (4.98)	13.61^{a} (185.72)	12.^{59a} (159.67)	13.14^{a} (172.70)
SEm		0.53	0.52	0.52	0.60	0.52	0.56	0.09	0.11	0.09	0.61	0.57	0.59
CD (0.05)		2.09	1.74	1.66	1.57	1.51	1.11	0.56	0.58	0.39	1.66	1.56	1.20

*$\sqrt{x + 0.5}$ transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** Original values before combined analysis in parentheses

Table 48. Effect of tank mixed herbicides on weed DMP (kg/ha) of grasses, sedges and broad leaf weeds at 30 days after application

Treatments		Grasses			Sedges			Broad leaf weeds			Total		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	7.38^{d*} (55.46)**	7.55^{de} (57.26)	7.48^{ef} (56.36)	10.19^{b} (105.60)	8.11^{b} (67.30)	9.21b (86.45)	1.81^{bc} (2.80)	2.05^{b} (3.79)	1.81^{b} (3.30)	12.71^{bc} (163.85)	11.28^{bcd} (128.35)	12.02^{cd} (146.10)
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	6.43^{d} (41.61)	6.33^{e} (40.27)	6.40^{f} (40.94)	5.99^{cd} (36.35)	5.69^{cd} (32.58)	5.87^{cde} (34.47)	1.22^{c} (1.16)	1.16^{c} (0.97)	1.00^{c} (1.07)	8.89^{e} (79.12)	8.59^{e} (73.82)	8.74^{f} (76.47)
T_3	Bispyribac-sodium + urea 1%	6.73^{d} (45.44)	6.69^{e} (44.96)	6.71^{f} (45.20)	5.68^{cd} (32.78)	5.36^{cd} (31.75)	5.66^{cdef} (32.26)	1.42^{bc} (1.52)	1.69^{b} (2.43)	1.39^{bc} (1.97)	8.92^{e} (79.73)	8.87^{e} (79.13)	8.91^{f} (79.43)
T_4	Fenoxaprop-p-ethyl + urea 1%	6.87^{d} (48.68)	7.83^{de} (62.32)	7.37^{ef} (55.50)	10.90^{ab} (119.46)	8.23^{b} (68.82)	9.66^{b} (94.14)	1.63^{bc} (2.29)	1.97^{b} (3.52)	1.65^{b} (2.90)	13.04^{bc} (170.42)	11.58^{bc} (134.66)	12.33^{bcd} (152.54)
T_5	Carfentrazone-ethyl + urea 1%	11.65^{b} (135.97)	11.22^{b} (127.99)	11.46^{bc} (131.98)	5.18^{cd} (27.02)	4.52^{cd} (21.22)	4.87^{def} (24.12)	1.52^{bc} (2.16)	1.83^{bc} (2.93)	1.54^{bc} (2.55)	12.84^{bc} (165.15)	12.27^{b} (152.14)	12.57^{bcd} (158.64)
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	11.38^{b} (132.62)	11.02^{b} (123.44)	11.22^{bc} (127.98)	4.47^{d} (20.53)	4.04^{d} (17.36)	4.34^{f} (18.95)	1.86^{bc} (3.01)	1.65^{bc} (2.75)	1.64^{b} (2.88)	12.40^{bc} (156.15)	11.91^{b} (143.45)	12.16^{cd} (149.81)
T_7	Cyhalofop-butyl	7.45^{d} (56.98)	7.92^{de} (64.04)	7.70^{ef} (60.51)	11.43^{ab} (132.24)	8.64^{b} (75.03)	10.17^{ab} (103.63)	2.02^{b} (3.58)	2.17^{b} (4.23)	1.97^{b} (3.90)	13.86^{b} (192.79)	11.92^{b} (143.30)	12.96^{bc} (168.05)
T_8	(Cyhalofop-butyl + penoxsulam)	6.96^{d} (48.39)	7.43^{de} (55.09)	7.20^{ef} (51.99)	6.63^{c} (43.90)	6.21^{c} (38.71)	6.42^{c} (41.31)	1.62^{bc} (2.18)	1.58^{bc} (2.14)	1.44^{bc} (2.16)	9.72^{de} (94.47)	9.82^{de} (96.43)	9.77^{f} (95.45)
T_9	Bispyribac-sodium	7.69^{d} (60.72)	7.81^{de} (61.34)	7.80^{ef} (61.03)	6.18^{cd} (39.53)	6.16^{c} (38.60)	6.18^{cd} (39.07)	1.84^{bc} (3.06)	1.98^{b} (3.45)	1.79^{b} (3.26)	10.16^{de} (103.31)	10.13^{cde} (103.39)	10.15^{ef} (103.35)
T_{10}	Fenoxaprop-p-ethyl	8.67^{cd} (77.35)	8.80^{cd} (77.65)	8.76^{de} (77.50)	11.29^{ab} (127.87)	9.06^{ab} (83.76)	10.27^{ab} (105.57)	1.89^{bc} (3.35)	1.89^{bc} (3.35)	1.80^{b} (3.35)	14.40^{b} (208.56)	12.81^{b} (164.26)	13.64^{b} (186.41)
T_{11}	Carfentrazone-ethyl	10.28^{bc} (106.81)	10.23^{bc} (105.43)	10.29^{cd} (106.12)	4.99^{cd} (25.28)	4.21^{d} (18.23)	4.63^{ef} (21.75)	1.80^{bc} (2.85)	1.92^{bc} (3.28)	1.72^{b} (3.07)	11.60^{cd} (134.93)	11.22^{bcd} (126.94)	11.44^{de} (130.97)
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	12.67^{ab} (166.73)	11.76^{b} (138.69)	12.31^{b} (152.71)	4.98^{cd} (26.52)	4.33^{d} (19.87)	4.69^{ef} (23.20)	1.93^{b} (3.30)	1.99^{b} (3.70)	1.84^{b} (3.50)	13.87^{b} (196.55)	12.73^{b} (162.26)	13.37^{bc} (179.40)
T_{13}	Hand weeded control	3.43^{e} (11.90)	3.45^{f} (12.33)	3.47^{g} (12.11)	2.21^{e} (5.02)	1.64^{e} (2.90)	1.97^{g} (3.96)	1.76^{bc} (2.61)	1.42^{bc} (1.53)	1.44^{bc} (2.07)	4.42^{f} (19.53)	4.08^{f} (16.76)	4.26^{g} (18.14)
T_{14}	Unweeded control	14.48^{a} (209.97)	15.04^{a} (227.61)	14.77^{a} (218.79)	12.22^{a} (150.79)	10.56^{a} (112.12)	11.42^{a} (131.45)	3.20^{a} (9.76)	3.92^{a} (15.02)	3.51^{a} (12.39)	19.22^{a} (370.52)	18.79^{a} (354.75)	19.01^{a} (362.63)
SEm		0.79	0.76	0.78	0.86	0.65	0.75	0.12	0.17	0.15	0.92	0.85	0.88
CD (0.05)		2.47	1.85	1.65	1.82	1.82	1.34	0.68	0.77	0.62	2.08	1.71	1.48

*√x + 0.5transformed values, original values in parentheses. In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** Original values before combined analysis in parenthesis

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

Following the trend of weed dry matter production, weed control efficiency was highest in the hand weeding treatment at 15 DAA (92.90%) and 30 DAA (95%) (Table 49). At both stages of observation, the next best treatments were (cyhalofop-butyl + penoxsulam) + urea (83.75 and 78.91% respectively), and bispyribac-sodium + urea (82.48 and 78.10% respectively). (Cyhalofop-butyl + penoxsulam) was the next best treatment (72.92% at 15 DAA and 73.68% at 30 DAA). Lowest values were recorded in the treatment fenoxaprop-p-ethyl (53.04% at 15 DAA and 48.59% at 30 DAA).

The WCE was seen to invariably higher when all herbicides except carfentrazone-ethyl were tank mixed with urea as compared to their application without urea. For cyhalofop-butyl, at 15 DAA, the values were 64 per cent on mixing with urea, while it was 55 per cent without mixing. Corresponding values for (cyhalofop-butyl + penoxsulam) were 84 and 73 per cent, for bispyribac-sodium 82 and 70 per cent, for fenoxaprop-p-ethyl 63 and 53 per cent, for (chlorimuron-ethyl + metsulfuron-methyl) 66 and 59 per cent. Only for carfentrazone-ethyl there was a difference, with a higher WCE of 66 per cent being observed without urea as compared to 61 per cent with urea mixing. At 30 DAA the values of WCE for cyhalofop-butyl were 60 and 54 per cent, for (cyhalofop-butyl + penoxsulam) were 79 and 74 per cent, for bispyribac-sodium were 78 and 71.50 per cent, for fenoxaprop-p-ethyl were 58 and 49 per cent, and for (chlorimuron-ethyl + metsulfuron-methyl) were 59 and 50 per cent. As at 15 DAA, the value for carfentrazone-ethyl increased from 56 to 64 per cent at 30 DAA.

Weed index was lowest (1.89%) for the treatment bispyribac-sodium + urea, followed by (cyhalofop-butyl + penoxsulam) + urea (3.64%). The values for other treatments ranged between 20 and 30 per cent, except for (chlorimuron-ethyl + metsulfuron-methyl) which had a weed index of 38.23 per cent and carfentrazone-ethyl + urea, which had an index of 32.83 per cent. Weed indices were lower when herbicides were tank mixed with urea except in the case of carfentrazone-ethyl, where an increase was observed.

4.1.3 Nutrient removal by weeds

Data on removed of nitrogen, phosphorus and potassium by weeds at 15 and 30 DAA are presented in Table 50 and 51.

At both stages of observations, highest removal of N, P and K was in the unweeded control (5.50, 0.86 and 3.36 kg/ha respectively at 15 DAA, and 12.03, 1.80 and 8.48 kg/ha respectively at 30 DAA). Lower values of removal were recorded in the hand weeded control (0.34, 0.04 and 0.19 kg/ha of N, P and K respectively at 15 DAA; 0.52, 0.04 and 0.32 kg/ha of N, P and K respectively at 30 DAA). At both 15 and 30 DAA, the treatments (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea, were comparable to the hand weeded control in uptake of the three major nutrients.

Nutrient removal by weeds was higher when herbicides were applied without urea mixing. An exception was in the case of carfentrazone-ethyl, where nutrient uptake was observed by weeds when urea was mixed with the herbicide.

Table 49. Effect of tank mixed herbicide combinations on weed control efficiency and weed index

Treatments		WCE (%)						WI (%)		
		1st year		2nd year		Pooled		1st year	2nd year	Pooled
		15 DAA*	30 DAA	15 DAA	30 DAA	15 DAA	30 DAA			
T_1	Cyhalofop-butyl + urea 1%	61.37	55.78	65.81	63.82	63.43	59.71	15.69	21.61	18.99
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	83.98	78.65	83.47	79.19	83.75	78.91	5.13	2.45	3.64
T_3	Bispyribac-sodium + urea 1%	82.36	78.48	82.62	77.69	82.48	78.10	2.93	1.05	1.89
T_4	Fenoxaprop-p-ethyl + urea 1%	60.02	54.00	65.66	62.04	62.63	57.93	19.79	21.73	20.87
T_5	Carfentrazone-ethyl + urea 1%	59.11	55.43	64.09	57.11	61.41	56.25	28.15	36.57	32.83
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	64.55	57.85	67.38	59.56	65.86	58.69	25.22	34.11	30.17
T_7	Cyhalofop-butyl	51.80	47.97	59.36	59.61	55.30	53.66	20.38	27.69	24.45
T_8	(Cyhalofop-butyl + penoxsulam)	74.06	74.50	71.60	72.82	72.92	73.68	18.04	19.39	18.79
T_9	Bispyribac-sodium	69.29	72.12	71.23	70.86	70.19	71.50	13.05	19.16	16.45
T_{10}	Fenoxaprop-p-ethyl	50.25	43.71	56.28	53.70	53.04	48.59	20.97	26.75	24.19
T_{11}	Carfentrazone-ethyl	64.65	63.58	67.50	64.22	65.97	63.89	25.51	30.37	28.22
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	59.07	46.95	58.28	54.26	58.70	50.53	33.43	42.06	38.23
T_{13}	Hand weeded control	91.32	94.73	94.73	95.28	92.90	95.00	-	-	-
T_{14}	Unweeded control	-	-	-	-	-	-	55.43	74.77	66.19

* DAA – Days after application

Table 50. Effect of tank mixed herbicides with urea on removal of nutrients by weeds at 15 DAA (kg/ha)

Treatments		Removal of nutrients by weeds at 15 DAA (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	$2.04^{bcd\,*}$	1.61^{b}	1.82^{bcde}	0.24^{de}	0.20^{cd}	0.22^{ef}	1.36^{bcd}	0.92^{bcde}	1.14^{bcde}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	0.82^{ef}	0.74^{cde}	0.78^{fg}	0.09^{fg}	0.09^{ef}	0.09^{hi}	0.50^{ef}	0.50^{ef}	0.50^{fg}
T_3	Bispyribac-sodium + urea 1%	0.82^{ef}	0.71^{de}	0.77^{fg}	0.09fg	0.09^{ef}	0.09^{ghi}	0.52^{ef}	0.52^{def}	0.52^{fg}
T_4	Fenoxaprop-p-ethyl + urea 1%	2.12^{bcd}	1.63^{b}	1.87^{bcde}	0.26cde	0.20^{cd}	0.23^{def}	1.41^{bcd}	0.96^{bcd}	1.19^{bcd}
T_5	Carfentrazone-ethyl + urea 1%	2.35^{bc}	1.83^{b}	2.09^{bcd}	0.37^{bc}	0.26^{bcd}	0.31^{bc}	1.49^{bc}	1.01^{bc}	1.25^{bcd}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	1.95^{bcd}	1.57^{bc}	1.76^{cde}	0.29^{bcd}	0.25^{bcd}	0.27^{cde}	1.29^{bcd}	1.00^{bc}	1.14^{bcde}
T_7	Cyhalofop-butyl	2.60^{b}	1.96^{b}	2.28^{bc}	0.35^{bcd}	0.26^{bcd}	0.31^{bcd}	1.70^{b}	1.16^{b}	1.43^{bc}
T_8	(Cyhalofop-butyl + penoxsulam)	1.38^{de}	1.33^{bcd}	1.36^{ef}	0.16^{ef}	0.17^{de}	0.16^{fgh}	0.90^{de}	0.70^{cde}	0.80^{ef}
T_9	Bispyribac-sodium	1.62^{cde}	1.32^{bcd}	1.48^{de}	0.17^{ef}	0.17^{de}	0.17^{fg}	1.03^{cde}	0.82^{bcde}	0.93^{de}
T_{10}	Fenoxaprop-p-ethyl	2.70^{b}	2.16^{b}	2.43^{b}	0.39^{b}	0.30^{bc}	0.35^{b}	1.78^{b}	1.20^{b}	1.49^{b}
T_{11}	Carfentrazone-ethyl	1.98^{bcd}	1.62^{b}	1.80^{bcde}	0.27^{bcde}	0.23^{cd}	0.25^{cde}	1.25^{bcd}	0.94^{bcde}	1.10^{cde}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	2.31^{bc}	2.14^{b}	2.22^{bc}	0.36^{bc}	0.34^{b}	0.35^{b}	1.56^{bc}	0.98^{bc}	1.27^{bcd}
T_{13}	Hand weeded control	0.44^{f}	0.23^{e}	0.34^{g}	0.04^{g}	0.03^{f}	0.04^{i}	0.24^{f}	0.16^{f}	0.19^{g}
T_{14}	Unweeded control	5.89^{a}	5.12^{a}	5.50^{a}	0.92^{a}	0.80^{a}	0.86^{a}	3.83^{a}	2.89^{a}	3.36^{a}
SEm		0.35	0.30	0.32	0.06	0.05	0.05	0.23	0.17	0.20
CD (0.05)		0.89	0.85	0.64	0.12	0.11	0.08	0.54	0.45	0.35

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

Table 51. Effect of tank mixed herbicides with urea on removal of nutrients by weeds at 30 DAA (kg/ha)

Treatments		Removal of nutrients by weeds at 30 DAA (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	4.73^{bcd*}	3.99^{cd}	4.36^{c}	0.62^{d}	0.39^{cdef}	0.51^{d}	3.13^{cd}	2.53^{bcdef}	2.83^{cd}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	2.21^{fg}	2.30^{e}	2.25^{e}	0.21^{e}	0.21^{efg}	0.21^{ef}	1.44^{fg}	1.39^{fg}	1.41^{e}
T_3	Bispyribac-sodium + urea 1%	2.17^{fg}	2.32^{e}	2.24^{e}	0.18^{e}	0.20^{fg}	0.19^{ef}	1.43^{fg}	1.48^{efg}	1.45^{e}
T_4	Fenoxaprop-p-ethyl + urea 1%	5.03^{bc}	4.27^{bcd}	4.65^{bc}	0.64^{cd}	0.43^{cde}	0.54^{cd}	3.47^{bc}	2.69^{bcd}	3.08^{bc}
T_5	Carfentrazone-ethyl + urea 1%	5.09^{bc}	5.15^{bc}	5.12^{bc}	0.74^{bcd}	0.57^{bc}	0.66^{bcd}	3.75^{bc}	3.06^{bc}	3.41^{bc}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	4.74^{bcd}	4.75^{bc}	4.75^{bc}	0.71^{bcd}	0.50^{cd}	0.60^{bcd}	3.53^{bc}	2.89^{bcd}	3.21^{bc}
T_7	Cyhalofop-butyl	5.64^{bc}	4.63^{bc}	5.14^{bc}	0.74^{bcd}	0.44^{cde}	0.59^{cd}	4.07^{bc}	2.91^{bcd}	3.49^{bc}
T_8	(Cyhalofop-butyl + penoxsulam)	2.71^{ef}	3.09^{de}	2.90^{de}	0.28^{e}	0.29^{def}	0.29^{e}	1.78^{ef}	1.88^{def}	1.83^{de}
T_9	Bispyribac-sodium	2.90^{def}	3.09^{d}e	2.99^{de}	0.30^{e}	0.25^{efg}	0.28^{e}	1.88^{def}	1.96^{cdef}	1.92^{de}
T_{10}	Fenoxaprop-p-ethyl	6.29^{b}	5.40^{b}	5.84^{b}	0.92^{b}	0.57^{bc}	0.74^{bc}	4.50^{b}	3.31^{b}	3.90^{b}
T_{11}	Carfentrazone-ethyl	4.17^{cde}	4.18^{bcd}	4.17^{cd}	0.61^{d}	0.41^{cdef}	0.51^{d}	2.98^{cde}	2.56^{bcde}	2.77^{cd}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	6.11^{b}	5.46^{b}	5.79^{b}	0.90^{bc}	0.73^{b}	0.81^{b}	4.49^{b}	3.49^{b}	3.99^{b}
T_{13}	Hand weeded control	0.52^{g}	0.51^{f}	0.52^{f}	0.04^{e}	0.04^{g}	0.04^{f}	0.33^{g}	0.31^{g}	0.32^{f}
T_{14}	Unweeded control	11.73^{a}	12.34^{a}	12.03^{a}	1.83^{a}	1.77^{a}	1.80^{a}	8.70^{a}	8.26^{a}	8.48^{a}
SEm		0.71	0.72	0.71	0.12	0.11	0.11	0.54	0.48	0.51
CD (0.05)		1.90	1.39	1.31	0.27	0.23	0.21	1.34	1.17	1.06

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

4.2 Studies on rice

4.2.1 Plant height

Treatments had no significant effect on plant height of rice (Table 52). Average plant height at 30, 60 DAS and harvest were 61.33, 93.55 and 97.51 cm respectively.

4.2.2 Number of tillers

Pooled analysis of data for two years (Table 53) revealed that the hand weeded plot had highest number of tillers per sq. m (529), followed by the treatment bispyribac-sodium + urea (527). The lowest number (251) was recorded in the unweeded control at 30 DAS. This trend was continued at 60 DAS and at harvest. The treatment (chlorimuron-ethyl + metsulfuron-methyl) recorded tiller number significantly inferior to other herbicidal treatments at all three stages of observation (322, 404 and 263 at 30, 60 DAS and harvest respectively).

Mixing of urea with herbicides led to higher tiller number per sq. m compared to application without urea mixing, except in the case of carfentrazone-ethyl, where a decrease was noticed at all stages of observation.

4.2.3 Yield attributes

Number of panicles

Higher number of panicles per sq. m was produced in hand weeded control in both years (346 and 334 in 2019-20 and 2020-21 respectively). This treatment was on par with bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea in both years.

The treatment hand weeded control, bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea recorded significantly higher number of panicles per sq. m (340, 331 and 328 respectively) as depicted in Table 54. Lowest number of panicles per sq. m was recorded in unweeded control (117), followed by (chlorimuron-ethyl + metsulfuron-methyl), which had 208 panicles per sq. m.

Tank mixing of bispyribac-sodium and (cyhalofop-butyl + penoxsulam) with urea resulted in significantly higher panicle number per sq. m (331 and 258) as compared to their application without urea mixing (275 and 272).

Number of grains per panicle

The number of grains per panicle was highest in the hand weeded plot (104) and was on par with the treatments bispyribac-sodium + urea (102) and (cyhalfop-butyl + penoxsulam) + urea (103) when data were pooled. In the unweeded control, the lowest number of grains per panicles (78) was recorded.

Urea mixing with herbicides had no specific significant effect on number of grains per panicle in both years.

Percentage filled grains per panicle

In both years, percentage of filled grain was higher in the hand weeded control, and was on par with bispyribac-sodium, with and without urea mixing. Unweeded control recorded lowest filling percentage, followed by carfentrazone-ethyl + urea and (chlorimuron-ethyl + metsulfuron-methyl).

On pooling the data over the years, the highest value for percentage filled grain was recorded in the hand weeded control (90), which was on par with the treatment bispyribac-sodium + urea (89) and bispyribac-sodium alone (88). Lowest percentage filled grain was observed in the unweeded control (66). Urea mixing had no significant effect as compared to herbicide application without urea.

Test weight

Treatment effects on test weight of grains were non-significant. The test weight of grain ranged from 30.25 to 31.35 g.

4.2.4 Grain yield, straw yield and harvest index

Grain yield was observed to be higher in the second year. In both years, after hand weeding the best treatments were bispyribac-sodium + urea and (cyhalofop-butyl

+ penoxsulam) + urea. Lowest grain yield was in unweeded control, followed by (chlorimuron-ethyl + metsulfuron-methyl).

Pooling of data two years showed that grain yield ranged from 5.13 t/ha (in hand weeded control) to 1.73 t/ha (in unweeded control) (Table 55). Grain yield in the treatment bispyribac-sodium + urea (5.03 t/ha) was on par with that in hand weeded control, followed by (cyhalofop-butyl + penoxsulam) + urea (4.94 t/ha). The treatment carfentrazone + urea recorded significantly lower grain yield (3.44 t/ha) than other treatments and was superior only to unweeded control. (Chlorimuron-ethyl + metsulfuron-methyl) + urea was on par with this treatment, registering only 3.58 t/ha.

Urea mixing was found to increase grain yield as compared to application of herbicides without urea mixing in all treatments except carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl), where yields were found to decrease on mixing. Significant yield increase on urea mixing was observed with bispyribac-sodium and fenoxaprop-p-ethyl.

Straw yield was also lowest in the unweeded control plot (2.63 t/ha), followed by (chlorimuron-ethyl + metsulfuron-methyl) which recorded a yield of 3.94 t/ha. The treatment carfentrazone-ethyl + urea recorded straw yield on par with this treatment (4.19 t/ha). Highest straw yield was observed in the hand weeded plot (5.67 t/ha), and was on par with bispyribac-sodium + urea (5.53 t/ha), (cyhalofop-butyl + penoxsulam) + urea (5.35 t/ha), bispyribac-sodium (5.28 t/ha), (cyhalofop-butyl + penoxsulam) (5.15 t/ha). Although urea mixing with herbicides led to an increase in straw yield, the effect was not significant.

The effect of treatments on harvest index was non-significant. The values ranged from of 0.40 to 0.47.

4.2.5 Nutrient uptake by rice

Data on nutrient uptake by rice at 60 DAS are shown (Table 56). A perusal of the data showed that uptake of N, P and K was highest in hand weeded control (111.8, 13.2 and 89.7 kg/ha respectively). The treatment bispyribac + urea also registered high uptake of N (109.3 kg/ha), P (12.7 kg/ha) and K (83.1 kg/ha). Uptake of P was also high in rice in the treatment (cyhalofop-butyl + penoxsulam) + urea (12.42 kg/ha). Lowest uptake values for all three major nutrients was recorded in the unweeded plots (41.3, 4.9 and 33.4 kg/ha respectively). Low uptake values for N, P and K were also recorded in the treatment (chlorimuron-ethyl + metsulfuron-methyl), i.e., 70.8, 8.9 and 54.9 kg/ha respectively.

4.2.6 Economics of cultivation

The economics of cultivation were calculated and the results are presented in Tables 57 and 58.

Income from grain and straw, and therefore, gross income were higher in the second year. In both years, income from grain was highest for hand weeded control, followed by bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea. Lowest income from grain was from unweeded control followed by (chlorimuron-ethyl + metsulfuron-methyl). Income from straw and net income followed the same trend.

Pooled analysis of data showed that highest income from grain and straw, and therefore, gross income was recorded in the hand weeded plot (Rs. 1,98,935, Rs. 24,106 and Rs. 1,61,661 per hectare respectively). The next highest gross income was recorded in the treatment bispyribac-sodium + urea (Rs. 1,55,210 per hectare) and (cyhalofop-butyl + penoxsulam) + urea (Rs. 1,51,554 per hectare).

Income from garin and straw and net income were seen to be higher in treatments where herbicides were tank mixed with urea as compared to their application without urea. Exceptions were carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl), where the sole application of the herbicides led to higher incomes.

However, pooled analysis of data revealed that net income and benefit: cost ratio was highest in the treatment bispyribac-sodium + urea (Rs. 93,509/ha and 2.51

respectively), followed by (cyhalofop-butyl + penoxsulam) + urea (Rs. 87,643/ha and 2.37 respectively). In the hand weeded plot, net income was Rs. 86,072 per hectare and the B: C ratio was 2.13. In the unweeded control, net income (deficit) was Rs. 1,276 per hectare and the B: C ratio was only 0.98.

Table 52. Effect of tank mixed herbicides with urea on plant height of rice

Treatments		Plant height (cm)								
		30 DAS			60 DAS			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	61.67	60.73	61.21bc*	89.00	98.30	93.65	94.60	101.37	97.98
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	62.23	62.60	62.41bc	89.07	95.53	92.30	93.17	98.80	95.98
T_3	Bispyribac-sodium + urea 1%	60.40	61.33	60.86bc	89.40	95.87	92.63	94.03	98.03	96.03
T_4	Fenoxaprop-p-ethyl + urea 1%	60.27	62.60	61.43bc	90.80	99.03	94.92	94.60	101.87	98.23
T_5	Carfentrazone-ethyl + urea 1%	63.30	60.00	61.64bc	92.57	101.20	96.88	94.40	104.20	99.30
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	62.17	64.03	63.09ab	91.47	101.33	96.40	92.83	104.37	98.59
T_7	Cyhalofop-butyl	58.07	61.53	59.82bc	87.80	96.63	92.22	91.33	102.03	96.69
T_8	(Cyhalofop-butyl + penoxsulam)	56.20	67.67	61.94bc	85.33	97.70	91.52	89.97	100.33	95.15
T_9	Bispyribac-sodium	56.10	61.97	59.03bc	87.03	99.67	93.35	93.13	101.90	97.50
T_{10}	Fenoxaprop-p-ethyl	59.23	58.53	58.90bc	84.20	101.63	92.92	90.07	104.40	97.24
T_{11}	Carfentrazone-ethyl	58.40	65.83	62.11bc	82.90	101.20	92.05	89.90	104.73	97.30
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	60.03	60.43	60.24bc	82.87	102.83	92.85	88.70	105.47	97.10
T_{13}	Hand weeded control	56.90	59.83	58.36c	89.77	91.73	90.75	94.43	97.67	96.06
T_{14}	Unweeded control	68.17	66.83	67.51a	91.23	103.20	97.22	95.70	108.20	101.94
SEm		0.86	0.73	0.61	0.86	0.87	0.61	0.59	0.81	0.46
CD (0.05)		NS	NS	4.45	NS	NS	NS	NS	NS	NS

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

Table 53. Effect of tank mixed herbicides with urea on number of tillers/m^2 of rice

Treatments		No. of tillers / m^2								
		30 DAS			60 DAS			Harvest		
		1st year*	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	504.67^{abcd}	406.13^{abc}	455.40^{abc}	555.87^{abcd}	494.93^{bc}	525.40^{bcd}	328.00^{cd}	341.33^{abcde}	334.67^{cde}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	529.87^{abc}	429.60^{abc}	479.73^{ab}	610.13^{abc}	533.60^{abc}	571.87^{abc}	359.33^{abc}	362.27^{abc}	360.80^{bcd}
T_3	Bispyribac-sodium + urea 1%	608.53^{a}	445.33^{ab}	526.93^{a}	684.93^{ab}	565.60^{ab}	625.27^{ab}	397.33^{ab}	373.73^{ab}	385.53^{ab}
T_4	Fenoxaprop-p-ethyl + urea 1%	450.53^{bcde}	366.40^{abc}	408.47^{bcd}	527.47^{abcde}	455.73^{bc}	491.60^{cde}	293.33^{def}	330.40^{bcde}	311.87^{efg}
T_5	Carfentrazone-ethyl + urea 1%	365.60^{def}	307.07^{cd}	336.33^{de}	419.20^{def}	444.27^{bc}	431.73^{de}	254.00^{ef}	290.13^{e}	272.07^{gh}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	402.80^{cdef}	317.73^{bcd}	360.27^{cd}	518.00^{bcde}	440.80^{bc}	479.40^{cde}	273.33^{def}	303.73^{cde}	288.53^{fgh}
T_7	Cyhalofop-butyl	481.60^{abcde}	403.20^{abc}	442.40^{abc}	556.93^{abcd}	489.60^{bc}	523.27^{bcd}	310.67^{cde}	334.27^{bcde}	322.47^{def}
T_8	(Cyhalofop-butyl + penoxsulam)	501.87^{abcd}	428.40^{abc}	465.13^{ab}	538.00^{abcde}	512.00^{bc}	525.00^{bcd}	334.00^{bcd}	343.87^{abcde}	338.93^{cde}
T_9	Bispyribac-sodium	506.67^{abcd}	420.27^{abc}	463.47^{ab}	610.40^{abc}	525.07^{bc}	567.73^{bc}	372.00^{abc}	357.87^{abcd}	364.93^{abc}
T_{10}	Fenoxaprop-p-ethyl	453.73^{abcde}	345.33^{bcd}	399.53^{bcd}	521.33^{abcde}	446.93^{bc}	484.13^{cde}	273.33^{def}	304.80^{cde}	289.07^{fgh}
T_{11}	Carfentrazone-ethyl	429.60^{bcdef}	343.20^{bcd}	386.40^{bcd}	479.47^{cde}	442.40^{bc}	460.93^{de}	269.33^{def}	300.53^{de}	284.93^{fgh}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	329.47^{ef}	314.40^{bcd}	321.93^{de}	375.73^{ef}	432.80^{c}	404.27^{e}	243.33^{f}	282.40^{e}	262.87^{h}
T_{13}	Hand weeded control	568.93^{ab}	489.87^{a}	529.40^{a}	688.27^{a}	653.87^{a}	671.07^{a}	406.67^{a}	401.47^{a}	404.07^{a}
T_{14}	Unweeded control	283.20^{f}	219.20^{d}	251.20^{e}	302.67^{f}	249.73^{d}	276.20^{f}	152.00^{g}	176.80^{f}	164.40^{i}
SEm		24.21	18.98	21.33	29.08	24.01	25.95	18.30	14.40	16.24
CD (0.05)		157.40	134.83	96.56	169.93	126.97	103.00	64.71	61.62	40.19

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

Table 54. Effect of tank mixed herbicides with urea on yield attributes of rice

Treatments		No. of panicles per m^2			No. of grains per panicle			% filled grains per panicle			Test weight(g)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	262.00^{c*}	263.67^{abc}	262.83^{bc}	89.00^{a}	106.00^{a}	97.50^{abc}	91.47^{abcd}	77.20^{cde}	84.33^{cde}	30.77	30.84	30.80
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	337.33^{ab}	318.33^{ab}	327.83^{a}	93.67^{a}	112.20^{a}	102.93^{ab}	93.62^{abc}	80.06^{abcd}	86.84^{abc}	31.05	31.01	31.03
T_3	Bispyribac-sodium + urea 1%	343.33^{a}	319.00^{ab}	331.17^{a}	94.53^{a}	110.20^{a}	102.37^{abc}	94.14^{ab}	83.27^{ab}	88.71^{ab}	31.38	31.30	31.34
T_4	Fenoxaprop-p-ethyl + urea 1%	260.67^{c}	254.33^{bc}	257.50^{bc}	87.20^{a}	105.80^{a}	96.50^{abc}	91.43^{abcd}	75.78^{defg}	83.60^{cde}	30.62	30.61	30.62
T_5	Carfentrazone-ethyl + urea 1%	221.33^{c}	220.33^{c}	220.83^{cd}	85.87^{a}	103.40^{a}	94.63^{bc}	86.47^{e}	70.83^{fg}	78.65^{fg}	30.21	30.29	30.25
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	224.00^{c}	227.67^{c}	225.83^{cd}	83.73^{ab}	104.00^{a}	93.87^{c}	89.91^{cde}	74.50^{defg}	82.20^{def}	30.53	30.45	30.49
T_7	Cyhalofop-butyl	255.33^{c}	250.33^{bc}	252.83^{bc}	88.87^{a}	104.60^{a}	96.74^{abc}	91.06^{abcd}	76.38^{cdef}	83.72^{cde}	30.52	30.62	30.57
T_8	(Cyhalofop-butyl + penoxsulam)	269.33^{bc}	275.00^{abc}	272.17^{b}	93.47^{a}	107.00^{a}	100.23^{abc}	92.68^{abc}	78.72^{bcde}	85.70^{bcd}	30.91	31.24	31.07
T_9	Bispyribac-sodium	270.67^{bc}	278.33^{abc}	274.50^{b}	93.07^{a}	110.00^{a}	101.54^{abc}	93.94^{ab}	81.97^{abc}	87.95^{ab}	31.22	31.49	31.35
T_{10}	Fenoxaprop-p-ethyl	252.67^{c}	243.67^{c}	248.17^{bc}	86.40^{a}	104.80^{a}	95.60^{bc}	90.83^{bcd}	75.07^{defg}	82.95^{de}	30.61	30.63	30.63
T_{11}	Carfentrazone-ethyl	230.67^{c}	239.67^{c}	235.17^{bc}	88.80^{a}	104.40^{a}	96.60^{abc}	87.75^{de}	74.21^{efg}	80.98^{efg}	30.55	30.65	30.60
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	210.00^{c}	206.33^{c}	208.17^{d}	86.73^{a}	106.00^{a}	96.37^{abc}	86.51^{e}	70.10^{g}	78.30^{g}	30.47	30.47	30.47
T_{13}	Hand weeded control	345.67^{a}	333.67^{a}	339.67^{a}	94.80^{a}	114.00^{a}	104.40^{a}	94.80^{a}	84.61^{a}	89.71^{a}	31.10	31.59	31.34
T_{14}	Unweeded control	118.00^{d}	115.67^{d}	116.83^{e}	72.47^{b}	83.33^{b}	77.90^{d}	77.39^{f}	54.86^{h}	66.13^{h}	30.77	30.43	30.60
SEm		16.03	14.71	15.33	1.56	1.91	1.71	1.22	1.96	1.58	0.09	0.11	0.10
CD (0.05)		69.74	73.38	44.30	11.52	12.99	8.57	3.96	5.84	3.61	NS	NS	NS

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

Table 55. Effect of tank mixed herbicides with urea on grain and straw yield and harvest index of rice

Treatments		Grain yield (t/ha)			Straw yield (t/ha)			Harvest index		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	3.83^{abcd*}	4.47^{bc}	4.15^{cd}	4.67^{abcd}	5.15^{bcd}	4.91^{bcdef}	0.45	0.47	0.46^{a}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	4.31^{ab}	5.57^{a}	4.94^{ab}	4.81^{abc}	5.89^{abc}	5.35^{abc}	0.47	0.47	0.47^{a}
T_3	Bispyribac-sodium + urea 1%	4.41^{ab}	5.65^{a}	5.03^{a}	5.01^{a}	6.04^{ab}	5.53^{ab}	0.47	0.46	0.47^{a}
T_4	Fenoxaprop-p-ethyl + urea 1%	3.65^{bcd}	4.47^{bc}	4.06^{cde}	4.48^{abcde}	5.23^{abcd}	4.85^{cdefg}	0.45	0.46	0.45^{a}
T_5	Carfentrazone-ethyl + urea 1%	3.27^{cd}	3.62^{cd}	3.44^{ef}	4.10^{cde}	4.28^{de}	4.19^{hi}	0.43	0.46	0.45^{a}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	3.40^{cd}	$3.76b^{cd}$	3.58^{def}	3.90^{de}	4.58^{de}	4.24^{ghi}	0.46	0.45	0.46^{a}
T_7	Cyhalofop-butyl	3.62^{bcd}	4.13^{bcd}	3.87^{cde}	4.45^{abcde}	5.00^{cde}	4.73^{defgh}	0.45	0.45	0.45^{a}
T_8	(Cyhalofop-butyl + penoxsulam)	3.73^{abcd}	4.60^{b}	4.16^{cd}	4.69^{abc}	5.60^{abc}	5.15^{abcde}	0.44	0.46	0.45^{a}
T_9	Bispyribac-sodium	3.95^{abc}	4.61^{b}	4.28^{bc}	4.95^{ab}	5.60^{abc}	5.28^{abcd}	0.44	0.46	0.45^{a}
T_{10}	Fenoxaprop-p-ethyl	3.59^{bcd}	4.18^{bcd}	3.89^{cde}	4.09^{cde}	5.04^{bcd}	4.57^{efgh}	0.47	0.45	0.46^{a}
T_{11}	Carfentrazone-ethyl	3.39^{cd}	3.97^{bcd}	3.68^{cdef}	4.22^{bcde}	4.55^{de}	4.39^{fghi}	0.45	0.46	0.46^{a}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	3.03^{d}	3.31^{d}	3.17^{f}	3.86^{e}	4.03^{e}	3.94^{i}	0.44	0.45	0.45^{a}
T_{13}	Hand weeded control	4.55^{a}	5.71^{a}	5.13^{a}	5.18^{a}	6.16^{a}	5.67^{a}	0.47	0.47	0.47^{a}
T_{14}	Unweeded control	2.03^{e}	1.44^{e}	1.73^{g}	3.03^{f}	2.23^{f}	2.63^{j}	0.40	0.39	0.40^{b}
SEm		0.17	0.29	0.23	0.15	0.27	0.21	0.00	0.01	0.00
CD (0.05)		0.87	0.93	0.70	0.78	1.01	0.62	NS	NS	0.03

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

Table 56. Effect of tank mixed herbicides with urea on nutrient uptake of rice at 60 DAS

Treatments		Rice nutrient uptake at 60 DAS (kg/ha)								
		Nitrogen			Phosphorus			Potassium		
		1st year*	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	88.88^{abcd}	99.29^{abcd}	94.09^{bcd}	10.16^{abc}	12.43^{abcde}	11.29^{abcd}	67.64^{abcde}	80.90^{abcde}	74.27^{bc}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	96.93^{abc}	108.24^{abc}	102.58^{abc}	10.70^{ab}	14.15^{abc}	12.42^{abc}	75.21^{abc}	89.17^{ab}	82.19^{ab}
T_3	Bispyribac-sodium + urea 1%	104.94^{ab}	113.59^{ab}	109.26^{ab}	10.95^{ab}	14.37^{ab}	12.66^{ab}	76.31^{ab}	89.88^{ab}	83.09^{ab}
T_4	Fenoxaprop-p-ethyl + urea 1%	83.80^{bcd}	98.85^{abcd}	91.32^{cd}	9.58^{abc}	12.40^{abcde}	10.99^{bcd}	62.81^{bcde}	74.40^{bcdef}	68.60^{cd}
T_5	Carfentrazone-ethyl + urea 1%	77.28^{cd}	83.03^{de}	80.16^{de}	8.68^{bc}	10.90^{de}	9.79^{de}	55.63^{de}	62.90^{ef}	59.27^{de}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	86.02^{bcd}	89.24^{cde}	87.63^{cd}	9.82^{abc}	11.43^{cde}	10.63^{cde}	61.82^{bcde}	66.13^{def}	63.98^{cde}
T_7	Cyhalofop-butyl	93.42^{abc}	92.59^{bcde}	93.00^{bcd}	9.56^{abc}	12.54^{abcde}	11.05^{bcd}	61.37^{bcde}	64.69^{def}	63.03^{cde}
T_8	(Cyhalofop-butyl + penoxsulam)	93.90^{abc}	109.63^{abc}	101.76^{abc}	9.37^{abc}	12.90^{abcd}	11.13^{bcd}	68.29^{abcd}	82.39^{abcd}	75.34^{bc}
T_9	Bispyribac-sodium	96.86^{abc}	107.91^{abc}	102.39^{abc}	9.94^{abc}	13.23^{abcd}	11.59^{abcd}	61.66^{bcde}	85.67^{abc}	73.66^{bc}
T_{10}	Fenoxaprop-p-ethyl	93.02^{abc}	96.57^{abcd}	94.80^{bcd}	9.69^{abc}	11.82^{bcde}	10.75^{bcde}	62.33^{bcde}	67.31^{def}	64.82^{cde}
T_{11}	Carfentrazone-ethyl	75.93^{cd}	83.94^{de}	79.94^{de}	9.08^{abc}	11.44^{bcde}	10.26d^{e}	60.27^{cde}	69.94^{cdef}	65.11^{cde}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	70.18^{d}	71.48^{e}	70.83^{e}	8.13^{c}	9.71^{e}	8.92^{e}	52.58^{ef}	57.19^{f}	54.88^{e}
T_{13}	Hand weeded control	107.42^{a}	116.13^{a}	111.78^{a}	11.21^{a}	15.18^{a}	13.20^{a}	81.74^{a}	97.63^{a}	89.68^{a}
T_{14}	Unweeded control	48.16^{e}	34.38^{f}	41.27^{f}	5.42d	4.36^{f}	4.89^{f}	40.01^{f}	26.76^{g}	33.38^{f}
SEm		4.12	5.68	4.86	0.38	0.70	0.54	2.80	4.75	3.73
CD (0.05)		21.35	22.94	16.68	2.38	2.94	2.02	15.59	18.19	12.89

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

** DAS – Days after sowing

Table 57. Effect of tank mixed herbicides with urea on economics of cultivation of rice

Treatments		Income from grain (Rs./ha)			Income from straw (Rs./ha)			Gross income (Rs./ha)			Cost of cultivation (Rs./ha)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	103500	125767	166383	19833	21882	20858	123333	147649	135491	60078	62650	61364
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	116460	141167	187043	20457	25024	22740	136917	166191	151554	62625	65197	63911
T_3	Bispyribac-sodium + urea 1%	119160	144283	191302	21307	25670	23488	140467	169953	155210	60415	62987	61701
T_4	Fenoxaprop-p-ethyl + urea 1%	98460	122833	159877	19040	22213	20627	117500	145047	131273	60350	62922	61636
T_5	Carfentrazone-ethyl + urea 1%	88200	99550	137975	17425	18187	17806	105625	117737	111681	58830	61402	60116
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	91800	103400	143500	16575	19485	18030	108375	122885	115630	58793	61365	60079
T_7	Cyhalofop-butyl	97740	113483	154482	18927	21239	20083	116667	134722	125694	60053	62625	61339
T_8	(Cyhalofop-butyl + penoxsulam)	100620	130350	165795	19947	23792	21869	120567	154142	137354	62600	65172	63886
T_9	Bispyribac-sodium	106740	132917	173198	21052	23817	22434	127792	156734	142263	60390	62962	61676
T_{10}	Fenoxaprop-p-ethyl	97020	114950	154495	17397	21417	19407	114417	136367	125392	60325	62897	61611
T_{11}	Carfentrazone-ethyl	91440	109267	146073	17935	19343	18639	109375	128610	118992	58805	61377	60091
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	81720	90933	127187	16405	17111	16758	98125	108044	103084	58768	61340	60054
T_{13}	Hand weeded control	122760	152350	198935	22015	26197	24106	144775	178547	161661	73325	77853	75589
T_{14}	Unweeded control	54720	39600	74520	12863	9486	11175	67583	49086	58335	58325	60897	59611

Table 58. Effect of tank mixed herbicides with urea on net income and benefit: cost ratio of rice

Treatments		Net income (Rs./ha)			Benefit: cost ratio			Additional cost due to weed management (Rs./ha)			Additional returns due to weed management (Rs./ha)		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	63255	84999	74127	2.05	2.36	2.20	1753	1753	1753	53997	96810	75403
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	74292	100994	87643	2.19	2.55	2.37	4300	4300	4300	65033	112805	88919
T_3	Bispyribac-sodium + urea 1%	80052	106966	93509	2.33	2.70	2.51	2090	2090	2090	70793	118777	94785
T_4	Fenoxaprop-p-ethyl + urea 1%	57150	82125	69637	1.95	2.31	2.13	2025	2025	2025	47892	93936	70914
T_5	Carfentrazone-ethyl + urea 1%	46795	56335	51565	1.80	1.92	1.86	505	505	505	37537	68146	52841
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	49583	61520	55551	1.84	2.00	1.92	467.5	468	468	40324	73331	56828
T_7	Cyhalofop-butyl	56614	72097	64355	1.94	2.15	2.05	1728	1728	1728	47355	83908	65632
T_8	(Cyhalofop-butyl + penoxsulam)	57967	88970	73468	1.93	2.37	2.15	4275	4275	4275	48708	100781	74744
T_9	Bispyribac-sodium	67402	93772	80587	2.12	2.49	2.30	2065	2065	2065	58143	105583	81863
T_{10}	Fenoxaprop-p-ethyl	54092	73470	63781	1.90	2.17	2.03	2000	2000	2000	44833	85281	65057
T_{11}	Carfentrazone-ethyl	50570	67233	58901	1.86	2.10	1.98	480	480	480	41312	79044	60178
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	39358	46704	43031	1.67	1.76	1.72	442.5	443	443	30099	58515	44307
T_{13}	Hand weeded control	71450	100694	86072	1.97	2.29	2.13	15000	16956	15978	62192	112505	87348
T_{14}	Unweeded control	9258	-11811	-1276	1.16	0.81	0.98	-	-	-	-	-	-

4.3 Studies on soil microbial activity

4.3.1 Dehydrogenase activity (DHA)

Dehydrogenase activity was seen to increase from 15 DAS to 30 DAA, and then reduce towards harvest during both years of study (Table 59). At 15 DAS, the effect of treatments was non-significant. At 30 DAA and at harvest, the activity was significantly higher in the unweeded control and hand weeded control (84.06 and 83.26 μg TPF/g soil/h and 62.12 and 61.94 μg TPF/g soil/h respectively). The treatments carfentrazone-ethyl, fenoxaprop-p-ethyl, cafentrazone-ethyl + urea also recorded high values for dehydrogenase activity at 30 DAA and at harvest. Lower vales were recorded in the treatments bispyribac-sodium and fenoxaprop-p-ethyl with and without urea mixing, and in cyhalofop-butyl + urea.

There was no significant effect of urea mixing with herbicides on soil dehydrogenase acticity.

4.3.2 Soil microbial biomass carbon (SMBC)

The effect of treatments on soil microbial biomass carbon was non-significant at 15 DAS (Table 60). As in the case of dehydrogenase activity highest microbial biomass carbon was observed in the unweeded control and hand weeded control treatments (148.9 and 147.4 μg/g soil and 128.1 and 127.4 μg/g soil respectively). At 30 DAA, lowest value was seen in the treatments bispyribac-sodium with and without urea, and in fenoxaprop-p-ethyl + urea. At harvest, lowest values were observed in the treatments bispyribac-sodium with and without urea.

Soil microbial biomass carbon was not significantly affected by tank mixing of urea with herbicides.

Table 59. Effect of tank mixed herbicides with urea on soil dehydrogenase activity

Treatments		Dehydrogenase activity (µg TPF/g soil/h)								
		15 DAS			30 DAA			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	62.59	62.26	62.43	72.21^{def*}	75.29^{abcd}	73.75^{ef}	56.59^{bc}	53.11^{cde}	54.85^{cde}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	62.67	61.94	62.30	76.41^{cde}	76.99^{abc}	76.70^{cde}	57.76^{abc}	55.56^{bcde}	56.66^{bcd}
T_3	Bispyribac-sodium + urea 1%	63.16	62.85	63.00	67.78^{f}	65.80^{e}	66.79^{g}	49.71^{d}	50.60^{e}	50.16^{f}
T_4	Fenoxaprop-p-ethyl + urea 1%	62.94	62.01	62.48	69.74^{ef}	69.88^{cde}	69.81^{fg}	53.18^{cd}	52.79^{de}	52.98^{def}
T_5	Carfentrazone-ethyl + urea 1%	63.77	62.84	63.30	79.43^{abcd}	80.54^{ab}	79.98^{abcd}	60.10^{ab}	58.72^{abc}	59.41^{ab}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	64.96	62.07	63.52	78.30^{abcd}	77.39^{abc}	77.84^{bcde}	59.92^{ab}	57.61^{abcd}	58.77^{ab}
T_7	Cyhalofop-butyl	62.91	62.56	62.73	73.19^{def}	76.31^{abcd}	74.75^{def}	56.96^{bc}	55.05^{bcde}	56.00^{bcd}
T_8	(Cyhalofop-butyl + penoxsulam)	63.19	63.53	63.36	77.07^{bcde}	78.35^{abc}	77.71^{bcde}	57.90^{abc}	57.63^{abcd}	57.76^{bc}
T_9	Bispyribac-sodium	63.65	63.27	63.46	68.12^{f}	67.21^{de}	67.66^{g}	50.75^{d}	51.88^{e}	51.31^{ef}
T_{10}	Fenoxaprop-p-ethyl	63.66	61.63	62.64	70.45^{ef}	71.61^{bcde}	71.03^{fg}	54.26^{cd}	53.74^{bcde}	54.00^{cde}
T_{11}	Carfentrazone-ethyl	64.84	61.18	63.01	81.11^{abc}	80.94^{a}	81.02^{abc}	60.68^{ab}	58.87^{ab}	59.78^{ab}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	64.19	61.24	62.72	79.36^{abcd}	78.41^{abc}	78.89^{abcde}	60.05^{ab}	57.90^{abcd}	58.98^{ab}
T_{13}	Hand weeded control	63.53	62.87	63.20	84.22^{ab}	82.31^{a}	83.26^{ab}	62.44^{a}	61.43^{a}	61.94^{a}
T_{14}	Unweeded control	64.95	63.41	64.18	85.73^{a}	82.40^{a}	84.06^{a}	62.54^{a}	61.70^{a}	62.12^{a}
SEm		0.22	0.20	0.14	1.55	1.44	1.48	1.09	0.93	1.00
CD (0.05)		NS	NS	NS	7.74	9.24	5.61	4.86	5.73	3.78

*In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** DAS- Days after sowing
*** DAA- Days after applications

Table 60. Effect of tank mixed herbicides with urea on soil microbial biomass carbon

Treatments		Soil microbial biomass carbon (µg/g soil)								
		15 DAS			30 DAA			Harvest		
		1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1	Cyhalofop-butyl + urea 1%	172.93	169.59	171.26	127.21^{defg*}	133.63^{defg}	130.42^{gh}	109.92^{cdef}	105.11^{defg}	107.51^{fgh}
T_2	(Cyhalofop-butyl + penoxsulam) + urea 1%	173.00	169.27	171.13	131.41^{cdef}	138.65^{bcde}	135.03^{efg}	112.76^{cde}	110.17^{cde}	111.47^{ef}
T_3	Bispyribac-sodium + urea 1%	173.49	170.19	171.84	122.78^{g}	124.14^{h}	123.46^{i}	99.71^{g}	95.60^{g}	97.66^{i}
T_4	Fenoxaprop-p-ethyl + urea 1%	173.28	169.34	171.31	124.74^{fg}	128.21^{fgh}	126.47^{hi}	103.18^{efg}	99.79^{efg}	101.48^{hi}
T_5	Carfentrazone-ethyl + urea 1%	174.11	170.17	172.14	137.76^{bc}	144.87^{abc}	141.32^{cd}	116.10^{abc}	123.72^{ab}	119.91^{cd}
T_6	(Chlorimuron-ethyl + metsulfuron-methyl) + urea 1%	175.30	169.40	172.35	133.30^{cde}	139.06^{bcd}	136.18^{def}	114.92^{bcd}	117.28^{bc}	116.10^{cde}
T_7	Cyhalofop-butyl	173.24	169.89	171.56	128.19^{defg}	134.64^{def}	131.42^{fgh}	111.29^{cde}	106.38^{def}	108.8^{fg}
T_8	(Cyhalofop-butyl + penoxsulam)	173.52	170.87	172.20	132.07^{cdef}	136.68^{cdef}	134.38^{efg}	113.90^{cd}	112.96^{cd}	113.43^{def}
T_9	Bispyribac-sodium	173.98	170.61	172.30	123.12^{g}	125.55^{gh}	124.33^{i}	100.75^{fg}	96.88^{fg}	98.81^{i}
T_{10}	Fenoxaprop-p-ethyl	174.00	168.96	171.48	125.45^{efg}	129.94^{efgh}	127.69^{hi}	105.26^{defg}	100.74^{efg}	103.00^{ghi}
T_{11}	Carfentrazone-ethyl	175.18	168.51	171.85	139.44^{abc}	145.60^{ab}	142.52^{bc}	117.68^{abc}	124.20^{ab}	120.94^{bc}
T_{12}	(Chlorimuron-ethyl + metsulfuron-methyl)	174.53	168.57	171.55	134.36^{cd}	140.08^{bcd}	137.22^{de}	115.39^{abc}	119.24^{bc}	117.31^{cde}
T_{13}	Hand weeded control	173.86	170.87	172.36	145.89^{ab}	148.97^{a}	147.43^{ab}	124.53^{ab}	130.33^{a}	127.43^{ab}
T_{14}	Unweeded control	175.28	169.08	172.18	147.39^{a}	150.40^{a}	148.89^{a}	125.20^{c}	131.04^{a}	128.12^{a}
SEm		0.22	0.21	0.12	2.12	2.24	2.17	2.11	3.25	2.66
CD (0.05)		NS	NS	NS	8.21	8.86	5.20	10.12	10.54	6.79

* In a column, means followed by common letters do not differ significantly at 5 % level in DMRT.
** DAS- Days after sowing
*** DAA- Days after application

4.3 Experiment-III *In vitro* evaluation of herbicides on beneficial and pathogenic microorganisms

The effect of herbicides on disease causing plant pathogens (*Rhizoctonia solani*, *Pyricularia oryzae* and *Xanthomonas oryzae* pv. *oryzae*) and microbial agents (*Trichoderma viride* and *Pseudomonas flourescens*) were tested in a laboratory study and the results are presented below.

4.3.1 Effect on plant pathogens

(i) Fungi

Data outlined in Table 61 indicated that increasing concentrations of the different herbicides significantly affected the radial growth and per cent inhibition zone of *Rhizoctonia solani*. Comparing the six herbicides tried, lower radial growth and highest per cent inhibition were observed in bispyribac-sodium (3.58 cm and 51.02%), (cyhalofop-butyl + penoxsulam) (3.69 cm and 50.23%), cyhalofop-butyl (3.77 cm and 49.66%) and fenoxaprop-p-ethyl (3.89 cm and 48.94%), followed by (chlorimuron-ethyl + metsulfuron-methyl). With increasing concentrations of herbicides, radial growth decreased and per cent inhibition zone increased, and highest dose recorded radial growth of 4.99 cm and per cent inhibition zone of 38.30 per cent.

Considering the interaction effect of different herbicides and concentrations on *R. solani*, lower radial growth was with higher doses of bispyribac-sodium (2.43 cm) and fenoxaprop-p-ethyl (2.93 cm), which were at par with each other. Similarly, highest per cent of inhibition zone was also with bispyribac-sodium (58.70%) followed by fenoxaprop-p-ethyl (55.21%) and (cyhalofop-butyl + penoxsulam) (54.40%), whereas all the concentrations of (chlorimuron-ethyl + metsulfuron-methyl) had no effect on radial growth (9.00 cm) and per cent inhibition zone (0.29%) and was at par to control (Plate 23).

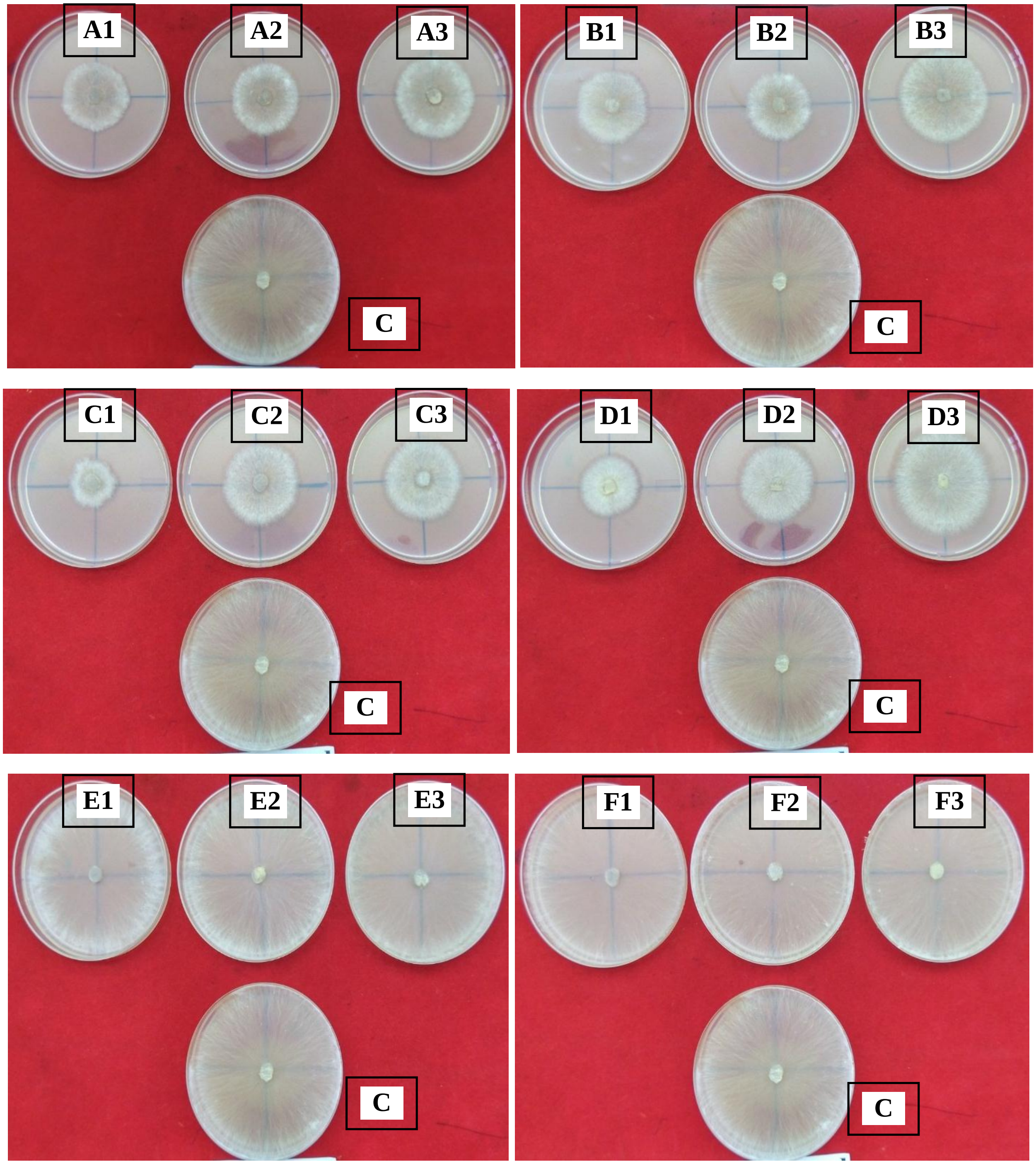


Plate 23. ***In vitro*** **evaluation of herbicides against** ***Rhizoctonia solani***

A1: Cyhalofop-butyl (240 ppm); A2 (160 ppm); A3 (80 ppm); B1: (Cyhalofop-butyl + penoxsulam) (450 ppm); B2: (300 ppm); B3: (150 ppm); C1: Bispyribac-sodium (75 ppm); C2: (50 ppm); C3: (25 ppm); D1: Fenoxaprop-p-ethyl (180 ppm); D2: (120 ppm); D3 (60 ppm); E1: Carfentrazone-ethyl (60 ppm); E2: (40 ppm); E3: (20 ppm); F1: (Chlorimuron-ethyl + metsulfuron-methyl) (8 ppm); F2: (4 ppm); F3: (2 ppm); C: Control plate

Table 61. Effect of herbicides on growth and per cent inhibition zone of *R. solani*

Treatments		Radial growth (cm)	% inhibition zone
Factor A (herbicide)			
Cyhalofop-butyl		3.77	49.66
(Cyhalofop-butyl + penoxsulam)		3.69	50.23
Bispyribac-sodium		3.58	51.02
Fenoxaprop-p-ethyl		3.89	48.94
Carfentrazone-ethyl		8.41	10.55
(Chlorimuron-ethyl + metsulfuron-methyl)		9.00	0.29
SEm		1.05	9.49
CD (P<0.05)		0.31	3.79
Factor B (concentration)			
Lower dose		5.96	30.32
Recommended dose		5.22	36.72
Higher dose		4.99	38.30
SEm		0.29	2.44
CD (p<0.05)		0.22	2.68
Herbicide x concentration (A×B)			
Cyhalofo-butyl	Lower dose @ 80 ppm	4.05	47.87
	Recommended dose @ 160 ppm	3.65	50.44
	Higher dose@ 240 ppm	3.62	50.66
(Cyhalofop-butyl + penoxsulam)	Lower dose @ 150 ppm	4.40	45.64
	Recommended dose @ 300 ppm	3.05	54.40
	Higher dose@ 450 ppm	3.62	50.66
Bispyribac-sodium	Lower dose @ 25 ppm	4.25	46.59
	Recommended dose @ 50 ppm	4.07	47.76
	Higher dose@ 75 ppm	2.43	58.70
Fenoxaprop-p-ethyl	Lower dose @ 60 ppm	5.08	41.27
	Recommended dose @ 120 ppm	3.67	50.35
	Higher dose@ 180 ppm	2.93	55.21
Carfentrazone-ethyl	Lower dose @ 20 ppm	9.00	0.29
	Recommended dose @ 40 ppm	7.88	17.07
	Higher dose@ 60 ppm	8.35	14.29
(Chlorimuron-ethyl + metsulfuron-methyl)	Lower dose @ 4 ppm	9.00	0.29
	Recommended dose @ 8 ppm	9.00	0.29
	Higher dose@ 12 ppm	9.00	0.29
CD (p<0.05)		0.53	6.56

Data shown Table 62 revealed that different herbicides and their concentrations significantly affected the radial growth and per cent inhibition zone of *Pyricularia oryzae*. The lowest radial growth and higher per cent inhibition zone were recorded with cyhalofop-butyl (1.72 cm and 62.18%) along with carfentrazone-ethyl (1.92 cm and 60.14%) and (cyhalofop-butyl + penoxsulam) (2.44 cm and 56.80%) when compared with control. Comparing the different concentrations of herbicides, lowest radial growth and highest per cent inhibition zone were recorded with higher dose of herbicides (2.89 cm and 51.10% respectively).

Interaction effect of different herbicides and concentrations on *P. oryzae* revealed that lower radial growth was with higher doses of cyhalofop-butyl (1.38 cm), carfentrazone-ethyl (1.48 cm) and (cyhalofop-butyl + penoxsulam) (1.53 cm) which were at par with each other. Similarly, highest per cent of inhibition zone was also with cyhalofop-butyl (65.45%) followed by carfentrazone-ethyl (64.50%) and (cyhalofop-butyl + penoxsulam) (64.05%), whereas (chlorimuron-ethyl + metsulfuron-methyl) at all the concentrations had no effect on radial growth (8.00 cm) and per cent inhibition zone (0.29%) as was the case in control (Plate 24).

(ii) Bacteria

Different herbicides and their concentrations did not significantly affect the radial growth and per cent inhibition zone of *Xanthomonas oryzae* pv. *oryzae* (Table 63 and Plate 25).

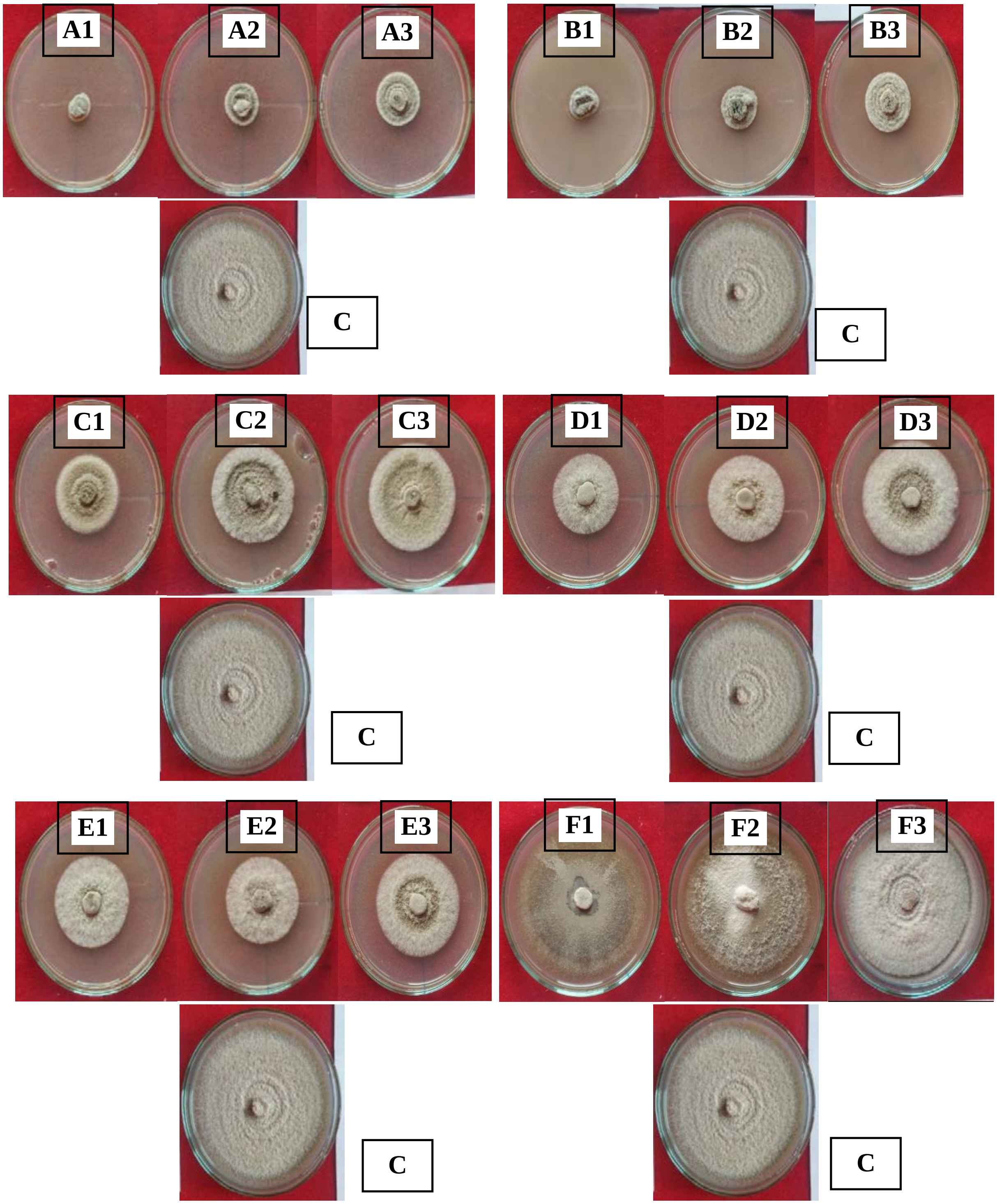


Plate 24. *In vitro* evaluation of herbicides against *Pyricularia oryzae*

A1: Cyhalofop-butyl (240 ppm); A2 (160 ppm); A3 (80 ppm); B1: (Cyhalofop-butyl + penoxsulam) (450 ppm); B2: (300 ppm); B3: (150 ppm); C1: Bispyribac-sodium (75 ppm); C2: (50 ppm); C3: (25 ppm); D1: Fenoxaprop-p-ethyl (180 ppm); D2: (120 ppm); D3 (60 ppm); E1: Carfentrazone-ethyl (60 ppm); E2: (40 ppm); E3: (20 ppm); F1: (Chlorimuron-ethyl + metsulfuron-methyl) (8 ppm); F2: (4 ppm); F3: (2 ppm); C: Control plate

Table 62. Effect of herbicides on growth and per cent inhibition zone of *Pyricularia oryzae*

Treatments		Radial growth (cm)	% inhibition zone
Factor A (herbicide)			
Cyhalofop-butyl		1.76	62.18
(Cyhalofop-butyl + penoxsulam)		1.92	60.74
Bispyribac-sodium		3.42	49.28
Fenoxaprop-p-ethyl		3.61	47.87
Carfentrazone-ethyl		2.44	56.80
(Chlorimuron-ethyl + metsulfuron-methyl)		8.00	0.29
SEm		0.95	9.49
CD (P<0.05)		0.10	0.80
Factor B (concentration)			
Lower dose (ppm)		3.98	42.68
Recommended dose (ppm)		3.70	44.80
Higher dose (ppm)		2.89	51.10
SEm		0.33	2.53
CD (P<0.05)		0.07	0.57
Herbicide x concentration (A×B)			
Cyhalofop-butyl	Lower dose @ 80 ppm	2.20	58.38
	Recommended dose @ 160 ppm	1.68	62.72
	Higher dose@ 240 ppm	1.38	65.45
(Cyhalofop-butyl + penoxsulam)	Lower dose @ 150 ppm	2.37	57.06
	Recommended dose @ 300 ppm	1.87	61.12
	Higher dose@ 450 ppm	1.53	64.05
Bispyribac-sodium	Lower dose @ 25 ppm	4.38	42.25
	Recommended dose @ 50 ppm	3.43	49.07
	Higher dose@ 75 ppm	2.43	56.53
Fenoxaprop-p-ethyl	Lower dose @ 60 ppm	4.55	41.05
	Recommended dose @ 120 ppm	3.75	46.80
	Higher dose@ 180 ppm	2.53	55.76
Carfentrazone-ethyl	Lower dose @ 20 ppm	2.37	57.05
	Recommended dose @ 40 ppm	3.47	48.83
	Higher dose@ 60 ppm	1.48	64.50
(Chlorimuron-ethyl + metsulfuron-methyl)	Lower dose @ 4 ppm	8.00	0.29
	Recommended dose @ 8 ppm	8.00	0.29
	Higher dose@ 12 ppm	8.00	0.29
CD (p<0.05)		0.17	1.39

Table 63. Effect of herbicides on growth and per cent inhibition zone of *Xanthomonas oryzae* pv. *oryzae*

Treatments		**Radial growth (cm)**	**% inhibition zone**
Factor A (herbicide)			
Cyhalofop-butyl		9.00	0.29
(Cyhalofop-butyl + penoxsulam)		9.00	0.29
Bispyribac-sodium		9.00	0.29
Fenoxaprop-p-ethyl		9.00	0.29
Carfentrazone-ethyl		9.00	0.29
(Chlorimuron-ethyl + metsulfuron-methyl)		9.00	0.29
SEm		0.00	0.00
CD (P<0.05)		NS	NS
Factor B (concentration)			
Lower dose (ppm)		9.00	0.29
Recommended dose (ppm)		9.00	0.29
Higher dose (ppm)		9.00	0.29
SEm		0.00	0.00
CD (P<0.05)		NS	NS
Herbicide x concentration (A×B)			
Cyhalofop-butyl	Lower dose @ 80 ppm	9.00	0.29
	Recommended dose @ 160 ppm	9.00	0.29
	Higher dose@ 240 ppm	9.00	0.29
(Cyhalofop-butyl + penoxsulam)	Lower dose @ 150 ppm	9.00	0.29
	Recommended dose @ 300 ppm	9.00	0.29
	Higher dose@ 450 ppm	9.00	0.29
Bispyribac-sodium	Lower dose @ 25 ppm	9.00	0.29
	Recommended dose @ 50 ppm	9.00	0.29
	Higher dose@ 75 ppm	9.00	0.29
Fenoxaprop-p-ethyl	Lower dose @ 60 ppm	9.00	0.29
	Recommended dose @ 120 ppm	9.00	0.29
	Higher dose@ 180 ppm	9.00	0.29
Carfentrazone-ethyl	Lower dose @ 20 ppm	9.00	0.29
	Recommended dose @ 40 ppm	9.00	0.29
	Higher dose@ 60 ppm	9.00	0.29
(Chlorimuro-ethyl + metsulfuron-methyl)	Lower dose @ 4 ppm	9.00	0.29
	Recommended dose @ 8 ppm	9.00	0.29
	Higher dose@ 12 ppm	9.00	0.29
CD (p<0.05)		NS	NS

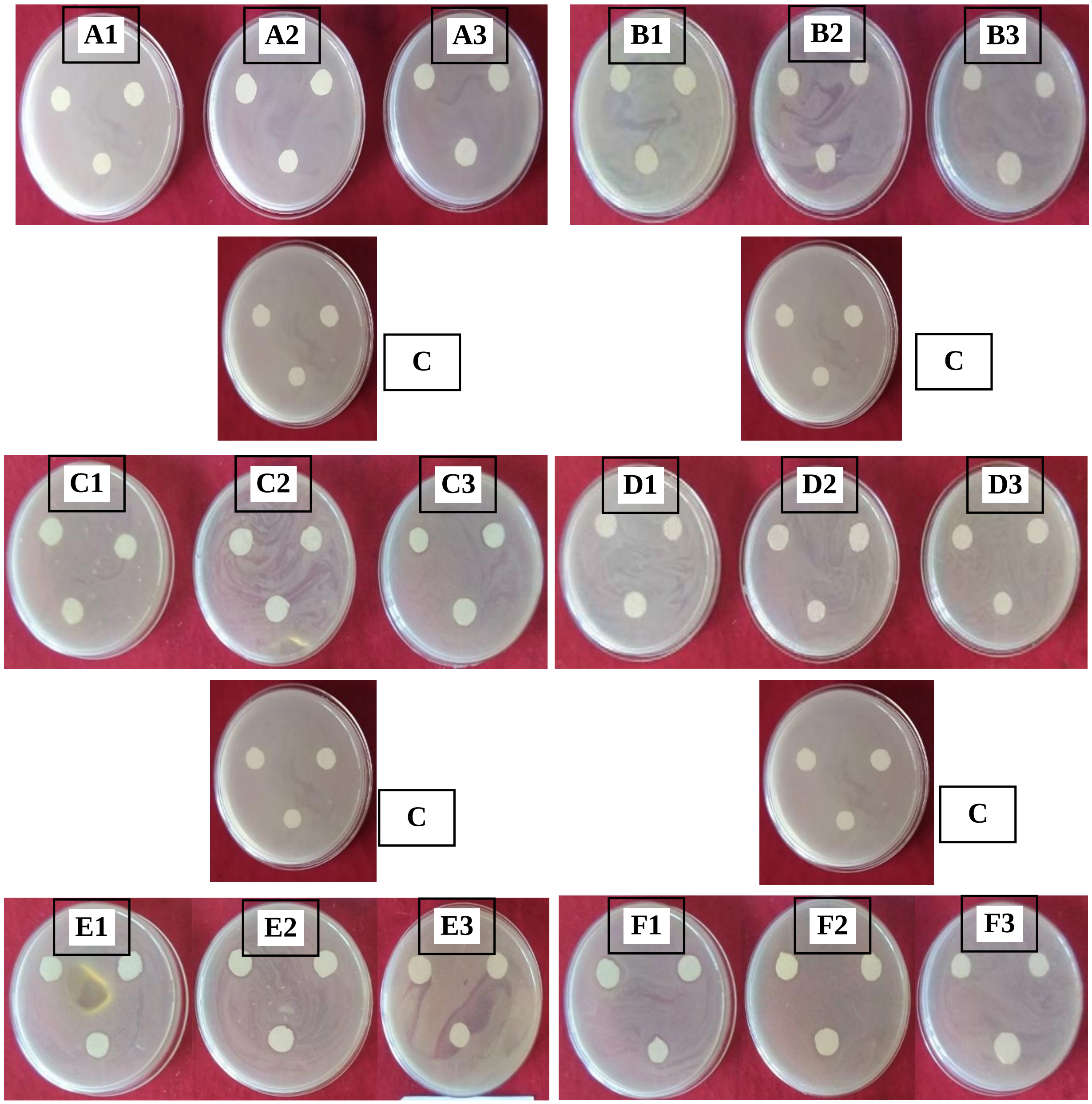


Plate 25. *In vitro* evaluation of herbicides against *Xanthomonas oryzae* pv. *oryzae*

A1: Cyhalofop-butyl (240 ppm); A2 (160 ppm); A3 (80 ppm); B1: (Cyhalofop-butyl + penoxsulam) (450 ppm); B2: (300 ppm); B3: (150 ppm); C1: Bispyribac-sodium (75 ppm); C2: (50 ppm); C3: (25 ppm); D1: Fenoxaprop-p-ethyl (180 ppm); D2: (120 ppm); D3 (60 ppm); E1: Carfentrazone-ethyl (60 ppm); E2: (40 ppm); E3: (20 ppm); F1: (Chlorimuron-ethyl + metsulfuron-methyl) (8 ppm); F2: (4 ppm); F3: (2 ppm); C: Control plate

4.3.2 Effect on biocontrol agents

(i) Fungi

Different herbicides at increasing concentrations significantly affected the radial growth and per cent inhibition zone of *Trichoderma viride* (Table 64). The lowest radial growth was observed with (cyhalofop butyl + penoxsulam) (3.95 cm), followed by cyhalofop butyl (4.52 cm) and (chlorimuron-ethyl + metsulfuron-methyl) (5.32 cm), and highest per cent inhibition zone was recorded in (cyhalofop butyl + penoxsulam) (48.54%) which was at par with cyhalofop butyl (44.89%), followed by (chlorimuron-ethyl + metsulfuron-methyl) (39.24%). Lowest radial growth and highest per cent inhibition zone were recorded with higher dose of herbicides (4.75 cm and 40.84% respectively).

However, interaction effect of different herbicides and concentrations on *T. viride* showed a different trend. Lowest radial growth and highest per cent of inhibition zone were with higher dose of bispyribac sodium (2.98 cm and 54.85%) followed by (cyhalofop-butyl + penoxsulam) (3.28 cm and 52.84%) and cyhalofop-butyl (3.80 cm and 49.49%), which were at par with each other. However, carfentrazone-ethyl at all concentrations and lower concentration of fenoxaprop-p-ethyl had no effect on radial growth (9.00 cm) and per cent inhibition zone (0.29%) as was seen in control (Plate 26).

Table 64. Effect of herbicides on growth and per cent inhibition zone of *Trichoderma viride*

<table>
<tr><th colspan="2">Treatments</th><th>Radial growth (cm)</th><th>% Inhibition zone</th></tr>
<tr><td colspan="4">Factor A (herbicide)</td></tr>
<tr><td colspan="2">Cyhalofop-butyl</td><td>4.52</td><td>44.89</td></tr>
<tr><td colspan="2">(Cyhalofop-butyl + penoxsulam)</td><td>3.95</td><td>48.54</td></tr>
<tr><td colspan="2">Bispyribac-sodium</td><td>5.42</td><td>38.49</td></tr>
<tr><td colspan="2">Fenoxaprop-p-ethyl</td><td>7.76</td><td>14.96</td></tr>
<tr><td colspan="2">Carfentrazone-ethyl</td><td>9.00</td><td>0.29</td></tr>
<tr><td colspan="2">(Chlorimuron-ethyl + metsulfuron-methyl)</td><td>5.32</td><td>39.24</td></tr>
<tr><td colspan="2">SEm</td><td>0.80</td><td>7.80</td></tr>
<tr><td colspan="2">CD (P<0.05)</td><td>0.41</td><td>3.73</td></tr>
<tr><td colspan="4">Factor B (concentration)</td></tr>
<tr><td colspan="2">Lower dose (ppm)</td><td>6.92</td><td>23.97</td></tr>
<tr><td colspan="2">Recommended dose (ppm)</td><td>6.33</td><td>28.39</td></tr>
<tr><td colspan="2">Higher dose (ppm)</td><td>4.74</td><td>40.84</td></tr>
<tr><td colspan="2">SEm</td><td>0.65</td><td>5.05</td></tr>
<tr><td colspan="2">CD (p<0.05)</td><td>0.29</td><td>2.64</td></tr>
<tr><td colspan="4">Herbicide x concentration (A×B)</td></tr>
<tr><td rowspan="3">Cyhalofop-butyl</td><td>Lower dose @ 80 ppm</td><td>5.38</td><td>39.34</td></tr>
<tr><td>Recommended dose @ 160 ppm</td><td>4.37</td><td>45.85</td></tr>
<tr><td>Higher dose@ 240 ppm</td><td>3.80</td><td>49.49</td></tr>
<tr><td rowspan="3">(Cyhalofop-butyl + penoxsulam)</td><td>Lower dose @ 150 ppm</td><td>4.78</td><td>43.19</td></tr>
<tr><td>Recommended dose @ 300 ppm</td><td>3.78</td><td>49.58</td></tr>
<tr><td>Higher dose@ 450 ppm</td><td>3.28</td><td>52.84</td></tr>
<tr><td rowspan="3">Bispyribac-sodium</td><td>Lower dose @ 25 ppm</td><td>6.07</td><td>34.81</td></tr>
<tr><td>Recommended dose @ 50 ppm</td><td>7.22</td><td>25.81</td></tr>
<tr><td>Higher dose@ 75 ppm</td><td>2.98</td><td>54.85</td></tr>
<tr><td rowspan="3">Fenoxaprop-p-ethyl</td><td>Lower dose @ 60 ppm</td><td>9.00</td><td>0.29</td></tr>
<tr><td>Recommended dose @ 120 ppm</td><td>8.67</td><td>6.68</td></tr>
<tr><td>Higher dose@ 180 ppm</td><td>5.60</td><td>37.90</td></tr>
<tr><td rowspan="3">Carfentrazone-ethyl</td><td>Lower dose @ 20 ppm</td><td>9.00</td><td>0.29</td></tr>
<tr><td>Recommended dose @ 40 ppm</td><td>9.00</td><td>0.29</td></tr>
<tr><td>Higher dose@ 60 ppm</td><td>9.00</td><td>0.29</td></tr>
<tr><td rowspan="3">(Chlorimuron-ethyl + metsulfuron-methyl)</td><td>Lower dose @ 4 ppm</td><td>7.27</td><td>25.91</td></tr>
<tr><td>Recommended dose @ 8 ppm</td><td>4.93</td><td>42.12</td></tr>
<tr><td>Higher dose@ 12 ppm</td><td>3.77</td><td>49.70</td></tr>
<tr><td colspan="2">CD (p<0.05)</td><td>0.72</td><td>6.46</td></tr>
</table>

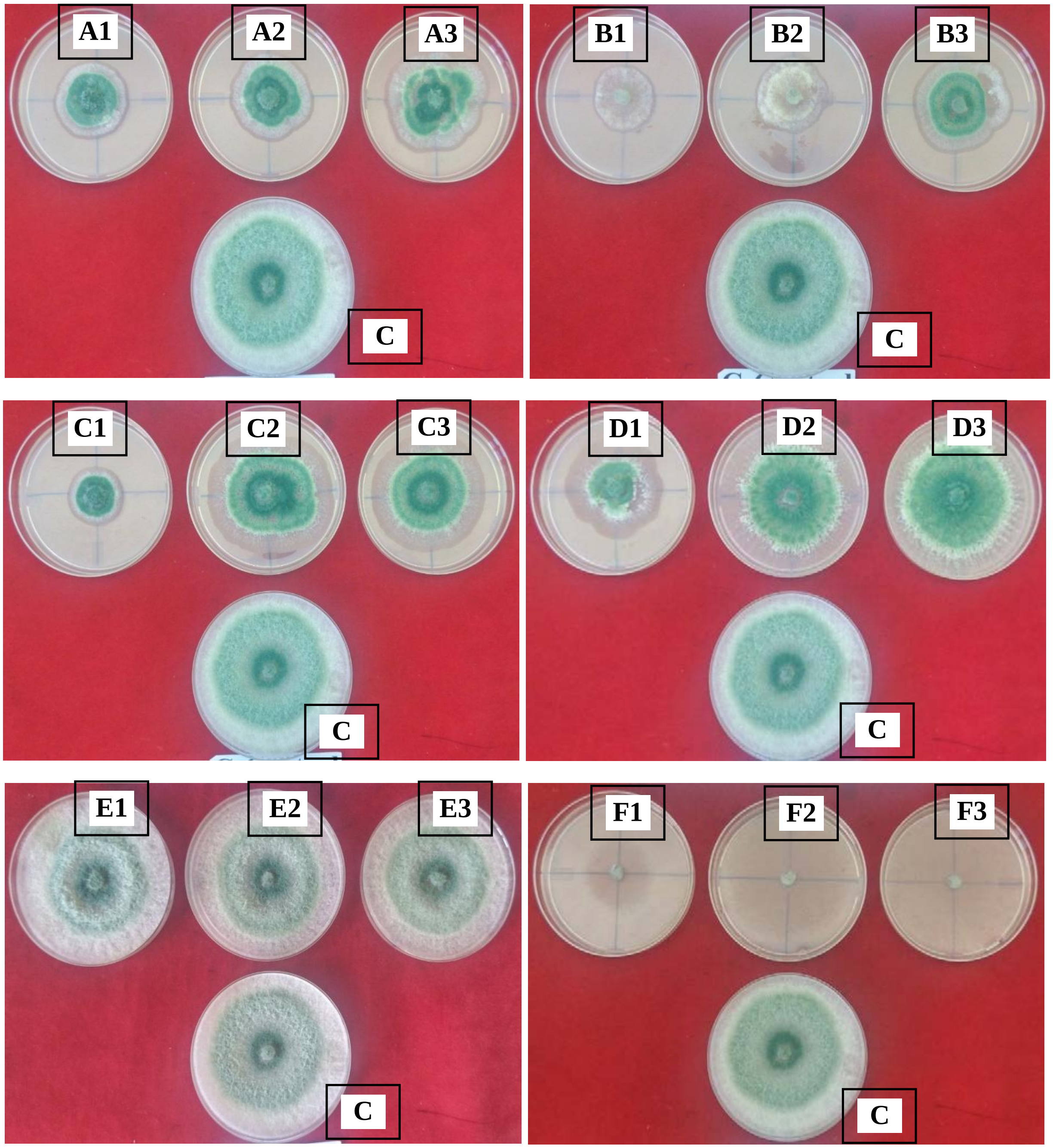
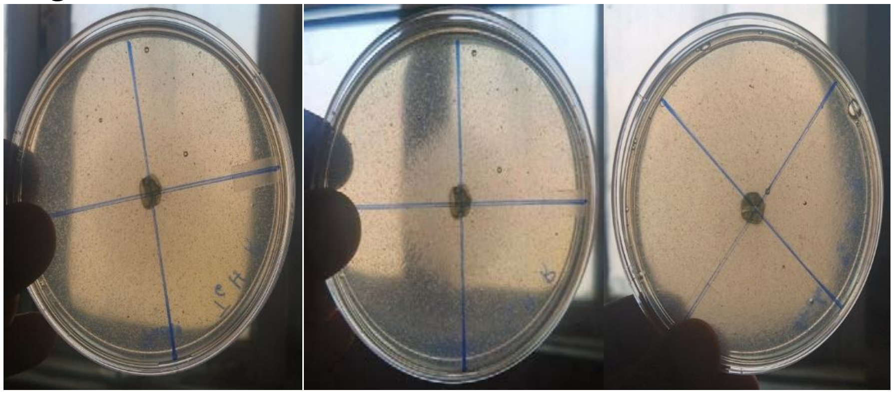
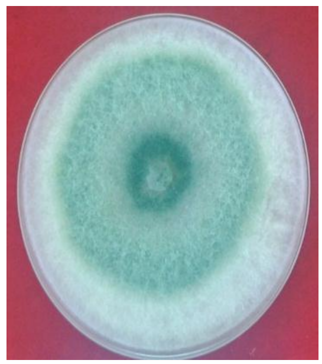


Plate 26. ***In vitro*** **evaluation of herbicides against** ***Trichoderma viride***

A1: Cyhalofop-butyl (240 ppm); A2 (160 ppm); A3 (80 ppm); B1: (Cyhalofop-butyl + penoxsulam) (450 ppm); B2: (300 ppm); B3: (150 ppm); C1: Bispyribac-sodium (75 ppm); C2: (50 ppm); C3: (25 ppm); D1: Fenoxaprop-p-ethyl (180 ppm); D2: (120 ppm); D3 (60 ppm); E1: Carfentrazone-ethyl (60 ppm); E2: (40 ppm); E3: (20 ppm); F1: (Chlorimuron-ethyl + metsulfuron-methyl) (8 ppm); F2: (4 ppm); F3: (2 ppm); C: Control plate

a. Higher dose **b. Recommended dose** **c. Lower dose**





Control

ii) Bacteria

Radial growth and per cent inhibition zone of *Pseudomonas fluorescens* were significantly affected by different herbicides and their concentrations (Table 65). The lowest radial growth and highest per cent inhibition zone were recorded in (chlorimuron-ethyl + metsulfuron-methyl) (7.75 cm and 21.87%). Highest radial growth and lowest per cent inhibition zone were recorded with higher dose of herbicides (8.55 cm and 7.76% respectively).

Considering interaction effect of different herbicides and concentrations on *P. fluorescens*, the lowest radial growth and highest per cent of inhibition zone were recorded with higher doses of (chlorimuron-ethyl + metsulfuron-methyl) (7.62 cm and 23.0%) followed by carfentrazone-ethyl (7.70 cm and 22.33%). Lower and recommended concentrations as well as higher concentration of cyhalofop-butyl, (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl had no effect on radial growth (9.00 cm) and per cent inhibition zone (0.29%) (Plate 27).

Table 65. Effect of herbicides on radial growth and per cent inhibition zone of *Pseudomonas fluorescens*

Treatments		Radial growth (cm)	% Inhibition zone
Factor A (herbicide)			
Cyhalofop-butyl		9.00	0.29
(Cyhalofop-butyl + penoxsulam)		9.00	0.29
Bispyribac-sodium		9.00	0.29
Fenoxaprop-p-ethyl		9.00	0.29
Carfentrazone-ethyl		7.78	21.62
(Chlorimuron-ethyl + metsulfuron-methyl)		7.75	21.87
SEm		0.26	4.38
CD (P<0.05)		0.03	0.27
Factor B (concentration)			
Lower dose (ppm)		8.62	7.17
Recommended dose (ppm)		8.59	7.38
Higher dose (ppm)		8.55	7.76
SEm		0.02	1.28
CD (p<0.05)		0.02	0.19
Herbicide x concentration (A×B)			
Cyhalofop-butyl	Lower dose @ 80 ppm	9.00	0.29
	Recommended dose @ 160 ppm	9.00	0.29
	Higher dose@ 240 ppm	9.00	0.29
(Cyhalofop-butyl + penoxsulam)	Lower dose @ 150 ppm	9.00	0.29
	Recommended dose @ 300 ppm	9.00	0.29
	Higher dose@ 450 ppm	9.00	0.29
Bispyribac-sodium	Lower dose @ 25 ppm	9.00	0.29
	Recommendeddose @ 50 ppm	9.00	0.29
	Higher dose@ 75 ppm	9.00	0.29
Fenoxaprop-p-ethyl	Lower dose @ 60 ppm	9.00	0.29
	Recommended dose @ 120 ppm	9.00	0.29
	Higher dose@ 180 ppm	9.00	0.29
Carfentrazone-ethyl	Lower dose @ 20 ppm	7.85	20.95
	Recommended dose @ 40 ppm	7.78	21.57
	Higher dose@ 60 ppm	7.70	22.33
(Chlorimuron-ethyl + metsulfuron-methyl)	Lower dose @ 4 ppm	7.85	20.95
	Recommended dose @ 8 ppm	7.78	21.57
	Higher dose@ 12 ppm	7.62	23.08
CD (p<0.05)		0.27	0.14

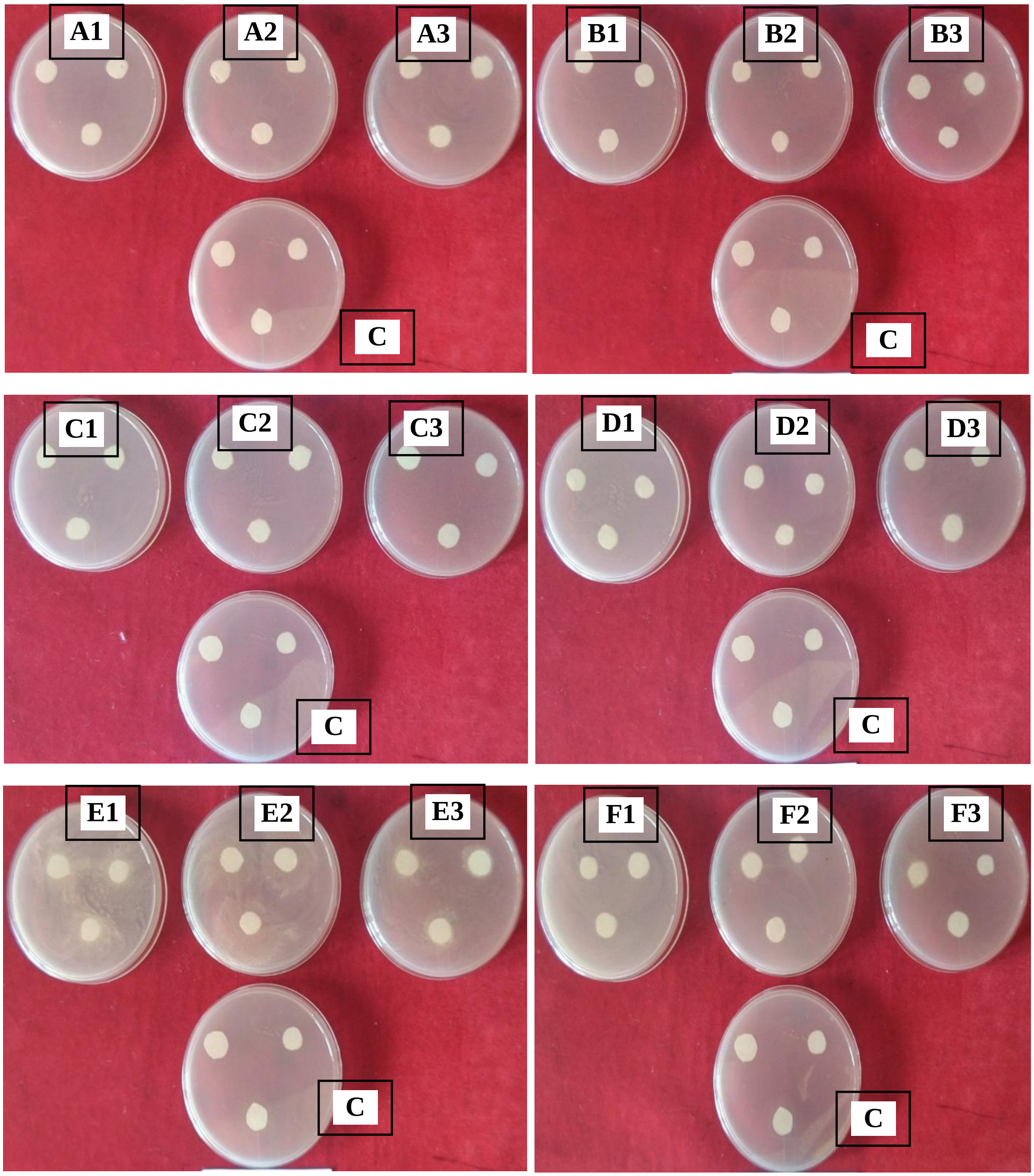


Plate 27. *In vitro* evaluation of herbicides against *Pseudomonas fluorescens*

A1: Cyhalofop-butyl (240 ppm); A2 (160 ppm); A3 (80 ppm); B1: (Cyhalofop-butyl + penoxsulam) (450 ppm); B2: (300 ppm); B3: (150 ppm); C1: Bispyribac-sodium (75 ppm); C2: (50 ppm); C3: (25 ppm); D1: Fenoxaprop-p-ethyl (180 ppm); D2: (120 ppm); D3 (60 ppm); E1: Carfentrazone-ethyl (60 ppm); E2: (40 ppm); E3: (20 ppm); F1: (Chlorimuron-ethyl + metsulfuron-methyl) (8 ppm); F2: (4 ppm); F3: (2 ppm); C: Control plate

Discussion

5. DISCUSSION

The results of the three experiments conducted in the research programme have been discussed separately below.

5.1 Experiment-I

Tank mixing of herbicides is commonly done by farmers to obtain broader spectrum weed control, to improve weed control efficiency and to reduce herbicide quantity. As herbicide mixing may cause antagonism in addition to additive or synergistic effects, a field experiment was conducted to identify suitable combinations of commonly used herbicides in the *Kole* lands.

5.1.1 Weed spectrum and phytotoxic effect of herbicides

The experimental area was infested with grasses, sedges and broad leaf weeds in which grasses and sedges dominated. Analysis of the relative proportion of grasses, sedges and broad leaf weeds in unweeded control revealed that sedges were dominant (Fig 6). Prameela *et al.* (2014) and Mounisha and Menon (2020) reported that grasses constituted the major weed component in *Kole* lands, but sedges were also significantly high. Latha and Jaikumaran (2015) reported that the sedge *Fimbristylis miliacea* was one of the most abundant weeds in *Kole* lands. Slight phytotoxicity symptoms were observed on rice when fenoxaprop-p-ethyl and carfentrazone-ethyl were applied, both on tank mixing and in sequential application (Table 6). These symptoms occurred in both years of the study, and persisted on the seventh day after application but disappeared by the tenth day. Bhullar *et al.* (2012), Chauhan and Abugho (2012) and Mounisha (2020) had also reported phytotoxic effect of fenoxaprop-p-ethyl and carfentrazone-ethyl on rice.

Phytotoxic effect of both tank mixed and sequentially applied herbicides were observed to bring about good control or very good control of weeds on the third day itself. The symptoms either persisted or were further intensified on the seventh day after application. Complete destruction of the weeds were observed on tank mixing of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) on the seventh day, while in other treatments, very good control of weeds was obtained, except for fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl), where only good control was seen (score 3).

5.1.2 Effect on weed species and weed dry matter production

Comparing the tank mixed and sequential application of fenoxaprop-p-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) on density of *Echinochloa colona*, sequential application was seen to give better control, especially in 2020-21. In 2019-20, the effect was seen only at 30 DAA. The efficiency of fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) in reducing weed growth was also documented by Saini (2005) and Prameela *et al.* (2014). At 30 DAA the sequential application of fenoxaprop-p-ethyl *fb* bispyribac-sodium was seen to be better in reducing the density of *E. colona* compared to tank mixing (Tables 7 and 9). There was no discernible benefit in tank mixing (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) in both years of experimentation. Individual application of bispyribac-sodium and (cyhalofop-butyl + penoxsulam) resulted in higher density of *E. colona* as compared to tank mixing or sequential application of herbicides. Superior control of the weed was obtained with hand weeding.

E. stagnina was better controlled by tank mixed application of fenoxaprop-p-ethyl and carfentrazone-ethyl in 2019-20 as compared to sequential application. However, in 2020-21, both treatments were similar in effect. Stewart *et al.* (2017) had opined that environmental conditions pre and post-emergence application could influence herbicide efficacy to a great extent. Tank mixed application of fenoxaprop-p-ethyl with bispyribac-sodium was also seen to be better in reducing density of *E. stagnina* than their sequential application (Tables 7 and 9). Tank mixed and sequential application of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) performed similarly in both years in reducing the density of the weed. Both bispyribac-sodium and (cyhalofop-butyl + penoxsulam) used individually without mixing with other herbicides were less effective in controlling *E. stagnina* at 15 and 30

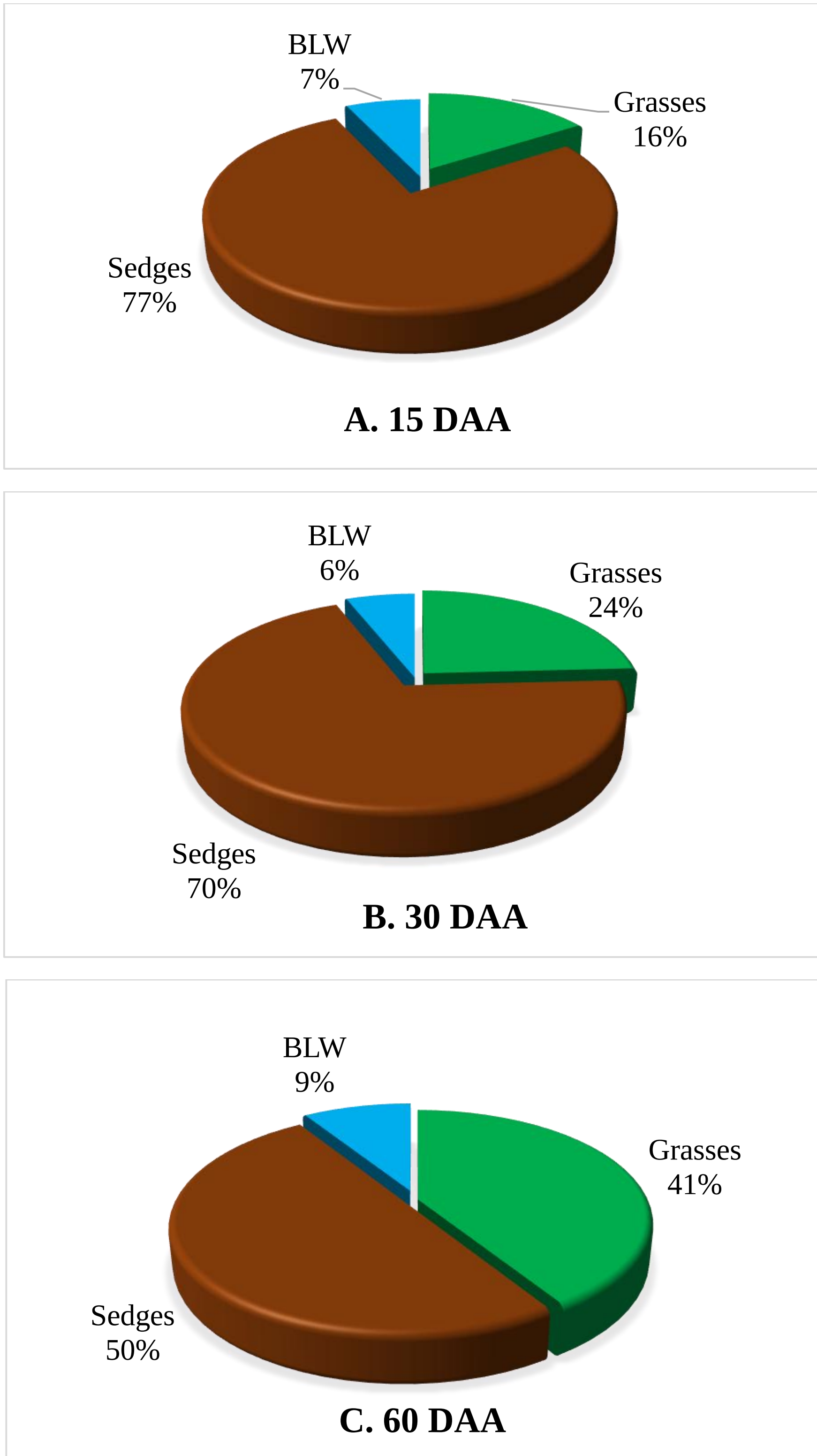


Fig.6. Weed spectrum in the experiment-I (UWC) at A.15 DAA; B.30 DAA; C.60 DAA

DAA. However, fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) was as effective as the best treatments in reducing the weed density and similar results were documented by Prameela *et al.* (2014).

Tank mixed and sequential application of herbicide combinations were seen to be equally effective in reducing the density of *Leptochloa chinensis* except with the combination (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl), which was seen to be more effective only on tank mixing in both years (Tables 7 and 9). (Cyhalofop-butyl + penoxsulam) was effective in controlling the weed in both years, while bispyribac-sodium failed to reduce weed density. Ineffectiveness of bispyribac-sodium to reduce density of *L. chinensis* has been reported by Menon *et al.* (2016), Jacob *et al.* (2017) and Mounisha and Menon (2020).

Hand weeding was significantly superior in reducing density of *Cyperus iria*. Both tank mixed and sequential application of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) were effective in reducing the population of *C. iria* in both years. Tank mixed application of fenoxaprop-p-ethyl with carfentrazone-ethyl was found better than sequential application in 2019-20, but in 2020-21, sequential application reduced weed density to a greater extent at 15 DAA. This difference could be attributed to the variation in environmental conditions (Stewart *et al.,* 2017). Regarding the combinations fenoxaprop-p-ethyl and bispyribac-sodium, and (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl), tank mixing was observed to better in reducing the density of *C. iria*. Both bispyribac-sodium and (cyhalofop-butyl + penoxsulam) were less effective in controlling the weed in both years (Tables 8 and 10).

Tank mixed combinations of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) and bispyribac-sodium were better than their sequential application in reducing the population of *Fimbristylis miliacea*. The tank mixed combination of fenoxaprop-p-ethyl with carfentrazone-ethyl was as good as their sequential application in controlling the weed (Tables 8 and 10). Tank mixing of (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) reduced density of *F. miliacea* to a better extent than their sequential application in

2019-20, while in 2020-21, both types of application were effective. Bispyribac-sodium effectively controlled *F. miliacea* in 2020-21, but was less effective in 2020-21 and (cyhalofop-butyl + penoxsulam) gave good control of the weed, especially in 2020-21. Hossain and Malik (2017) also found that bispyribac-sodium + ethoxysulfuron, penoxsulam + cyhalofop and triafamone + ethoxysulfuron were effective in controlling sedges, including *F. miliacea*.

While tank mixed fenoxaprop-p-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) reduced density of *Ludwigia perennis* to a greater extent than sequential application in 2019-20 (Table 8), sequential application was found to more effective in 2020-21 (Table 10). Tank mixing of fenoxaprop-p-ethyl with carfentrazone-ethyl reduced weed density to a greater extent than sequential application of the herbicides. Good control of *L. perennis* was obtained by both tank mixed and sequential application of fenoxaprop-p-ethyl and bispyribac-sodium in both years, while (cyhalofop-butyl + penoxsulam) tank mixed with (chlorimuron-ethyl + metsulfuron-methyl) reduced weed density to a greater extent in 2020-21 as compared to sequential application. Both bispyribac-sodium and (cyhalofop-butyl + penoxsulam) reduced population of *L. perennis* to an appreciable level. Similar results were documented by Menon *et al.* (2016).

Sequential application of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) reduced density of *Monochoria vaginalis* as compared to tank mixing in both years (Tables 8 and 11). Tank and sequential application of the other herbicide combinations were found to be equally good in reducing weed density except for the tank mixed application of fenoxaprop-p-ethyl with carfentrazone-ethyl, which was seen to be more effective than their sequential application in 2019-20. While bispyribac-sodium was seen to be less effective in reducing density of *M. vaginalis* in 2019-20, moderate control was obtained in 2020-21, while (cyhalofop-butyl + penoxsulam) was effective in both years in reducing weed density.

Sphenoclea zeylanica was present only in the second year of experimentation. Fenoxaprop-p-ethyl combined with (chlorimuron-ethyl + metsulfuron-methyl) performed similarly, whether tank mixed or applied sequentially, in reducing weed density (Table 11). Sequential application was better than tank mixing in the case of fenoxaprop-p-ethyl and carfentrazone-ethyl, while tank mixing of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) was more effective than their sequential application in reducing density of *S. zeylanica*. Bispyribac-sodium was effective in reducing weed density while (cyhalofop-butyl + penoxsulam) failed to do so.

Tank mixing of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) was more effective than their sequential application in reducing density of *Limnocharis flava*, which was present in the plots only in 2020-21 (Table 11). The effect of application of fenoxaprop-p-ethyl and carfentrazone-ethyl on tank mixing was similar to their application in sequence. Similar was the case with (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl). Bispyribac-sodium effectively reduced population of *L. flava* while (cyhalofop-butyl + penoxsulam) could not do so.

Analysis of the densities of grasses, sedges and broad leaf weeds (Tables 12, 13 and 14), sequential application of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) was superior in reducing grasses and broad leaf weed density as compared to their tank mixed application at 15, 30 and 60 DAA (Fig. 7, 8 and 9). However, total weed density was affected similarly by both methods of application, probably as sedges were better controlled by tank mixing (Fig. 10). Tank mixing of the other combinations were superior to their sequential application in reducing total weed density, and this could be explained by their greater effect on densities of grasses and broad leaf weeds. Sreelakshmi *et al.* (2016) also found that tank mixture application of bispyribac-sodium + metsulfuron-methyl + chlorimuron-ethyl reduced the weed density, while Mounisha and Menon (2020) observed that the herbicide combination florpyrauxifen-benzyl + cyhalofop-butyl was most effective in reducing total weed density.

Both bispyribac-sodium and (cyhalofop-butyl + penoxsulam) were less effective on total weed density than the herbicide combinations when applied either by tank mixing or in sequence.

5.1.3 Effect on weed dry matter production

The data on weed dry matter production at 15 days after application would correspond to the critical period of weed control in direct-seeded rice (Rao *et al*., 2007; Chauhan and Johnson, 2011). Fenoxaprop-p-ethyl when applied in sequence with (chlorimuron-ethyl + metsulfuron-methyl) was found to be more effective in controlling *Echinochloa colona* in both seasons at this stage, as well as at 30 and 60 DAA in 2019-20 (Table 15). In 2020-21, tank mixing and sequential application did not differ significantly in their effect on *E. colona* at 30 and 60 DAA. Tank mixing fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) resulted in 6.99 kg/ha, while in sequential application 1.85 kg/ha of weed dry matter was produced at 15 DAA.

At 30 DAA, the dry matter production was 31.67 and 23.11 kg/ha for tank mixed and sequential application respectively. Similar increases for tank mixing with carfentrazone-ethyl and bispyribac-sodium were noticed in both years. A significant trend in weed dry matter production on tank mixing fenoxaprop-p-ethyl with carfentrazone-ethyl could not be observed at 30 and 60 DAA in the two years. Sequential application of fenoxaprop-p-ethyl with bispyribac-sodium was found to reduce weed dry matter production significantly at 30 and 60 DAA as compared to their tank mixed application in both years.

A definite decrease in effectiveness of fenoxaprop-p-ethyl on tank mixing with broad leaf weed killers on *E. colona* was seen. Fenoxaprop-p-ethyl is a very effective graminicide, used widely in the *Kole* area for the control of *Echinochloa* spp and *L. chinensis*. As it controls only grasses, it is tank mixed with broad leaf herbicides like (chlorimuron-ethyl + metsulfuron-methyl) and carfentrazone-ethyl, and also with broad spectrum herbicides like bispyribac-sodium to get a wider swath of control. Tank mixing of these herbicides was seen to reduce the effectiveness of fenoxaprop-p-ethyl against *E. colona*. The reduction of the efficacy of the mixture fenoxaprop-p-ethyl with bispyribac-sodium was reported by Blouin *et al.* (2010). The antagonistic effect of the mixture of bispyribac-sodium with fenoxaprop-p-ethyl on *Dactyloctenium aegyptium*,

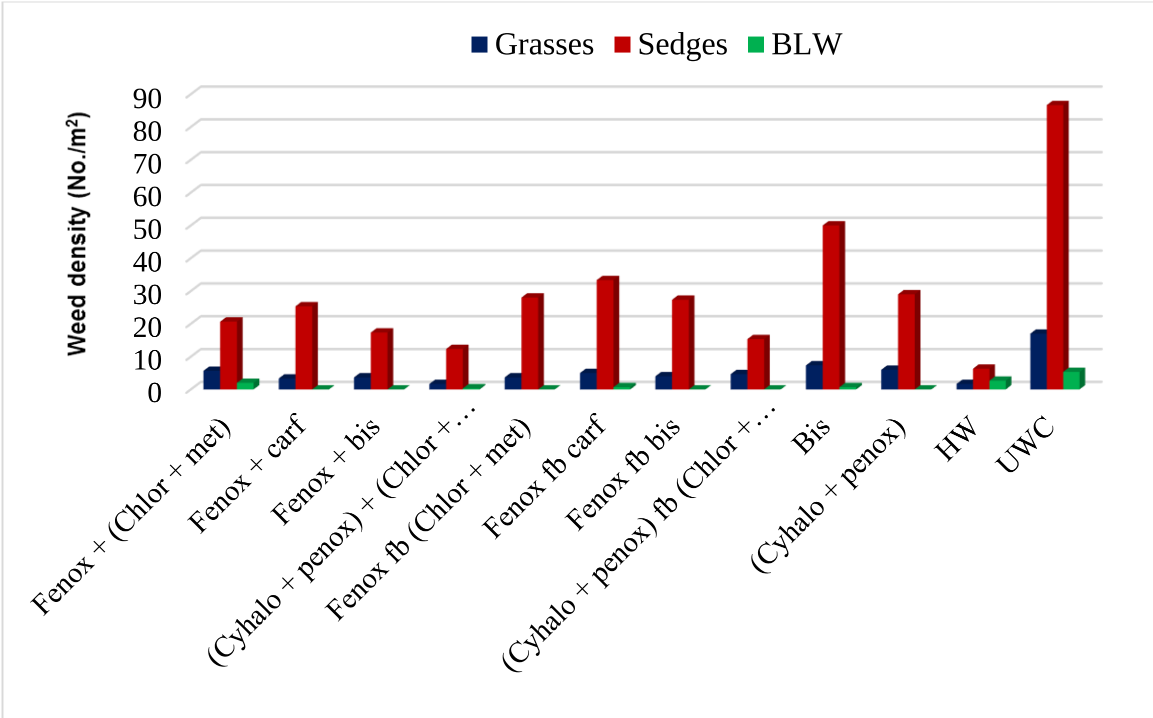


Fig. 7. Effect of tank mixed herbicide combinations on weed density at 15 DAA

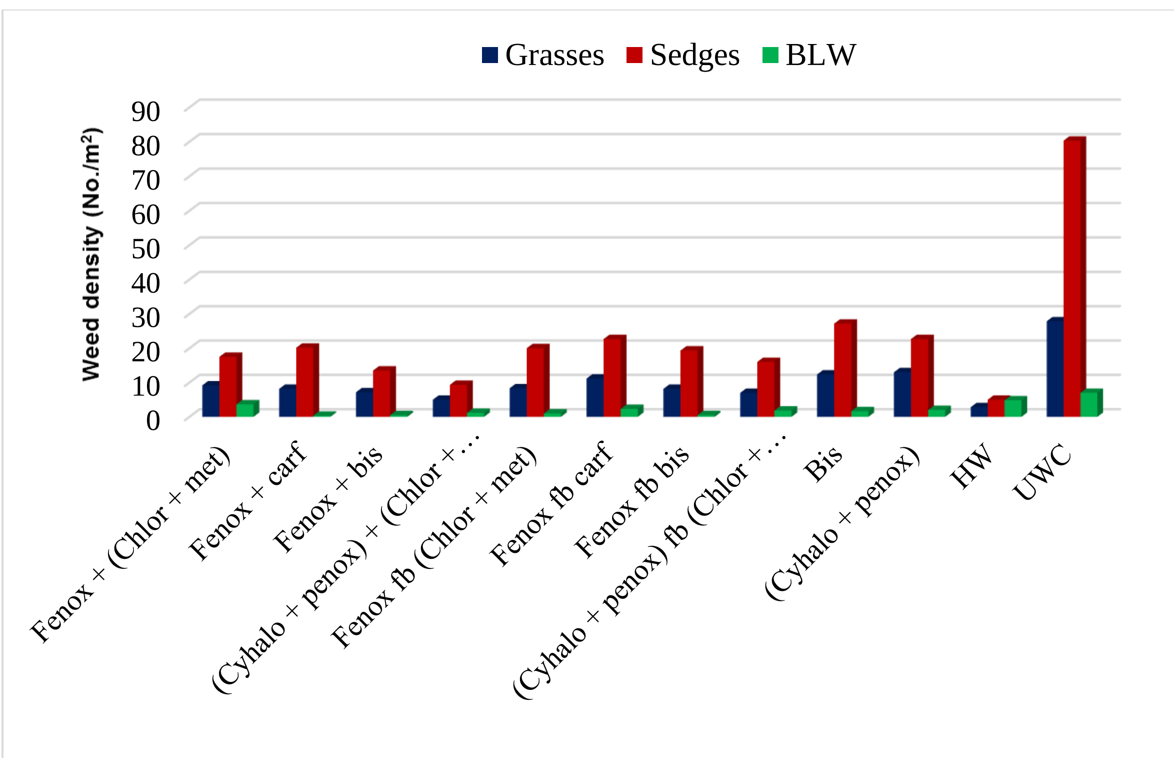


Fig. 8. Effect of tank mixed herbicide combinations on weed density at 30 DAA

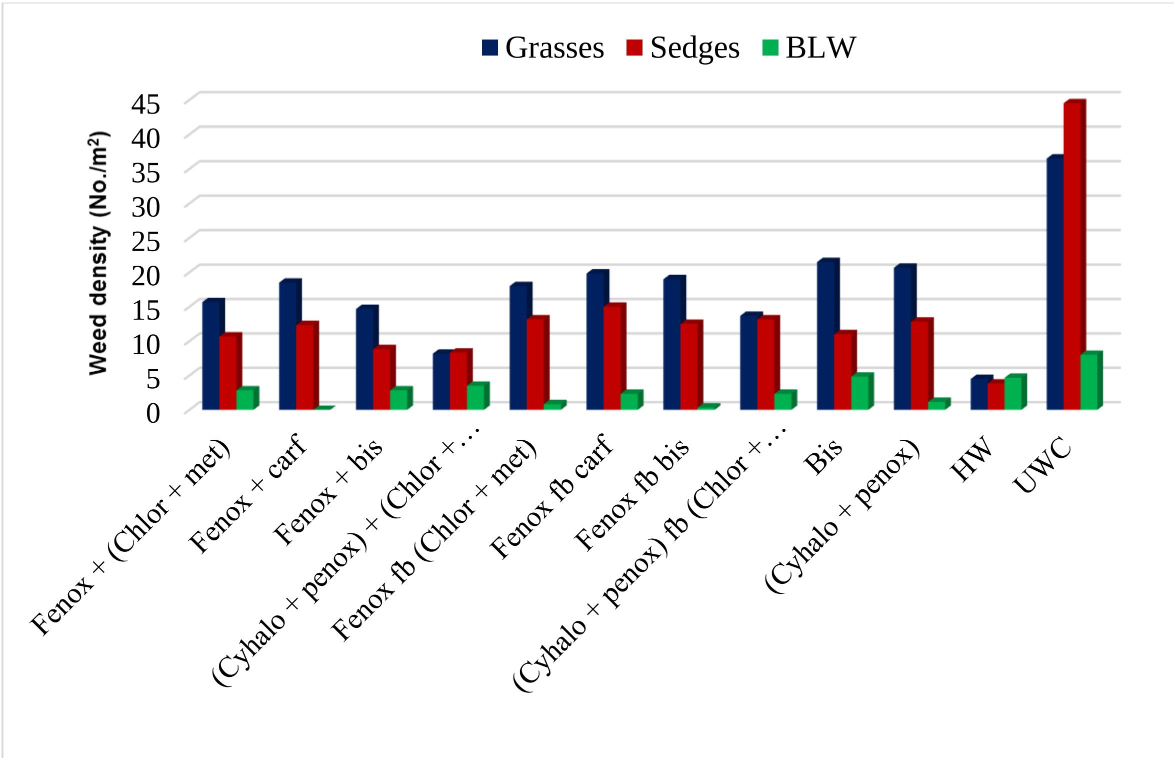


Fig. 9. Effect of tank mixed herbicide combinations on weed density at 60 DAA

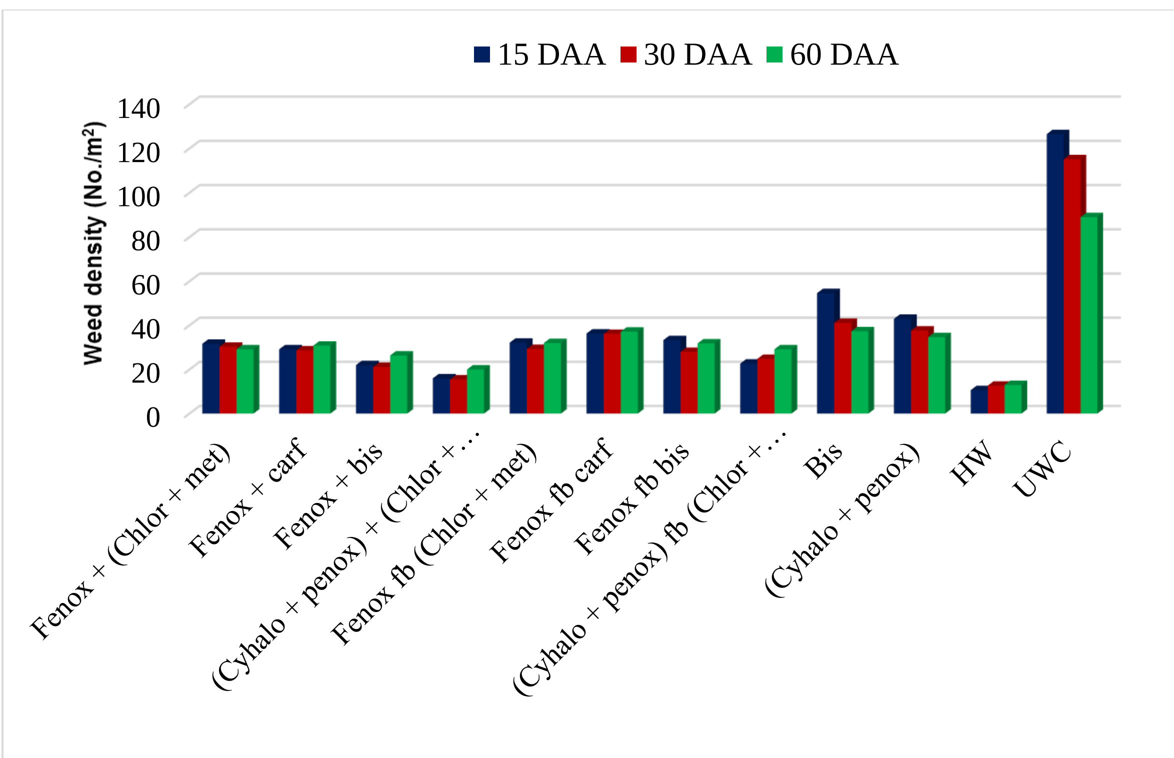


Fig. 10. Effect of tank mixed herbicide combinations on total weed density

Achrachne racemosa and *L. chinensis* (Bhullar *et al*., 2016), and fenoxaprop-p-ethyl with halosulfuron on *E. crus-galli* (Zhang *et al*., 2005) were reported earlier.

The tank mixture of fenoxaprop-p-ethyl and carfentrazone-ethyl was however, reported to be effective in controlling *Phalaris mino*r in wheat (Singh and Singh, 2005; Yadav *et al*., 2009). In the present study, fenoxaprop-p-ethyl applied in sequence with (chlorimuron-ethyl + metsulfuron-methyl) and bispyribac-sodium, was more effective in controlling *E. colona*, but was less effective against *L. chinensis* and broad leaf weeds. Chauhan and Abugho (2012) recorded the effectiveness of fenoxaprop-p-ethyl + ethoxysulfuron against *L. chinensis* at the four-leaf stage. *Echinochloa stagnina*, however, was better controlled by the tank mixture of fenoxaprop-p-ethyl and carfentrazone-ethyl than by sequential application, indicating variation in effectiveness against different species of *Echinochloa.* This mixture was also seen to be more effective against *C. iria* than sequential application of the herbicides. However, tank mixing of the pre-mix herbicide (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) resulted in significantly lower dry matter production at 15 and 30 DAA in both years (0.58 and 3.18 kg/ha at 15 DAA and 11.98 and 13.57 kg/ha at 30 DAA) of *E. colona* as compared to (cyhalofop-butyl + penoxsulam) used alone in both seasons (5.01and 18.05 kg/ha, and 4.60 and 33.12 kg/ha at 15and 30 DAA respectively) (Table 16 and 18).

Cyperus iria was the predominant and most vigorously growing sedge in the area in both years of experimentation. Though there was no significant difference in the effect of herbicides applied after tank mixing or in sequence on *C. iria*, it was observed that tank mixing of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) reduced sedge dry matter production as compared to application of (cyhalofop-butyl + penoxsulam) alone at all three stages of application (Tables 17 and 19). A clear synergism was noticed between these two herbicides which was reflected in the total weed dry matter production. A similar effect was observed for tank mixing of fenoxaprop-p-ethyl with bispyribac-sodium as compared to their sequential application. A synergistic effect of the tank mixture of fenoxaprop-p-ethyl and ethoxysulfuron for the control of *E. crus-galli* and *E. colona* (Bhullar *et al*., 2016), *D.*

aegyptium (Chauhan, 2011) and of complex weed flora (Ramachandran and Balasubramanian, 2010) was documented earlier.

E. stagnina, a species as important as *E. colona* in the *Kole* lands, did not respond as clearly as the latter to tank mixing of fenoxaprop-p-ethyl. Mixing of fenoxaprop-p-ethyl with bispyribac-sodium, was found to increase the herbicidal efficacy against *E. stagnina* as compared to their sequential application at 15 DAA, 30 DAA and 60 DAA in 201-20 and 2020-21 respectively (Tables 16 and 18). Tank mixing with carfentrazone-ethyl did not elicit a specific trend.

L. chinensis or Chinese sprangletop is a grass weed which had become problematic in the last two decades in the *Kole* area, probably due to the sole indiscriminate use of bispyribac-sodium which was reported to be ineffective in controlling the weed (Jacob *et al*., 2017). Tank mixing of fenoxaprop-p-ethyl with carfentrazone-ethyl was seen to reduce the efficacy of fenoxaprop-p-ethyl against *L. chinensis* as compared to the sequential application of the herbicides. Tank mixed application resulted in considerable weed dry matter production at 15, 30 and 60 DAA, while sequential application resulted in no dry matter production at the same three stages in 2019-20. In 2020-21 the same trend was repeated (Table 16 and 18). Sekhar *et al.* (2020) also observed that dry matter production of *L. chinensis* was lower with the sole application of fenoxaprop-p-ethyl or cyhalofop-butyl than their tank mixed combination with bispyribac sodium. However, Chopra and Chopra (2005) found that in wheat, tank mixture of clodinafop and fenoxaprop-p-ethyl with carfentrazone-ethyl controlled both grassy and broadleaf weeds resulting in 88-90 per cent weed control efficiency.

Grasses and sedges were the main contributors to weed dry matter production, with sedges producing more dry matter than grasses as seen in the data for unweeded control (Table 20). Tank mixing of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) was seen to reduce the efficacy of fenoxaprop-p-ethyl against grasses, as it led to 125 per cent higher dry matter production than the sequential application. Fenoxaprop-p-ethyl followed by (chlorimuron-ethyl + metsulfuron-methyl) has been reported to result in high weed control efficiency in wet seeded rice by Menon *et al*. (2014). Similarly, tank mixing of fenoxaprop-p-ethyl with bispyribac-sodium reduced efficacy against grasses by 19 per cent. However, Malik *et al.* (2005) observed that tank mixture of triasulfuron with fenoxaprop-p-ethyl was effective in reducing dry matter production of both grasses and non-grasses in wheat. The best treatment for reducing weed dry matter production of grasses and sedges was (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) tank mixing at all three stages of observations.

Tank mixing of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) increased efficacy against sedges in terms of dry matter production by almost 10 per cent. Weed dry matter production was reduced by 43 per cent when fenoxaprop-p-ethyl was tank mixed with bispyribac-sodium as compared to sequential application. Tank mixed application of (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) was also beneficial in reducing sedge dry matter production by 35 per cent as compared to sequential application. Dry matter production of broad leaf weeds was significantly reduced by tank mixing of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) as compared to their application in sequence. A reduction of 96 per cent in weed dry matter production was observed.

Antagonistic effect of tank mixing of fenoxaprop-p-ethyl with (chlorimuron-ethyl + metsulfuron-methyl) on grass weed dry matter production was reflected in the total weed dry matter production also, with an increase of about 25 per cent in tank mixing. Although tank mixing of fenoxaprop-p-ethyl with bispyribac-sodium reduced the efficiency of grass weed control, there was a reduction in total weed dry matter production by about 20 per cent as compared to sequential application. In spite of antagonistic effect of tank mixtures of fenoxaprop-p-ethyl with broad leaf and broad spectrum herbicides against grasses, total weed dry matter production in the tank mixture of fenoxaprop-p-ethyl with bispyribac was at par with the above treatment, probably due to good control of specific grasses and sedges. Similarly, there was a reduction in total weed dry matter production by 37.6 per cent when (cyhalofop-butyl + penoxsulam) was tank mixed with (chlorimuron-ethyl + metsulfuron-methyl), as compared to their sequential application. Sole applications of bispyribac-sodium and (cyhalofop-butyl + penoxsulam) resulted in significantly increased weed dry matter production as compared to their application with other herbicides tested, either on tank mixing or in sequence (Fig. 11).

5.1.4 Weed control efficiency and weed index

Highest weed control efficiencies at the three stages of observation were recorded in hand weeded control (Table 20). However comparable values of WCE (91, 88 and 83%) were obtained in T_4 followed by 85, 80 and 69 per cent in T_8, and 84, 80 and 70 per cent in T_3. While the grain yield in hand weeded plot was 3.95 t/ha, that in T_4 was 3.97 t/ha, 3.65 t/ha in T_3 and 3.50 t/ha in T_8 (Table 30), indicating that weed control efficiencies ranging from 70 to 85 per cent were sufficient to achieve grain yields at par with hand weeding (Fig. 15). This fact was further reinforced by the low weed indices of -0.51, 7.51 and 11.39 per cent obtained in these three treatments (Table 20). The low weed index of -0.51 per cent in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] was because grain yield was higher in this treatment that in the hand weeded control. This could be related to the better weed control and lower weed competition in this treatment. Hand weeded control was given two hand weedings, at 20 and 40 DAS. Apparently, this was not sufficient to control all weeds and bring weed competition to a minimum.

On comparison, higher weed control efficiency and lower weed indices were recorded in the tank mixed herbicide combinations than in their application in sequence. The synergistic effects of tank mixing of herbicides were brought out, as well as the benefits of application in sequence, as compared to application of individual broad spectrum herbicides (Fig. 16). Mounisha and Menon (2020) have also pointed out the higher weed control efficiencies and lower weed indices obtained with ready mix herbicide combinations. Similarly Teja *et al.* (2016) achieved higher values of weed control efficiency and yield of rice with combined application of azimsulfuron with 2, 4-D, followed by pretilachlor + pyrazosulfuron-ethyl.

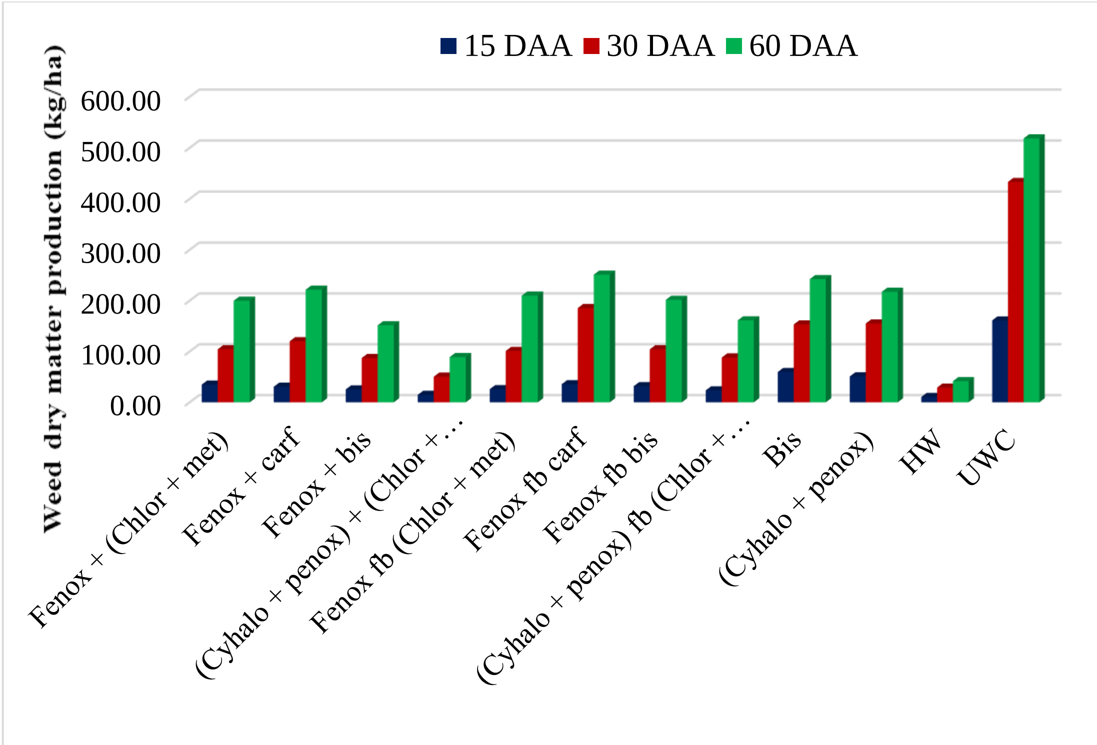


Fig. 11. Effect of tank mixed herbicide combinations on total weed DMP

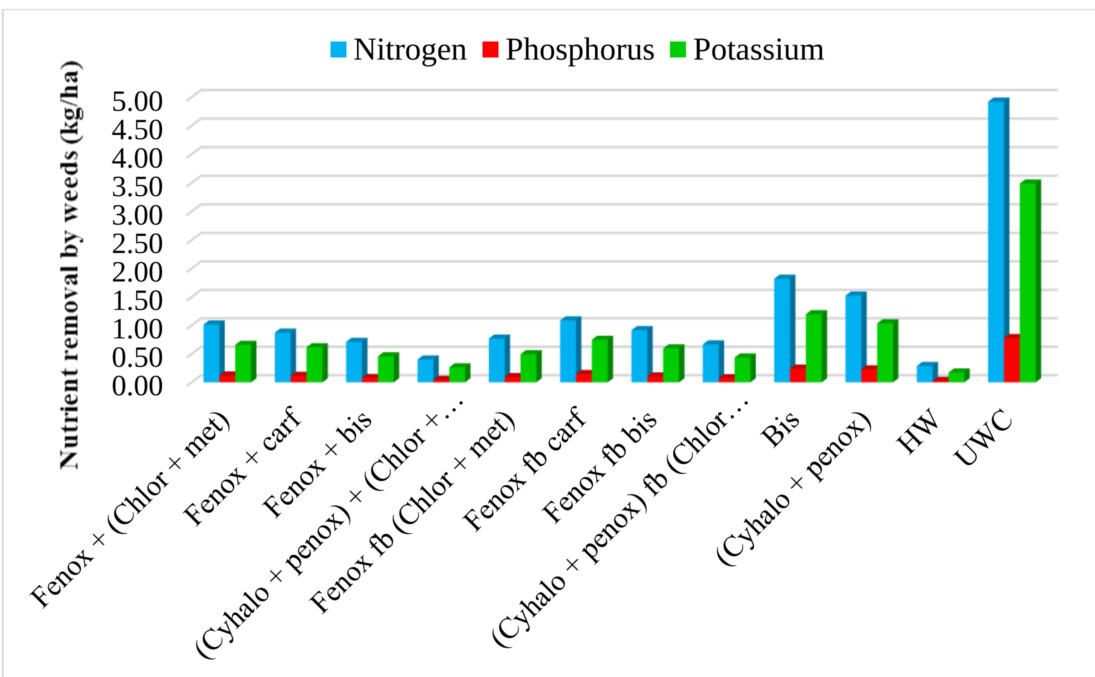


Fig. 12. Effect of tank mixed herbicide combinations on nutrient removal by weeds at 15 DAA

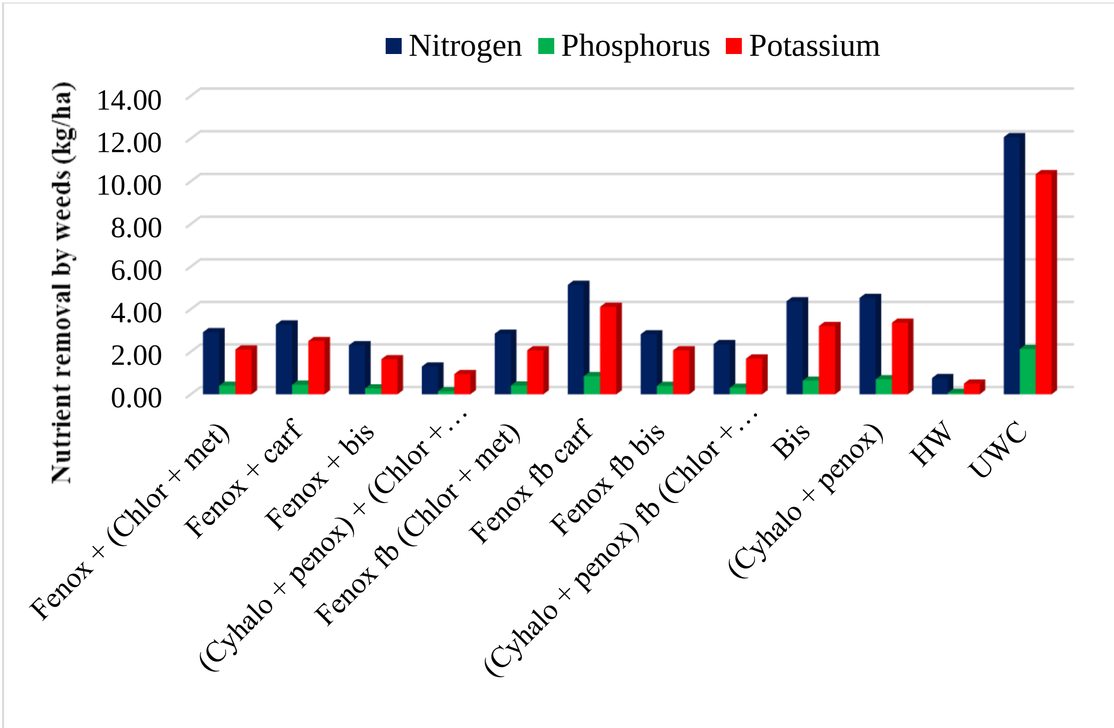


Fig. 13. Effect of tank mixed herbicide combinations on nutrient removal by weeds at 30 DAA

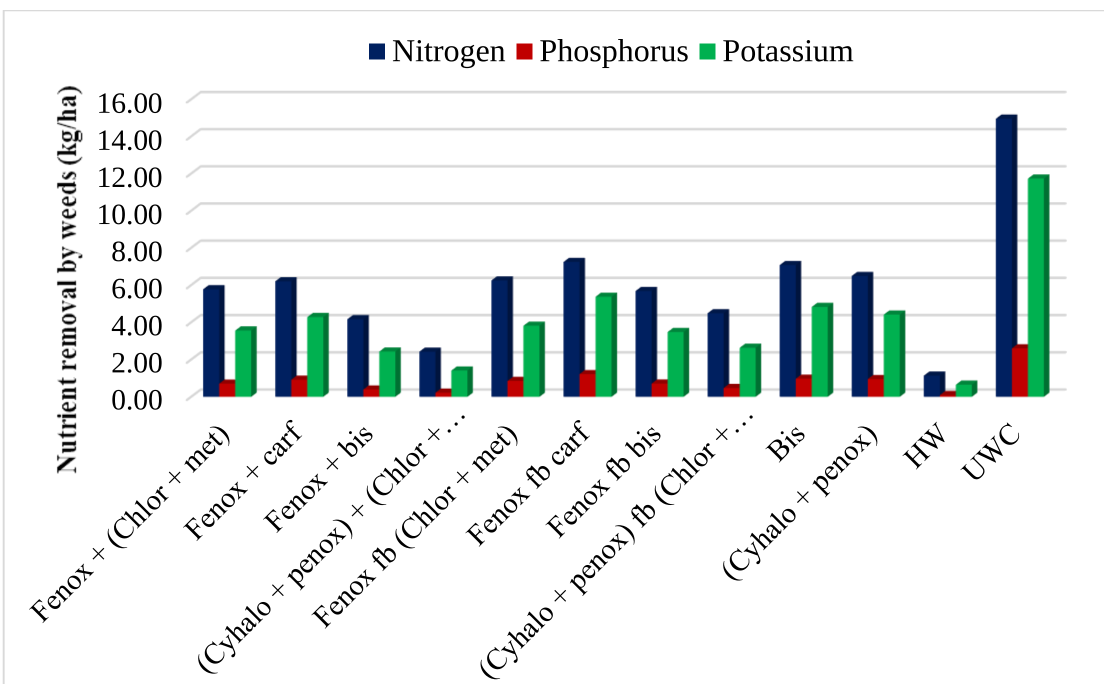


Fig. 14. Effect of tank mixed herbicide combinations on nutrient removal by weeds at 60 DAA

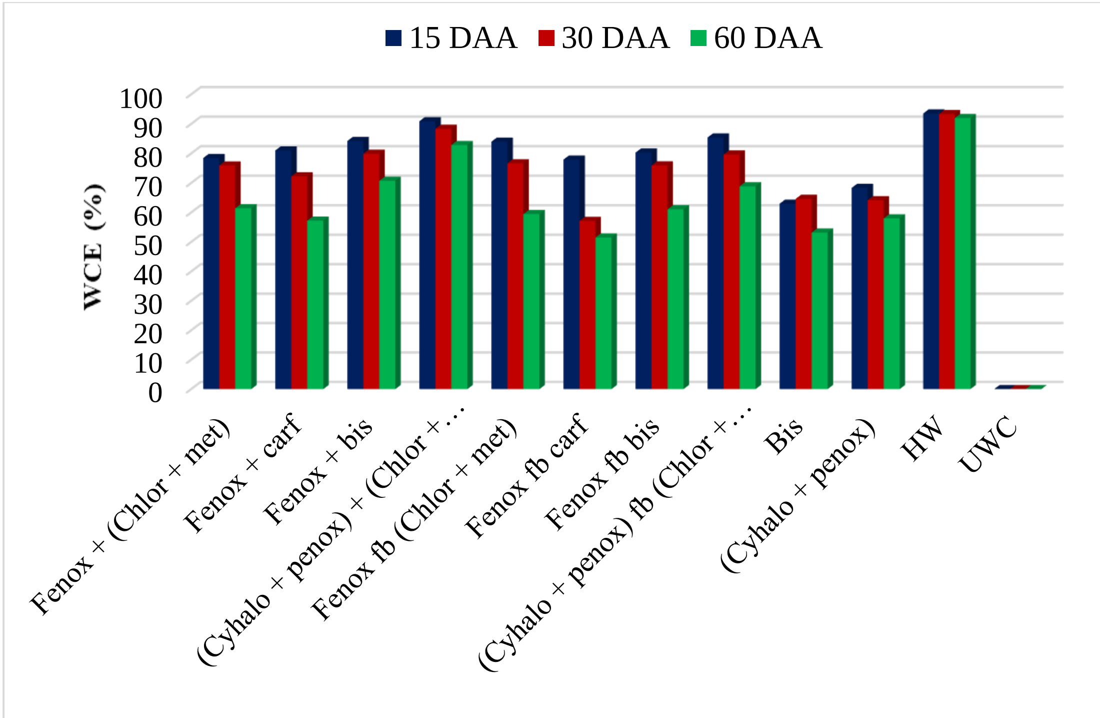


Fig. 15. Effect of tank mixed herbicide combinations on WCE

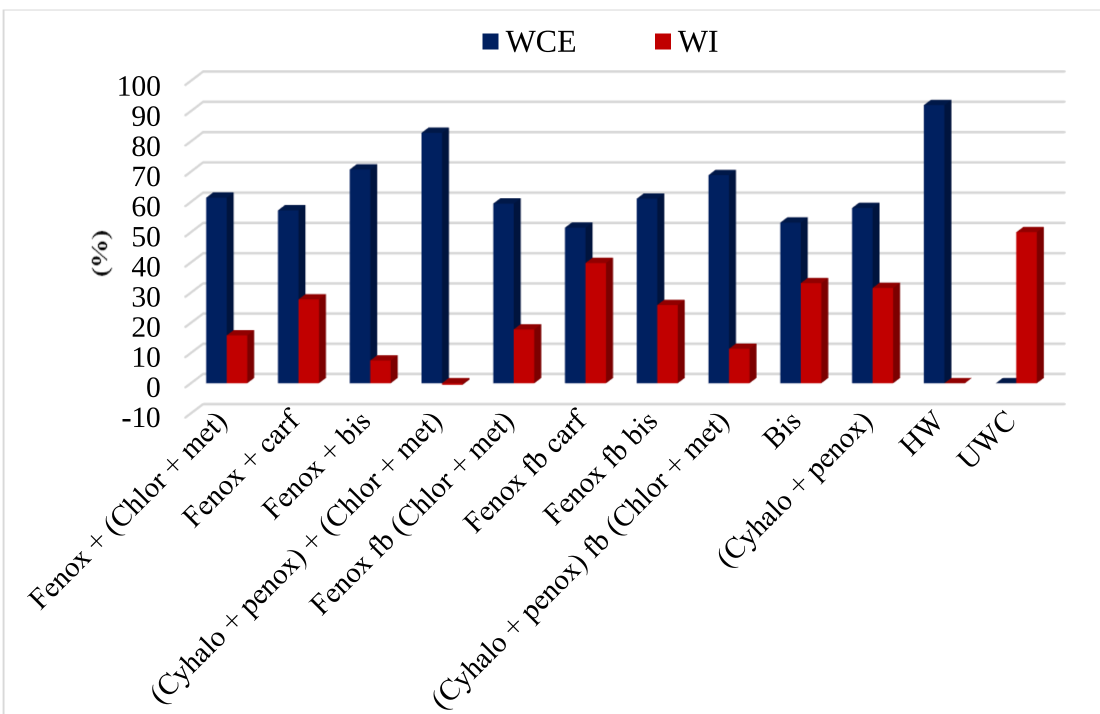


Fig. 16. Effect of tank mixed herbicide combinations on WCE and WI

5.1.5 Rice yield

Significantly higher number of panicles per sq. m (287), number of grains per panicle (102), percentage of filled grains per panicle (91.6) and grain yield (3.97 t/ha) were recorded with (cyhalofop-butyl + penoxsulam) tank mixed with (chlorimuron-ethyl + metsulfuron-methyl) (Table 30). The hand weeded control treatment was on par with this (250, 100, 89.6 and 3.95 respectively) (Fig. 17). Tank mixing of fenoxaprop-p-ethyl with bispyribac-sodium was also at par with this treatment with regard to number of grains per panicle and percentage of filled grains per panicle. Hossain and Mondal (2014) reported that highest rice grain yield was obtained when bispyribac-sodium was applied with (chlorimuron-ethyl + metsulfuron-methyl).

Effective weed control by the tank mixture of (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) was reflected in the high grain yield in this treatment, which was more than 100 per cent greater than that in the unweeded control, while that in the tank mixture of fenoxaprop-p-ethyl with bispyribac-sodium was 85 per cent higher. Increased yield due to better weed control have been reported by many researchers (Lap *et al*., 2013: Awana *et al*., 2015). Fenoxaprop-p-ethyl followed by (chlorimuron-ethyl + metsulfuron-methyl) has been reported to result in higher grain yield in wet seeded rice by Menon *et al*. (2014)

5.1.6 Economics of cultivation

An analysis of the economics of rice cultivation showed that even though gross returns were highest for hand weeding (Rs. 1,26,865/ha), due to higher additional costs for weed management (Rs. 15,978/ha), the benefit:cost ratio was only 1.86. Compared to this, it was 2.25 in T_4 in which the additional cost for weed management was Rs. 15,978/ha. In T_8, the benefit:cost ratio was 1.99, while in T_1 it was 1.97. Except for T_2, all tank mixed combinations had benefit:cost ratio close to 2.0, and the sequential application of (cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl) was at par with these treatments in gross and net returns and B:C ratio. Higher net returns and B:C ratio have been reported on the combined application of bispyribac-sodium and (chlorimuron-ethyl + metsulfuron-methyl) (Hossain and Mondal, 2014).

Combinations with carfentrazone-ethyl had low grain yields which could be related to the high weed index of 27.8 per cent in tank mixing and 39.8 per cent in sequential application (Table 32 and 33). It could be inferred that the phytotoxic effects of carfentrazone-ethyl manifested in reduced grain yields of rice.

5.1.6 Effect of herbicides on nutrient uptake by weeds and rice

The trend of nutrient uptake by rice followed grain and straw yields, with highest uptake of N, P and K in the hand weeded control, followed by T_4 (cyhalofop-butyl + penoxsulam) tank mixed with (chlorimuron-ethyl + metsulfuron-methyl). Subhalakshmi and Venkataramana (2009) and Mounisha (2020) and also reported highest nutrient uptake in hand weeded plots (Table 31 and Fig. 18).

Removal of N, P and K by weeds was highest in unweeded control and lowest in hand weeded control at all stages of observation. Comparably low values of removal were recorded in T_4 (cyhalofop-butyl + penoxsulam) tank mixed with (chlorimuron-ethyl + metsulfuron-methyl) (Fig. 12, 13 and 14). These results were supported by Singh *et al.* (2005), Singh *et al.* (2007), Mukherjee and Malty (2011), and Mounisha (2020).

5.1.7 Soil dehydrogenase and microbial biomass production carbon activity

Soil microbial activity, as measured by the dehydrogenase activity and soil microbial biomass production carbon, was higher in the hand weeded plot and unweeded control, probably due to no negative impacts of herbicide application. Lower activity of dehydrogenase at harvest stage of rice may be due to decline in rhizosphere activity and organic carbon content coupled with dry condition prevailing at harvest of rice. Metabolism and survival of the soil microorganisms are affected by the soil moisture availability (Tables 34 and 35). Herbicide treatment resulted in a significant drop in dehydrogenase activity of soil samples when compared to the unsprayed control. This might be due to the effect of herbicide application on the activity of this intracellular enzyme (Uhlirova *et al.,* 2005). Among the herbicide treatments, higher reduction in MBC was observed in bispyribac-sodium treatment followed by

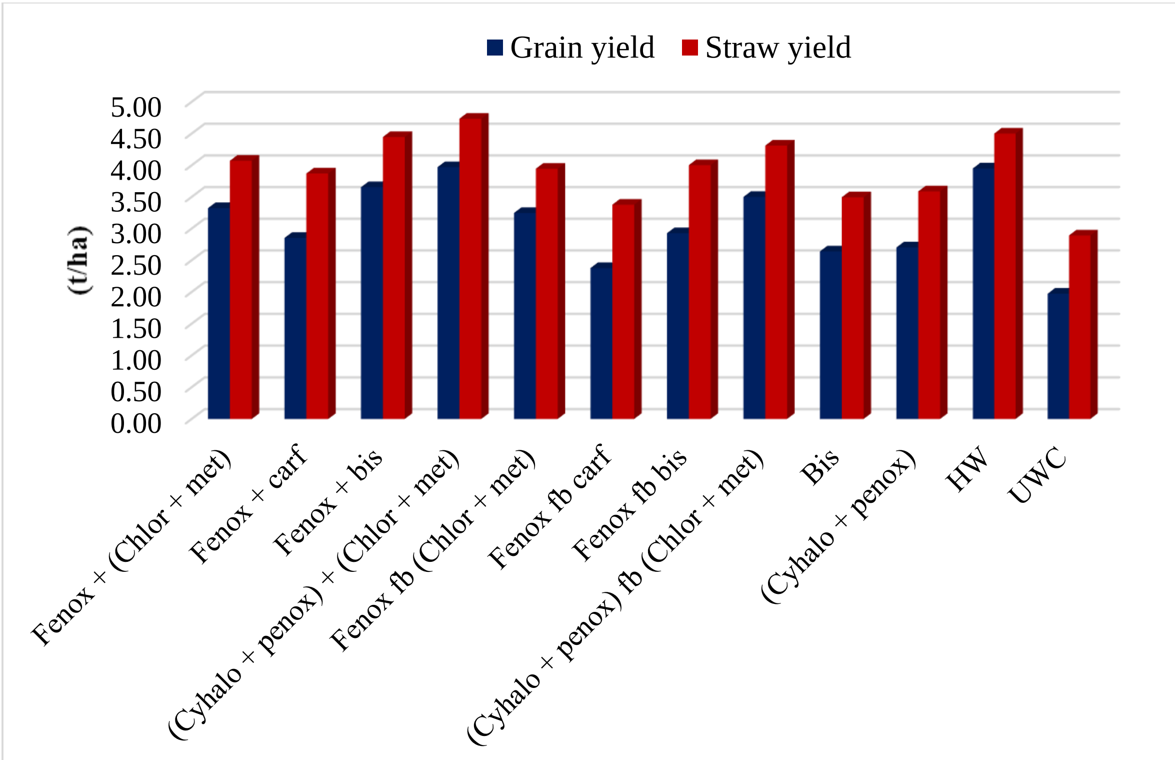


Fig. 17. Effect of tank mixed herbicide combinations on grain and straw yield

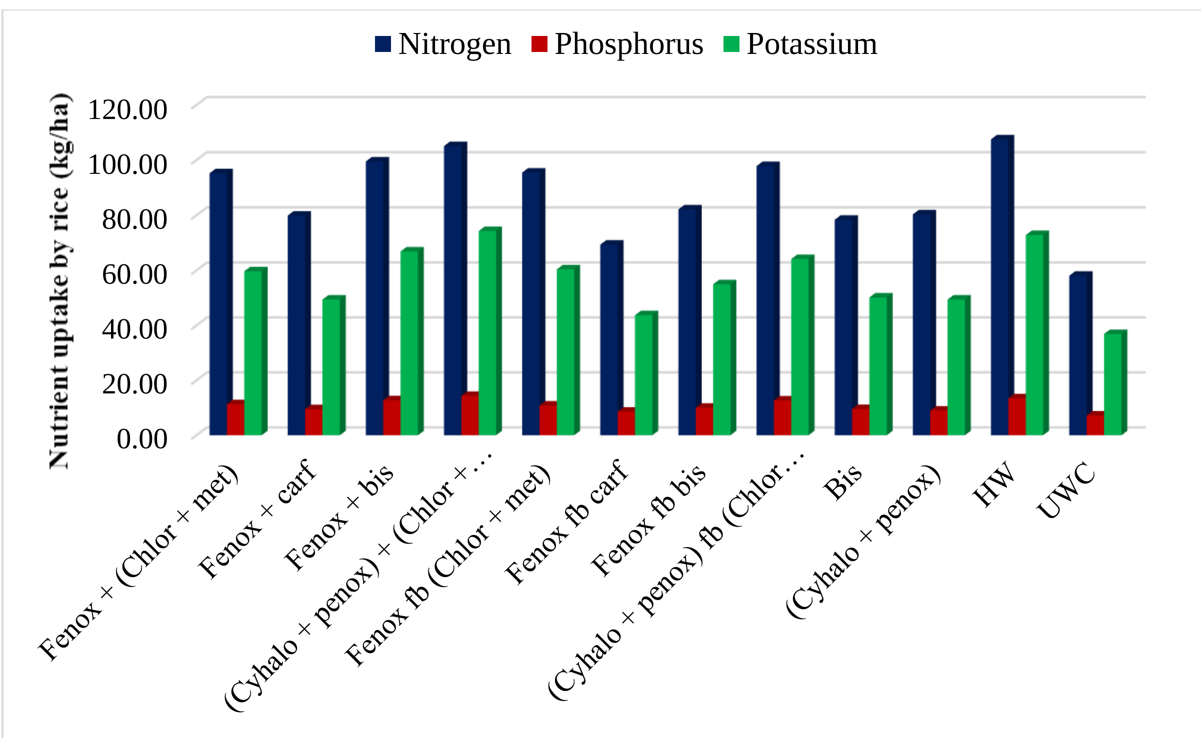


Fig. 18. Effect of tank mixed herbicide combinations on nutrient uptake by rice

fenoxaprop-p-ethyl, (cyhalofop-butyl + penoxsulam), and cyhalofop-butyl. Mammalian toxicity (oral LD_{50}) and persistence of the herbicides in the soil also followed the same order: (fenoxaprop-p-ethyl + bispyribac-sodium)> (fenoxaprop-p-ethyl *fb* bispyribac-sodium)> bispyribac-sodium> (fenoxaprop-p-ethyl + carfentrazone-ethyl) (Hartley, 1987). These results supported by Amritha and Devi (2017) and Priya *et al*. (2017).

5.2 Experiment-II

Mixing of herbicides with other agrochemicals like fertilizers, fungicides and pesticides is a common practice among farmers, done to reduce labour costs as well mechanical damage to crop foliage. In the *Kole* area, herbicides are mixed urea to increase the effectiveness of herbicides, a practice which needed to be validated.

5.2.1 Weed spectrum and phytotoxic effect of herbicides

The weed species in the experimental plots were similar to those in the first experiment, with grasses and sedges dominating. Analysis of the relative proportion of grasses, sedges and broad leaf weeds in unweeded control revealed that sedges were dominant (Fig 19). Mixing of urea with the herbicides did not affect the phytotoxicity scoring of the various herbicides. Injury due to herbicides on rice was noticed only with carfentrazone-ethyl (both with and without urea tank mixing), and in fenoxaprop-p-ethyl. Both these herbicides are already reported to cause slight scorching injury in rice.

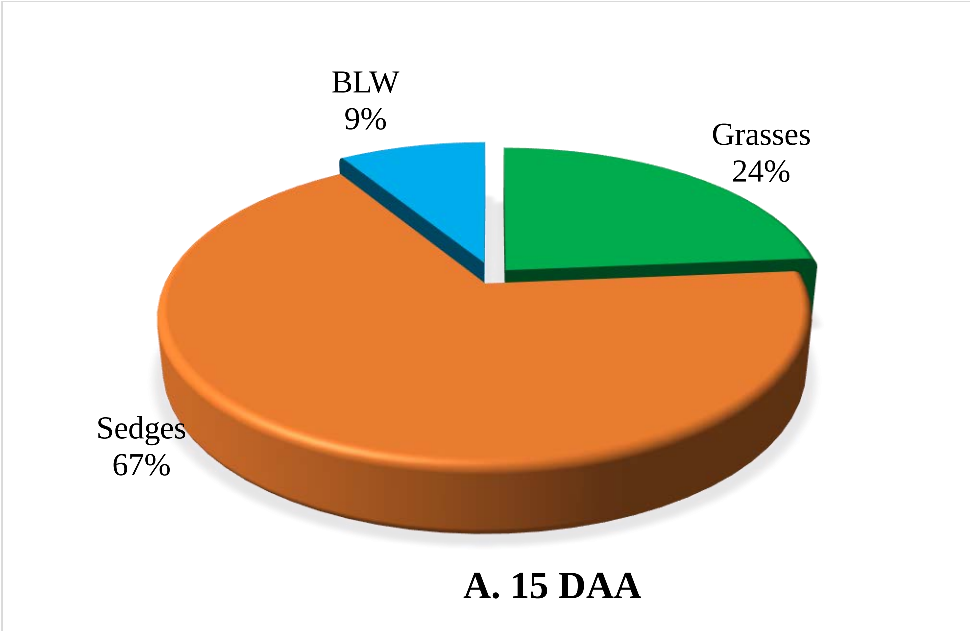
The mixing of urea with bispyribac-sodium, (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-ethyl) was seen to improve phytotoxicity to weeds as compared to their application without urea. The effect was noted on the third day after application itself, and progressed rapidly so that complete destruction of weeds was evident by the 7th day. However, mixing of urea failed to improve phytotoxic effect of carfentrazone-ethyl on weeds, and even a slight reduction in activity was noticed (Table 36) by Mounisha (2020). Moody (1981) opined that combinations of herbicides with fertilizers could improve weed control and enhance crop yields either by synergism or more efficient utilization of the fertilizer.

5.2.2 Effect on weed species

Echinochloa colona was the most dominant grass species in the area, followed by *E. stagnina* and *Leptochloa chinensis*. In the first year of experimentation (2019-20), beneficial effect of urea mixing was observed with the herbicides (cyhalofop-butyl + penoxsulam) and bispyribac-sodium at 15 days after application (Tables 37 and 39). Weed density in these treatments were significantly less than in other herbicidal treatments and was on par with hand weeding. The beneficial effect of urea mixing with (cyhalofop-butyl + penoxsulam) was reported by Singh *et al.* (2015). However, this effect was not seen in 2020-21. This could be due to the difference in weather conditions in the two years. At this stage, failure to control *E. colona* was noted in carfentrazone-ethyl + urea, and (chlorimuron-ethyl + metsulfuron-ethyl), both with and without tank mixing with urea. As both these herbicides were recommended only for killing broad leaf weeds and sedges, this was expected.

At 30 DAA in the first year *E. colona* was found to be well controlled by bispyribac-sodium mixed with urea (density of 1 no./sq. m) and was on par with hand weeding. This effect was not seen in the second year of experimentation, where hand weeding was significantly superior to all other treatments. Pietryga and Drzewiecki (2011) observed 92-99 per cent efficacy of the herbicides Maister® and Mustang® when jointly used with multi compound foliar fertilizers against *E. crus-galli*.

Commensurate with the low density of *E. colona*, weed dry weight was also lowest at 15 DAA in 2019-20 when urea was mixed with (cyhalofop-butyl + penoxsulam) and bispyribac-sodium. The reduction in dry weight as compared to these herbicides applied without urea mixing was 51 and 71 per cent respectively. In 2020-21, urea mixing with bispyribac-sodium resulted in a reduction of 60 per cent in the dry matter production of *E. colona* at 15 DAA. At 30 DAA, these two treatments [(cyhalofop-butyl + penoxsulam) and bispyribac-sodium] succeeded in reducing the dry weights by 33 and 29 per cent respectively. It was reported by Soliman *et al.* (2011) that application of herbicides on mixing with (1%) urea increased the efficiency in controlling annual weeds of wheat.



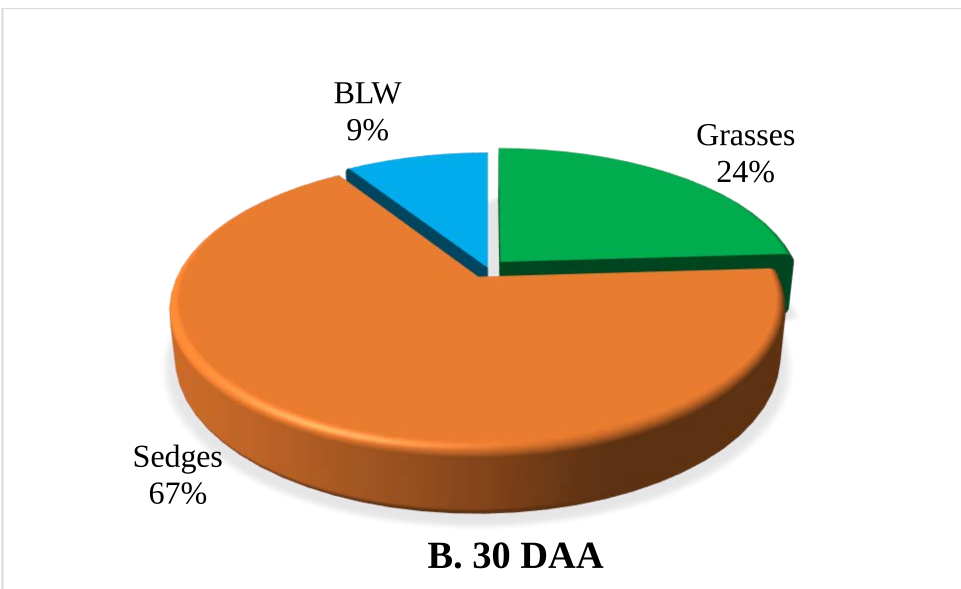


Fig. 19. Weed spectrum in the experiment-II (UWC) at A. 15 DAA; B. 30 DAA

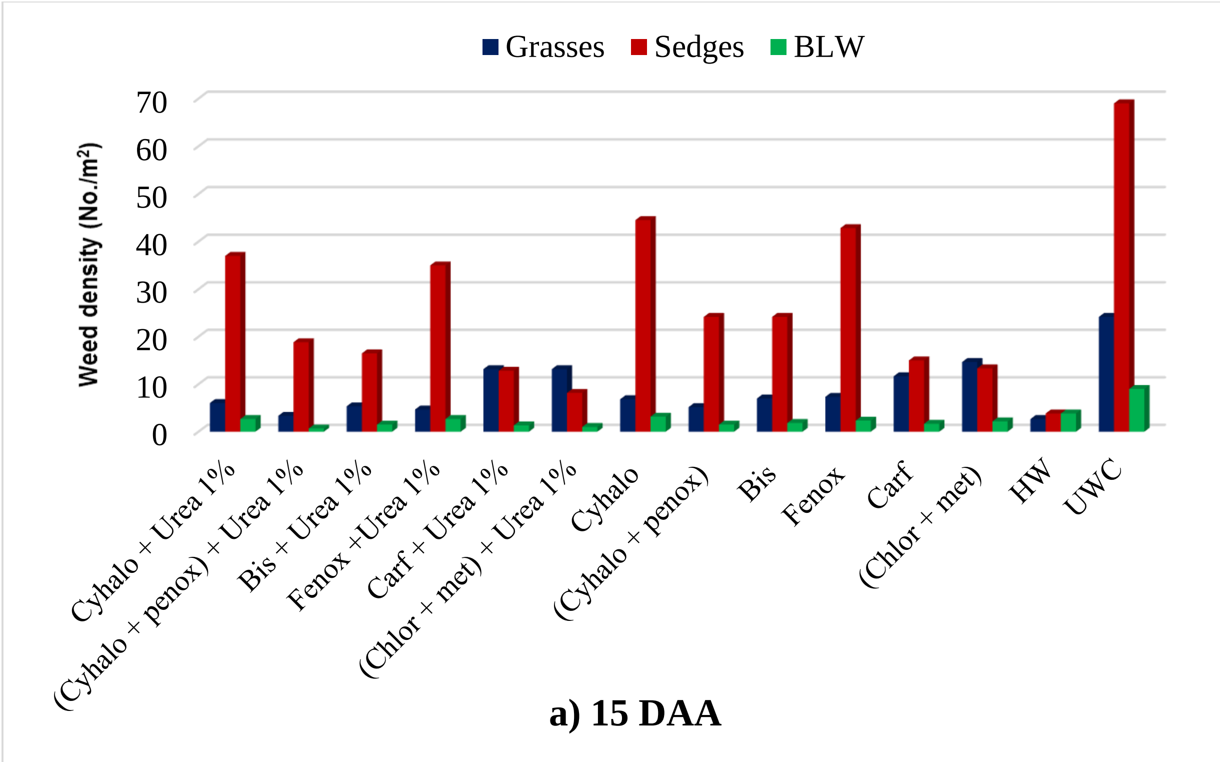


Fig. 20. Effect of tank mixed herbicides with urea on weed count at 15 DAA

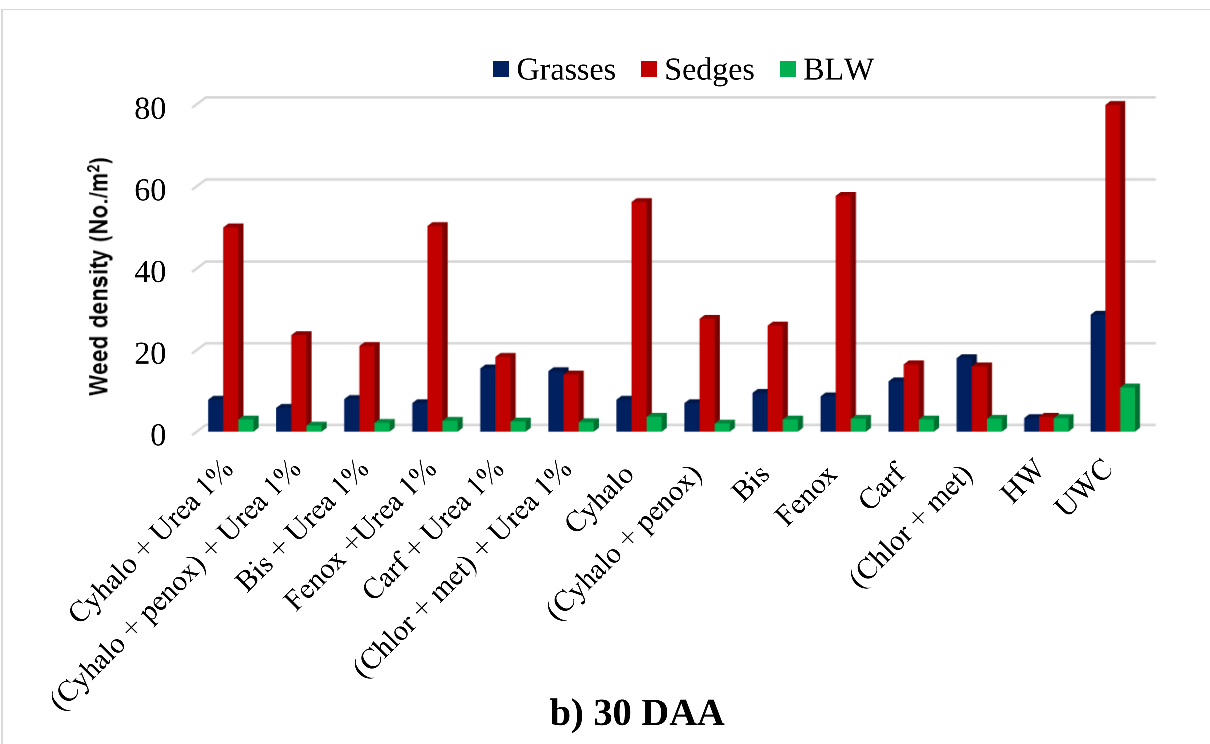


Fig. 21. Effect of tank mixed herbicides with urea on weed count at 30 DAA

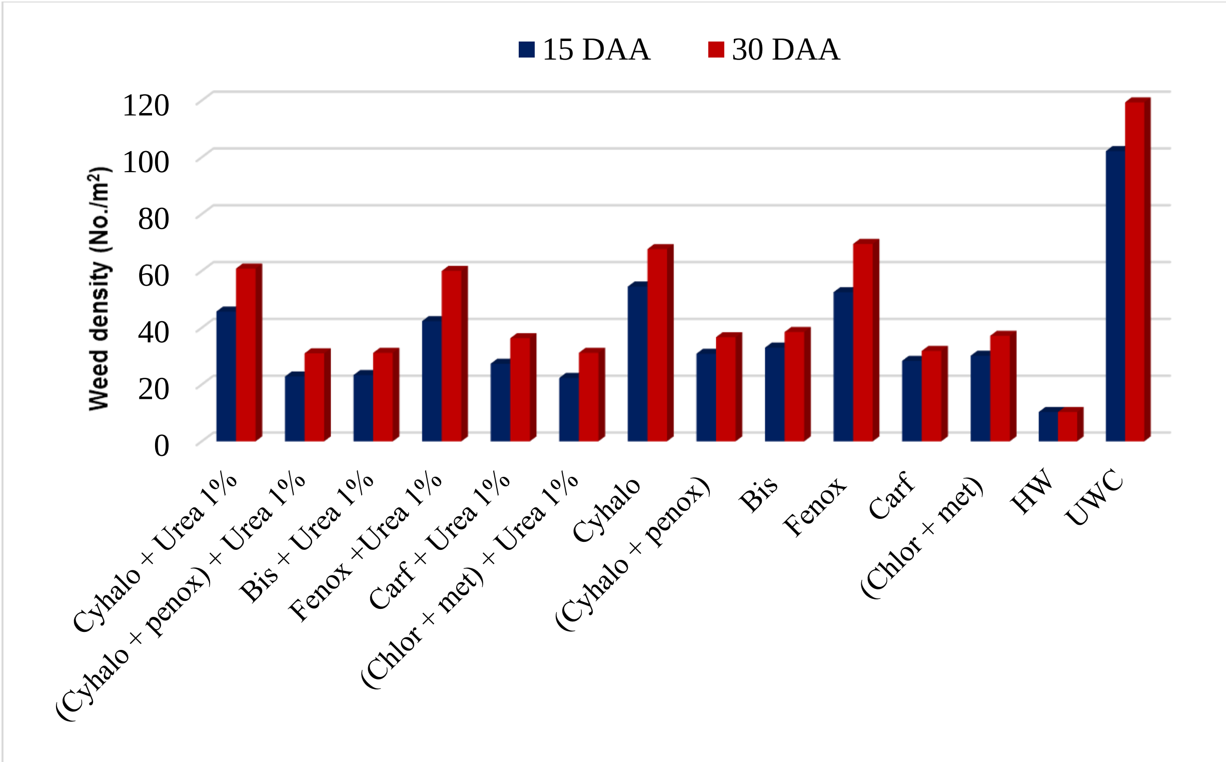


Fig. 22. Effect of tank mixed herbicides with urea on total weed count

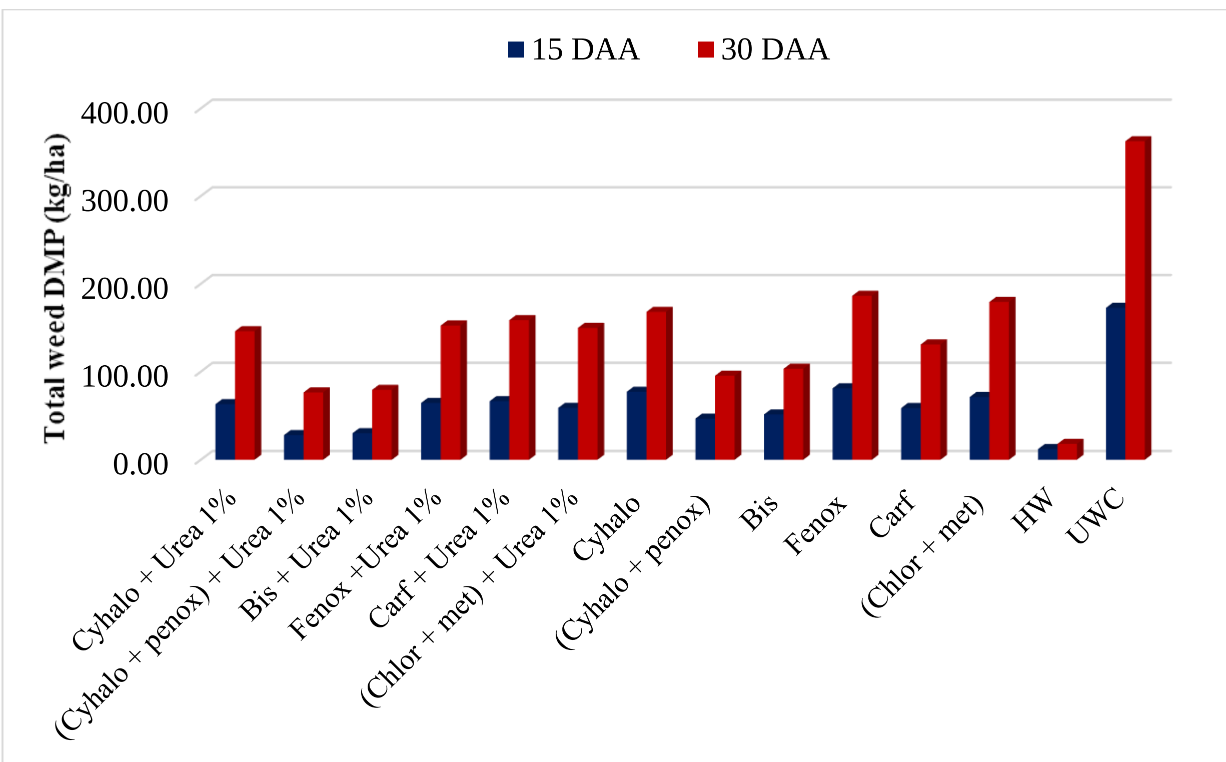


Fig. 23. Effect of tank mixed herbicides with urea on total weed DMP

Urea mixing did not confer any additional advantage to the grass herbicides, fenoxaprop-p-ethyl, or the broad spectrum herbicides (cyhalofop-butyl + penoxsulam) and bispyribac-sodium in killing *E. stagnina*. They acted similarly on the weed whether mixed or unmixed with urea at 15 DAA in both years. This effect was also visible at 30 DAA in the second year of study. However, urea mixing had a synergistic effect on reducing weed dry matter production of *E. stagnina* in both years at both stages of observation with respect to (cyhalofop-butyl + penoxsulam) and bispyribac-sodium. In 2019-20 dry matter reduction was to the tune of 100 per cent for both herbicides at 15 DAA, and 2.7 and 33.5 per cent respectively at 30 DAA. Corresponding figures in 2020-21 were 50 and 60 per cent at 15 DAA and 31.5 and 29 per cent at 30 DAA respectively (Tables 47 and 48).

A similar effect was seen in the case of *Leptochloa chinensis*. (Cyhalofop-butyl + penoxsulam), fenoxaprop-p-ethyl and cyhalofop-butyl were very effective at 15 DAA in both years, irrespective of urea mixing, in controlling *L.chinensis*. Cyhalofop-butyl alone, with or without urea mixing, was also effective in at 30 DAA in 2019-20, while the effect was not seen in 2020-21, where hand weeding was most effective. No significant effect of urea mixing with herbicides could be observed in the control of *L. chinensis*.

The synergistic effect of urea on herbicide activity was thus evident only with (cyhalofop-butyl + penoxsulam) and bispyribac-sodium on *E. colona*. Herbicidal activity of other grass killers and broad spectrum herbicides was not affected by urea mixing. The synergistic effect of combining fertilizers with herbicides in weed control would depend on several factors including type of weed (Moody, 1981).

Cyperus iria and *Fimbristylis miliacea* were the main sedges in the area, of which *C. iria* was more problematic. (Chlorimuron-ethyl + metsulfuron-methyl) and carfentrazone-ethyl were effective against *C. iria* at 15 and 30 DAA, but the effect of urea mixing was not distinct. Some slight advantage of urea mixing was observed in both years. Though density of *C. iria* was not affected by urea mixing with herbicides, dry matter was significantly and positively affected in both years of study at 15 DAA and 30 DAA. Urea had a distinct synergistic effect on the efficacy of (cyhalofop-butyl

+ penoxsulam), bispyribac-sodium and (chlorimuron-ethyl + metsulfuron-methyl) on *C. iria*.

Urea mixing with herbicides had no effect on the herbicides carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) in controlling *Fimbristylis miliacea*. Similar to the effect in *C. iria*, urea mixing favourably influenced the herbicidal activity of (cyhalofop-butyl + penoxsulam), bispyribac-sodium and (chlorimuron-ethyl + metsulfuron-methyl) on *Fimbristylis miliacea*. Significantly reduced dry matter production was registered on mixing with urea at both stages of observation in both years.

Though tank mixing of urea with carfentrazone-ethyl, (chlorimuron-ethyl + metsulfuron-methyl) and bispyribac-sodium completely controlled *Monochoria vaginalis* at 15 DAA in 2020-21, this effect was not seen in 2019-20. Moody (1981) had remarked that the prevailing environmental conditions had influence on the synergistic or antagonistic effects of herbicide-fertilizer mixing. At 30 DAA, (cyhalofop-butyl + penoxsulam) mixed with urea was effective in controlling the weed in both years, while urea mixing with bispyribac-sodium, carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) was efficacious in 2020-21 alone. Thus, urea mixing had some synergistic effect on herbicides in controlling *M. vaginalis*. Broad leaf weeds *Ludwigia perennis* and *M. vaginalis* were not a severe problem in the experimental plots. However, significant effect of urea mixing with the herbicides (cyhalofop-butyl + penoxsulam), carfentrazone-ethyl and (chlorimuron-ethyl + metsulfuron-methyl) was seen at both stages of observation in both years. Bispyribac-sodium + urea could drastically reduce dry matter production as compared to bispyribac-sodium alone at 30 DAA in 2020-21 also (Table 38 and 40).

Considering the total weed density of the three classes of weeds, urea mixing had synergistic effect on bispyribac-sodium and fenaxprop-p-ethyl in controlling grasses at 15 DAA, on (chlorimuron-ethyl + metsulfuron-methyl) in controlling sedges at 15 DAA, and on (cyhalofop-butyl + penoxsulam) and (chlorimuron-ethyl + metsulfuron-methyl) in controlling broad leaf weeds at 15 DAA (Tables 41 and 42).

Weed density at initial stages was therefore more sensitive to the synergistic effect of urea mixing (Fig. 20, 21 and 22).

Tank mixing of urea was seen to considerably enhance the efficacy of (cyhalofop-butyl + penoxsulam) and urea against grass weeds as compared to their application without urea at both 15 and 30 DAA. When urea was not mixed with (cyhalofop-butyl + penoxsulam), at 15 DAA, dry matter production of grasses increased by 49 per cent when compared to urea mixed application, while at 30 DAA, the increase was 27 per cent. For bispyribac-sodium the corresponding figures were 101 and 35 per cent.

For sedge control, urea mixing with (chlorimuron-ethyl + metsulfuron-methyl) was found to reduce dry matter production as compared to the application without urea. At 15 DAA, dry matter production of sedges was reduced by 28.3 per cent, by mixing urea with the herbicide while at 30 DAA the reduction was 18.3 per cent.

The same effect was seen in broad leaf weeds when urea was tank mixed with (cyhalofop-butyl + penoxsulam). Dry matter production reduction was to the tune of 68.2 per cent at 15 DAA and 50.5 per cent at 30 DAA.

Considering the total weed dry matter production, the superiority of the treatments (cyhalofop-butyl + penoxsulam) and bispyribac-sodium when tank mixed with urea was undeniable (Fig. 23). These treatments were significantly superior to their application without urea mixing, and the reduction in dry matter production at 15 DAA was 40 and 41.2 per cent respectively (Table 47 and 48). This result supported by findings of Moeini *et al.* (2006) and Soliman *et al.* (2011).

As per the trend of nutrient removal weeds at both 15 and 30 DAA, the treatments (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea, were comparable to the hand weeded plot (Fig. 24 and 25). This result is supported by reports of Singh *et al.* (2005), Singh *et al.* (2007) and Mukherjee and Malty (2011).

5.2.3 Weed control efficiency and weed index

Both weed control efficiency (Fig. 26) and weed index were at optimum values for the treatments (cyhalofop-butyl + penoxsulam) and bispyribac-sodium tank mixed with urea (Table 49). WCE followed the trend of weed dry matter production which was lowest in these treatments, consequently leading lower weed indices due to higher grain yields (Fig. 27).

5.2.4 Effect on rice growth

Rice growth in terms of tiller number per sq. m was proportional to the weed competition. At 30 DAS, tiller number was significantly higher in the hand weeded plot which recorded lowest weed dry matter production. On par with this was the treatment bispyribac-sodium tank mixed with urea. The treatment (cyhalofop-butyl + penoxsulam) mixed with urea was next best, and on par with the above two herbicides applied without urea mixing. Urea mixing with these two herbicides again led to lower weed growth and competition and higher tiller production at 60 DAS. These treatments were on par with hand weeded control (Table 53).

5.2.5 Yield attributes and yield of rice

Yield attributes of rice were affected by the growth of weeds and extent of competition offered. Following the trend of tiller number, number of panicles per sq. m was significantly higher in the treatments (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea (Table 54). The number of grains per panicle was also significantly higher in these treatments and on par with hand weeding. However, percentage of filled grain was seen to be higher on application of bispyribac-sodium, with and without urea. Reduced competition from weeds resulted in higher grain number, better grain development and filling. Similar results have been reported by Moeini *et al.* (2006), Singh *et al.* (2015), Sreedevi *et al.* (2018) and Mounisha and Menon (2020).

The trend of tiller number per sq. m and yield attributes was repeated in the grain and straw yield. Straw yields were also higher in the treatments where (cyhalofop-

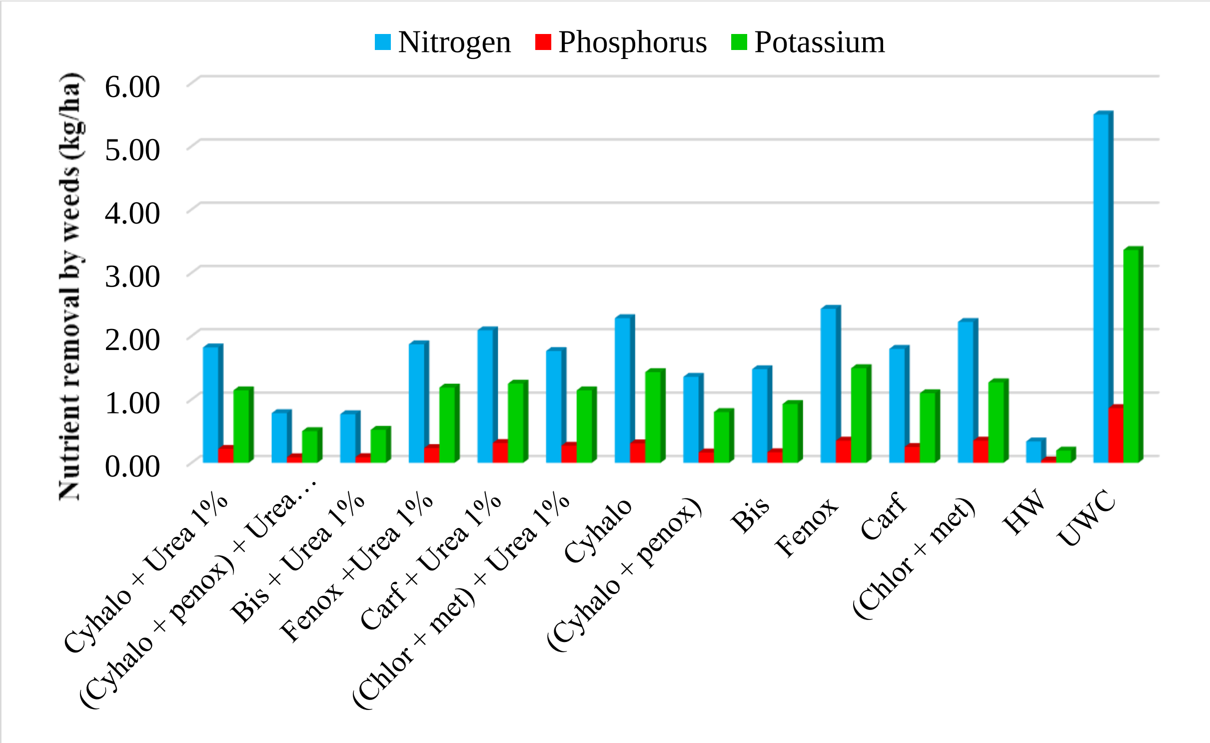


Fig. 24. Effect of tank mixed herbicides with urea on nutrient removal by weeds at 15 DAA

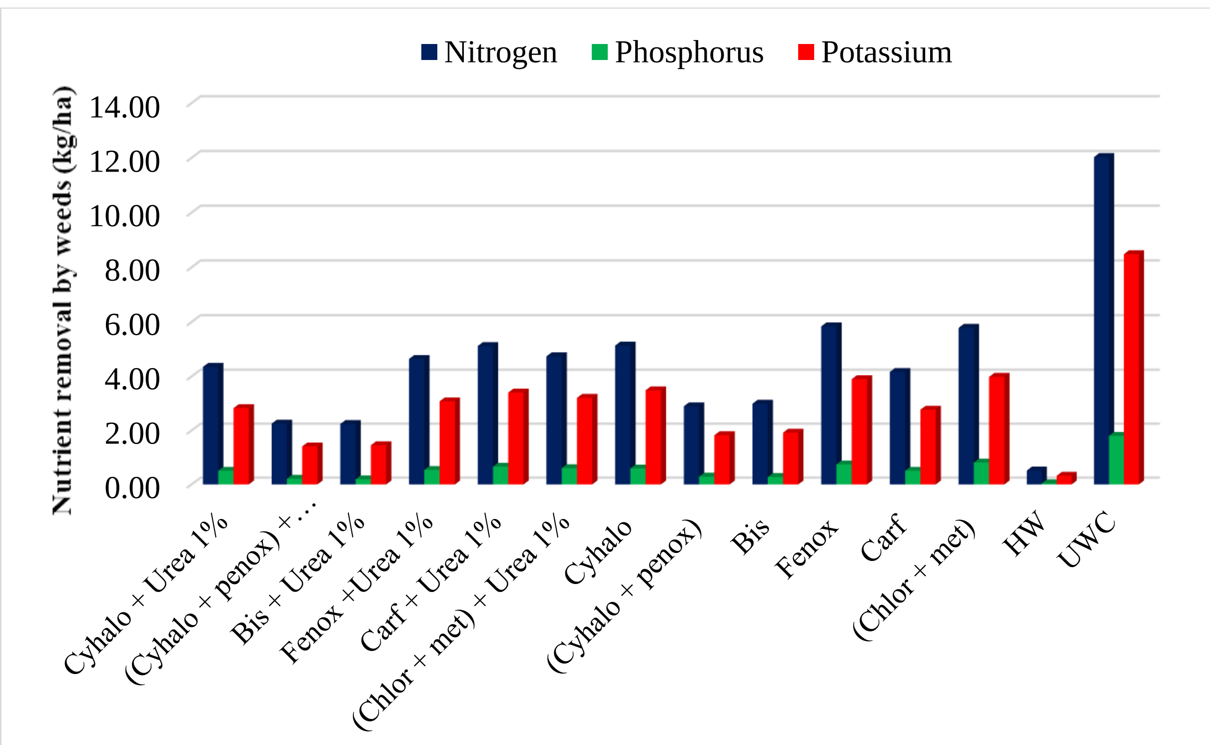


Fig. 25. Effect of tank mixed herbicides with urea on nutrient removal by weeds at 30 DAA

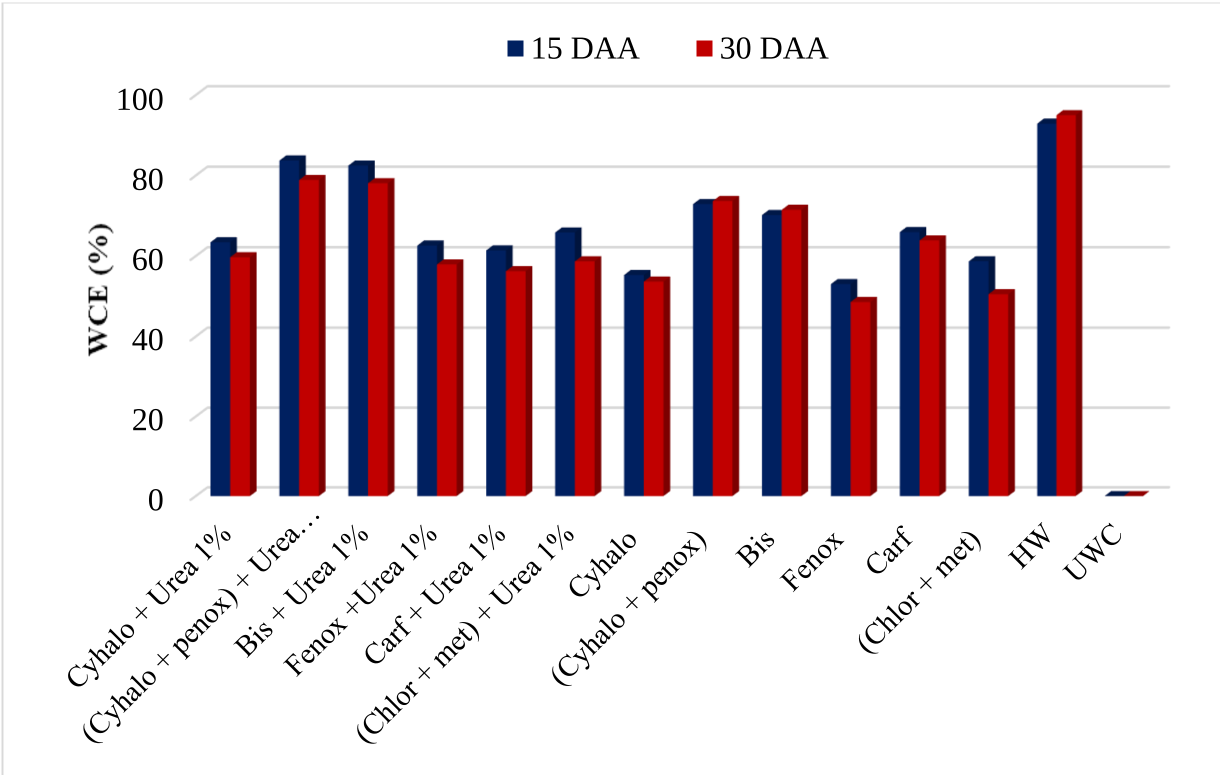


Fig. 26. Effect of tank mixed herbicides with urea on weed control efficiency

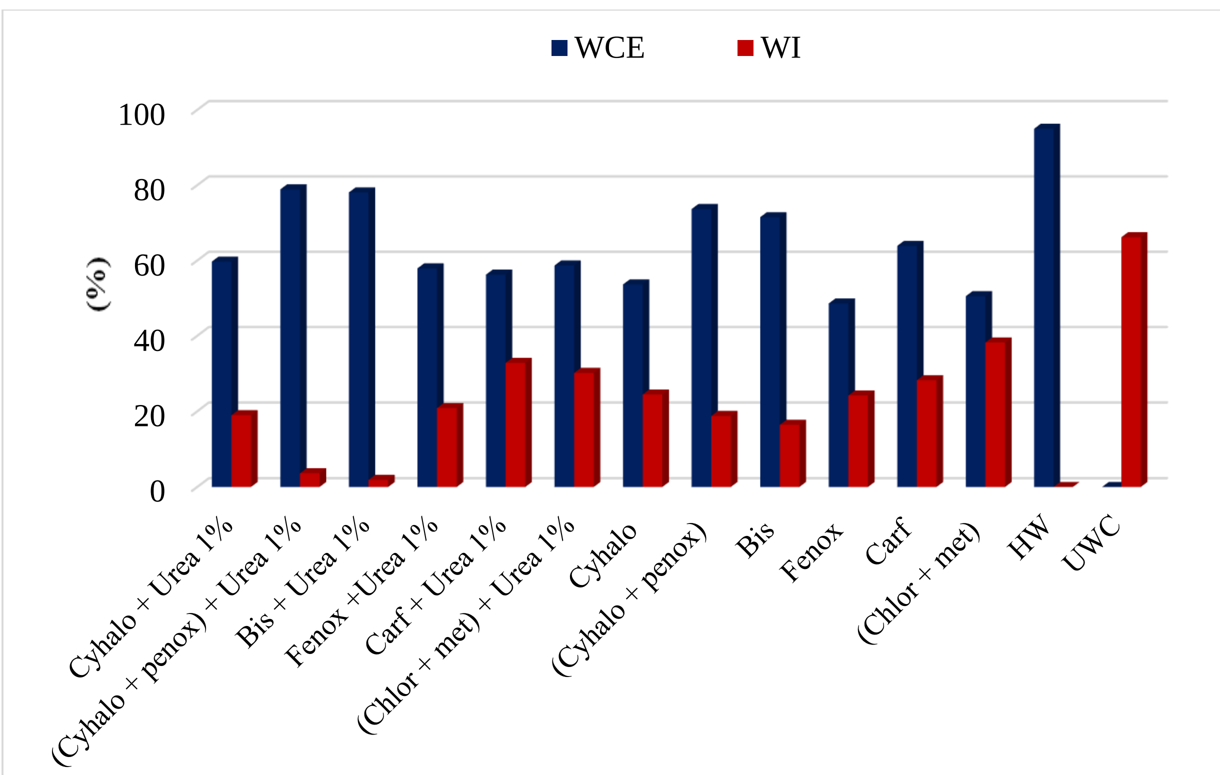


Fig. 27. Effect of tank mixed herbicides with urea on WCI and WI

butyl + penoxsulam) and bispyribac-sodium were applied without urea mixing, reflecting the superior efficacy of these two herbicides, in keeping with their broad spectrum action, but urea mixing undoubtedly imparted an added advantage to these two herbicides in increasing yields. In the same line, increased grain yield in wheat due to mixing herbicides with 1 per cent urea was also reported by Pandey and Singh (1994), Moeini *et al.*(2006) and Soliman *et al.* (2011), which was attributed to the higher weed control efficiencies in these treatments.

Straw yields followed the same trend as grain yields, in the order hand weeded control> bispyribac-sodium with urea> (cyhalofop-butyl + penoxsulam) with urea> bispyribac-sodium> (cyhalofop-butyl + penoxsulam) (Table 55 and Fig 28).

5.2.6 Nutrient uptake of rice

The trend of nutrient uptake by rice followed grain and straw yields, with highest uptake of N, P and K in the hand weeded control, followed by bispyribac-sodium + urea, P uptake and (cyhalofop-butyl + penoxsulam) + urea (Table 56 and Fig. 29). Similar results have been reported by Subhalakshmi and Venkataramana (2009).

5.2.7 Economics of cultivation

Although grain and straw yields were highest in the hand weeded control, net income and B:C ratio were seen to be higher in the treatments bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea. This was directly related to the additional costs accrued for hand weeding, which amounted to Rs. 15,978/- per hectare, as compared to Rs. 2,090/- in the treatment bispyribac-sodium + urea and Rs. 4,300/- for (cyhalofop-butyl + penoxsulam) + urea. The B:C ratio in hand weeded plot was correspondingly reduced to 2.13 as compared to 2.51 and 2.37 in the best treatments (Table 58). Similar results have been documented by Subramanian *et al*. (2006), Singh *et al.* (2007), Veeraputhiran and Balasubramanian (2010), Jacob *et al.* (2014), Govindan (2014) and Hossain (2015).

5.2.8 Soil microbial activity

Soil microbial activity, as measured by the dehydrogenase activity and soil microbial biomass carbon, was highest in the hand weeded plot and unweeded control, probably due to no negative impacts of herbicide application. There was a sudden increase in activity from initial to panicle stages and then decrease at final stages. No specific trend could be detected in the microbial activity except that more negative impact was observed on application of bispyribac-sodium and fenoxaprop-p-ethyl (Table 59 and 60). Lower activity in the herbicide treated plots could be due to effect on the enzyme activity (Uhlirova *et al*., 2005). This result was similar as the studies conducted by Amritha and Devi (2017) and Priya *et al*. (2017).

5.3 Experiment-III

Herbicides applied to control weeds may also affect disease causing pathogens, which would be an added advantage. Such effects need to be assessed, especially in areas where certain pathogens are endemic. Microbial bioagents occurring naturally in nature play an important role in integrated pest management. They also stimulate plant growth even if there is no disease, which results in better yield. Application of chemical herbicides may affect the bioagents adversely and hence it is essential to test the compatibility of herbicides with the bioagents used in rice cultivation.

5.3.1 Effect on plant pathogens

In vitro evaluation of herbicides against rice sheath blight pathogen *Rhizoctonia solani* and blast pathogen *Pyricularia oryzae* was carried out. Six herbicides at three different doses viz., cyhalofop-butyl (80, 160 and 240 ppm), (cyhalofop-butyl + penoxsulam) (150, 300 and 450 ppm), bispyribac-sodium (25, 50 and 75 ppm), fenoxaprop-p-ethyl (60, 12 and 180 ppm), carfentrazone-ethyl (20, 40 and 60 ppm) and (chlorimuron-ethyl + metsulfuron-methyl) (4, 8 and 12 ppm) were used in poison food technique, while for bacterial blight pathogen (*Xanthomonas oryzae* pv. *oryzae*) filter paper disc method was adopted.

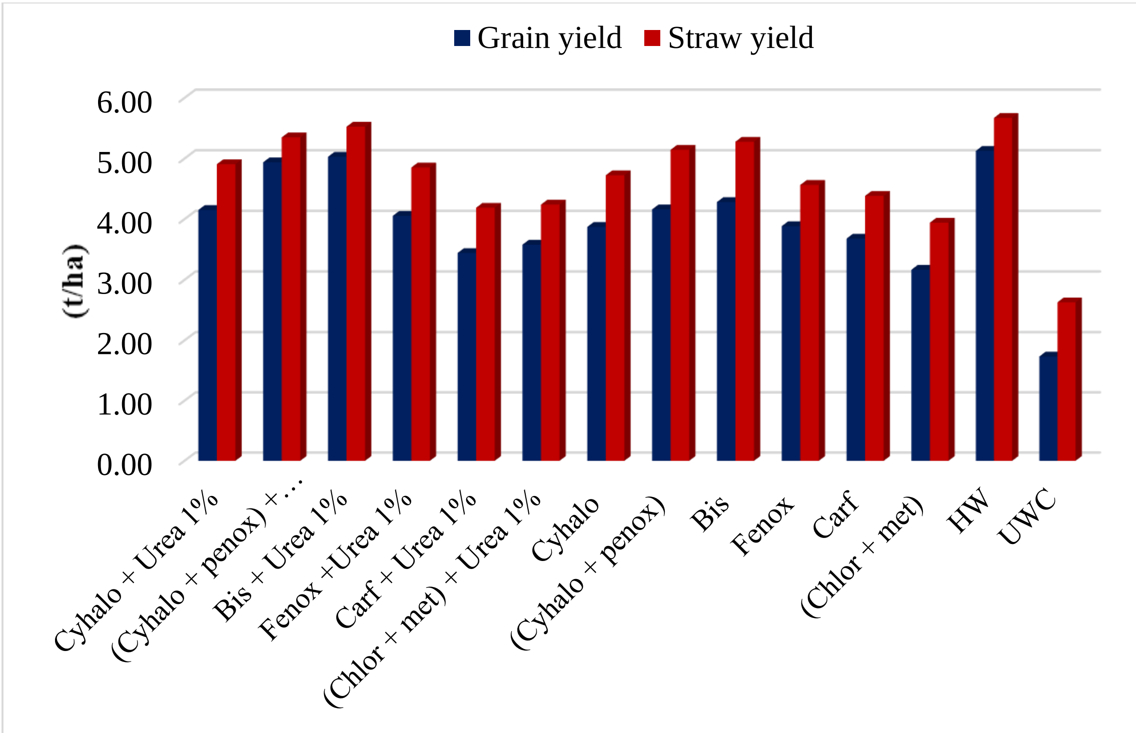


Fig. 28. Effect of tank mixed herbicides with urea on grain and straw yield

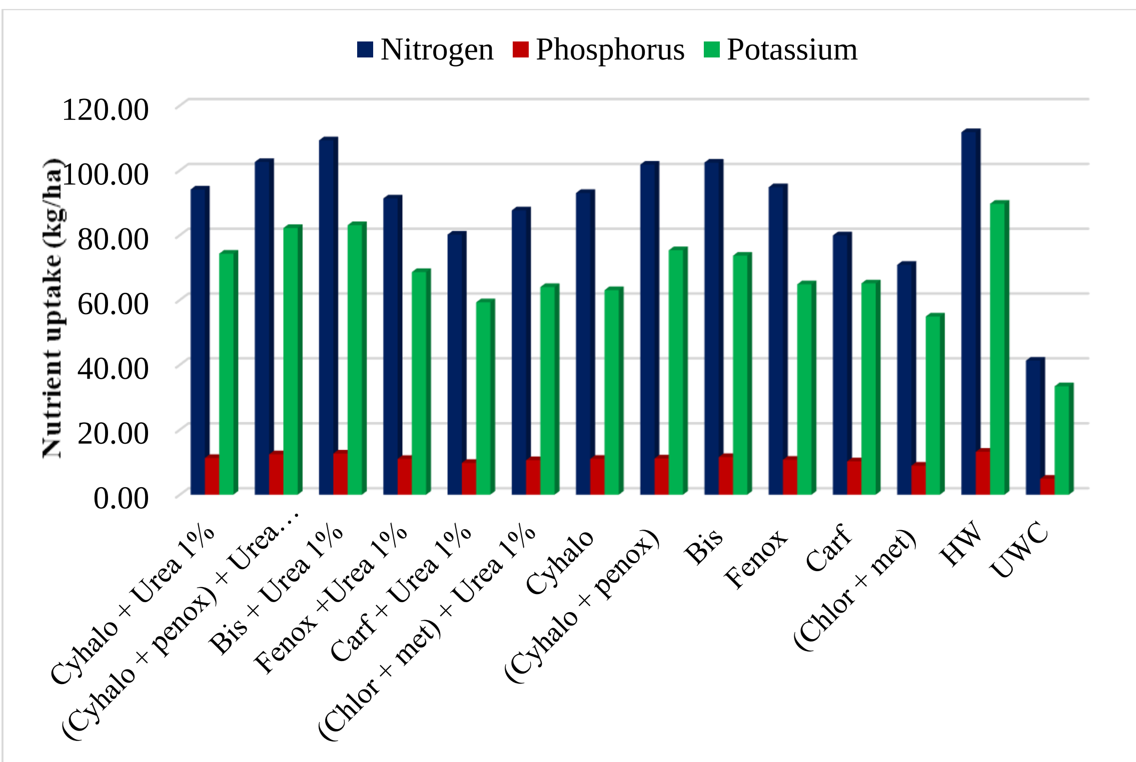


Fig. 29. Effect of tank mixed herbicides with urea on nutrient uptake at 60 DAS of rice

Bispyribac-sodium, fenoxaprop-p-ethyl and (cyhalofop-butyl + penoxsulam) were highly effective against *Rhizoctonia solani* when applied at all the three doses i.e. higher, recommended and lower doses and were at par. At recommended doses of application the per cent inhibition zone ranged from 47 to 54 for all herbicides except carfentrazone-ethyl which recorded an inhibition of 17 per cent and (chlorimuron-ethyl + metsulfuron-methyl) which did not inhibit the fungus (Table 61). Raj *et al.* (2017), as per experimental results, indicated that the herbicide mixtures (bispyribac-sodium + metamifop) and (penoxsulam + cyhalofop-butyl) had immense suppressive effect on the growth of *R. solani*. Cyhalofop-butyl showed 100 per cent inhibition of *R. solani* at 24 h incubation, followed by 89 per cent inhibition at 18 h incubation. However it was ineffective in inhibiting at 5 min (56.66%), 30 min (0%) and 6 h (26.67%) incubation (Sandhya *et al.,* 2018). A similar study reported retardation in the growth of the pathogen by the herbicides pendimethalin, anilofos, paraquat, butachlor, isoproturon, alachlor and 2,4-D at 25, 50, 100 or 500 ppm. Paraquat inhibited fungal growth by 99.5 and 78.6 per cent when applied at 500 and 25 ppm, respectively. Alachlor at 500 ppm reduced fungal growth by 92.2 per cent (Rai *et al.*, 2007).

Increased zone of inhibition of *Pyricularia oryzae* with higher doses of cyhalofop-butyl (65.45%), carfentrazone-ethyl-ethyl (64.50%) and (cyhalofop-butyl + penoxsulam) (64.05%) was recorded. At recommended concentrations, the inhibition ranged from 47 to 62 per cent, except in (chlorimuron-ethyl + metsulfuron-methyl) which did not inhibit fungal growth (Table 62).

Xanthomonas oryzae pv. *oryzae*, causing rice bacterial blight, was found to be unaffected by the herbicides tested (Table 63).

5.3.2 Effect on biocontrol agents

In vitro evaluation of herbicides against fungal biocontrol agent *Trichoderma viride* and bacterial biocontrol agent *Pseudomonas fluorescens* was also carried out. Six herbicides at three different doses, viz., cyhalofop-butyl (80, 160 and 240 ppm), (cyhalofop-butyl + penoxsulam) (150, 300 and 450 ppm), bispyribac-sodium (25, 50 and 75 ppm), fenoxaprop-p-ethyl (60, 12 and 180 ppm), carfentrazone-ethyl (20, 40 and 60 ppm) and (chlorimuron-ethyl + metsulfuron-methyl) (4, 8 and 12 ppm) were used in poison food technique, whereas *P. fluorescens* was used in filter paper disc method.

The inhibition zone of *T. viride* with higher herbicide doses was 54.85 per cent with bispyribac-sodium and 52.84 per cent with (cyhalofop-butyl + penoxsulam). At recommended dose it was 45.8 per cent with cyhalofop-butyl and 49.5 per cent with (cyhalofop-butyl + penoxsulam) (Table 64). Unlike its effect on plant pathogens, (chlorimuron-ethyl + metsulfuron-methyl) had a high inhibition zone of 44 per cent, indicating that its application was detrimental to the bioagent *T. viride*. Reyes *et al.* (2012) showed that the concentrations of control (0D), recommended dose (1D) and 10 times higher dose of fenoxaprop-p-ethyl products and 2,4-D amine salt affected the mycelial growth of the strains T.17 and T.75; however, germination at the 0, 1D concentration was not affected. None of the strains evaluated were affected by bispyribac-sodium. Similarly, bispyribac-sodium + metamifop was harmless and safe to antagonistic fungi, *T. viride* at doses ranging from 60 to 90 g/ha which fell in Class I (growth inhibition of 8.15 to 22.95%). Class II toxicity category (higher doses 100 and 110 g/ha) recorded a growth inhibition of 31.48 and 37.04 per cent, respectively and were slightly harmful to *T. viride* (Raj *et al.,* 2017).

An inhibition zone of around 25 per cent was observed only at higher doses of (chlorimuron-ethyl + metsulfuron-methyl) and carfentrazone-ethyl (21.08 and 22.33%, respectively) (Table 65). This observation was in agreement with the findings of Surendra *et al.* (2012) that *P. fluorescens* (PF 43) was highly compatible with 2,4-D sodium salt, metsulfuron methyl + chlorimuron ethyl, cyhalofop-butyl, pyrazosulfuron ethyl, pretilachlor, penoxsulam and bispyribac-sodium. Raj *et al.* (2017) found that that bispyribac-sodium + metamifop at different tested concentrations viz., 100, 120, 140, 160, 180, 200 and 220 µL/L (corresponding to the field doses of 50, 60, 70, 80, 90, 100 and 120 g/ha) did not exert any inhibition on the growth of *P. fluorescens*. Hanuman and Madhavi (2018), documenting experimental results pertaining to compatibility of *P. fluorescens* with herbicides, found that the strain *P. fluorescens* was compatible with all the tested herbicides viz., quizalofop ethyl, pyrithiobac sodium, oxyflourfen, cyhalofop-butyl, glyphosate + ammonium sulphate, pendimethalin, 2,4-D sodium salt, imazethapyr, atrazine and glyphosate at all the three concentrations (100, 500 and 1000 ppm) tested.

Most of the commonly used herbicides at recommended doses had inhibitory effects on growth of plant pathogens *R. solani* and *P. oryzae*. However, beneficial bioagent *T. viride* was also inhibited. Herbicides used in combination could have an additive effect and result in enhanced disease control compared to their individual application. The judicious selection and use of herbicides is warranted to obtain disease control in addition to weed control. The possibility of their utilization in integrated disease management needs to be investigated.

Summary

6. SUMMARY

The research programme entitled "Bio-efficacy of tank mixed herbicides and urea in wet seeded rice" consisted of three experiments viz.,

Experiment I- Bio-efficacy of tank mixed herbicide combinations in wet seeded rice.

Experiment II- Bio-efficacy of tank mixing of herbicides and urea in wet seeded rice.

Experiment III- *In vitro* evaluation of herbicides on beneficial and pathogenic microorganisms.

The summaries of the results of the three experiments are presented separately.

Experiment-I

The experimental area was infested with grasses, sedges and broad leaf weeds of which grasses and sedges dominated. The main grass species in the experimental area included *Echinochloa colona*, *Echinochloa stagnina*, *Oryza sativa* f. *spontanea* (weedy rice), and *Leptochloa chinensis*. *Cyperus iria* and *Fimbristylis miliacea* were the main sedges, and *Ludwigia perennis* and *Monochoria vaginalis* were the chief broad leaf weeds.

Grass density was lowest in the hand weeded plot and [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] at the three stages of observations. Lowest density of sedges was recorded in the hand weeded plot followed by [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] at all three stages of observation. At 30 DAA, fenoxaprop-p-ethyl + bispyribac-sodium, and fenoxaprop-p-ethyl *fb* bispyribac-sodium registered lowest density of broad leaf weeds, while at 60 DAA highest density was noticed in fenoxaprop-p-ethyl *fb* carfentrazone among combinations of herbicides. Lowest total weed density was in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and the hand weeded plot.

At 15 DAA, hand weeding, [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and fenoxaprop-p-ethyl *fb* (chlorimuron-ethyl + metsulfuron-methyl) were most effective in reducing dry matter production of grasses. At 30 DAA and 60 DAA, hand weeding and application of [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] were most effective. Hand weeding, followed by [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] treatments recorded lowest dry matter production of sedges, while dry matter production of broad leaf weeds did not register a constant trend. The most effective treatments for reducing dry matter production were hand weeding and [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)].

Lowest removal of nutrients by weeds was registered in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)]. At all three stages of observation, hand weed control registered highest WCE followed by the treatments [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], fenoxaprop-p-ethyl + bispyribac-sodium and [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)]. Weed Index was lowest for [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] followed by fenoxaprop-p-ethyl + bispyribac-sodium and [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)].

There was no significant effect of treatments on plant height of rice. Highest number of rice tillers per m^2 was recorded in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and hand weeding. The highest number of panicles per sq. m was recorded [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], followed by hand weeding. Tank mixed application of [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] (T_4) resulted in highest number of grains per panicle and percentage of filled grain followed by hand weeding and fenoxaprop-p-ethyl +bispyribac-sodium.

Highest grain and straw yields were obtained in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] followed by the treatments hand weeded control and fenoxaprop-p-ethyl + bispyribac-sodium. Highest N, P and K uptake in rice was in hand weeded treatment followed by [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)] and fenoxaprop with bispyribac-sodium.

Net returns and benefit:cost ratio were highest in [(cyhalofop-butyl + penoxsulam) + (chlorimuron-ethyl + metsulfuron-methyl)], followed by fenoxaprop-p-ethyl + bispyribac-sodium, hand weeded control and [(cyhalofop-butyl + penoxsulam) *fb* (chlorimuron-ethyl + metsulfuron-methyl)].

Experiment-II

The major grass species in the experimental area were *Echinochloa colona*, *E. stagnina*, *Leptochloa chinensis* and *Oryza sativa* f. *spontanea* (weedy rice). *Cyperus iria* and *Fimbristylis miliacea* were the main sedges and the main broad leaf weeds were *Ludwigia perennis* and *Monochoria vaginalis.*

At 15 DAA hand weeding resulted in lowest density of grasses and was on par with tank mixed application of urea with (cyhalofop-butyl + penoxsulam), bispyribac-sodium and fenoxaprop-p-ethyl and (cyhalofop-butyl + penoxsulam) applied alone. At 30 DAA, (cyhalofop-butyl + penoxsulam) was on par with hand weeding. At 15 DAA the density of sedges in the treatment (chlorimuron-ethyl + metsulfuron-methyl) + urea was comparable to hand weeding. At 30 DAA, all herbicide treatments were significantly inferior to hand weeding, which recorded lowest density. Lowest density of broad leaf weeds was recorded in (cyhalofop-butyl + penoxsulam) + urea both at 15 and 30 DAA. Total density of weeds was lowest in the hand weeded plot at the two stages. At 15 DAA, application of (chlorimuron-ethyl + metsulfuron-methyl) tank mixed with urea resulted in total weed density comparable to hand weeding. In both years, at both stages of observation, hand weeding and combination of (cyhalofop-butyl + penoxsulam) and bispyribac-sodium with urea were most effective in reducing weed biomass of *E. colona*.

At 15 DAA and 30 DAA, lowest dry weight of grasses was recorded in the hand weeded plot which was on par with (cyhalofop-butyl + penoxsulam) + urea.

This was followed by bispyribac-sodium + urea. At 15 and 30 DAA sedge dry matter production was lowest in hand weeding, followed by (chlorimuron-ethyl + metsulfuron-methyl) tank mixed with urea. Lowest dry matter production of broad leaf weeds at both stages was recorded in the treatment (cyhalofop-butyl + penoxsulam) + urea. Total weed dry matter was lowest in the hand weeding treatment at 15 DAA followed by (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea. At 30 DAA, the superior treatments after hand weeding were the same two treatments along with (cyhalofop-butyl + penoxsulam).

Weed control efficiency was highest in the hand weeding treatment at 15 DAA and 30 DAA. At both stages of observation, the next best treatments were (cyhalofop-butyl + penoxsulam) + urea, bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam). Weed index was lowest for bispyribac-sodium + urea, followed by (cyhalofop-butyl + penoxsulam) + urea. Nutrient removal by weeds was lowest in the hand weeded control followed by (cyhalofop-butyl + penoxsulam) and bispyribac-sodium, both tank mixed with urea.

Treatments had no significant effect on plant height of rice. The hand weeded plot had highest number of tillers per sq. m, followed by the treatment bispyribac-sodium + urea. Hand weeded control, bispyribac-sodium + urea and (cyhalofop - butyl+ penoxsulam) + urea recorded significantly higher number of panicles per sq. m number of grains per panicle. Highest percentage of filled grain was recorded in the hand weeded control which was on par with bispyribac-sodium + urea and bispyribac-sodium alone. Grain yield was highest in hand weeded control followed by bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea. Highest straw yield was observed in the hand weeded plot and was on par with bispyribac-sodium + urea, (cyhalofop-butyl + penoxsulam) + urea), bispyribac-sodium, and (cyhalofop-butyl + penoxsulam).

Uptake of N, P and K by rice was highest in hand weeded control and bispyribac-sodium + urea and (cyhalofop-butyl + penoxsulam) + urea. Net income and benefit: cost ratio was highest in the treatment bispyribac-sodium + urea followed by (cyhalofop-butyl + penoxsulam) + urea.

Experiment-III

The lowest radial growth and highest per cent inhibition of *Rhizoctonia solani* were observed in bispyribac-sodium, (cyhalofop-butyl + penoxsulam), cyhalofop-butyl and fenoxaprop-p-ethyl, followed by (chlorimuron-ethyl + metsulfuron-methyl). With increasing concentrations of herbicides, radial growth decreased and per cent inhibition zone increased. The lowest radial growth and zone of inhibition was with higher doses of bispyribac-sodium and fenoxaprop-p-ethyl.

For *Pyricularia oryzae,* the lowest radial growth and highest per cent inhibition zone were recorded with cyhalofop-butyl along with carfentrazone-ethyl and (cyhalofop-butyl + penoxsulam). The lowest radial growth and greatest inhibition zone was with higher doses of cyhalofop-butyl, carfentrazone-ethyl and (cyhalofop-butyl + penoxsulam).

The lowest radial growth and greatest inhibition zone for *Trichoderma viride* was observed with (cyhalofop-butyl + penoxsulam), followed by cyhalofop-butyl and (chlorimuron-ethyl + metsulfuron-methyl). Lowest radial growth and highest per cent of inhibition zone were with higher dose of bispyribac-sodium followed by (cyhalofop-butyl + penoxsulam) and cyhalofop-butyl.

The lowest radial growth and highest per cent inhibition zone for *Pseudomonas fluorescens* were recorded in (chlorimuron-ethyl + metsulfuron-methyl) followed by bispyribac-sodium and (cyhalofop-butyl + penoxsulam). Highest radial growth and lowest per cent inhibition zone were recorded with higher dose of herbicides. Lowest radial growth and highest per cent of inhibition zone were recorded with higher doses of bispyribac-sodium, followed by (cyhalofop-butyl + penoxsulam) and cyhalofop-butyl.

Conclusion

The results of the three experiments are highlighted as follows:

- Tank mix combination of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) was the best treatment with compatibility, efficient weed control, high grain yield and net returns.
- Tank mixing of bispyribac-sodium with urea 1 per cent had synergistic effect resulting in highest weed control efficiency, production and profitability over the other treatments. Mixing of (cyhalofop-butyl + penoxsulam) with urea 1 per cent can also be recommended for good results.
- Bispyribac-sodium and (cyhalofop-butyl + penoxsulam) were the best herbicides on *in vitro* evaluation in their effect on pathogenic microorganisms *Rhizoctonia solani* and *Pyricularia oryzae*, and at recommended doses were compatible with biocontrol agents *Trichoderma viride* and *Pseudomonas fluorescens*.

References

REFERENCES

Abdull, R., Punia, S.S., Manjeet, K. and Punia, S. 2020. Management of herbicide resistant *Phalaris minor* through sequential application of pre and post-emergence herbicides in wheat. *Indian J. Weed Sci.* 52(2): 190-193.

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

Anderson, T.H. and Domsch, K.H. 1989. Ratios of microbial biomass carbon to total organic-C in arable soils. *Soil Biol. Biochem.* 21: 471-479.

Arya, S.R. Syriac, E.K. and Aparna, B. 2018. Enzyme dynamics and organic carbon status of soil as influenced by flucetosulfuron in wet seeded rice. *J. Trop. Agric*. 56(1): 1-8.

Aswathi, S., Gade, R.M. and Shitole, A.V. 2016. Studies on tolerance and sensitivity of fungal and bacterial bioagent to three pesticides commonly used in agriculture. IPS (New Delhi), 14th International Workshop on *Trichoderma* and *Gliocladium*, Nagpur. p. 133.

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.

Awana, T.H., Sta-Cruz, P.C. and Chauhan, B.S. 2015. Agronomic indices, growth, yield-contributing traits, and yield of dry-seeded rice under varying herbicides. *Field Crops Res.* 177: 15-25.

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.

Barla, S., Upasani, R.R. and Puran, A.N. 2017. Herbicide combinations for control of complex weed flora in wheat. *Indian J. Weed Sci.* 49(1): 36-40.

Bhatt, P.S., Yakadri, M., Madhavi, M., Sridevi, S. and Rani, L. 2017. Productivity of transplanted rice as influenced by herbicide combinations. *Indian J. Weed Sci.* 49(2): 128-131.

Bhullar, M.S., Kumar, S., Kaur, S., Kaur, T., Singh, J., Yadav, R., Chauhan, B.S. and Gill, G. 2016. Management of complex weed flora in dry-seeded rice. *Crop Prot.* 83: 20-26.

Bhullar, M.S., Shergill, L.S., Kaur, R., Walia, U.S. and Kaur, T. 2012. Bio efficacy of herbicides in relation to sowing methods in wheat. *Indian J. Weed Sci.* 44(4): 214-217.

Blouin, D.C., Webster, E.P. and Bond, J.A. 2010. On a method of analysis for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice (*Oryza sativa*). *Weed Technol.* 24(4): 583-589.

Buehring, N.W., Talbert, R.E. and Baldwin, F.L. 2006. Interactions of graminicides with other herbicides applied to rice (*Oryza sativa*). *Weed Technol*. 20: 215-220.

Camargo, E.R., Senseman, S.A., McCauley, G.N. and Guice, J.B. 2012. Rice (*Oryza sativa* L.) response and weed control from tank-mix applications of saflufenacil and imazethapyr. *Crop Prot.* 31: 94-98.

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. Effect of bispyribac-sodium on *Echinochloa* sp. in rice nursery (*Oryza sativa* L.). *J. Farm Sci.* 30(2): 281-282.

Chattannavar, S.N., Kulkarni, S. and Khadi, B.M. 2006. Effect of herbicide on *Trichoderma harzianum*. *J. Cotton Res. Dev.* 20(2): 296-297.

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, B.S. and Abugho, S.B. 2012. Effect of growth stage on the efficacy of post-emergence herbicides on four weed species of direct-seeded rice. *Sci. World J.* 123071: 7. Doi:10.1100/2012/123071v.

Chauhan, B.S., Ahmed, S., Awan, T.H., Jabran, K. and Manalil, S. 2015. Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. *Crop Prot.* 71: 19-24.

Chauhan, B.S. and Johnson, D.E. 2011. Growth response of direct-seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. *Weed Sci*. 59: 119-122.

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. and Chopra, N.K. 2005. Bio-efficacy of fenoxaprop, clodinafop, metribuzin alone and in combination against weeds in wheat and their residual effect on succeeding crops. *Indian J. Weed Sci.* 37(3&4): 163-166.

Choudhary, V.K. and Anil, D. 2018. Herbicide weed management on weed dynamics, crop growth and yield in direct-seeded rice. *Indian J. Weed Sci.* 50(1): 6-12.

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.

Ciraj, M. 1996. Impact of some sulfonylurea herbicides upon selected soil fungi. *Sodobnokmetijstvo.* 29: 99-108.

Das, A.C., Debnath, A. and Mukherjee, D. 2003. Effect of the herbicides oxadiazon and oxyfluorfen on phosphates solubilizing microorganisms and their persistence in rice fields. *Chemosphere* 53: 217-221.

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.

Desai, S.A. and Kulkarni, S. (2004). Effect of fungicides, insecticides and weedicides on the growth and sporulation of native *Trichoderma harzianum* Rifai. *Karnataka J. Agric. Sci.* 17(1): 57-62.

Devi, B.R. and Singh, Y. 2018. Effect of nitrogen and weed management on nutrient removal by weed in direct seeded rice. *Int. J. Curr. Microbiol. App. Sci.* 7(6): 1452-1459.

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.

Diaz-ravina, M., Acea, M.J. and Carballas, T. 1995. Seasonal changes in microbial biomass and nutrient flush in forest soils. *Biol. Fertil. Soils* 19: 220-226.

Dick, R.P. 1997. Soil enzyme activities as integrative indicators of soil health. In: Pankhurst, C.E., Doube, B.M. and Gupta, V.V.S.R. (eds). *Biological Indicators of Soil Health*. CAB International, New York, pp. 121-156.

Dick, W.A. and Tabatabai, M.A. 1993. Significance and potential uses of soil enzymes, In: B. Metting (ed.), *Soil Microbial Ecology*, Marcel Dekker, New York. pp. 95-127.

Dubey, S.K., Kumar, A., Singh, M., Singh, A. K., Tyagi, S. and Kumar, V. 2018. Effect of six herbicides on soil microbial population and yield in direct seeded rice. *J. Pharmacog. Phytochem.* 4: 83-87.

Freed, R. 1986. MSTAT version 4.0. Department of Crop and Soil Sciences, Michigan State University.

Gangireddy, G., Subramanyam, D., Hemalatha, S. and Murthy, B.R. 2019. Sequential application of herbicides for weed management in rainfed lowland rice. *Indian J. Weed Sci.* 51(2): 203-205.

Gangwar, G.P. 2013. Compatibility of fungal bio agent for bacterial leaf blight of rice with chemical pesticides, commonly used in rice cultivation, *J. Appl. Nat. Sci.* 5(2): 378-381.

Gharde, Y., Singh, P.K., Dubey, R.P. and Gupta, P.K. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Prot.* 107: 12-18.

Ghosh, D., Singh, R. and Chander, S. 2018. Effect of nitrogen fertilizer and weed management practices on weed growth and crop yield of zero-till transplanted rice. *Indian J. Weed Sci.* 50(3): 287-289.

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

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

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.

Gupta, D. and Joshi, M. 2009. Changes in microbial biomass and phosphatase activity exposed to 2, 4-D and glyphosate. *J. Environ. Res. Dev*. 3(3): 663-669.

Gupta, V. 2004. Compatibility of biocontrol agent *Trichoderma harzianum* with pesticides. *J. Mycol. Plant Pathol.* 34: 504-505.

Haney, R.L., Senseman, S.A., Hons, F.M. and Zuberer, D.A. 2000. Effect of glyphosate on soil microbial activity and biomass. *Weed Sci*. 48: 89-93.

Hanuman, L.N. and Madhavi, G. Bindu. 2018. Compatibility of *Pseudomonas fluorescens* with pesticides *in vitro. Int. J. Curr. Microbiol. App. Sci.* 7(3): 3310-3315.

Harikrishnan, R. and Yang, X.B. 2001. Influence of herbicides on growth and sclerotia production in *Rhizoctonia solani*. *Weed Sci*. 49: 241-247.

Hartley, D. (ed.) 1987. *Agro Chemical Handbook* (2^{nd} Ed.) The Royal Society of Chemistry, Nottingham, UK, pp. 111-936.

Hemalatha, K., Ramana, A.V., Murthy, K.V.R. and Jagannadam, J. 2017. Nutrient uptake by rice and weeds as influenced by different weed management practices in dry-seeded rice. *Indian J. Weed Sci.* 49(3): 287-289.

Hossain, A. and Malik, G.C. 2017. Herbicides combinations for control of complex weed flora in transplanted rice in Lateritic belt of West Bengal. *Indian J. Weed Sci.* 49(3): 276-278.

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.

Hua, Z., Li, H.B., Hua, N.G., Cai, W.J. and Zhong, S.Y. 2002. Influence of some herbicides on *Rhizoctonia solani*. *J. Yangzhou Univ*., *Agric. Life Sci. Ed*. 23(2): 71-73, 78.

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

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

Jacob, G., Menon M.V. and Abraham, C.T. 2017. Herbicidal management of Chinese sprangletop (*L. chinensis*) in direct seeded rice. *Indian J. Weed Sci.* 49(2): 176-178.

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

Januszek, K. 2011. The enzyme activity of the forest soils of Southern Poland as a measure of soil quality. *Electr. J. Polish Agric. Univ.* Available: http://www.ejpau.media.pl/volume14/issue2/art-01.html [20 Jan.2014].

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

Jha, P., Kumar, V., Godara, R.K. and Chauhan, B.S., 2017. Weed management using crop competition in the United States: a review. Crop Prot. 95: 31-37.

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

Karumuri, L. and Singh, R.K. (2015). Effect of agrochemicals on the growth of different *Trichoderma* isolates. *Bioscan* 10(4): 1863-1867.

KAU (Kerala Agricultural University). 2016. *Package of Practices Recommendations: Crops 2016* (15th Ed). Kerala Agricultural University, Thrissur. 392 p.

Kaur, H.R. and Dhillon, B.S. 2018. Control of *Phalaris minor* with sequential application of pre-and post-emergence herbicides and herbicide combinations in wheat. *Indian J. Weed Sci.* 50(4): 351-354.

Kaur, S., Bhullar, M.S. and Kaur, T. 2016. Management of mixed weed flora in transplanted rice using herbicide combinations. *Agric. Res. J.* 53(4): 483-487.

Kaur, S., Kaur, T. and Bhullar, M.S. 2017. Control of mixed weed flora in wheat with sequential application of pre and post-emergence herbicides. *Indian J. Weed Sci.* 49(1): 29-32.

Khaliq, A., Matloob, A., Mahmood, S., Abbas, R.N. and Khan, M.B. 2012. Seeding density and herbicide tank mixtures furnish better weed control and improve growth, yield and quality of direct seeded fine rice. *Int. J. Agric. Biol.* 14: 499-508.

Kumar, J., Kumar, A., and Sharma, B.C. 2010. Effect of chemicals 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, K.C. and Tripathi, N.N. 2007. Screening of agrochemicals against *Rhizoctonia solani* under laboratory conditions. *Agric. Sci. Digest.* 27(4): 247-250.

Kurhade, K.C., Gade, R.M., Belkar, Y.K. and Chaitanya, B.H. 2016. Detecting tolerance in *Pseudomonas fluorescens* to pesticides. *Agric. Sci. Digest.* 36(3): 247-249.

Lal, B. and Maharshi, R.P. (2007). Compatibility of biocontrol agents *Trichoderma* spp. with pesticides. *J. Mycol. Plant Path.* 37(2): 369-370.

Lap, N., Somsak, S., Yuli, I.M., Duy, L., Choy, L.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 Asian countries. The 4th Tropical Weed Science Conference, Chiang Mai, Thailand.

Latha, A. and Jaikumaran, U. 2015. Assessment of frequency, abundance and density of weed species in rice fields of *Kole* lands of Kerala, India. In: Proceedings volume III (Poster paper), 25th Asian-Pacific Weed Science Society Conference, Hyderabad, India. 12p.

Lupwayi, N.Z., Harker, K.N., Clayton, G.W., Turkington, T.K., Rice, W.A. and O'Donovan, J.T. 2003. Soil microbial biomass and diversity after herbicide application. *Can. J. Plant Sci*. 677-685.

Macek, J. and Lesnik, M. 1994. The influence of primiand triasulfuron herbicides on mycelial growth and sporulation of some parasitic soil fungi. *Zeitschrift-fuer Pflanzenkrankheiten und Pflanzenschutz*. 101: 492-497.

Madhavi, G.B., Bhattiprolu, S.L. and Reddy, V.B. 2011. Compatibility of biocontrol agent *Trichoderma viride* with various pesticides. *J. Hort. Sci.* 6(1): 71-73.

Madhavi, M., Kumar, C.P.C., Reddy, D.R. and Singh, T.V.K. (2008). Compatibility of mutant isolates of *Trichoderma* spp with agrochemicals. *J. Biol. Control* 22(1): 51-55.

Madhavi, M., Yakadri, M., Rani, P.L. and Ramprakash, T. 2016. Herbicide combinations for weed control in direct-seeded rice. *Indian J. Weed Sci.* 48(4): 369-371.

Madhuri, V., Arunodhayam, K. and Eswara Reddy, N.P. 2013. A review on non-target effect of herbicides and compatibility of herbicides with fungicides on soil borne plant pathogens- *Sclerotium rolfsii* Sacc., *Rhizoctonia solani* Kuhn. and *Fusarium udum* Butler. *Current Biotica* 7(1&2): 105-123.

Mahajan, G. and Chauhan, B.S. 2015. Weed control in dry direct-seeded rice using tank mixtures of herbicides in South Asia. *Crop Prot.* 72: 90-96.

Mahapatra, A., Saha, S., Munda, S., Meher, S., Jangde, H., Jena, J., Bastia, R. and Narayan, H. 2021. Herbicide mixture mediated soil environment analysis in wet direct-sown rice. *Int. J. Chem. Stud*. 9(1): 07-11.

Malik, R.S., Yadav, A., Malik, R.K. and Singh, S. 2005. Efficacy of clodinafop, fenoxaprop, sulfosulfuron and triasulfuron alone and as tank mixture against weeds in wheat. *Indian J. Weed Sci.* 37(3&4): 180-183.

Mani, V.S. and Gautam, K.G. 1973. Chemical weed control-effective and economical. *Indian Fmg.* 22: 191-121.

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.

Matzenbacher, F.O., Kalsing, A., Dalazen, G., Markus, C. and Merotto, A. 2015. Antagonism is the predominant effect of herbicide mixtures used for imidazolinone-resistant barnyard grass (*Echinichloa crus-galli*) control. *Plant Daniha* 33(3): 587-597.

Menon, M.V., Bridgit, T.K. and Girija, T. 2016. Efficacy of herbicide combinations for weed management in transplanted rice. *J. Trop. Agric.* 54(2): 204-208.

Menon, S.S., Prameela, P. and Abraham, C.T. 2014. Weed control in wet-seeded rice by post-emergence herbicides. *Indian J. Weed Sci.* 46(2): 169-171.

Menon. M.V. 2019. Herbicide mixtures for weed management in wet-seeded rice. *Indian J. Weed Sci.* 51(3): 295-297.

Mijangos, I., Perez, R., Albizu, I. and Garbisu, C. 2006. Effects of fertilization and tillage on soil biological parameters. *Enzyme Microbiol. Technol.* 40: 100-106.

Milicic, B., Terzic, V.A. and Kuzmanovic, D. 2003. Examination of capability of some soil microorganisms of inactivating simazine and atrazine. Zemljiste-i-biljka (Serbia and Montenegro). *Acta Biologica Yugoslavica* 52: 35-44.

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*. Doi: 10.1017/wet.2017.107.

Mishra, B.D., Sahoo, K.C., Sugata, G. and Rout, M.K. 2005. *In vitro* evaluation of plant extracts, oilcakes and agrochemicals against Web blight of greengram caused by *Rhizoctonia solani*. *J. Mycopathol. Res.* 43(2): 255-257.

Moeini, M.M., Baghestani, M. A. and Mashhadi, H.R. 2006. Possibility of tank mixing and foliar application of urea and selective herbicides in wheat (*Triticum aestivum* L.). *Appl. Entomol. Phytopathol.* 74(1-81): 103-121.

Mohapatra, S. and Tripathy, S.K. 2017. Tank mix application of selected herbicides and insecticides for weed and insect control in transplanted rice. *Indian J. Weed Sci.* 49(4): 312-316.

Mohapatra, S., Tripathy, S.K. and Mohanty, A.K. 2020. Herbicide combinations and nitrogen scheduling for weed management and yield improvement in transplanted rice. *Indian J. Weed Sci.* 52(4): 313-317.

Mondal, S., Kuiry, S.C., Ghosh, G.K., Biswas, P.K. and Malik, G.C. 2011. Effects of pyrazosulfuron-ethyl on soil microbial biomass carbon and ammonification in a lateritic soil of West Bengal. *J. Crop Weed* 7(2): 155-158.

Moody, K. 1981. Weed - Fertilizer interactions in Rice. *IRRI Research Paper Series. No. 68*. 35p.

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.

Mounisha, J. 2020. Bio-efficacy of pre-mix herbicide combinations for broad spectrum weed control in wet seeded rice. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 150p.

Mounisha, J. and Menon, M.V. 2020. Broad-spectrum weed management in wet-seeded rice by pre-mix herbicide combinations. *Indian J. Weed Sci.* 52(4): 378-380.

Mukherjee, D. 2020. Herbicide combinations effect on weeds and yield of wheat in North-Eastern plain. *Indian J. Weed Sci.* 52(2): 116-122.

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.

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.

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.

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

Nigam, A.K. and Gupta, V.K. (1979). *Handbook on Analysis of Agricultural Experiments*. IASRI, New Delhi.

Pandey, J. and Singh, R.P. 1994. Effect of sulfonylurea herbicides on weed control in wheat. *Indian J. Agron.* 39(4): 565-568.

Panse, V. and Sukhatme, P.V. (1976). *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Papavizas, G.C. 1983. *Trichoderma* and *Gliocladium*- Their biology, ecology and potential of biocontrol. *Ann. Rev. Phytopathol.* 23: 23-54.

Parime, B.C., Ingle, R.W., Deshmukh, V.V. and Dikkar, M. 2017. Compatibility of PSM associated with medicinal plants. *Indo-Am. J. Agric. Vet. Sci.* 5(2): 5-15.

Patel, T.U., Lodaya, D.H., Italiya, A.P., Patel, D.D. and Patel, H.H. 2018. Bio-efficacy of herbicides in direct-seeded rice. *Indian J. Weed Sci.* 50(2): 120-123.

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.

Pauli, A. and Schilcher, H. 2010. *In vitro* antimicrobial activities of essential oils monographed in the European Pharmacopoeia. In: Baser, C.K.H. and Buchbauer, G. (eds). *Handbook of Essential Oils. Science, Technology and Application* (6th Ed). New York, NY: CRC Press, Taylor & Francis Group, pp.353-548.

Pertile, M., Antunes, J.E.L., Araujo, F.F., Mendes, L.W., Van-den-Brink, P.J. and Araujo, A.S.F. 2020. Responses of soil microbial biomass and enzyme activity to herbicides imazethapyr and fumioxazin. *Sci. Rep.* 10: 7694. https://doi.org/10.1038/s41598-020-64648-3.

Pietryga, J. and Drzewiecki, S. 2011. Herbicide-fertilizer mixtures in integrated maize production. *Prog. Plant Prot.* 51(3):1371-1375.

Prakash, J., Singh, R., Yadav, R.S., Yadav, V.R.B., Dhyani, B.P. and Sengar, R.S. 2017. Effect of different herbicide and their combination on weed dynamics in transplanted rice. *Res. J. Chem. Environ. Sci.* 5(4): 71-75.

Prameela, P., Menon, S.S, Menon, M.V. 2014. Effect of new post-emergence herbicides on weed dynamics in wet seeded rice. *J. Trop. Agric.* 52(1): 94 -100.

Pratap, T., Singh, V.P., Singh, S.P. and Rekha. 2016. Effect of herbicides and their combinations on weed growth and yield of transplanted rice. *Indian J. Weed Sci.* 48(4): 356-359.

Pratap, T., Singh, V.P., Singh, S.P. and Rekha. 2016a. Herbicides combination for control of complex weed flora in transplanted rice (*Oryza sativa* L.). *Res. Crops* 17(4): 657-661.

Priya, R.S., Chinnusamy, S., 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(15): 1205-1212.

Rai, J. P., Dubey, K.S. and Kumar, B. 2007. *In vitro* screening of different fungicides and antifungal antibiotics against *Rhizoctonia solani* causing aerial blight of soybean. *J. Plant Dis. Sci*. 2(1): 54-56.

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.

Raj, S.K. Syriac, E.K., Girija Devi, L., Meenakumari, K.S., Kumar, V. and Aparna, B. 2015. Impact of new herbicide molecule bispyribac-sodium + metamifop on soil health under direct seeded rice lowland condition. *Crop Res.* 50(1, 2&3): 1-8.

Raj, S.K. and Syriac, E.K. 2016. A new herbicide mixture: bispyribac-sodium + metamifop 14% SE for weed control in wet seeded rice. *Res. Crops* 17(3): 421-427.

Raj, S.K., Syriac, E.K., Anith, K.N. and Meenakumari, K.S. 2017. Compatibility of biocontrol agents and N fixing organisms with post-emergence pre-mix herbicide-bispyribac-sodium + metamifop 14 % SE. *J. Appl. Nat. Sci.* 9(3): 1510-1514.

Rakes, M., Grützmacher, A.D., Pazini, J.B., Pasini, R.A. and Schaedler, C.E. 2017. Physicochemical compatibility of agrochemical mixtures in spray tanks for paddy field rice crops. *Planta Daninha* 35.

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.

Ramalakshmi, A., Arthanari, P.M. and Chinnusamy, C. 2017. Effect of pyrasosulfuron ethyl, bensulfuron methyl, pretilachlor and bispyribac-sodium on soil microbial community and soil enzymes under rice-rice cropping system. *Int. J. Curr. Microbiol. Appl. Sci.* 6 (12): 990-998.

Ramesha Y.M., Manjunatha, B., Kumar, G.S., Krishamurthy, and D., Umesh, M.R. 2017. Weed management in irrigated dry-seeded rice. *Indian J. Weed Sci.* 49(2): 113-116.

Rana, S.S., Badiyala, D. and Brari, P. 2017. Evaluation of herbicide combinations for controlling complex weed flora in wheat. *Indian J. Weed Sci.* 49(4): 335-340.

Rana, S.S., Badiyala, D., Sharma, N., Kumar, R., Thakur, R., Kumar, S. and Pathania, P. 2016. Herbicide combinations for weed management in direct-seeded rice. *Indian J. Weed Sci.* 48(3): 266-271.

Ranganathswamy, M., Patibanda, A.K., Chandrasekhar, G.S., Sandeep, D., Mallesh, S.B., and Kumar, H.B.H. 2012. Compatibility of *Trichoderma* isolates with selected fungicides *in vitro*. *Int. J. Plant Prot.* 5(1): 12-15.

Rao, C.V.R. and Divakar, B.J. 2002. Effect of three pesticides on the fungal bioagent, *Trichoderma viride*. *Frontiers Microbiol. Biotechnol. Plant Pathol.* 24: 183-186.

Rao, U.R., Murthy, K.M.D. and Reddy, C.V. 2009. Efficacy of bispyribac-sodium 10% SC- an early post-emergence herbicide on rice. *Proceedings of the National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity*, TNAU, Coimbatore, pp.2-3.

Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K. and Mortimer, A.M. 2007. Weed management in direct-seeded rice. *Adv. Agron*. 93: 153-255.

Reddy, K.R.N., Choudary, K.A. and Reddy, M.S. 2007. Antifungal metabolites of *Pseudomonas fluorescens* isolated from rhizosphere of rice crop. *J. Mycol. Plant Pathol.* 37(2).

Revathi, M. and Annadura, K. 2014. Effect of pre and post-emergence herbicides and various establishment methods on productivity and profitability of rice under sodic soil environment. *Madras Agric. J.* 101(1-3): 40-43.

Reyes, Y., Infante, D., García-Borrego, J., Pozo, E.D., Cruz, A. and Martínez, B. 2012. Compatibilidad de *Trichoderma asperellum* Samuels con herbicidas de mayor uso en el cultivo del arroz. Rev. *Protección Veg.* 27: 45-53.

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

Saini, J.P. 2005. Efficacy of cyhalofop-butyl alone and in combination with 2,4-D against mixed weed flora in direct seeded upland rice. *Indian J. Agron.* 50: 38-40.

Sandhya, Y., Rajan, C.P.D., Kumar, M.R. and Rani, A.R. 2018. Screening of herbicides against sclerotial viability of the *Rhizoctonia solani in vitro* and in soil. *Int. J. Curr. Microbiol. App. Sci.* 7(7): 1290-1297.

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.

Saravanan, L., Kalidas, P., Phanikumar, T., Deepthi, P. and Ravi babu, K. (2014). *In vitro* compatibility of *Trichoderma viride* with agrochemicals. *Ann. Plant Prot. Sci.* 22(1): 224-226.

Saravanane, P. 2020. Effect of different weed management options on weed flora, rice grain yield and economics in dry direct-seeded rice. *Indian J. Weed Sci.* 52(2): 102-106.

Sarkar, S.K., Patra, B.C., Jana, K. and Ghosh, K. 2016. Impact of different herbicides and their combinations on production economics of winter rice in West Bengal. *Indian J. Weed Sci.* 48(4): 442-444.

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.

Sekhar, L., Ameena, M. and Nimmy, J. 2020. Herbicides and herbicide combinations for management of *Leptochloa chinensis* in wet-seeded rice. *Indian J. Weed Sci.* 52(3): 211-216.

Sen, S., Kaur, R. and Das, T.K. 2020. Weed management in dry direct-seeded rice: Assessing the impacts on weeds and crop. *Indian J. Weed Sci.* 52(2): 169-174.

Sharma, L. 2105. Studies on compatibility of *Trichoderma viride* with recommended fungicides, insecticides, herbicides and plant products against major soil borne pathogen. M.Sc. (Ag) thesis, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, 67p.

Shinde, V.V., Jagtap, D.N., More, V.G., Mane, M.J. and Dademal, A.A. 2018. Study of bio efficacy and phytotoxicity of carfentrazone-ethyl 40% DF in direct seeded rice. *Int. J. Bio-resource Stress Manag.* 9(6): 695-701.

Shrivastava, S. 2015. Non target effects of various herbicides on bio control agent *Trichoderma* spp. and pathogen *Sclerotium rolfsii*, *Indian J. Appl. Pure Biol.* 30(1): 11-19.

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.

Singh, A.K., Singh, M.K. and Kumari, S. 2018. Effects of nitrogen levels and weed management in direct-seeded rice. *Indian J. Weed Sci.* 50(3): 290-293.

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 and Singh, V.P. 2005. Compatibility of clodinafop-propargyl and fenoxaprop-p-ethyl with carfentrazone-ethyl, metsulfuron-methyl and 2, 4-D. *Indian J. Weed Sci.* 37(1&2): 1-5.

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., Kaur, H., Aggarwal, N. and Sharma, P., 2015. Effect of herbicides on weeds growth and yield of greengram. *Indian J. Weed Sci*. 47(1): 38-42.

Singh, K., Singh, S. and Pannu, R.K. 2019. Efficacy of pendimethalin and cyhalofop-butyl + penoxsulam against major grass weeds of direct-seeded rice. *Indian J. Weed Sci.* 51(3): 227-231.

Singh, K.S. 2020. On farm assessment of ready mix herbicide combinations for broad-spectrum weed control in wheat. *Indian J. Weed Sci.* 52(2): 194-196.

Singh, M., Singh, M.K., Singh, S.P. and Sahu, R. 2015. Herbicide and nitrogen application effects on weeds and yield of wheat. *Indian J. Weed Sci.* 47(2): 125-130.

Singh, R., Pramanick, B., Singh, A.P., Neelam, S. K., Kumar, A. and Singh, G. 2017. Bio-efficacy of fenoxaprop-p-ethyl for grassy weed control in onion and its residual effect on succeeding maize crop. *Indian J. Weed Sci.* 49(1): 63-66.

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., 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, 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. Eco-friendly Agric.* 10(1): 74-76.

Soliman, I.E., Abd El-Hamid, G.M. and Fadl-Allah, A.M. 2011. Effect of herbicides and urea as additive on wheat, nutrient uptake, photosynthetic pigments and associated weeds. *J. Plant Prod., Mansoura Univ.* 2(10): 1393-1407.

Soni, J.K., Amarjeet, S.S.P. and Choudhary, V.K. 2021. Herbicide combinations for management of resistance in *Phalaris minor*. *Indian J. Weed Sci.* 53(1): 41-48.

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.

Sreelakshmi, K., Balasubramanian, R., Babu, R. and Balakrishnan, K. 2016. Herbicide combinations for weed management in transplanted rice. *Indian J. Weed Sci.* 48(1): 60-63.

Stewart, L.C., Nurse, R.E., Hamill, A.S. and Sikkema, P.H. 2017. Environment and soil conditions influence pre- and post-emergence herbicide efficacy in soybean. *Weed Technol.* 24(3).

Subbiah, B.V. and Asija, G.L.A. 1956. A rapid procedure for the estimation of available nitrogen in soils. *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: *Proceedings of National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity*, TNAU, Coimbatore, 63p.

Subhani, A., El-ghamry, M.A., Changyong, H. and Jianming, X. 2000. Effects of pesticides (herbicides) on soil microbial biomass carbon- a review. *Pakist. J. Biol. Sci*. 3(5): 705-709.

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.

Sudha, T., Babu, R. and Biradar, D.P. 2016. Weed management through tank mix and premix herbicides in wheat. *Indian J. Weed Sci.* 48(4): 378-380.

Surendran, M., Kannan G.S., Kamala, N. and Leenakumary, S. 2012. Compatibility of *Pseudomonas fluorescens* with agricultural chemicals. *J. Biol. Control* 26 (2): 190-193.

Sushir, M.A., Gaikwad, R.T., Aghav, S.T. and Bhadane, R.S. 2008. Induction of higher tolerance in *Trichoderma harzianum* against pesticides. *Asian J. Biol. Sci.* 3(1): 137-139.

Sushir, M.A., Sawashe, S.G. and Sali, V.M. 2016. Induction of higher tolerance in *Trichoderma harzianum* Rifai against selective pesticides *in vitro*. IPS (New Delhi), 14th International Workshop on *Trichoderma* and *Gliocladium*, Nagpur. p. 131.

Swanton, C.J., Nkoa, R. and Blackshaw, R.E., 2015. Experimental methods for crop-weed competition studies. *Weed Sci*. 63: 2-11.

Teja, K.C., Duary, B. and Dash, S. 2016. Sole and combined application of herbicides on composite weed flora of transplanted rice. *Indian J. Weed Sci.* 48(3): 254-258.

Thomas, C.G. and Abraham, C.T. 2007. *Methods in Weed Science*. AICRP on Weed Control, College of Horticulture, Vellanikkara, 108p.

Tsubo, M., Fukai, S., Basanayake, J., Tuong, T.P., Bouman, B. and Harnpichitvitaya, D. 2005. Estimating percolation and lateral water flow on sloping land in rainfed lowland rice ecosystem. *Plant Prod. Sci.* 8: 354-357.

Uhlirova, E., Elhottova, D., Triska, J. and Santruckova, H. 2005. Physiology and microbial community structure in soil at extreme water content. *Folia Microbiol.* 50: 161-166.

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&2): 50-58.

Vasudev, M., Kaushik, M.K., Dotaniya, M.L. and Das, H. 2020. Assessing bio-efficacy potential of herbicide combinations for broad-spectrum weed control in late-sown wheat. *Indian J. Weed Sci.* 52(3): 232-236.

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.

Verma, D.K., Pandey, A., Giri, S.P., Verma, S., Singh, J., Singh, A.K. and Kumar, A. 2017. Efficacy of different herbicidal formulation and its effect on soil microflora in transplanted rice of eastern Uttar Pradesh. *J. Pharmacog. Phytochem.* SP1: 522-525.

Vincent, J.M. 1927. Distortion of fungal hyphae in the presence of certain inhibitors. *Nature* 159: 850.

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

Yadav, D.B., Singh, N., Duhan, A., Yada, A. and. Punia, S.S. 2018. Penoxsulam + cyhalofop-butyl (premix) evaluation for control of complex weed flora in transplanted rice and its residual effects in rice-wheat cropping system. *Indian J. Weed Sci.* 50(4): 333-339.

Yadav, D.B., Singh, N., Kumar, J. and Yadav, A. 2019. Penoxsulam + butachlor: A new ready-mix herbicide for control of complex weed flora in transplanted rice. *Indian J. Weed Sci.* 51(4): 324-327.

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 bispyribac-sodium for weed control in transplanted rice. *Indian J. Weed Sci.* 41(1&2): 23-27.

Yadav, D.B., Yadav, A., Singh, S. and Lal, R. 2009a. Compatibility of fenoxaprop-p-ethyl with carfentrazone-ethyl, metsulfuron-methyl and 2,4-D for controlling complex weeds of Wheat. *Indian J. Weed Sci.* 41(3&4): 157-160.

Yakadri, M., Madhavi, M., Rampraksh, T. and Rani, L. 2016. Herbicide combinations for control of complex weed flora in transplanted rice. *Indian J. Weed Sci.* 48(2): 155-157.

Yogananda, S.B., Thimmegowda, P. and Shruthi, G. K. 2019. Sequential application of pre- and post-emergence herbicides for control of complex weed flora in dry direct-seeded rice under Cauvery command area of Karnataka. *Indian J. Weed Sci.* 51(2): 111-115.

Yogananda, S.B., Thimmegowda, P. and Shruthi, G.K. 2017. Weed management effect on growth and yield of wet direct-seeded rice in Cauvery command area of Karnataka. *Indian J. Weed Sci.* 49(3): 219-222.

Zentmyer, G. A. 1955. The world of *Phytophthora.* In: Erwin, D. C., Bartnicki-Garcia, S. and Tsao, P. H. (eds), *Phytophthora*: *Its Biology, Taxonomy, Ecology and Pathology*, American Phytopathological Society, St Paul, Minnesota, USA, pp. 1-8.

Zhang, W., Webster, E.P., Blouin, D.C., & Leon, C.T. 2005. Fenoxaprop interactions for Barnyardgrass (*Echinochloa crus-galli*) control in rice. *Weed Technol.* 19(02): 293-297.

Appedix

Appendix- I

Mean Monthly weather parameters recorded during crop growth period of 2019-20 and 2020-21

Year	Month	Rain fall (mm)		Temperature (^oC)		Relative humidity (%)	Bright sunshine (hrs/day)		Wind Speed (km/h)	Evaporation	
		Total	Rainy days	Max.	Min.	Mean	Total	Mean		Total (mm)	Mean (mm/day)
2019-20	October	418.4	16	32.4	21.4	80	170.2	5.5	1.8	84.0	2.7
	November	205.0	5	32.9	21.7	71	224.9	7.5	4.0	101.5	3.4
	December	4.4	1	32.3	22.1	63	208.8	6.7	8.7	140.7	4.5
	January	0.0	0	34.1	22.4	61	290.2	9.4	5.9	151.0	4.9
2020-21	October	310.3	12	31.0	21.5	82	170	5.5	1.5	75.5	2.4
	November	56.1	2	33.0	22.0	70	198.5	6.6	4.4	107.4	3.6
	December	7.7	1	32.0	21.9	65	193.9	6.3	6.7	135.2	4.4
	January	45.7	1	32.3	21.3	64	206.1	6.6	5.9	132.4	4.3

Appendix- II

Details of cost of cultivation

S. No.	Particulars	Men/ha		Women/ha		Amount (Rs./ha)	
		1st year	2nd year	1st year	2nd year	1st year	2nd year
1	Cleaning the field	12	12	-	-	7,200	7536
2	Land preparation (Ploughing and puddling 2000 Rs./acre)	-	-	-	-	5,000	5,000
3	Lime application	2	2	-	-	1,200	1,250
4	Sowing (700/acre)	2	2	-	-	1,200	1,250
5	Herbicide spraying	2	2	-	-	1,200	1,250
6	Hand weeding Twice	25	-	-	27	15,000	16,956
7	Plant protection chemical and organic foliar spraying by drone	-	-	-	-	1,500	1,500
8	Fertilizer and top dressing	2	2	-	-	1,200	1,200
9	Harvesting	20	-	-	22	12,000	13,750
Total						**45,500**	**49,692**

- Labour charge 1st year-Rs. 600/day, and 2nd year- Rs. 625/day
- In experiment –II, labour charges for complete removal of weeds except in unweeded control plot, in 1st year and 2nd year were Rs. 7,200 and 7536 /ha for 12 men and women labourers, respectively

Appendix- III

Details of cost of inputs

S. No.	Particulars	Quantity/ha	Amount/ha
1	Lime @ 10/kg	600 kg	6,000
2	Urea@ Rs. 6.16/kg Factom phos @ Rs. 20.5/kg MOP @ Rs. 19.2/kg	196 kg 175 kg 75 kg	1,207.5 3,587.5 1,440
3	Seed @ Rs. 44/kg	100 kg	4,400
4	Micronutrient mixture	12.5	2,490
5	PP chemicals	-	1,500
6	(Chlorimuron-ethyl + metsulfuron-methyl)	20 g	442.5
7	Cyhalofop-butyl	800 ml	1,728
8	(Cyhalofop-butyl + penoxsulam)	2,250 ml	4,275
9	Carfentrazone-ethyl	50 g	480
10	Bispyribac-sodium	250 ml	2,065
11	Fenoxaprop-p-ethyl	900 ml	2,000
		Total	**31,652.5**

- In experiment -II urea used 200 kg in 1st year and 2nd year were 1232 Rs./ha cost.

Bio-efficacy of tank mixed herbicides and urea in wet seeded rice

By

THUMU VENKATESWARA REDDY

2018-21-052

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

Doctor of Philosophy in Agriculture

(AGRONOMY)

Faculty of Agriculture

Kerala Agricultural University

Department of Agronomy

COLLEGE OF AGRICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

ABSTRACT

The use of herbicides has become an indispensable part of agriculture, particularly in rice cultivation, where weeds are the most harmful of the biotic constraints to production. A usual practice among rice farmers in the *Kole* lands of Kerala is the tank mixing of herbicides, for a broader spectrum of weed control, enhanced weed control efficiency and reduction in the cost of application. However, mixing of herbicides is done without any knowledge of the probable synergistic or antagonistic interactions on weed flora. Herbicides are also mixed with fertilizers like urea under the common belief that herbicidal efficiency is enhanced by this practice.

Application of herbicides may affect various plant pathogens and microbial bioagents which occur naturally in the rice ecosystem. Information of the effect on main disease causing as well as beneficial microorganisms would help in selecting appropriate herbicides.

Hence the major objectives of the research programme entitled “Bio-efficacy of tank mixed herbicides and urea in wet seeded rice” were to study the synergistic or antagonistic effect of tank mixing of commonly used herbicides, and to evaluate the efficiency of these herbicides on mixing with urea, on major weeds of rice. The effect of these herbicides on beneficial and pathogenic microorganisms were also investigated.

Two field experiments were conducted at Alappad *padasekharam* in the *Kole* lands of Thrissur from October to January 2019-20 and 2020-21. The soil of experimental field was clayey in texture, high in organic carbon (1.1-1.3%), low available nitrogen (180-188 kg/ha), and medium phosphorus (20-21.5 kg/ha) and potash (152-159 kg/ha), with a soil pH of 4.5-4.7. The feasibility of mixing herbicides was evaluated in experiment I (Bio-efficacy of tank mixed herbicide combinations in wet seeded rice). There were fourteen treatments and they included tank mixtures and sequential applications of five herbicides viz., fenoxaprop-p-ethyl (0.06 kg/ha), (chlorimuron-ethyl + metsulfuron-ethyl) (0.004 kg/ha), carfentrazone ethyl (0.02

kg/ha), bispyribac-sodium (0.025 kg/ha), and (cyhalofop-butyl + penoxsulam) (0.15 kg/ha). These were compared with two broad spectrum herbicides, bispyribac-sodium (0.025 kg/ha) and (cyhalofop-butyl + penoxsulam) (0.15 kg/ha), as well hand weeded and unweeded controls. In experiment II (Bio-efficacy of tank mixed herbicides and urea in wet seeded rice), there were twelve treatments. Six herbicides, viz., cyhalofop butyl (0.08 kg/ha), (cyhalofop butyl + penoxsulam) (0.15 kg/ha), bispyribac-sodium (0.025 kg/ha), fenoxaprop-p-ethyl (0.06 kg/ha), carfentrazone ethyl (0.02 kg/ha) and (chlorimuron ethyl + metsulfuron methyl) (0.004 kg/ha) were applied with and without urea (1%) mixing. Hand weeded and unweeded controls were also included for comparison. Randomized Block Design with three replications was adopted for both experiments. Wet seeding of rice at the seed rate of 100 kg/ha was done. Nitrogen, phosphorus and potassium @ 90:35:45 kg/ha were supplied through urea, factomphos and muriate of potash (KAU, 2016).

In experiment III (*In vitro* evaluation of herbicides on beneficial and pathogenic microorganisms) treatments included the effect of herbicides mentioned in experiment II which were evaluated under *in vitro* conditions with recommended, higher and lower doses on beneficial microbial bioagents (*Trichoderma viride* and *Pseudomonas fluorescens*) and pathogenic microorganisms (*Rhizoctonia solani*, *Pyricularia oryzae* and *Xanthomonas oryzae* pv. *oryzae*). Factorial Completely Randomized Block Design was adopted with 18 treatments and three replications each.

Tank mixing of herbicides was found to be more effective than their sequential application for most of the combinations. Tank mixed combination of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) showed synergistic effect and had lowest weed density (32, 16 and 20 nos./m^2), lowest weed dry matter production (14.68, 50.50 and 88.95 kg/ha), and highest weed control efficiency (91, 88, and 82%) at 15, 30 and 60 days after application respectively. The number of tillers per sq. m (411), number of panicles per sq. m (288), number of grains per panicle (103), percentage of filled grain (91.6) at harvest, nutrient uptake by rice at 60 DAS (105.06, 14.32 and 74.28 kg/ha of N, P and K respectively), grain yield (3.97 t/ha), net returns (Rs.71,406/ha) and benefit: cost ratio (2.25) were highest in the same treatment. The next best treatment was fenoxaprop-p-ethyl + bispyribac sodium.

On tank mixing of herbicides with urea, bispyribac-sodium and urea interacted synergistically, resulting in highest weed control efficiency (82.5 and 78% at 15 and 30 days after application respectively), highest grain yield (5.03 t/ha), and profitability (Rs. 93,509/ha) over the other treatments. Mixing of (cyhalofop-butyl + penoxsulam) with urea could also be recommended for good results (grain yield of 4.94 t/ha and net returns of Rs.87,463/ha).

In vitro evaluation of herbicides revealed that bispyribac-sodium and (cyhalofop-butyl + penoxsulam) had greatest inhibitory effect on pathogenic microorganisms *Rhizoctonia solani* and *Pyricularia oryzae*, but showed no effect on *Xanthomonas oryzae* pv. *oryzae*, and were less harmful to biocontrol agents *Trichoderma viride* and *Pseudomonas fluorescens* at recommended doses.

Tank mix combination of (cyhalofop-butyl + penoxsulam) with (chlorimuron-ethyl + metsulfuron-methyl) was the best treatment with compatibility, efficient weed control, high grain yield and net returns. Tank mixing of bispyribac-sodium with urea 1% had synergistic effect resulting in highest weed control efficiency, production and profitability over the other treatments. Mixing of (cyhalofop-butyl + penoxsulam) with urea 1% could also be recommended for good results. Bispyribac-sodium and (cyhalofop-butyl + penoxsulam) were the best herbicides on *in vitro* evaluation in their effect on pathogenic microorganisms *Rhizoctonia solani* and *Pyricularia oryzae*, and at recommended doses were compatible with biocontrol agents *Trichoderma viride* and *Pseudomonas flourescens*.