GERMINATION ECOLOGY AND MANAGEMENT OF CHINESE SPRANGLETOP [*Leptochloa chinensis* (L.) Nees.] IN WET SEEDED RICE

by

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(2017-21-023)

THESIS

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DECLARATION

I, Lekshmi Sekhar (2017-21-023) hereby declare that this thesis entitled **"GERMINATION ECOLOGY AND MANAGEMENT OF CHINESE SPRANGLETOP [*Leptochloa chinensis* (L.) Nees.] IN WET SEEDED RICE"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"GERMINATION ECOLOGY AND MANAGEMENT OF CHINESE SPRANGLETOP [*Leptochloa chinensis* (L.) Nees.] IN WET SEEDED RICE"** is a record of research work done independently by **Miss. Lekshmi Sekhar** (2017-21-023) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Lekshmi Sekhar

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATION

ACCase	-	Acetyl Coenzyme-A carboxylase
a.i.	-	Active ingredient
ALS	-	Acetolactate synthase
B: C/BCR	-	Benefit: Cost ratio
BLW	-	Broad leaf weeds
BS	-	Bispyribac sodium
C	-	Carbon
CB	-	Cyhalofop butyl
CD(0.05)	-	Critical difference at 5 per cent level
CE	-	Control efficiency/Carfentrazone ethyl
cm	-	Centimeter
CRD	-	Completely randomized design
CV	-	Coefficient of variation
d	-	Days
DALP	-	Days after land preparation
DAS	-	Days after sowing
DASP	-	Days after spraying
DAT	-	Days after transplanting
DATA		Days after treatment application
DF	-	Dry flowables
DMP	-	Dry matter production
ds m^{-1}	-	Deci seimens per meter
DSR	-	Direct seeded rice
EC	-	Electrical conductivity/ Emulsifiable concentrate
EPSP	-	5-enol pyruvylshikimate-3- phosphate
et al.	-	Co-workers/ Co-authors
etc.	-	Excetra
f	-	Form species

fb	-	Followed by
Fig	-	Figure
FPE	-	Fenoxaprop-p-ethyl
FRD	-	Field recommended dose
FYM	-	Farmyard manure
g L^{-1}	-	Gram per litre
g m^{-2}	-	Gram per square meter
g $plant^{-1}$	-	Gram per plant
g $plot^{-1}$	-	Gram per plot
GR	-	Granules
h	-	hour
ha	-	Hectare
ha^{-1}	-	Per hectare
HI	-	Harvest index
hills m^{-2}	-	Hills per square metre
HW	-	Hand weeding
i.e.	-	That is
K	-	Potassium
K_2O	-	Potash
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
L	-	Litre
L^{-1}	-	Per litre
L ha^{-1}	-	Litre per hectare
m	-	Meter
m^2	-	Square meter
m^{-2}	-	Per square meter
Max	-	Maximum
mg	-	Milligram
mg dL^{-1}	-	Milligram per decilitre

mg mL^{-1}	-	Milligram per millilitre
m ha	-	Million hectares
Min	-	Minimum
ml	-	Millilitre
mm	-	Millimeter
mM	-	Millimolar
MSE		Months from the start of the experiment
MSL	-	Mean sea level
mt	-	Million tonnes
N	-	Nitrogen
NaCl	-	Sodium chloride
nm	-	Nanometer
No.	-	Number
no. m^{-2}	-	Number per square metre
OC	-	Organic carbon
OD	-	Oil dispersion
P	-	Phosphorus
P_2O_5	-	Phosphoric acid
pH	-	Potential hydrogen
plant $^{-1}$	-	Per plant
PS	-	Penoxsulam
RA	-	Relative abundance
RBD	-	Randomized block design
RD	-	Relative density
RF	-	Relative frequency
rpm	-	Rotations per minute
SC	-	Soluble concentrate
SDR	-	Summed dominance ratio
SDS PAGE	-	Sodium Dodecyl Sulphate - Poly Acrylamide Gel Electrophoresis
SEm	-	Standard error mean

SL	-	Soluble liquid
Sl. No.	-	Serial number
SP	-	Soluble powder
sp./spp.	-	Species
SSB	-	Stale seedbed
t ha^{-1}	-	Tonnes per hectare
UV	-	Ultra violet
viz.	-	Namely
WCE	-	Weed control efficiency
WI	-	Weed index
WSR	-	Wet seeded rice
µL	-	Micro litre

LIST OF SYMBOLS

@	-	At the rate of
-	-	To
%	-	Per cent
₹	-	Rupees
±	-	Plus or minus
^{o}C	-	Degree centigrade
^{o}E	-	Degree east
^{o}N	-	Degree north
/	-	Or
>	-	Greater than

Introduction

1. INTRODUCTION

Rice is one of the most important staple foods for more than 3.5 billion people all over the world (CGIAR, 2020), the majority of which are located in Asia. In South Asia, rice was cultivated in 60 million hectares (m ha) and production was slightly above 242 million tonnes (mt) accounting for 37.9 and 34.5 per cent of global area and production in 2018, respectively. In India, it is grown in an area of about 40.10 m ha with a total production of 102.36 mt with a productivity of 2.55 t ha^{-1} during 2020-21 (GOI, 2020).

Transplanting of rice seedlings after repeated puddling is the traditional and conventional system of crop establishment, but it demands huge quantity of water. The forbidding water scenario in agriculture demands crop establishment technologies that inherently require less water and are more efficient in water use. Direct seeded rice (DSR) cultivation has been introduced as an alternative to traditional transplanted rice in many Asian countries. Coupled with water scarcity, increased crop production costs have led to a widespread shift from transplanted to direct seeded rice production systems across the globe. However, weed flora tends to be more diverse under direct seeded rice cultivation and several flushes of weeds emerge during the crop growth period and cause substantial yield loss due to severe weed competition. Weeds tend to be more problematic in DSR as the emerging weeds are more competitive than the concurrently emerging DSR seedlings and absence of water layer in wet and dry DSR makes these crops more susceptible to early weed infestation (Rao *et al*., 2007).

Effective weed management measures are critical in the success of direct seeded rice (Kumar and Ladha, 2011). Hand weeding, though effective, is fetching less attention and more difficult owing to increased labour paucity, mounting wages and its dependence on weather conditions. Furthermore, the morphological similarity of grass weeds to cultivated rice makes hand weeding incomplete and ineffective. Escape or regeneration of perennial weeds with many flushes also makes hand weeding imperfect and impractical during adverse weather conditions (Singh, 2008).

Due to the long critical infestation timing of some weeds (5-8 weeks), repeated hand weeding should be conducted in DSR to avoid economic yield loss, making this practice uneconomical (Ahmed and Chauhan, 2014). Herbicides are more labor efficient than hand/manual or mechanical weed management methods and provide excellent weed control (Chauhan *et al*., 2014) and ensure a high B: C ratio (Bahar and Singh, 2004).

In rice ecosystems, extensive introduction of direct seeding and repetitive herbicide use are the key factors accountable for the shift in weed species populations (Chauhan and Johnson, 2008). One such example resulted from the adoption of these practices is the dominance of the weed *Leptochloa chinensis,* also known as 'Chinese sprangletop'. It was earlier confined to the alkaline soils of Chittoor taluk as a weed specific to alkaline conditions. Of late, *L. chinensis* has emerged as one of the problematic weeds in rice due to the shift in weed flora in the paddy fields of Kerala (Jacob, 2014). The continuous use of bispyribac sodium for broad spectrum weed control by the rice farmers of Kerala has aggravated the situation and severe infestation of this weed has been reported from the major rice growing tracts of Kerala, *viz*., Kuttanad, *Kole* and Palakkad.

Being identified as a major grass weed in the majority of rice growing areas of the state, formulating an effective and economically viable management strategy for *L. chinensis* is highly essential before its infestation reaches alarming proportion. Farmers prefer broad spectrum weed management technologies to save on crop expenses. The use of compatible mixtures of novel herbicides is one option to broaden the spectrum of weed control and to prevent further build-up of herbicide resistance. Moreover, an understanding of the germination ecology, emergence dynamics and growth requirements of weeds is highly essential both for managing the infestation dynamics of different weed species and for formulating effective management strategies. One major constraint in the development of long-term management strategies in crop ecosystems is the insufficient understanding of the reasons for weed species infestation and dominance.

Knowledge of weed biology and ecology is highly essential and serves as a guide for the adoption of appropriate management techniques. Determining specific management tactics for certain species can be derived from knowledge of their seed biology and their floristic associations (Bhowmik, 1997). Effective control of weeds could be attained with a better understanding of the factors that impede or encourage weed seed germination (Chauhan, 2012).

The availability of effective herbicides for weed control is important to the success of direct seeding in rice and herbicides with both foliar and soil activity have better weed control efficiency as they can effectively check the subsequent establishment by reducing weed seed bank. Though herbicides are effective and economical in controlling weeds in DSR, repeated and non-judicious use of the same herbicides or herbicides with a similar mode of action ensues a gradual or rapid inter and intraspecific shift in the weed flora of rice ecosystems. Testing comparative efficiency of tank mix application of herbicides is essential for standardizing the effective dose for herbicide combinations. Though information on the mode of action of individual herbicides is available, the mode of action of herbicide combinations for effective weed management is not yet explored fully. Testing the efficacy of these herbicides and herbicide combinations in wet seeded rice (WSR) with special reference to *L. chinensis* is essential for formulating a cost-effective integrated weed management strategy. In this context, the present study was undertaken with the following objectives:

1. To study the habitat features and distribution of *L. chinensis* in major rice tracts of Kerala.
2. To study the germination ecology of *L. chinensis* under varying conditions
3. To study the bio-efficacy and mode of action of tank mix combinations of novel herbicides for the management of *L. chinensis*
4. To study the sensitivity of *L. chinensis* to herbicide combinations

Review of Literature

2. REVIEW OF LITERATURE

Among the biotic constrains in rice production, weeds create a greater threat especially in direct seeded rice (DSR). Weed flora in DSR is more diverse and several flushes of weeds get emerged during the crop growth period causing severe crop weed competition leading to substantial yield loss. The availability of effective herbicides for weed control is the key for success of DSR. Herbicidal weed management can be made more effective with suitable combinations, and could be helpful in reducing the build-up of resistance and weed shift. Continuous use of bispyribac sodium for broad spectrum weed control in rice and use of cyhalofop butyl for the control of barnyard grass has led to the dominance of *Leptochloa chinensis* in the paddy fields of Kerala. This calls for the development of an effective weed management strategy for *L. chinensis* in wet seeded rice (WSR).

This chapter provides a brief overview of biology and germination ecology of *L. chinensis*, crop weed competition with a focus on *L. chinensis*, weed management options and their impact on yield attributes and yield in WSR.

2.1 BIOLOGY AND ECOLOGY OF *Leptochloa chinensis*

2.1.1 Classification

Leptochloa chinensis (L.) Nees is a grass under the family Poaceae, class monocotyledonae, subphylum angiospermae, phylum spermatophyta and order cyperales.

2.1.2 Variability in *Leptochloa* sp.

The genus Leptochloa, belonging to the Poaceae family comprises of 45 species extensively seen in tropical and subtropical regions (MacFarlane, 1987). Morphological and physiological adaptations permit some species of Leptochloa to behave as halophytic and xerophytic species (*L. dubia*), whereas others (*L. filiformis*, *L. fascicularis* and

L. chinensis) are found in wetland or flooded environments (Manidool, 1992). These habitat requirements along with noticeable competitiveness, make *L. chinensis*, *L. fascicularis* and *L. filiformis* as typical rice (*Oryza sativa* L.) weeds globally (Fisher *et al*., 1993).

2.1.3 Origin, spread and distribution

Leptochloa chinensis is a native of tropical Asia and widely distributed in the Pacific basin (Hafliger and Scholz, 1981), South Asia, East Asia, South East Asia, Africa, and Australia (Chauhan and Johnson, 2008), North America, Fiji, Samoa and Papua New Guinea (IRRI, 2020a).

Leptochloa chinensis generally known as 'Chinese sprangletop' or 'Red sprangletop' or 'Asian spangletop' is one of the most problematic grass weeds in DSR fields (Chin 2001). It also invades sugarcane (*Saccharum officinarum* L.), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), soybean (*Glycine max*), sweet potato (*Ipomoea batatas* L.), peanut (*Arachis hypogaea* L.), banana (*Musa* sp.), pineapple (*Ananas comosus* L.), tea (*Camellia sinensis* L.) and other crops (CABI, 2019).

Leptochloa chinensis is listed as a 'Federal Noxious Weed' in the USA (Westbrooks, 1989). *L. chinensis* has been documented to occur in dry seeded rice in 16 countries and in WSR in seven more countries (Rao *et al*., 2007). Despite being a relatively new entrant, *L. chinensis* has established itself as a troublesome weed in the major rice growing areas of Kerala (Jacob, 2014).

When the seeds of *L. chinensis* are occasionally co-harvested in crops, the infestation can occur and its small sized seeds can be removed by thorough cleaning and the spread was aided by the use of contaminated rice stocks (Holm *et al*., 1977). Seeds, seed heads, and stolons of *L. chinensis* are likely to be found as contaminants of rice and row crop seeds (Westbrooks, 1989). According to Benvenuti *et al*. (2004), *L. chinensis* was introduced into rice farms in northern Italy via contaminated rice seeds.

2.1.4 Habit and Habitat

Leptochloa chinensis is an aquatic or semiaquatic strongly tufted, annual or short lived perennial grass in croplands, wetlands, waterways, swamps, or streams in open lowland regions of the tropics and is adaptive to heavy or light soil conditions. It can also grow in upland and lowland rice fields. In Java (Indonesia), it grows from sea level to 900 m in altitude (Holm *et al*., 1977).

As *L. chinensis* can thrive in both flooded and upland habitats, it is a prevalent weed in rice and other crops (Galinato *et al*., 1999). Although it is an annual plant, it can become perennial in the appropriate growing conditions (Chauhan and Johnson, 2008). As a C_4 grass, proliferation of this weed is likely under conditions of increased levels of atmospheric CO_2 due to climate change.

2.1.5 Morphology of *L. chinensis*

Leptochloa chinensis is a slender, strongly tufted C_4 grass species that grows to a height upto 1.2 m with smooth glabrous linear leaves with terminal loose panicle and a fibrous root system (Soerjani *et al*., 1987).

Leptochloa chinensis has erect or ascending flowering culms that grow from a branching base. They have 3-6 nodes with smooth, grooved, and striate glabrous internodes that are hollow. The leaf sheaths are keeled, glabrous, smooth, not ciliate, distinctly nerved, and usually longer than the associated internodes. They are erose and deeply split into hair-like pieces (CABI, 2019).

2.1.6 Characters of *L. chinensis*

Leptochloa chinensis is normally propagated by seeds, although it can be vegetatively reproduced by dividing culm clumps or rootstocks after cultivation or ploughing. Each inflorescence has the ability to produce hundreds of seeds and an individual plant may have numerous inflorescences (Holm *et al*., 1977).

Leptochloa chinensis has a propensity to be invasive, which has been associated with its prolific seed production (Manidool, 1992; Chin, 2001). Kathiresan (2004) also reported *L. chinensis* as an invasive alien weed in rice.

2.1.7 Germination, Dormancy and Longevity

Studies conducted in South West Japan revealed that the germination of *L. chinensis* seeds were light sensitive and germinated under moist conditions in light at 30-40°C (Matsuo *et al*., 1987). Germination of *L. chinensis* was phytochrome dependent and was strongly influenced by warm fluctuating temperatures with minimum germination at 15°C and optimum germination at 25-35°C (Benvenuti *et al*., 2004). Temperature fluctuation caused an increase of seed germination in the dark (Benvenuti *et al*., 2004).

A small period of dry conditions resulted in higher germination and emergence of *L. chinensis* (Chin, 2001). An unusual germination was observed with seed burial and concomitant flooding and seed burial suppressed the germination and emergence of *L. chinensis*. Only five per cent of seedlings emerged under flooded conditions at 5 cm burial depth, while at the same depth, no seedling emergence was observed without flooding (Benvenuti *et al*., 2004). Seed burial depth in soil sturdily influenced emergence of *L. chinensis* and maximum emergence (80%) was observed from seeds placed on the soil surface whereas, no seedlings emerged from seeds buried at depths of greater than 0.5 cm (Chauhan and Johnson, 2008). Flooding had a suppressive effect on the emergence of *L. chinensis* (Chauhan and Johnson, 2008) and seeds does not germinate when submerged in water (IRRI, 2020a).

Matsuo and Kataoka (1983) stated that the breaking of *L. chinensis* seed dormancy fluctuated with storage conditions. Compared to upland conditions in summer, seeds exhibited greater longevity under flooded conditions especially in May-September (Matsuo *et al*., 1987).

2.1.8 Uses

Leptochloa chinensis is used as feed for animals. It is an excellent pasture grass with tender panicles much relished by livestock (Maideen, 1889). The grain is used as famine food in East Africa (IRRI, 2020a).

2.1.9 Importance

In the Philippines, *L. chinensis* has been documented as an alternate host of sheath blight, blast and Udbatta diseases, which are caused by *Rhizoctonia solani* Kuhn, *Pyricularia oryzae* Cavara and *Ephelis oryzae* Sydow, respectively (Mackill and Bonman, 1986). *L. chinensis* has a potential role in the dispersal of leaf hoppers such as *Nephotettix virescens, N. nigropictus, N. malayanus*, and *Recilia dorsalis,* which transmits rice viruses such as rice tungro spherical virus (RTSV) and rice tungro bacilliform badna virus (RTBV) (Khan *et al*., 1996).

Leptochloa chinensis is an alternate host of several insects and nematodes (Barrion and Litsinger, 1987) and includes *Nephotettix* spp., *Cnaphalocrocis medinalis* (Guenee), *Scotinophara latiscula* (Heinrich *et al.*, 2017), *Creatonotus gangis* Linnaeus, *Cicadulina bipunctata* (Melichar), *Marasmia* spp., *Peregrinus maidis* (Ashmead), *Spodoptera mauritia* acronyctoides (Guenee), *Pseudococcus saccharicola* Takahashi and nematodes such as *Meloidogyne* sp. and *Hirschmanniella* sp. (IRRI, 2020a)

2.2 DIRECT SEEDED RICE/ WET SEEDED RICE

The forbidding water scenario in agriculture necessitates crop establishment technologies that inherently consume less water and are more water efficient. Transplanting of rice seedlings after repeated puddling is the traditional and conventional system of rice cultivation in many Asian countries, which involves extensive amount of water. Direct seeding of rice, a water wise technology is gaining more popularity owing to its low input demand and now is the only viable option to enhance water productivity in rice production (Kaur and Singh, 2017).

Direct seeded rice cultivation has been introduced as an alternative to traditional transplanting in many Asian countries. The rice production system in many Asian countries has shifted from transplanted rice to DSR (Benvenuti *et al*., 2004; Kumar and Ladha, 2011).

Direct seeding is a more cost-effective and labor-saving alternative to transplanting and involves the practice of either wet seeding or dry seeding. Awan *et al*. (2006) reported that DSR yielded nearly as much as transplanted crop. In wet seeding, pre-germinated seeds are sown either on wet soil using drum seeder or by broadcasting and in dry seeding, dry seeds are broadcasted or place in rows using seed drill either on zero tilled or tilled soil (Rao *et al*., 2007; Rao and Nagamani, 2013).

Direct seeding has several advantages, including reduced labour and drudgery, more efficient water use and higher tolerance to water deficit (Bhushan *et al*., 2007), lower methane emissions (Farooq *et al*., 2011), higher profit in areas with assured water supply (Rao and Ladha, 2013) and earlier crop maturity (matures 7 to 10 days earlier than transplanted rice) due to absence of transplanting shock (Rana *et al*., 2014).

Despite the fact that DSR has various advantages and could be a viable alternative to traditional transplanting, poor germination, inconsistent crop stand and significant weed infestation are the major constrains in DSR (Farooq *et al*., 2011).

Weed competition is greater in WSR than transplanted rice due to similarities in morphological characters of grass weeds and rice seedlings and growth (Moody, 1983), lack of water to inhibit weeds at seedling emergence and the presence of difficult-to-control competitive weeds (Choubey *et al*., 2001). As the crop and weeds emerge simultaneously in DSR, the crop suffers competition even from early stages of growth which in turn reduces the grain yield (Choubey *et al*., 2001). Weeds are the most significant biotic constraint in DSR, as emerging weeds are more competitive than simultaneously emerging DSR seedlings, and the lack of a water layer in both wet and dry DSR makes these crops more susceptible to initial weed infestation (Rao *et al.*, 2007).

Weeds emerge concurrently with rice in direct seeded fields and offers competition for resources making it a major stumbling block for farmers practicing direct seeding (Rao and Nagamani, 2007).

2.2.1 Weed spectrum in direct seeded rice

Weed flora related with an ecosystem be influenced by environmental characters, cultivation practices followed and several biotic and abiotic factors. Among the flora, grass weeds pose serious threat followed by (*fb*) sedges and dicot weeds causing substantial yield reduction across the globe (Ali *et al.*, 2018).

Prasuna and Rammohan (2015) reported that grass weeds were the predominant weed flora in DSR (89.96% and 98.32% at 30 and 70 days after sowing (DAS), respectively), *fb* broad leaf weeds (BLWs) (8.75% and 1.26% at 30 and 70 DAS, respectively) and sedges (1.29% and 0.42% at 30 and 70 DAS, respectively).

In DSR, Hussain *et al.* (2008) and Singh and Singh (2010a) observed *Cyperus difformis, Cyperus iria, Sphenoclea zeylanica, Echinochloa crus-galli, Echinochloa colona, Fimbristylis miliacea* and *Eclipta alba* as the dominant weed species. According to Balasubramanian *et al.* (2010), *E. colona* and *Panicum repens* under grass weeds, *C. difformis and F. miliacea* under sedges, *E. alba, Marsilea quadrifolia, Ammania baccifera* and *Ludwigia parviflora* under BLWs were the weeds of major concern in DSR. Weed flora in DSR fields of Tamil Nadu comprised of *Ischaemum rugosum, L. chinensis, Digitaria sanguinalis, Dactyloctenium aegyptium, C. iria, F. miliacea* and *C. difformis* (Muthukrishnan *et al*., 2010). *E. crus-galli, E. colona, Commelina benghalensis, Monochoria vaginalis* and *Ludwigia perennis* were the major weed species in DSR as noticed by Tiwari *et al.* (2010). Chauhan and Johnson (2011a) reported that barnyard grass (*E. crus-galli* (L.) Beauv.), Chinese sprangletop (*L. chinensis* L.), jungle rice (*E. colona* (L.) Link), and Southern crabgrass (*Digitaria ciliaris* (Retz.) Koel.) were the most problematic grass species in DSR.

The weed flora in DSR, according to Mukherjee and Maity (2011), included grass weeds like *Cynodon dactylon* and *E. colona,* sedges like *Cyperus rotundus, C. iria* and *F. miliacea* and BLWs including *L. parviflora, Ageratum conyzoides*, *Spilanthes paniculata, E. alba* and *Enhydra fluctans*. Ahmed *et al*. (2013) reported *L. chinensis* L., *Celosia argentea* L., *C. rotundus* L., *D. aegyptium* (L.) Willd., *D. ciliaris* (Retz.) Koel., *E. colona* (L.) Link., *Eleusine indica* (L.) Gaertn, *Phyllanthus niruri* L., and *S. paniculata* Wall. as the dominant weed species in the experiment field. Prasuna and Rammohan (2015) noted that *E. colona* and *E. crus-galli* were the dominant weed species *fb L. chinensis, D. sanguinalis, Brachiaria deflexa, Chloris barbata, D. aegyptium, C. rotundus, C. iria, Cleome viscosa, Aeschynomene indicia* and *E. alba* in DSR.

Studies conducted by Mahajan and Chauhan (2015) noticed the occurrence of *C. iria, C. rotundus, D. aegyptium, D. sanguinalis, L. chinensis, E. colona, E. indica, Digera arvensis, Ludwigia octovalvis, Panicum brevifolium, Euphorbia* spp., and *Eragrostis pilosa* in the dry direct seeded plots. Raj and Syriac (2017) reported that *E. colona* (L.), *E. crus-galli* (L.) P. Beauv., *L. chinensis* (L.) Nees, *Oryza sativa* (L.) *f. spontanea* Roshev and *I. rugosum* Salisb were the grass weeds, *C. iria* L., *C. diffor*mis L., and *Schoenoplectus juncoides* (Roxb.) Palla were the sedge species and *Eclipta prostrata* (L.), *S. zeylanica* Gaertner and *Ludwigia hyssop*ifolia (G. Don.) Excell were the BLWs species causing major yield losses in DSR. As per Singh *et al*. (2017), *C. difformis, C. rotundus, L. chinensis, Echinochloa glabrescens, E. alba*, and *Ammania* spp. dominated the weed flora in DSR. Kashyap *et al.* (2019) observed that *E. crus-galli, E. colona, L. chinensis, C. iria, C. difformis, A. baccifera* and *Alternanthera sessilis* were the dominant weeds in the dry DSR under irrigated ecosystem.

IRRI (2020b) documented five grass species (*L. chinensis, E. colona, E. crus-galli, I. rugosum, Oryza sativa*), 4 sedge species (*F. miliacea, C. difformis, C. iria, S. juncoides*) and three BLWs (*E. prostata, S. zeylanica, L. hyssopifolia*) as most problematic weeds in rice fields of Asia.

Reddy (2020) reported that *L. chinensis*, *E. colona, I. rugosum* were the major grass weeds present in the experimental field whereas, *S. zeylanica*, *L. parviflora, Bergia capensis, Lindernia rotundifolia* and *M. vaginalis* were seen as the major BLWs and *F. miliacea, C. difformis* and *C. iria* were the major sedge species observed in the crop field.

2.2.2 Weed spectrum in wet seeded rice

Joy *et al*. (1993) stated that the weed flora in WSR fields of Kerala comprised of mainly grass weeds (37%), BLWs (30%) and sedges (33%) at 55 DAS. Raghavendra *et al*. (2015) reported that *E. colona, E. crus-galli, F. miliacea, E. alba, A. baccifera, L. parviflora*, *M. quadrifolia* and *M. vaginalis* were the most common weed species in direct WSR. According to Mohapatra *et al*. (2017), *E. crus-galli, D. sanguinalis, E. colona, L. chinensis, C. iria, C. difformis, F. miliacea, A. baccifera, E. prostrata, L. parviflora, Lippa nodiflora, S. zeylanica* and *M. quadrifolia* were the major weed flora in WSR.

As reported by Umkhulzum *et al*. (2018), sedges were the dominant weed flora in WSR including *S. juncoides, F. miliacea*, *C. difformis*, *C. iria, Cyperus exaltataus*, *Cyperus cyperoides fb* grass weeds such as *Isachne miliacea*, *D. sanguinalis* and BLWs such as *Limnocharis flava, L. rotundifolia* and *L. perennis*. Rathika and Ramesh (2019) reported that *E. crus-galli, E. colona, L. chinensis* and *P. repens* were the major grass weeds, *E. alba, A. baccifera* and *L. parviflora* were the BLWs and *C. difformis, C. iria*, and *F. miliacea* were the major sedges in direct WSR.

2.2.3 Critical period of crop-weed competition in rice

There is a critical moment during crop growth when the crop is extremely vulnerable to weed competition. The presence of weed for an extended period of time will result in a considerable drop in yield.

Critical period of crop-weed competition (CPWC) is the period in the course of the crop growth when weeding results in highest economic returns. Weed flora, growth characteristics of rice and weeds, cultural practices and environmental factors are the elements that determine the time and duration of CPWC (Moody, 1977).

The depletion of nutrients by weeds and the subsequent suppression of plant height in rice marks the starting of crop-weed competition (Ramamoorthy *et al.,* 1974). Competition offered by weeds for different growth factors at various stages of crop induces severe stress on crops. Higher photosynthetic ability guaranteed by the C_4 nature makes the weeds more competitive compared to rice with C_3 photosynthetic pathway (Matsunaka, 1983; Kim and Moody, 1989).

According to Ladu and Singh (2006), DSR kept weed free during the first 30 days yielded grain yields comparable to those obtained during the weed free period till harvest. Effective weed control during the early phases of rice growth (0 to 40 DAS) may contribute in improving DSR productivity (Maity and Mukherjee, 2008). As per Singh *et al*. (2008), the critical time of weed competition is prolonged for direct seeded rice (15 to 45 DAS). According to Singh (2008), weed free conditions for the first 60 or 70 DAS produced yields comparable to weed-free conditions until harvesting.

2.2.4 Critical period of rice-*L. chinensis* competition

For the first three weeks after sowing (WAS), competition between the rice plant and the *L. chinensis* resulted in three per cent yield reduction, but when competition occurred only for the first two weeks, the yield gained was comparable to the weed free condition. In contrast, yield loss ranged from 17 to 19 per cent when plots were weed free for only the first two to three weeks. Crops must be weed free for the first four WAS in order to produce high yields. *L. chinensis* lowered the height and number of tillers on rice plants and there was competition between *L. chinensis* and rice from the middle stage of vegetative growth until grain-filling (Pane and Mansor, 1996).

The critical period for weed management of *L. chinensis* in direct seeded rice was observed to be between two and four WAS of rice (Pane, 1998).

2.2.5 Effect of weed competition on growth parameters and yield loss in DSR

Weeds dominate the crop habitat and limit yield potential due to their adaptability and rapid growth (Rao, 2011). Yield loss is influenced by a variety of factors, including the related weed flora, degree of infestation, rice growing habitat, growth season, cultivar used, cultural and management measures used (Abraham and Jose, 2014).

Under DSR, nearly 35 per cent loss in yield occurred globally due to severe weed competition (Oerke and Dehne, 2004). Uncontrolled weeds reduced the grain yield by 96 per cent in dry DSR, 61 per cent in wet DSR (Maity and Mukherjee, 2008) and 50 to 90 per cent in DSR (Chauhan and Johnson, 2011b).

Uncontrolled weeds in direct WSR could lower yields by as much as 53 per cent with losses as high as 90 per cent (Bhatt and Kukal, 2011). Weeds alone caused a yield loss of roughly 111.81 thousand tonnes of rice per year in Tamil Nadu (Chinnusamy *et al*., 2012). Studies conducted at Rice Research Station, Moncompu, revealed that season long weed competition resulted in 69.71 and 67.40 per cent reduction in grain yield during *Kharif* and *Rabi* season, respectively in WSR (Raj *et al*., 2013). In DSR, the loss in rice grain yield caused by uncontrolled weed growth throughout the crop growth phase is estimated to be 30 to 75 per cent (Kumar, 2015).

Singh *et al*. (2018) reported that the annual loss of rice grain yield in India was estimated to be over 15 million tonnes due to high weed infestation. The unfavourable environment caused by weeds throughout the crop cycle in the weedy check plots in dry DSR resulted in shorter panicle length and lower thousand grain weight (Chaudhary *et al*., 2018). According to Karthika *et al*. (2019), the yield drop in the unweeded check was upto 67 per cent.

As the weeds emerge concurrently with rice and farmers are rarely able to use standing water to inhibit weeds in the early stages of growth, the risks of crop yield loss due to competition from weeds in DSR is greater than in transplanted rice (Chauhan and Johnson, 2010). In India, weeds caused 45, 34 and 67 per cent yield reduction, respectively in direct seeded low land rice, transplanted rice and upland rice (Muthukrishnan *et al*., 2010). Weeds resulted in 15-35, 30-65 and 45-90 per cent yield reduction respectively under DSR cultivation, transplanted rice and upland rice cultivation (DRR, 2011). Weeds reduced yields by 34 per cent in transplanted rice (*Oryza sativa* L.), 50 per cent in DSR and 70 per cent in upland rice (Kevin *et al.*, 2013). Weeds competed with rice, culminating in yield losses of upto 76 per cent in WSR and 50-65 per cent in transplanted rice (Prakash *et al*., 2017). When compared to transplanted rice, DSR is more susceptible to loss of grain yield owing to weeds, and has a negative impact on not only grain yield but also crop quality (Arunbabu and Jena, 2018).

According to Manhas *et al*. (2012), unrestrained weed growth resulted in a 33 to 38 per cent loss in rice yield due to reduction in yield characteristics such as number of panicles, grains per panicle and thousand grain weight. Weed competition in rice limited the availability of nutrients to the crop, negatively affecting growth and yield characteristics, leading to increased competition and ultimately reduced rice yield (Teja *et al*., 2015). Weed growth caused 52.2 per cent reduction in grain yield in WSR, as reported by Umkhulzum and Ameena (2019) and highlighted the importance of keeping the field weed free at critical periods of crop growth.

2.2.6 Competitive ability of *L. chinensis* and yield loss in rice

At varying densities of *L. chinensis* in transplanted rice, yield decline of 14 to 44 per cent have been documented by Prusty *et al*. (1993). Increased densities of *L. chinensis* from 0 to 30 plants per m^{-2} decreased rice production from 6.45 to 1.37 t ha^{-1} with direct-sown rice, while 0 to 26 plants of *L. chinensis* decreased yields from 7.59 to 2.82 t ha^{-1} with direct-sown rice.

Hand weeding (HW) had an economic threshold of 1.73 to 2.31 plants of *L. chinensis* m^{-2} (SongHan *et al*., 1996). Nitrogen content was reduced by 0.03 to 0.13 g per plant due to *L. chinensis* competition, resulting in a reduction of 4.0 to 21 kg N per hectare (Pane and Mansor, 1996) and caused 41 per cent yield reduction in unweeded rice (Pane, 1998).

Two, four, six and eight plants of *L. chinensis* accumulated 63, 89, 150 and 159 g of dry matter per pot, respectively, and rice yields were 43.8, 22.0, 21.0 and 13.8 g per pot, respectively, compared to weed free control with 97.7 g per pot (Chin, 2001). According to Zhang *et al*. (2001), five *L. chinensis* seeds m^{-2} could reduce yield by 51.2 per cent in direct sown rice. According to Chauhan and Abugho (2013), the impact of *L. chinensis* competition on rainfed rice under low water conditions was detrimental to rice. Among the 28 weed species commonly found in DSR systems in China, Wang *et al*. (2013) observed that short-lived perennial grass *L. chinensis* and the sedge *C. difformis* were the two most prevalent weeds that inflicted considerable yield reductions in DSR system. As reported by Jacob (2014), *L. chinensis* competed with rice from the middle of the vegetative stage to grain filling and caused one third loss in yield in plots with 40 *L. chinensis* plants m^{-2}. According to Bergeron (2017), a density of two to six *L. chinensis* m^{-2} lowered rice yield by 14 to 44 per cent. Ho *et al*. (2021) stated that competitiveness of *L. chinensis* could attributed to the fact that they are C_4 plants, with more efficient photosynthesis having increased biomass.

2.2.7 Nutrient removal by *L. chinensis*

Leptochloa chinensis removed 16.5 kg N, 3.5 kg P, and 25.8 kg K ha^{-1} under unweeded conditions (Reddy, 2000). Studies conducted by Aulakh and Mehra (2008) reported that *L. chinensis* removed 3.7, 3.0, and 2.3 kg N; 1.0, 0.9, and 0.6 kg P; and 5.3, 4.3, and 3.3 kg K ha^{-1}, while the crop removed 132, 144, and 156 kg N; 33, 36, and 38 kg P; and 133, 144, and 153 kg K ha^{-1}, respectively under crop plant densities of 22, 33, and 44 hills m^{-2}. When compared to undisturbed field, frequent cultivation techniques during the off season reduced *L. chinensis* count as well as nutrient removal (2 kg N, 0.6 kg P, and 2.9 kg K ha^{-1}) and enhanced crop nutrient uptake (155 kg N, 38 kg P, and 150 kg K ha^{-1}).

2.2.8 Scenario of weed shift in rice ecosystem

In many Asian countries, system of rice establishment has shifted from conventional manual transplanting to direct seeding in response to rising production costs, notably due to higher labour expenses and water constraint. Changes in crop establishment, from transplanting to direct seeding resulted in significant variations in weed flora composition (Singh *et al*., 2008).

Itoh *et al*. (1996) noted a steady shift from BLWs and sedges dominated weed flora to grasses and certain BLWs with the introduction of DSR in the Muda, Seberang Perak, PBLS, and Sungai Manik granaries. Azmi *et al*. (2005) stated that the main factors responsible for the shift in weed species abundance in rice ecosystems were the widespread introduction of direct seeding and the recurrent use of herbicides. Kumar and Ladha (2011) opined that the adoption of direct seeding techniques might result in a change in weed flora toward more difficult-to-control and competitive grasses and sedges. Broad leaf weeds were initially prominent under DSR cultivation, but grass weeds such as *E. crus-galli* (L.) P. Beauv, *L. chinensis* and *I. rugosum* Salisb. became prevalent after a decade of DSR cultivation in Vietnam (Chin, 2001) and Malaysia (Ziska *et al.*, 2015).

A shift in dry DSR weed flora towards more aggressive competitive grasses and sedges had been recorded in South East Asia. Annual grasses including *E. crus-galli*, *E. colona*, and *L. chinensis*, perennial sedge *C. rotundus*, and BLW like *Commelina diffusa* and *Caesulia axillaris* all flourished with direct seeding (Singh *et al*., 2008).

Several studies have linked the shift in weed dominance in transplanted rice from dicotyledonous and sedge species to competitive grass weeds in DSR due to the persistent use of herbicides in weed control operations (Azmi and Baki, 1995; Ho, 1998). In China, most broad leaf and sedge weeds were adequately managed after many years of usage of the acetolactate synthase (ALS) herbicide bensulfuron methyl, but graminaceous weeds like *E. crus-galli* (L.) Beauv. and *L. chinensis* were poorly controlled and became dominant weeds in these cropping systems (Chen and Yang, 2011).

2.2.9 Scenario of weed shift to *L. chinensis* in rice ecosystem

Long-term use of bispyribac sodium to manage propanil-resistant *E. crus-galli* has resulted in the domination of *L. chinensis* in Sri Lanka (Marambe, 2002). Conversely, prolonged usage of Butachlor [chloracetanilide] and Molinate [thiocarbamate] in rice has resulted in an increase in the population of *L. chinensis* in the Eastern Chinese provinces, Jiangsu and Zhejiang (Zhang, 2003). Azmi *et al*. (2005) presented that *L. chinensis* was not a common or dominating weed in Malaysian rice fields when rice was transplanted instead of direct seeded, but it became so when switched to direct seeding. With change in crop establishment methods, the population of *L. chinensis* increased significantly, becoming far more dominant than *Echinochloa* spp. (Evelyn *et al*., 2005). In the Philippines also, *L. chinensis* became more prevalent when the system was switched to direct seeding, whereas, *Echinochloa* spp. was the most troublesome weed in rice fields under transplanted conditions (Singh *et al*. 2008).

Rao *et al*. (2007) indicated that herbicide use has resulted in the evolution of resistance to clefoxydim, fenoxaprop-p-ethyl, and quizalofop-p in *L. chinensis* in Thailand. As reported by Dong *et al*. (2016), *L. chinensis* has recently emerged as a severe weed in China, particularly in rice grown by direct seeding. Leptochloa species became a serious concern in Asia around the end of the last century, and they are now a problem in Europe as well (Kraehmer *et al*., 2016).

Weedy rice and *L. chinensis* were initially sparse in long-term field studies with DSR, but they emerged only after 2 and 4 years, respectively as reported by Shekhawat *et al*. (2020).

In Kerala, *L. chinensis* was found as a new weed in alkaline soils of Chittoor taluk during a survey of weeds in rice agro ecosystems made by Vidya *et al*. (2004) and listed as an indicator plant for alkaline conditions. Later it was found to be fast expanding in acidic soils as evidenced by its presence in the rice fields of Palakkad, *Kole* lands, and the Kuttanad region (KAU, 2009). According to Jacob (2014), the continued usage of bispyribac sodium, one of the most widely used rice herbicides in Kerala, to suppress barnyard grass resulted in the dominance of *L. chinensis*

2.3 MANAGEMENT OF *L. chinensis*

2.3.1 Cultural methods of weed control

2.3.1.1 Flooding

Flooding is an imperative component of cultural weed management in rice as it prevents weed germination and seedling growth. The extent of weed reduction is determined by the timing, length, and depth of flooding (Hill *et al*., 2001; Chauhan and Johnson, 2008), which are all key factors in limiting weed germination and proliferation.

Weed species have different responses to flooding, and each weed species has an ideal soil moisture level below or above which its growth is impeded. Flooding can be used to suppress weed species such as *F. miliacea*, *C. iria, E. crus-galli* (Smith and Fox 1973; Civico and Moody 1979), *L. hyssopifolia* (Chauhan and Johnson, 2009a), *E. glabrescens* (Opena *et al*., 2014), and *I. rugosum* (Lim *et al*., 2015). However, certain weeds that are well adapted to flooded conditions, such as *M. vaginalis* (Pons, 1982) and *S. zeylanica* (Kent and De Johnson, 2001), are difficult to manage by flooding.

As reported by Chauhan and Johnson (2008), early and continuous flooding to a shallow depth of 2 cm helped to suppress the emergence and growth of *L. chinensis.* Continuous flooding to a depth of 2 to 4 cm aided in the suppression of the emergence and growth of weeds such as *F. miliacea, C. iria, L. hyssopifolia* and *L. chinensis* (Raj and Syriac, 2017).

2.3.1.2 Stale seedbed technique

Stale seedbeds (SSB), commonly known as the false seeding technique, are indeed a cultural weed control approach used to reduce the weed seed bank in rice cultivation (Ferrero, 2003). Weeds are permitted to germinate in SSB and the emergent weed seedlings are destroyed by a non-selective herbicide such as glyphosate or shallow tillage and the plots were flooded for 10-15 days after glyphosate application (Jose *et al.*, 2013).

As reported by Ferrero (2003), the effectiveness of SSB is determined by various aspects, including seedbed preparation, duration of SSB, weed species, method of killing emerged weeds and environmental conditions (e.g., temperature) throughout the SSB period. The species composition and potential densities of weeds that subsequently interfere with crops all through the growing season are mostly determined by the weed seed bank in the soil profile or on the soil surface (Karim *et al*., 2004). This approach not only reduces the amount of weed seeds in the soil seed bank, but it also restricted weed emergence (Rao *et al*., 2007).

The application of SSB technique in combination with pre emergence herbicide sprays or HW, or concomitant cultivation of green manure crops resulted in better weed control and higher grain yields (Sindhu *et al*., 2010). In dry DSR, Singh (2013) found that SSB with glyphosate @ 1 kg ha^{-1} was more effective in reducing weed density and had greater grain yield and benefit: cost ratio (BCR) than SSB with shallow tillage.

Kartaatmadja *et al*. (2004) documented that paraquat applied to minimum tillage in irrigated lowland rice efficiently suppressed BLWs and annual grass weeds such as *L. chinensis* and *E. crus-galli*. Chauhan and Johnson (2010) reported that weed species such as *C. iria, C. difformis, F. miliacea, L. chinensis*, and *E. prostrata* were more susceptible to the SSB technique owing to their poor seed dormancy and inability to emerge from a depth more than 1 cm. According to Jose *et al*. (2013), SSB was exceptionally successful in controlling weedy rice in DSR.

2.3.1.3 Hand weeding

Hand weeding twice at 20 and 40 DAS improved growth and yield parameters the most (Singh and Namdeo, 2004). Payman and Singh (2008) found that HW twice at 30 and 45 DAS resulted in the maximum weed control efficiency (WCE) of 66 per cent. In DSR, HW twice resulted in the lowest weed count and weed dry weight as reported by Roy *et al*. (2010). HW, according to Akbar and Ali (2011), was more effective than mechanical hoeing and chemical weed control in reducing weed density and dry weight, boosting WCE, and enhancing rice yield. Raj *et al*. (2013) reported that HW at 20 and 45 DAS in DSR brought about considerably increased plant height and dry matter production.

Studies conducted by Nath *et al.* (2014) revealed that HW at 20 and 40 DAS recorded the highest WCE of 75.7 per cent in DSR. In accordance with Kankal (2015), HW thrice at 20, 40 and 60 DAS recorded the maximum height, number of tillers and dry matter accumulation in the drilled rice. HW twice yielded the highest thousand grain weight in dry DSR, according to Chaudhary *et al*. (2018). As reported by Devi and Singh (2018), HW twice at 20 and 40 DAS resulted in the highest yield, grain and straw NPK content in DSR. Srinithan *et al*. (2020) pointed out that HW twice at 20 and 40 DAT had the lowest weed dry matter production (83.81 kg ha^{-1}), the highest weed index (89.54%), the highest grain yield (5563 kg ha^{-1}), and the highest straw yield (7599 kg ha^{-1}), which was statistically on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (15 DAT).

2.3.2 Chemical control

As weeds emerge almost concurrently with the crop in WSR, crop weed competition is greater and chemical weed control is more critical (Singh and Singh, 2010b). Herbicides could be seen as a feasible alternative to HW (Anwar *et al*., 2012). Herbicides are more labour efficient than manual or mechanical weed control methods and provide improved weed control (Chauhan *et al*., 2014).

According to Jacob *et al*. (2014), the major benefit of using herbicides to control weeds in DSR is the lower cost of cultivation. Application of herbicide may be reckoned as a feasible substitute than HW in DSR (Ghosh *et al*., 2016; Jana *et al*., 2020).

2.3.2.1 Use of herbicides before sowing of crop

Sadohara *et al*. (2000) observed that applying herbicide to the soil surface three to four days before sowing reduced soil seed bank and early weed growth. Surface application of herbicides prior to sowing was superior to soil incorporation or pre emergence application after sowing (Jose *et al*., 2013).

2.3.2.1.1 Oxyfluorfen

Oxyfluorfen, chemically 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoro methyl) benzene, is a diphenyl-ether herbicide used for broad spectrum pre and post emergence control of annual broad leaf and grass weeds (EPA, 2012).

Oxyfluorfen is used in a variety of field crops to control annual and perennial BLWs and sedges, and it kills weed seedlings by contact action and membrane disruption. As light is required for herbicidal activity, phytotoxicity of diphenyl ether is associated with the process of photosynthesis and inhibition of both electron transport and ATP synthesis (Janaki *et al*., 2013).

2.3.2.1.1.1 Effect of oxyfluorfen on weeds

Abraham *et al*. (2010) observed that oxyfluorfen has both foliar and soil activity and could effectively control the weeds at a dose of 150 g ha^{-1} or above, which were at par with the hand weeded plot and the effectiveness was observed even at 60 DAT. Pre sowing surface application of oxyfluorfen at 0.1 kg ha^{-1} provided broad spectrum control of all types of weeds emerging from the soil and reduced 75 per cent density of weedy rice, while emerging shoots of pre-germinated crop seeds sown later were protected from the herbicide due to spatial and temporal differences.

The contact and residual action offered by oxyfluorfen eliminated weed seeds in the top layer of soil, reduced initial crop weed competition and standing water prevented further seed germination (Jose *et al*., 2013). As stated by Abraham and Menon (2015), WCE in WSR was 90 per cent after application of oxyfluorfen 23.5 per cent EC at 150 g ha^{-1} *fb* HW at 30 DAS. Pre emergence application of oxyfluorfen at 300 and 400 g ha^{-1} considerably reduced the weed dry weight at all the stages of observation (Sathyapriya *et al*., 2017).

2.3.2.1.1.2 Effect of oxyfluorfen on L. chinensis

According to Jiang (1989), oxyfluorfen at 0.1 kg ha^{-1} provided 90-100 per cent control of *L. chinensis*. Prakash *et al*. (1995) reported that oxyfluorfen 0.25 kg ha^{-1} + manual weeding at 40 DAT effectively controlled *L. chinensis* and *E. crus-galli*. Pre emergence application of oxyfluorfen 23.5 EC at 3 DAS resulted in 100 per cent control of *L. chinensis* at 30 DAS as reported by Jacob *et al*. (2014).

2.3.2.1.1.3 Effect of oxyfluorfen on rice

Kumar and Gautam (1986) reported that oxyfluorfen at 0.15 kg ha^{-1} was effective in direct seeded puddled rice. At 100 g ha^{-1}, oxyfluorfen caused reduced plant height than at 150 g ha^{-1}, and at 150-200 g ha^{-1}, this herbicide would successfully manage grass weeds, sedges, and BLWs (Abraham *et al*., 2010).

Podder *et al*. (2014) reported that application of oxyfluorfen at 300 g ha^{-1} recorded significantly higher weed control and grain yield in DSR. Due to greater weed control at critical phases and thus providing a favourable environment for better growth and development, pre emergence spraying of oxyfluorfen at 250 g ha^{-1} resulted in higher grain yields of 6645 and 7102 kg ha^{-1} in transplanted rice (Sathyapriya *et al*., 2017). As reported by Sumit *et al.* (2020), pre emergence application of oxyfluorfen at 240 g a.i. ha^{-1} resulted in a greater leaf area index of 5.75 at 60 DAS.

2.3.2.2 Use of herbicides during the crop period

2.3.2.2.1 Cyhalofop butyl

Cyhalofop butyl, chemically, 2-[4-(4-cyano-2-fluorophenoxy) phenoxy] propanoic acid, butylester (R) (EPA, 2002), is an Aryloxyphenoxy propionate herbicide that inhibits acetyl coenzyme-A carboxylase, a crucial enzyme in the synthesis of fatty acids in plants. Cyhalofop butyl becomes active with the subsequent absorption through the leaves. Weed growth ceases instantly, and after a week, the most recent leaves become necrotic and depending on the temperature and the size of the weeds, death happens in 2-3 weeks. Cyhalofop butyl will not suppress BLWs as its biochemical mode of action is exclusive to certain grasses. Saini (2003) reported that application of cyhalofop butyl to WSR resulted in reduction of annual grass weeds. As observed by Singh *et al*. (2017), grass weeds were better controlled with cyhalofop butyl than non-grass weeds, with maximum WCE, greater yield characteristics, and yield.

2.3.2.2.1.1 Effect of cyhalofop butyl on weeds

Cyhalofop butyl, the low cost post emergence selective herbicide that kills grass weeds, was very effective in controlling *Echinochloa* spp. and *L. chinensis* as reported by Saini *et al*. (2001) and Lap *et al*. (2013). Through the use of cyhalofop butyl, *E. colona* was effectively controlled (Jannu *et al*., 2017).

Saini (2005) reported that application of cyhalofop butyl (120 g ha^{-1}) at 15 DAS resulted in lower total weed dry weight and increased WCE. Jacob *et al*. (2014) noticed cyhalofop butyl @ 80 g ha^{-1} administered at 20 DAS as the best herbicide for controlling grass weeds. The application of cyhalofop butyl @ 125 g ha^{-1} was reported to have 95.51 per cent weed control rate (Sasikala *et al*., 2015).

The use of cyhalofop butyl alone as a post emergence herbicide was ineffective in controlling BLWs (Saini *et al*., 2001; Kiran and Subramanyan, 2010).

As reported by Sangeetha *et al*. (2009), application of cyhalofop butyl at 15 DAS *fb* HW at 45 DAS resulted in lower weed density and was comparable to HW twice at 20 and 45 DAS. Atheena *et al*. (2017) reported that tank mix combination of cyhalofop butyl (80 g ha^{-1}) with pyrazosulfuron ethyl (30 g ha^{-1}) applied at 18 DAS effectively controlled the complex weed flora in WSR.

2.3.2.2.1.2 Effect of cyhalofop butyl on L. chinensis

Abeysekera and Wickrama (2004) reported that cyhalofop butyl 100% EC applied at 7-10 DAS showed 90-94 per cent control over *L. chinensis.* As reported by Sumiyoshi and Suzuki (2006) depicted that application of both cyhalofop butyl emulsion and granules (GR) effectively controlled of *L. chinensis*. Sumiyoshi (2008) compared the efficiency of different formulations of cyhalofop butyl and realized that emulsion was efficient in controlling *L. chinensis* plants younger than nine leaf stage and shorter than 20 cm. GR formulation was effective in controlling *L. chinensis* plants at its six to eight leaf stages or earlier and shorter than 14.3 cm. Jacob (2014) compared the efficacy of grass killers and noticed that cyhalofop butyl was the next best herbicide for controlling *L. chinensis* after fenoxaprop-p-ethyl.

Zhang *et al*. (2001) studied the efficacy of a mixture of cyhalofop butyl at 75 g a.i. ha^{-1} and bensulfuron at 225-300 g per hectare and realized 95 per cent control of *L. chinensis* when applied at three leaf stage of rice.

Despite the fact that cyhalofop butyl was effective in suppressing *L. chinensis*, its long term use resulted in tolerance in many areas (Chen *et al.*, 2021).

2.3.2.2.1.3 Effect of cyhalofop butyl on rice

Cyhalofop butyl 100% EC was found to have outstanding weed control with no negative impact on grain yield (Abeysekera and Wickrama, 2004). Saini (2005) studied the efficacy of sequential application of cyhalofop butyl and 2,4-D and stated that cyhalofop butyl 120 g ha^{-1} (15 DAS) *fb* 2,4-D at 1 kg ha^{-1} (20 DAS) and 2,4-D at 15 DAS *fb* cyhalofop butyl at 20 DAS were comparable in terms of panicle number, panicle length, grains per panicle and thousand grain weight. Sangeetha *et al.* (2009) noticed that application of cyhalofop butyl at 15 DAS + HW at 45 DAS resulted in more panicles m^{-2}, filled grains per panicle, and yield equivalent to HW twice.

Angiras and Attri (2002) reported that cyhalofop butyl @ 90 g ha^{-1} resulted in more number of panicles and higher grain yield of rice (4.5 t ha^{-1}). Application of cyhalofop butyl at 10, 15 and 20 DAS increased rice yield (Saini, 2003). According to the reports, application of cyhalofop butyl had no phytotoxic effects on rice (Abeysekera and Wickrama, 2004) or subsequent wheat crops (Singh *et al*., 2017).

2.3.2.2.2 Penoxsulam

Penoxsulam is a post emergence systemic rice herbicide that belongs to the triazolopyrimidine sulfonamide chemical family and is chemically 2-(2,2-difluoroethoxy)-6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo [1,5,-c] pyrimid in-2-yl)) benzenesul fonamide). Penoxsulam is absorbed primarily by the leaves and secondarily through the roots, and it moves throughout the plant tissue, inhibiting the synthesize of an enzyme called ALS, which is not found in animals (WDNR, 2012a). Plants that are susceptible to the herbicide will cease growing and turn reddish at the tips. Plant death and decay will take from weeks to months to occur.

Penoxsulam is an ALS inhibitor herbicide for post emergence control of annual grass weeds, sedges and BLWs in either transplanted or wet or dry direct sown method of rice cultivation (Jabusch and Tjeerdema, 2005). Penoxsulam is a low dose, high efficacy broad spectrum herbicide that provides eco-friendly weed management (Sasna *et al*., 2016).

2.3.2.2.2.1 Effect of penoxsulam on weeds

As reported by Jabusch and Tjeerdema (2005), application of penoxsulam 22.5 and 25 g ha^{-1} had significantly lower weed population than weedy check at 30 DAS. Lap *et al*. (2013) reported that *Echinochloa* spp., annual sedges, and many BLWs were controlled by penoxsulam. Sasna *et al*. (2016) observed reduced density of sedges, grass weeds, and BLWs, as well as considerably lower total dry matter production with higher doses of penoxsulam at 25.0 and 22.5 g ha^{-1}.

Sanodiya and Singh (2019) reported that penoxsulam 35 g ha^{-1} at 10 DAS *fb* HW at 35 DAS had the highest WCE, net returns and BCR. The treatment significantly influenced grain yield, straw yield and harvest index over rest of the treatments, except HW twice at 15 and 35 DAS. Penoxsulam, applied at 20 g a.i. ha^{-1} was successful in controlling grass weeds but less effective in controlling sedges and BLWs (Biswas *et al*., 2020).

2.3.2.2.2.2 Effect of penoxsulam on L. chinensis

Single application of penoxsulam at 15 g a.i. ha^{-1} reduced only 21 per cent of the *L. chinensis* population however, sequential application of penoxsulam with any pre emergence herbicide like pendimethalin could control *L. chinensis* upto 80 per cent (Khaliq *et al*., 2011). Lap *et al*. (2013) also reported the ineffectiveness of penoxsulam at 10, 12.5 and 15 g a.i. ha^{-1} against *L. chinensis*.

2.3.2.2.2.3 Effect of penoxsulam on rice

Jabusch and Tjeerdema (2005) observed that penoxsulam 25 g ha^{-1} produced significantly higher number of panicles (182 m^{-2}) than other treatments, with the exception of the weed free plot (191 m^{-2}) and achieved the highest WCE of 84 per cent and grain yield of 4.47 t ha^{-1}. Sasna *et al*. (2016) registered the highest value of productive tillers m^{-2} and filled grains per panicle with penoxsulam 22.5 g ha^{-1}, which was comparable with penoxsulam 25.0 g ha^{-1} with regard to number of productive tillers m^{-2}. The highest yield (5.40 t ha^{-1}) was obtained with penoxsulam 22.5 g ha^{-1}, which was statistically comparable to all herbicide treatments and HW, and produced the highest net yields and BCR.

2.3.2.2.3 Carfentrazone ethyl

Carfentrazone ethyl is a contact herbicide that was approved by the Environmental Protection Agency (EPA) in 1998. Ethyl 2-chloro-3-[2-chloro-4-fluoro-5-[4-(difluoromethyl)-4,5-diydro-3-methyl 5-oxo-1H-1,2,4-trizol-1-yl] phenyl] propanoate is the active component and belongs to Aryl Triazolinone group. The herbicide regulated plants by disrupting their membranes, which is caused by the suppression of the enzyme protoporphyrinogen oxidase, which interrupts the chlorophyll synthesis process. Plants absorb the herbicide through their leaves, causing damaging signs to appear within hours after application and necrosis and death in the weeks following (WDNR, 2012b).

2.3.2.2.3.1 Effect of carfentrazone ethyl on weeds

Activity of carfentrazone ethyl at low dose rates (20 g ha^{-1}) made it an ideal partner for other common cereal herbicides such sulfonyl ureas, diflufenican, and phenoxy herbicides (Cauchy, 2000). Carfentrazone ethyl, which had significant levels of Group B herbicide resistance exhibited a high level of activity against *Malva parviflora*, *Echium plantagineum*, *Trifolium subterraneum. Emex australis* and brassica species, particularly *Raphanus raphanistrum*, had also been well controlled (Cumming, 2002). Carfentrazone ethyl, according to Vencill (2002), is effective against BLWs but ineffective against grass weeds. When administered at 35-40 DAS, *i.e*., at maximum tillering stage in wheat, carfentrazone ethyl at 20 and 25 g ha^{-1} was found to be superior to 2,4-D in terms of reduction in weed dry matter production (Walia and Singh, 2006). The application of carfentrazone ethyl reduced the biomass of Ivyleaf morning glory by 40-47 per cent, while the use of glyphosate and carfentrazone ethyl in a tank mix boosted the effect (Sharma and Singh, 2007). When applied at 20 g ha^{-1} and 25 g ha^{-1} on 15-20 DAS in DSR, carfentrazone ethyl effectively controlled both sedges and BLWs, with the lower dose (20 g ha^{-1}) being more effective in controlling BLWs and the higher dose (25 g ha^{-1}) being more effective in controlling sedges (Raj *et al*., 2013).

2.3.2.2.3.2 Effect of carfentrazone ethyl on rice

Raj *et al*. (2013) observed that carfentrazone ethyl 40 DF (20 g ha^{-1}) applied at 15-20 DAS resulted in higher grain yield (3.68 t ha^{-1}) with a WCE of 90.7 per cent and a weed index of 9.5, and was comparable to 2,4-D Na salt @ 800 g ha^{-1} applied at 20-25 DAS. The study also observed absence of phytotoxicicty effect at 20 and 25 g ha^{-1}. On the other hand, Atheena (2016), pointed out that carfentrazone ethyl application caused phytotoxic symptoms in rice, with the leaves turning brownish. However, the injury was less severe than with tank mix treatment, and the crop recovered within seven days.

2.3.2.2.4 Bispyribac sodium

Bispyribac sodium, chemically, sodium 2,6-bis [(4, 6-dimethoxy-2-pyrimidinyl) oxy] benzoate, is a systemic herbicide that inhibits the plant enzyme ALS, involved in biosynthesis of the branched chain amino acids. Protein synthesis and growth are impeded without certain amino acids, resulting in plant mortality (WSSA, 2007). Bispyribac sodium is absorbed by the roots and leaves and inhibits the enzyme ALS in susceptible weed plants (Pathak *et al*., 2011).

2.3.2.2.4.1 Effect of bispyribac sodium on weeds

Yadav *et al*. (2009) reported that bispyribac sodium @ 25 g ha^{-1} applied at 15-25 days after transplanting (DAT) effectively suppressed complex weed flora in transplanted rice. According to Rao and Ratnan (2010), post emergence application of bispyribac sodium @ 30 g ha^{-1} at 15 DAS offered broad spectrum weed control with great selectivity to rice. Jabran *et al*. (2012) reported that post emergence application of bispyribac sodium@ 25 g ha^{-1} reduced total weed density (2.2 m^{-2}) and weed biomass (1.9 g m^{-2}) with 89.8 per cent WCE. Khaliq *et al*. (2013) stated that bispyribac sodium (30 g ha^{-1}) application at 15 DAS *fb* manual weeding at 30 DAS resulted in 91 per cent reduction in weed dry weight.

Post emergence application of bispyribac sodium @ 30 g a.i. ha^{-1} reduced the dry weight of grass weeds and BLWs in rice by 88 per cent when compared to unweeded control at harvest (Naseeruddin and Subramanyam, 2013). Raj *et al*. (2013) claimed that bispyribac sodium 10 SC (30 g ha^{-1}) was highly effective against *Echinochloa stagnina, E. glabrescens, M. vaginalis, L. perennis* and *S. zeylanica*. The highest WCE was 98.5 per cent was observed with post emergence application of bispyribac sodium @ 50 g ha^{-1} at 20 DAT, which was higher than manual weeding twice. Veeraputhiran and Balasubramanian (2013) also observed that applying bispyribac sodium at rates of 25, 30, and 50 g ha^{-1} resulted in lower weed dry weight than applying butachlor (1500 g ha^{-1}) at 3 DAT.

Early post emergence application of bispyribac sodium @ 30 g ha^{-1} at 15 DAS, combined with HW at 30 DAS resulted in higher weed suppression. (Ihsan *et al*., 2014), Bispyribac sodium 10% SC (30 g ha^{-1}) was successful in controlling quinclorac resistant barnyard grass, with a WCE of over 90 per cent as reported by Lan *et al*. (2014). Kumaran *et al*. (2015) reported that early post emergence application of bispyribac sodium 10% SC @ 40 g ha^{-1} at 40 and 60 DAS resulted in the lowest weed density and dry weight.

Bispyribac sodium 10% SC at 35 g ha^{-1} (15 DAT) was reported to be effective against *C. difformis, C. iria, Fimbristylis woodrowii, P. repens, E. colona, E. crus-galli, C. dactylon, Rotala densiflora, E. alba* and *Spilanthes calva* (Prashanth *et al*., 2015).

Jacob (2014) reported that in places where Leptochloa is not a serious problem, bispyribac sodium @ 30 g a.i. ha^{-1} sprayed at 20 DAS could be the herbicide option for broad spectrum weed control producing high grain and straw yields. Spraying bispyribac sodium @ 20 g ha^{-1} at 21 DAT, *fb* manual weeding at 45 DAT, effectively managed weeds in transplanted rice, with a WCE of 87.74 per cent and a weed index of 2.83 (Kashid, 2019). Biswas *et al*. (2020) reported that bispyribac sodium 10% SC applied at 30 g a.i. ha^{-1} (20 DAT) reduced *M. vaginalis* density by 37 per cent compared to the weedy control. Studies conducted by Kundu *et al*. (2020) revealed that bispyribac sodium @ 250 ml ha^{-1} treated plots removed the least amount of N, P and K (5.56, 0.86, and 5.41 kg ha^{-1}, respectively) by weeds.

2.3.2.2.4.2 Effect of bispyribac sodium on L. chinensis

As reported by Abeysekera and Wickrama (2004), bispyribac sodium is indeed the least efficient at controlling *L. chinensis* in Sri Lanka. Jacob (2014) found that bispyribac sodium was ineffective in controlling *L. chinensis* and reported a higher dry weight of 527.7 kg ha^{-1}, which was observed to be close to unweeded control with a dry weight of 614 kg ha^{-1}. Bispyribac sodium, according to Awan *et al*. (2015), was effective against most grasses but not *L. chinensis*.

2.3.2.2.4.3 Effect of bispyribac sodium on rice

Bispyribac sodium @ 25 g ha^{-1} applied at 15-25 DAT improved grain production by 41 per cent (Yadav *et al*., 2009). According to Veeraputhiran and Balasubramanian (2013), bispyribac sodium @ 25 g ha^{-1} (20 DAT) produced the highest grain yields of 6838 kg ha^{-1} and 6510 kg ha^{-1} in two consecutive years (2011 and 2012), and was comparable to higher doses of bispyribac sodium at 50 g and 30 g ha^{-1}.

Early post emergence application of bispyribac sodium 10 SC at 40 g ha^{-1} yielded 5058 kg ha^{-1}, which was comparable to pre emergence application of pretilachlor @ 0.45 kg ha^{-1} at 3 DAS *fb* HW at 40 DAS, but bispyribac sodium 10% SC @ 20 g ha^{-1} yielded 13 per cent less grain as reported by Kumaran *et al*. (2015).

Ihsan *et al*. (2014) reported that bispyribac-sodium @ 30 g ha^{-1} at 15 DAS, along with manual weeding at 30 DAS, resulted in more productive tillers m^{-2}, grains per panicle, thousand grain weight, grain yield and harvest index, which were comparable to HW twice at 20 and 40 DAS. Antralina *et al*. (2015) found a similar result, where post emergent spraying with bispyribac sodium @ 25 g ha^{-1} at 20 DAT resulted in more number of panicles (38 m^{-2}), thousand grain weight (32.2 g), filled grain percentage (67.03%), and yield that was comparable to HW twice at 20 and 45 DAT. Application of bispyribac sodium 10% SC (25 g ha^{-1}) applied at 15 DAT recorded a grain and straw yield of 6474 and 7658 kg ha^{-1}, respectively, with lower phytotoxicity, and was equivalent to HW twice at 20 and 40 DAT with 6243 and 7492 kg ha^{-1}, respectively (Prashanth *et al*., 2015). As mentioned by Kundu *et al*. (2020), application of bispyribac sodium 10% SC (250 ml ha^{-1}) substantially reduced total weed density (77.38%) and dry weight (81.50%) over control at 30 days after herbicide application and consequently yielded 4.07 t ha^{-1}. Biswas *et al*. (2020) documented, the highest rice yield (5.45 t ha^{-1}), net return (₹ 42,677 ha^{-1}), and BCR (1.72) with bispyribac sodium.

2.3.2.2.5 Fenoxaprop-p-ethyl

Fenoxaprop-p-ethyl is an aryl oxy phenoxy propionate post emergence herbicide (chemically (+)-ethyl 2-[4-[(6-chloro-2-benzoxazolyl)oxy] phenoxy] propanoate) that inhibits the Acetyl Co-A carboxylase (Accase) enzyme and kills grass weeds in rice.

Fenoxaprop-p-ethyl is a selective post emergence herbicide that kills a wide range of grass weeds (Rana *et al*., 2004). The active substance of fenoxaprop-p-ethyl is readily absorbed by the leaves and stems of grass weeds, and it primarily inhibits the synthesis of fatty acids in the meristemetic tissues of grass weeds (Kundu *et al*., 2020).

2.3.2.2.5.1 Effect of fenoxaprop-p-ethyl on weeds

In DSR, fenoxaprop-p-ethyl at 60 g ha^{-1} was very effective in controlling grass weeds (Dixit and Varshney, 2008). According to Blouin *et al*. (2010), fenoxaprop-p-ethyl was effective against main grasses found in DSR fields, including *L. chinensis, D. aegyptium, D. sanguinalis* and *E. colona*. Mahajan and Chauhan (2015) also reported the reduction of *D. sanguinalis* count with fenoxaprop-p-ethyl (9 and 12) as compared to the non-treated control (29 and 23) plants m^{-2}, respectively in 2013 and 2014.

The application of fenoxaprop-p-ethyl (6.9% EC) resulted in a steady decrease in density and dry weight of grass weeds (Mallick *et al*., 2009). Kumar *et al*. (2010) found that application of fenoxaprop-p-ethyl at 60 g ha^{-1} (20 DAT) *fb* HW at 30 DAT significantly reduced total weed population and weed dry weight compared to weedy check at all crop growth stages. Fenoxaprop-p-ethyl applied at 86 g a.i. ha^{-1} was successful in controlling grass weeds but less effective in controlling sedges and BLWs (Biswas *et al*., 2020).

2.3.2.2.5.2 Effect of fenoxaprop-p-ethyl on L. chinensis

In a DSR trial, Kuah and Sallehuddin (1988) found that fenoxaprop-p-ethyl (0.5-0.1 L ha^{-1}) administered 14-25 DAS offered effective control of *L. chinensis* in both dry and flooded conditions. Fenoxaprop treatments resulted in 95 to 97 per cent control of Chinese sprangletop (*L. chinensis*), according to Yokohama *et al.* (2001). Singh *et al*. (2004) found that application of fenoxaprop-p-ethyl (56.25 g ha^{-1}) at 10 DAT efficiently controlled *L. chinensis*. As reported by Yang *et al*. (2004), application of fenoxaprop-p-ethyl to rice plants with more than 6 leaves resulted in more than 90 per cent control of *L. chinensis* in DSR. According to Gopal *et al*. (2010), fenoxaprop-p-ethyl without a safener was formerly used in DSR to control *L. chinensis* and *D. aegyptium*, but it was hazardous to the rice crop. Fenoxaprop-p-ethyl was the most effective herbicide against *L. chinensis* at 30 and 60 DAS, attaining 100 per cent control of the weed (Jacob, 2014).

The grass weeds *L. chinensis*, *D. aegyptium*, and *D. sanguinalis* provided significant competition to the crop, according to Mahajan and Chauhan (2015), and their suppression using fenoxaprop helped to increase yield.

2.3.2.2.5.3 Effect of fenoxaprop-p-ethyl on rice

Post emergence application of fenoxaprop-p-ethyl resulted in higher number of panicles m^{-2} (236) and grains per panicle (71) as reported by Dixit and Varshney (2008). Kumar *et al*. (2009) observed that application of fenoxaprop-p-ethyl *fb* HW resulted in higher grain yield (4268 kg ha^{-1}) and straw yield (5583 kg ha^{-1}), which was comparable to mechanical hoeing. With the application of fenoxaprop-p-ethyl, Sreedevi *et al*. (2009) noticed a higher mean plant height. Kumar *et al*. (2010) noticed higher panicles m^{-2} (228) with lesser weed dry weight (15.3 g m^{-2}) and higher yield (4.3 t ha^{-1}) with application of fenoxaprop-p-ethyl at 60 g ha^{-1} *fb* HW. Fenoxaprop-p-ethyl (0.06 kg ha^{-1}) in combination with ethoxysulfuron (0.015 kg ha^{-1}) resulted in increased grain production (Tiwari *et al*., 2010). Jacob *et al*. (2014) reported that fenoxaprop-p-ethyl at 60 g a.i. ha^{-1} applied at 20 DAS was the most effective herbicide to control grass weeds, which was on par with the HW treatment and recorded a grain yield of 5.88 t ha^{-1} with the highest WCE of 69.19 per cent at harvest and the highest BCR of 2.1.

2.3.2.3 Herbicide mixtures: ready mix and tank mix application of herbicides

A variety of herbicides have been used to control weeds in DSR, though chemical management methods focused on single herbicide may be ineffective due to their limited weed control spectrum. Application of herbicide combination reduced the herbicide use rates compared to single herbicide use (Aurora and De Datta, 1992). In addition to broad spectrum weed control, herbicide combinations condense herbicide load in the environment and application costs. As stated by Avudaithai and Veerabadran (2000), combining different herbicides, even at lower doses, was more efficient against a wide range of weeds.

Herbicide mixtures are considered powerful tools for cost effective control in intensive agriculture and herbicide combinations (both tank and proprietary mixture) increased the weed control spectrum with a single application (Damalas, 2004). In DSR, a combination of graminicides and one of the herbicides for sedges and BLWs was found to be more effective for broad spectrum weed control (Karim *et al*., 2004). A grass effective herbicide used in conjunction with a herbicide specified for BLWs would control both types of weeds; similarly, a grass effective herbicide used in conjunction with a herbicide that controls both BLW and sedges would give a broader range of weed control (Mukherjee, 2006).

Herbicides with distinct modes of action, according to Paswan *et al*. (2012), bind to different target sites in weeds when used together, preventing target site resistance in vulnerable species. Chauhan and Yadav (2013) discoursed that using two or more herbicides may become a component of a more effective and integrated technique in the future to achieve better control of complex weed flora in DSR. Herbicide mixes will help to avoid the resistance problem and weed population shifts that are always a concern when using a single herbicide (Duary *et al*., 2015). Herbicides used in combination, whether pre-plant incorporated, pre emergence, or post emergence, increased the weed control spectrum or the duration of residual weed control. Herbicide tank mixing might improve the spectrum of weeds controlled in a single application, saving time and labour in a weed control programme. Combining suitable herbicides from various chemical families, such as 2,4-D and dicamba for BLWs, can help manage specific weed populations. Combinations of herbicides can also manage multiple weed categories at once, such as grass and BLWs (Choudhury *et al.*, 2016).

When two herbicides are combined, they could exhibit additive, synergistic, or antagonistic effects. When the individual effects are summed together, additivity occurs; synergism happens when the observed effect is more than the individual effect; and antagonism occurs when the combined effect of several herbicides is less than the individual effect (Zhang *et al*., 1995).

These interactions take place on the ground, in the spray solution, on the leaf surface, in the absorption and translocation tissues and at the herbicide site of action. (Matzenbacher *et al*., 2015). In agriculture, determining the proper herbicide tank combinations is critical for long term weed control since it lowers input costs, prevents yield losses and pollutes the environment less (Pala, 2020).

2.3.2.3.1 Penoxsulam + cyhalofop

2.3.2.3.1.1 Effect on weeds

The ready mix formulation of penoxsulam + cyhalofop butyl (10 + 50 g a.i. L^{-1}) and the tank mix of penoxsulam + cyhalofop butyl provided outstanding control of many grass weeds, BLWs and sedges with excellent rice tolerance in ASEAN countries (Lap *et al*., 2013). As reported by Yao *et al*. (2013), post emergence foliar application of the ready mix combination of penoxsulam + cyhalofop butyl (10 + 50 g a.i. L^{-1}) (RicerTM60OD) at 10 to 15 days after rice seeding provided excellent control of *E. crus-galli, L. chinensis, Paspalum distichum, C. difformis, C. iria, Scirpus juncoides, M. vaginalis, Monochoria korsakowii, Sagittaria* spp., *Alisma plantago-aquatica* and *Rotala indica*.

When treated at 1.0 L ha^{-1}, the penoxsulam + cyhalofop butyl ready mix provided greater than 90 per cent control of *F. miliacea* and *E. crus-galli* at 0 to 18 days after planting (DAP), *S. zeylanica* and *C. difformis* at 0 to 14 DAP and *C. iria* at 4 to 14 DAP in Thailand and 4 to 18 DAP in the Philippines (Lap *et al*., 2013). The field studies conducted at Thrissur, Kerala by Abraham and Menon (2015) revealed that post emergence application of penoxsulam + cyhalofop butyl @ 135 and 150 g ha^{-1} resulted in very good control of all types of weeds in WSR.

Reddy and Ameena (2021a) documented that the premix herbicide penoxsulam + cyhalofop butyl applied at 20 DAS *fb* HW effectively suppressed grass weeds, BLWs and sedges during initial stages of crop growth in WSR.

Raj and Syriac (2018) recommended the post emergence application of penoxsulam + cyhalofop butyl at 125, 130, or 135 g ha^{-1} at 15 DAS for successful weed seed bank management in wet DSR. Singh *et al*. (2019) stated that cyhalofop butyl + penoxsulam could be used as a post emergence herbicide in fields dominated by *E. glabrescens* and *L. chinensis*. Sen *et al*. (2020) opined that ready mix combination of penoxsulam + cyhalofop-butyl (130 g ha^{-1}) substantially reduced weed dry weight by 87.6 per cent at 25 DAS, outperforming other treatments. Srinithan *et al*. (2020) reported that among the herbicidal treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (15 DAT) recorded lower weed dry matter production of 93.01 kg ha^{-1} and higher weed index of 88.39 per cent. Reddy and Ameena (2021a), recorded lower weed dry weight and nutrient removal and displayed superior weed control efficiency with the application of penoxsulam + cyhalofop butyl applied at 20 DAS *fb* HW in direct seeded rainfed lowland rice.

Lap *et al*. (2013) reported that the ready mix combination of penoxsulam + cyhalofop butyl at 1.0, 1.25, and 1.5 L ha^{-1} gave excellent control of *L. chinensis* and achieved more than 85 per cent control at 10 + 50 or 12.5 + 62.5 g a.i. ha^{-1} administered 3 to 16 DAP. Singh *et al*. (2019) documented 100 per cent mortality of *L. chinensis* when cyhalofop butyl + penoxsulam was administered at 270 g ha^{-1}.

2.3.2.3.1.2 Effect on yield parameters and economics of rice cultivation

Penoxsulam + cyhalofop butyl ready mix sprayed at 1.0 L ha-1 offered excellent weed control and enhanced rice grain production by as much as 121 per cent, when compared to yield from untreated plots (Lap *et al*., 2013). Higher grain yield of 6.32 t ha^{-1} were obtained in penoxsulam + cyhalofop-butyl 6 per cent OD @ 135g ha^{-1}, which was statistically comparable to HW twice at 20 and 40 DAS (Kailkhura *et al*., 2015). According to Yadav *et al*. (2018), penoxsulam + cyhalofop @135 gha^{-1} or 150 g ha^{-1} ready mix application resulted in higher tillers m^{-2}, panicle weight, straw yield and grain yield (5.58 t ha^{-1}) than weed free treatment (5.60 t ha^{-1}).

Srinithan *et al*. (2020) reported that among the herbicidal treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (15 DAT) recorded higher grain and straw yield of 5453 and 7471 kg ha^{-1}, respectively.

When sprayed at two to four leaf stage, penoxsulam + cyhalofop butyl 6 per cent OD @ 135 g ha^{-1} exhibited excellent weed control, with greater grain production of 4167 kg ha^{-1}, net returns of ₹ 40,150 ha^{-1}, and BCR of 2.36 compared to hand weeded treatment in DSR (Patil, 2014). As reported by Yadav *et al*. (2018), post emergence spraying of penoxsulam + cyhalofop butyl 6 per cent OD @ 135 g ha^{-1} resulted in greater net returns in transplanted rice, with a BCR of 1.91, which was superior to the weed free condition (1.66). Ready mix combination of penoxsulam + cyhalofop-butyl (130 g ha^{-1}) increased rice grain yield (3.92 t ha^{-1}) by 378.9 per cent over unweeded control, increased gross benefit: cost (2.30) by 31.4 per cent over weed free control, gave the highest overall impact index (1.27) with an economic threshold level of 9.0 weeds m^{-2}, and was found to be the best weed management option in DSR (Sen *et al*., 2020). Reddy and Ameena (2021b) adjudged penoxsulam + cyhalofop butyl 6 % OD @ 150 g ha^{-1} at 20 DAS *fb* HW at 40 DAS as the best weed management option in direct seeded rainfed lowland rice, recorded higher grain yield and crop nutrient uptake.

2.3.2.3.2 Cyhalofop butyl + carfentrazone ethyl

2.3.2.3.2.1 Effect on weeds

The efficiency of carfentrazone ethyl at lower dose rates of 20 g ha^{-1} made it a good partner for other common cereal herbicides such as sulfonyl ureas, diflufenican, and phenoxy herbicides (Cauchy, 2000). According to Atheena (2016), tank mix application of cyhalofop butyl with carfentrazone ethyl resulted in complete control of *E. stagnina* and *Ludwigia* sp. but had no effect on *M. vaginalis*, whereas sequential application resulted in a lower population of *M. vaginalis*, which decreased from 15 to 5 no. m^{-2} from 18 DAS to 30 DAS. The treatment resulted in 72.4 and 87.6 per cent WCE, respectively at 30 and 60 DAS.

On the contrary, reduction in control of *Leptochloa panicoides* (Amazon sprangletop) by cyhalofop butyl on combination with carfentrazone ethyl was reported by Buehring *et al*. (2006).

2.3.2.3.2.2 Effect on yield parameters and economics of rice cultivation

Atheena (2016) observed that tank mix application of cyhalofop butyl + carfentrazone ethyl caused severe injury on rice and yielded only 3.9 t ha^{-1} with a BCR of 2.3 in WSR.

2.3.2.3.3 Bispyribac sodium + fenoxaprop-p-ethyl

2.3.2.3.3.1 Effect on weeds

As fenoxaprop-p-ethyl has little activity against broad leaf or sedge weeds, other herbicides having activity on broad leaf or sedge weed will almost certainly be required in a weed management programme incorporating fenoxaprop-p-ethyl, saving both time and money, and it would be helpful in DSR (Mahajan and Chauhan, 2015).

The study conducted by Ali *et al*. (2015) found that applying bispyribac sodium at 25 g ha^{-1} *fb* fenoxaprop-p-ethyl at 1406 g ha^{-1} sequentially was more successful (>80%) in changing the weed population at 30 and 45 DAS and was on par to bispyribac sodium + fenoxaprop-p-ethyl at 25 and 1171 g ha^{-1}, where a count of 44 and 53.33 m^{-2} were observed, respectively. Mahajan and Chauhan (2015) observed that the tank mix application of azimsulfuron + bispyribac + fenoxaprop considerably reduced the density of *C. iria*, *C. rotundus* and *L. chinensis* in dry DSR, compared to the non-treated control.

As bispyribac sodium activity was low in *L. chinensis*, it was recommended that 10% bispyribac sodium SC be used in combination with thiobencarb or fenoxaprop-p-ethyl for control *L. chinensis* (Wang *et al*., 2000). However, broad leaf or sedge herbicides may antagonise or lessen the herbicide effectiveness on grass weeds in a mixture comprising herbicides with grass activity, such as fenoxaprop-p-ethyl (Mahajan and Chauhan, 2015).

2.3.2.3.3.2 Effect on yield parameters and economics of rice cultivation

Tank mix combination of bispyribac sodium + fenoxaprop-p-ethyl at 25 + 937 g ha^{-1} produced the highest yield attributes (421 tiller m^{-2}, 406.25 panicles m^{-2} and 102 kernels $panicle^{-1}$), grain yield (3.80 t ha^{-1}) and the highest net revenue of ₹ 83,006 per hectare (Ali *et al*., 2015). According to Mahajan and Chauhan (2015), tank mix application of azimsulfuron plus bispyribac plus fenoxaprop recorded the highest grain yield of 7.23 t ha^{-1} in 2013 and 7.86 t ha^{-1} in 2014 and an additional profit of greater than 1000 USD ha^{-1} was observed in dry DSR.

2.4 DIFFERENTIAL RESPONSE OF GRASS WEEDS TO BISPYRIBAC SODIUM

Bispyribac sodium, sodium 2, 6-bis [(4, 6-dimethoxy-2-pyrimidinyl) oxy] benzoate, is a broad spectrum herbicide used in rice production. It is recommended for the post emergence control of grass weeds, some dicot weeds and certain sedges. ALS also referred to as acetohydroxyacid synthase is the enzyme in the biosynthetic pathway leading to the production of branched-chain amino acids *viz*., leucine, isoleucine, and valine. However, being an ALS inhibiting herbicide bispyribac sodium have a tendency to develop resistance rapidly to selected weed accessions (Tranel and Wright, 2002). The fact has more relevance in the background of ALS inhibiting herbicides developing resistance rapidly with 126 weed species on the list having developed resistance to ALS inhibitors already (Tranel *et al*., 2012).

A study on differential responses of *E. crus-galli* and *E. colona* to bispyribac sodium was conducted by Khedr *et al*. (2018). It was revealed that the growth of *E. crus-galli* was reduced by 93.87 and 86.3 per cent, respectively at 100 per cent field recommended dose (FRD) in terms of fresh and dry weight. In *E. colona,* growth was decreased by 84 and 71 per cent, respectively, at 100 per cent FRD.

The protein content in *E. colona* was found to be increased with increasing concentration of bispyribac sodium from 50 to 200 per cent FRD. However, it decreased by 18.4 per cent at 300 per cent FRD. The study indicated that *E. crus-galli* was susceptible to bispyribac sodium but *E. colona* showed some resistance (Khedr *et al*., 2018)

Differential responses to bispyribac sodium by *E. crus-galli* population was reported by Riar *et al*. (2012). In the study, *E. crus-galli* population from rice fields in Arkansas (AR1 and AR2) and Mississippi (MS1) showed differential responses with reduction in dry weight of 99 per cent in AR2 (susceptible population), 54 to 62 per cent and 71 to 73 per cent in resistant populations (AR1and MS1), respectively. Kaloumenos *et al*. (2013) also specified that bispyribac sodium applied at FRD reduced the fresh weight of nine susceptible *Echinochloa oryzicola* accessions by 83-100 per cent.

Lipid biosynthesis inhibitors work by inhibiting the activity of the ACCase enzyme and are commonly used to control grasses. The ACCase enzyme catalyses the first step in fatty acid synthesis, preventing the production of phospholipids required for lipid bilayer synthesis, which is essential for cell structure and function. When ACCase inhibitor herbicides are used in conjunction with ALS inhibitors at far lower than labelled rates, the combined action outperforms the individual components. Furthermore, no antagonistic effects exist; rather, the effect is synergistic (Mahajan and Chauhan, 2015).

From this brief review, it can be concluded that *L. chinensis* is a major weed in DSR. The review signifies the need for understanding the factors favouring the growth and establishment of the weed and developing suitable management practices involving herbicide combinations for broad spectrum managemnt. Hence, the present investigation was conducted to study the ecological factors favouring the growth and development of the weed and an effective management strategy for its control under WSR.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Germination ecology and management of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees.] in wet seeded rice" comprised of a phytosociological survey, pot culture experiments, field experiments and a series of laboratory experiments. The phytosociological survey was conducted in different rice tracts of Kerala *viz.*, Palakkad, *Kole* and Kuttanad after selecting three severely infested *padasekharam* in each tract during 2018 and 2019. Pot culture experiments on germination ecology and bioassay experiments were carried out at the College of Agriculture, Vellayani from 2018 to 2020. The management study was conducted at Integrated Farming System Research Station (IFSRS), Karamana during 2018 and 2019, where, a severe infestation of *Leptochloa chinensis* has been reported. The details of the materials and methodology adopted during the course of the investigation are presented below. The whole programme was carried out under six major heads or parts *viz.*,

Experiment I : Phytosociological survey

Experiment II : Germination ecology

Experiment III : Management of *Leptochloa chinensis* in wet seeded rice

Experiment IV : Sensitivity of weed to herbicide combinations using whole plant bioassay technique

Experiment V : Assessment of mode of action of tank mix herbicide combinations

Experiment VI : Assessment of differential response of grass weeds to bispyribac sodium

3.1 PHYTOSOCIOLOGICAL SURVEY

3.1.1 General details (Details of the study area)

3.1.1.1 Location

a) Kuttanad

Kuttanad is a unique low land ecosystem positioned at 9^0 27' N latitude and 76^0 25' E longitude, lying 0.5 to 2.0 m below mean sea level (MSL). The texture of the soil is found to be silty clay and belongs to the soil order Entisol. The pH of the soil is around 3.5 to 4.5 and the status of organic carbon, available phosphorus and exchangeable potassium is medium to high.

b) *Kole*

The *Kole* lands that shape the rice granaries of Thrissur and Malappuram districts comprise of a completely unique system in Kerala, extending out more than 13,000 ha. These wetlands are located 0.5 to 1 m below MSL and lie between 10^0 20' and 10^0 40' N latitudes and 75^0 58' and 76^0 11' E longitudes. The soil is clayey in texture and belongs to the order Inceptisol. The soil pH is 5.0 and is high in organic carbon, available phosphorus and medium in exchangeable potassium.

c) Palakkad

Palakkad is situated within the latitudes stretching from 10^0 21' to 11^0 14' N and longitudes extending from 76^0 02' to 76^0 45' E. The soil is lateritic with a pH of around 5.0 and belongs to the soil order Altisol. They are low in organic carbon, available phosphorus and exchangeable potassium. The gross paddy cropped area of Palakkad extends over 1.07 lakh ha. During the *Kharif* season, rice is grown mainly under semi-dry situations and in *Rabi*, cultivation is done utilizing the canal irrigation water from Mangalam, Pothundy, and Malampuzha dams.

3.1.1.2 Climate and weather

The Kuttanad, *Kole* and Palakkad rice growing tracts enjoy a tropical monsoon climate with more than 80 per cent of rainfall distributed through southwest and northeast monsoon showers. Weather conditions, which prevailed during the experimental period were largely normal with slight variations in the onset of the monsoon in the dry sown tracts of Palakkad and high temperatures during *Rabi*. The state received comparatively more rainfall (27.5%) during August 2018 than normal, which led to unusual floods.

3.1.1.3 Cropping pattern

The surveyed fields of Kuttanad are double-cropped wetlands, with two crop seasons *i.e.,* May-June to September-October and Novemeber-December to March-April. Broadcasting of sprouted seeds on receipt of the monsoon has evolved as a viable technology for rice farming in Kuttanad, owing to the availability of sufficient labourers at the right time. Chemical weed control has become almost an integral part of rice cultivation under wet seeded conditions.

In *Kole* lands, only one crop of rice is cultivated from September-October to February-March and the area remains submerged during the rest of the year. In certain *padasekharams* where conditions are favourable, farmers go for a second crop during February-May, before the southwest monsoon, using short duration varieties.

Palakkad is a semi-dry tract with two rice cropping seasons, from May-June to August-September and September-October to December-January. The first crop is under a semi-dry system, where sowing is done in moist soil on receipt of pre-monsoon showers, and the second is transplanted or irrigated rice under puddled conditions.

3.1.2 Experimental details

The survey was conducted in three severely infested *padasekharams* in the major rice growing tracts of Kerala, including Kuttanad, *Kole* and Palakkad during 2018 and

2019 to study the habitat features, composition and distribution of *L. chinensis.* The details of the surveyed areas are furnished in Table 1.

Table 1. Details of the surveyed areas

Location	Geographical position		District	Taluk	Panchayath
	Latitude	Longitude			
Kutttanad tract					
Karukappadam	9^0 37' 0032"N	76^0 46' 0403"E	Alappuzha	Kuttanad	Edathua
Maambuzhakari	9^0 41' 738"N	76^0 47' 165"E	Alappuzha	Kuttanad	Veliyanad, Thakazhy
Ramankari	9^0 42' 834"N	76^0 46' 500"E	Alappuzha	Kuttanad	Ramankari
Palakkad tract					
Alathur	10^0 64' 3447"N	76^0 54' 4150"E	Palakkad	Alathur	Alathur
Chithali	10^0 68' 8926"N	76^0 58' 3270"E	Palakkad	Alathur	Kuzhalmannam
Kavasseri	10^0 65' 7897"N	76^0 52' 0427"E	Palakkad	Alathur	Kavasseri
Kole **tract**					
Alappad *Kole*	10^0 44' 140"N	76^0 15' 808"E	Thrissur	Thrissur	Chazhoor
Enamavu *Kole*	10^0 51' 1512"N	76^0 09' 6162"E	Thrissur	Thrissur	Anthikad
Thiruthumthaad *Kole*	10^0 54' 5425" N	76^0 14' 7052"E	Thrissur	Thrissur	Adat

The survey was undertaken in the Kuttanad region during July-September 2018 and in the *Puncha* crop season during December-March 2018-19. In the Palakkad region, the survey was conducted in the first crop season during July-September 2018 and in the second crop season during December-February 2018-19. The survey in the *Kole* lands was done during January-March 2018 and December-January 2018-19.

3.1.3 Observations

3.1.3.1 Species wise count of all weeds

The species wise count of all weeds was taken from three different *padasekharams* of each rice growing tract *viz*., Kuttanad, *Kole* and Palakkad. For this, a total of 15 quadrats were sampled using a 0.5 m × 0.5 m quadrat with the quadrat being randomly positioned in each location. Each year's data was pooled for each locality, and average counts of various weeds were calculated. Based on the collected data, indices such as density, abundance, frequency and summed dominance ratio of each weed species were worked out for each rice tract.

a) Density

The number of weeds was recorded from fifteen randomly selected quadrats (0.5 m x 0.5 m) at each survey location and the mean value was recorded. The weeds were categorized based on their species. Density indicates the numerical strength of a species per unit area. The density of all species was calculated using the formula suggested by Philips (1959).

$$\text{Density} = \frac{\text{Total number of individuals of a species in all the quadrats}}{\text{Total number of quadrats sampled}}$$

b) Abundance

Abundance is the number of individuals of different species in the community per unit area of their occurrence. The abundance of all species of weeds from the quadrat was calculated using the formula suggested by Philips (1959).

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all the quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

c) Frequency

Frequency is the degree of dispersion of individual species in an area, usually expressed in terms of percentage occurrence. The frequency of weed occurrence was calculated using the formula suggested by Philips (1959).

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the particular species occurred}}{\text{Total number of quadrats sampled}} \times 100$$

d) Relative density (RD)

$$\text{RD} = \frac{\text{Total number of individuals of the given species}}{\text{Total number of individuals of all the species}} \times 100$$

e) Relative abundance (RA)

$$\text{RA} = \frac{\text{Abundance of a given species}}{\text{Total abundance of all the species}} \times 100$$

f) Relative frequency (RF)

$$\text{RF} = \frac{\text{Number of occurrence of a species}}{\text{Number of occurrences of all the species}} \times 100$$

g) Summed dominance ratio

The summed dominance ratio (SDR) of all weed species was separately worked out according to the formula developed by Misra (1968).

$$\text{SDR} = \frac{\text{Relative density} + \text{Relative frequency} + \text{Relative abundance}}{3}$$

3.1.3.2 Weed vegetation analysis

Weed vegetation analysis (habitat analysis) was done to quantify the diversity as well as evenness of weed flora in each tract. Weed biodiversity in these rice tracts was studied using the following indices.

a) Species richness (R)

Total number of species which occurred in the community (field).

b) Species diversity (H) (Shannon-Wiener, 1963)

Measured by the Shannon-Wiener diversity index, $H = \sum_{i=1}^{s} \mathrm{p}i \ln \mathrm{pi}$

where, pi is the proportion of the total number of individuals composed of species i and pi = Ni/N, where N is the total individual number of each weed species, S is the total number of species in the community and Ni is the individual number of the i^{th} species, and ln = natural logarithm.

c) Degree of community dominance (D) (Simpson, 1949)

Measured by Simpson's diversity index, $D = 1/\sum_{i=1}^{s} \mathrm{p}i^2$

where S = total number of species in the community (*i.e*., richness)

pi = proportion of the total number of individuals composed of species i.

d) Community evenness (J) (Pielou, 1966)

Measured by the evenness index (Pielou index), J = H/logR

where, H indicates species diversity and R indicates species richness

3.1.3.3 Characteristics of Leptochloa chinensis ecotypes at flowering

a) Plant height

The height of 10 randomly selected plants from each surveyed area was measured from the base of the plant to the tip of the longest leaf or panicle at the flowering stage, mean value worked out and expressed in centimeters.

b) Number of tillers per plant

The total number of tillers per plant was counted. Observations were recorded from 10 plants in each location and the mean value was worked out.

c) Number of panicles per plant

The number of panicles per plant was recorded from 10 plants in each surveyed location and the mean value was calculated.

d) Seed production capacity

Panicles from 10 plants in a locality were collected. The number of seeds per panicle was counted and, from this data, the total number of seeds per plant was derived and the mean value was recorded.

3.1.3.4 Content of major nutrients in L. chinensis

The content of major nutrients *viz*., N, P and K in *L. chinensis* from different locations of the collection were analyzed. Ten plants were collected from each location at the flowering stage and was air-dried for three days. The samples were then dried in a hot air oven at 80 ± 5^0C to constant weight, ground and sieved through a 0.5 mm sieve. The required quantities of samples were weighed out accurately and were subjected to acid extraction and the N, P, K content were determined.

a) Total nitrogen content

The total nitrogen content of plant samples was determined by the micro kjeldahl digestion and distillation method (Jackson, 1973).

b) Total phosphorus content

The plant sample was digested in a di-acid mixture and the total phosphorus content was determined by the Vanado-molybdo phosphoric yellow colour method. The intensity of colour was read using a Spectronic 20 spectrophotometer at 420 nm (Jackson, 1973).

c) Total potassium content

Potassium content in the di-acid digest was estimated using a flame photometer (Jackson, 1973).

3.1.3.5 Soil analysis

To study the association of dominance and occurrence of *L. chinensis* with soil properties, composite soil samples were collected from each location of the survey and soil analysis was done for the status of pH, EC, OC and major nutrients (NPK) in soils. The standard procedures for soil chemical analysis are given below.

a) Soil pH and EC

The soil pH and EC were analyzed in a soil : water suspension of 1 : 2.5 using pH and EC meters respectively.

b) Organic C

Soil samples were shade dried, sieved through a 0.2 mm sieve and analyzed for organic carbon content by rapid titration method (Walkley and Black, 1934).

c) Available soil N

The available nitrogen content of the soil was estimated by the alkaline permanganate method (Subbiah and Asija, 1956).

d) Available soil P

The available phosphorus content of the soil was determined by Dickman and Bray's molybdenum blue method using a spectrophotometer (Jackson, 1973).

e) Available soil K

The available potassium content of the soil was determined using neutral normal ammonium acetate and estimated using a flame photometer (Jackson, 1973).

3.2 GERMINATION ECOLOGY

3.2.1 Experimental details

3.2.1.1 Studies in biology

To study the biology of *L. chinensis,* 10 plants were randomly selected from the wetland rice fields of IFSRS, Karamana and observed from germination to maturity.

3.2.1.2 Studies on phenology

Experiments were conducted at the Agronomy field of the College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India. Mature seeds of *L. chinensis* were collected from lowland rice fields of the IFSRS, Karamana (80 47' N latitude and 760 96' E longitude), the rice growing belts of Kuttanad (90 35' N latitude and 760 40' E longitude), *Kole* (20 30' N latitude and 320 76' E longitude) and Palakkad (100 78' N latitude and 760 65' E longitude). Panicles were collected from more than 50 arbitrarily selected plants. Shattered seeds were bulked, cleaned, and stored in airtight plastic containers at room temperature until used.

Seeds obtained from different rice growing tracts were raised in pots of 27 cm diameter and 22 cm height filled with soil collected from rice fields (the soil was solarized to destroy the soil seed bank) to study the phenological phases of the weed plant. Twenty five seeds of *L. chinensis* were placed on the surface. The moisture in the pots was maintained at a saturation level.

Design : Completely randomized design (CRD)

Treatments : 4

Replications : 5

No. of pots per replication : 3

3.2.1.3 Germination studies

3.2.1.3.1 Studies on the effect of light and temperature on germination

To assess the influence effect of the light regime and varying temperatures on germination of *L. chinensis*, 100 seeds were placed inside a petri dish lined with filter paper and moistened with distilled water (5 ml). The petri dishes were incubated in growth chambers with fluctuating day/night temperatures (35/25 and 25/15°C) and different light regimes (light/ dark (12 h/12 h) for day/night environment and dark (24 h) for the complete no-light environment. These fluctuating temperature regimes were chosen to replicate temperature variations in the tropics. To prevent light penetration, the petri dishes in the dark regime were wrapped with three layers of aluminum foil. Seeds with emerged radicles were considered to have germinated. The number of germinated seeds was counted at 3 days (d) intervals for upto 15 d (T).

3.2.1.3.2 Studies on the effect of salinity on germination

The effect of salt stress on germination of *L. chinensis* was determined by placing 20 seeds in petri dishes containing 5 ml solutions of 0, 25, 50, 100, 150, 200, and 250 mM sodium chloride. NaCl salt with a molecular weight of 58.44 was used to induce salinity. To assess germination, the petri dishes were placed inside growth chambers under light conditions. Seeds that did not germinate at the highest salt concentrations were rinsed in running water for 5 minutes before being re-incuated with 5 ml of distilled water. The number of germinated seeds was counted for 15 days at 3-d interval.

3.2.1.3.3 Studies on field conditions favourable for the emergence of L. chinensis

The effect of different moisture conditions on seed germination and seedling emergence was studied in a pot experiment. The pots used in the experiment had 27 cm diameter and 22 cm height with sealed holes at the bottom and protected with transparent roofing. The soil used in the experiment was collected from lowland rice fields, solarized to destroy the soil seed bank and passed through 3 mm sieve. Twenty seeds of *L. chinensis* were sown in pots simulating five different field moisture conditions as detailed below. The number of seedlings emerged was counted at 5, 10, 15, 20, 25 and 30 days after sowing (DAS) and germination was expressed in percentage.

Design : Completely randomized design (CRD)

Treatments : 5

Replications : 4

No. of pots per replication : 3

Treatment details

T_1 : moist conditions maintained by irrigating on alternate days for a period of one month

T_2 : lowland with continuous flooding – puddled soil is flooded to 5 cm height throughout for a period of one month

T_3 : lowland conditions with alternate flooding and draining – puddled soil will be flooded after 5 days alternated with 5 days without flooding for a period of one month

T_4 : moist conditions with a thin layer of water (3 cm) maintained by irrigating every day for a period of one month

T_5 : soil irrigated to 5 cm depth once in 15 days

3.2.1.3.4 Studies on the effect of depth of burial and means of propagation on weed survival

The effect of burial depth on weed survival was determined by conducting a pot experiment. The pots used in the experiment had 27 cm diameter and 22 cm height with holes at the bottom. The soil used in the experiment was collected from lowland rice fields, solarized to destroy the soil seed bank and passed through 3 mm sieve. Twenty seeds and three double noded slips of *L. chinensis* were kept at a depth of 0, 2, 4, 6 and 10 cm in pots and was irrigated on alternate days. The number of seedlings with visible coleoptiles that emerged on the soil surface indicated seedling emergence and was recorded at three days intervals upto 30 DAS. The emergence of plants from the slips was also recorded at 3-d intervals upto 30 days.

Design : Completely randomized design (CRD)

Treatments : 10

Replications : 3

No. of pots per replication : 3

3.2.1.3.5 Studies on seed longevity

Seeds of *L. chinensis* along with soil were placed in 12 plastic bottles (25 seeds per bottle) and stored for testing the seed longevity. The seeds were tested for germination at monthly intervals for a period of one year. The study was conducted by sowing the seeds in pots of 27 cm diameter and 22 cm height filled with soil collected from rice fields (the soil was solarized to destroy the soil seed bank) and the germination percentage was recorded. The experiment started on 7th February 2019 and continued for a period of one year.

3.2.2 Observations

3.2.2.1 Biometric observations

a) Plant height

The height of 10 *L. chinensis* plants was measured from the base of the plant to the tip of the longest leaf or panicle, mean value was worked out and recorded in centimeters.

b) Number of tillers per plant

The total number of tillers per plant was counted from 10 *L. chinensis* plants at maturity and the mean value was recorded.

c) Leaf length

The length of five leaves of each plant was recorded at maturity, mean value was calculated and expressed in centimeters.

d) Number of panicles per plant

The total number of panicles that emerged from a single plant was recorded at maturity, and the mean value was calculated from the observations of 10 plants.

e) Number of primary branches of panicle

The total number of primary branches in a single panicle was recorded at maturity, and the mean value was calculated from the observations of 10 panicles.

f) Length of panicle

The length of panicles was measured from the base of the inflorescence to the tip at the maturity stage from 10 plants, mean value was calculated and recorded in centimeters.

g) Seed production capacity

The number of seeds per panicle was counted and from this data, the total number of seeds per plant was derived.

h) Thousand seed weight

The weight of thousand seeds was measured and expressed in grams.

3.2.2.2 Germination percentage

The number of seeds germinated was counted from the day of the first count to the last count and the germination percentage worked out using the formula

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds kept for germination}} \times 100$$

3.2.2.3 Emergence percentage

The number of seedlings with visible coleoptiles that emerged on the soil surface indicated seedling emergence and the emergence percentage was worked out using the formula

$$\text{Emergence percentage} = \frac{\text{Number of seedlings emerged}}{\text{Number of seeds kept for emergence}} \times 100$$

3.2.2.4 Time of emergence

In the pots, the number of days required for the emergence of weed sprouts was noticed and expressed in days.

3.2.2.5 Duration of growth stages

The growth stages of the weeds were identified and the duration and the mean number of days taken for each stage were recorded separately for seeds collected from each tract and expressed in days.

3.2.2.6 Incidence of pest and disease

The incidence of pests and diseases, if any, during the growing period was noted.

3.2.2.7 Metereological parameters

Data on important meteorological parameters such as rainfall and temperature prevailed at the time of the experiment *3.2.1.3.3* and *3.2.1.3.4* are furnished in Appendix I and II, respectively.

3.3 MANAGEMENT OF *L. chinensis* IN WET SEEDED RICE

3.3.1 General details

3.3.1.1 Location

The experiment was conducted at IFSRS, Karamana, Thiruvananthapuram, Kerala, where, a severe infestation of *L. chinensis* was observed. The field is situated geographically at 8^0 47’ N latitude and 76^0 96’ E longitude, at an altitude of 40 m above MSL.

3.3.1.2 Climate and weather conditions

The climate of the area is typical tropical monsoon type with occasionally excessive rainfall and dry, hot summer with three well defined seasons. Weather data pertaining to important meteorological parameters were collected from the agrometeorological observatory at IFSRS, Karamana during both 2018 and 2019. The data was tabulated based on the standard meteorological weeks, presented in Appendix III and IV and graphically represented in Fig. 1 and 2.

3.3.1.3 Cropping season

The experiment was conducted for two years during *Kharif*, from June to October 2018 and 2019.

3.3.1.4 Soil characters

The soil of the experimental site was sandy clay loam with medium texture, acidic in reaction with a pH of 4.5-6.1. It comes under typic tropofluent deep riverine alluvium. The physico-chemical properties of the soil of the experimental field are depicted in Table 2.

Table 2. Physico-chemical characteristics of the soil

A. Physical properties (particle size composition) of the soil in the experimental area

Sl. No.	Fractions	Value	Textural class	Method used
1	sand (%)	61.7	Sandy clay loam	Robinson International Pipette Method (Piper, 1942)
2	silt (%)	9.3		
3	clay (%)	28.1		

B. Chemical composition/ Initial chemical properties of the soil of the experimental area

Sl. No.	Fractions	Content		Method
		2018	2019	
1	Soil reaction (pH)	4.84 (very strongly acidic)	5.56 (moderately acidic)	1:2.5 soil water ratio using pH meter (Jackson,1973)
2	Electrical conductivity (EC), dS m^{-1}at 25^0C	0.28 (normal)	0.19 (normal)	1:2.5 soil water ratio (Jackson,1973)
3	Organic C (%)	1.55 (high)	2.18 (high)	Walkley and Black Method (Jackson, 1973)
4	Available N (kg ha^{-1})	225.8 (low)	175.6 (low)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg ha^{-1})	32 (high)	29 (high)	Bray colorimetric method (Jackson, 1973)
6	Available K (kg ha^{-1})	450.9 (high)	377.6 (high)	Neutral normal ammonium acetate extraction and estimation using flame photometry (Jackson, 1973)

3.3.1.5 Cropping history of the experimental site

The experimental site was under wet seeded rice cultivation for the past several years and was infested with all categories of weed plants, *viz*., grasses, sedges and broad leaf weeds (BLWs). Severe infestation of *L. chinensis* in the fields was experienced in recent periods only.

3.3.2 Materials

3.3.2.1 Crop variety

The popular rice variety of the state, ‘Uma’ (MO 16) was used in the experimental fields. It is a medium duration (120-135 days), red kernelled, medium bold, non-lodging, high yielding rice cultivar suitable for both direct seeding and transplanting during all seasons (*Virippu*, *Mundakan* and *Puncha*). It is resistant to brown plant hopper and gall midge and exhibits seed dormancy for upto three weeks.

3.3.2.2 Source of seed

The paddy seeds were procured from IFSRS, Karamana, Thiruvananthapuram, where, the experiment was laid out.

3.3.2.3 Manures and fertilizers

Well decomposed farmyard manure containing 0.53 per cent N, 0.20 per cent P_2O_5 and 0.42 per cent K_2O was used as the organic source. Fertilizers such as urea (46 per cent N), Rajphos (20 per cent P_2O_5) and Muriate of potash (60 per cent K_2O) were used for supplying the nutrients.

3.3.2.4 Herbicides

The following table (Table 3) gives the list and general information about the herbicides used as per the technical programme. Details are given as per the revised classification of herbicides based on the site of action (Mallory-Smith and Retzinger, 2003).

Table 3. General information of the herbicides used in the experiment

Common name	Trade name and formulation	Chemical family	Site of action	Recommended dose (kg ha^{-1})
Oxyfluorfen	Goal 23.5 EC	Diphenyl ether	Protox enzyme	0.15
Glyphosate	Roundup 41 SL	Organo phosphorus	EPSP synthase	0.80
Cyhalofop butyl	Clincher 10 EC	Aryloxyphenoxy propionate	ACCase	0.08

Penoxsulam + cyhalofop butyl	Vivaya (6% OD)	_	ALS + ACCase	0.15
Carfentrazone ethyl	Affinity 40 DF	Aryl triazolinone	Protox enzyme	0.02
Bispyribac sodium	Nominee Gold 10 SC	Pyrimidinyl thio-benzoate	ALS	0.025
Fenoxaprop-p-ethyl	Ricestar 6.7 EC	Aryloxyphenoxy propionate	ACCase	0.06

3.3.3 Methods

3.3.3.1 Design and Layout

The experimental design, field culture and observations were the same for both years. The detailed layout plan of the experiment is depicted below.

Design : Randomized Block Design (RBD)

Treatments : 10

Replications : 3

Plot size : 5.0 m x 4.0 m

3.3.3.2 Experimental details

The study was conducted from June to October, *Kharif* 2018 and 2019. The treatment details are given below:

Treatments

T_1 : cyhalofop butyl @ 0.08 kg ha^{-1}

T_2 : penoxsulam + cyhalofop butyl (6% OD) - commercial formulation @ 0.15 kg ha^{-1}

T_3 : cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}

T_4 : bispyribac sodium @ 0.025 kg ha^{-1}

T_5 : bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}

T_6 : bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}

T_7 : fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}

T_8 : stale seedbed *fb* chemical weeding with glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 days after land preparation + T_3

T_9 : unweeded control

T_{10} : hand weeding twice at 20 and 45 DAS

3.3.3.3 Field operations

The details of various field operations, from land preparation to harvest, are given below.

3.3.3.3.1 Land preparation

The field was thoroughly ploughed with a power tiller, puddled and was uniformly levelled. After land preparation, the experiment was laid out as per the technical programme. Raised bunds of 30 cm height and channels of 30 cm width were taken around each plot and 60 cm wide channels were taken along the length of each block between the replications. The plot size adopted was 20 m^2 (5 m x 4 m). A brief layout of the experimental field is shown in Fig. 3 and 4.

3.3.3.3.2 Sowing

Healthy seeds were soaked in salt water for four hours to remove the chaffy grains and weedy rice seeds and then soaked for 12-14 hours in water to trigger germination.

The seeds were then taken out and incubated in gunny bags for 32 hours for sprouting. The sprouted seeds were broadcast in individual plots @ 200 g per plot (100 kg ha^{-1}).

3.3.3.3.3 Manure and fertilizer application

The crop was fertilized with the recommended dose of FYM (5 t ha^{-1}) and chemical fertilizers. The entire dose of FYM was incorporated at the time of last ploughing. The fertilizers were applied in three splits @ 90: 45: 45 kg ha^{-1} N: P_2O_5: K_2O as per the package of practices (POP) recommendations for medium duration, high yielding cultivar Uma (MO 16) (KAU, 2016). The full dose of phosphatic fertilizer was given as basal. One-third dose each of nitrogen was given as top dressing at 15 DAS, active tillering (35 DAS) and panicle initiation stages (60 DAS). Potassium was applied as equal doses at seedling stage (15 DAS) and the panicle initiation stage (60 DAS).

3.3.3.3.4 Water management

Water management was carried out as per the KAU package of practices (POP) (KAU, 2016).

3.3.3.3.5 Weed management

Weed management was done as per the treatments. The herbicides were applied at 18 DAS, when weeds reached the 3-4 leaf stage. The spray volume used in the study was 500 L ha^{-1} and herbicides were sprayed with a hand operated knapsack sprayer fitted with a flat fan nozzle. In stale seedbed treatment, the fields were drained and allowed the weed seeds to germinate for 15 days, followed by chemical weeding with glyphosate 41% SL @ 0.8 kg ha^{-1} + oxyfluorfen 23.5% EC @ 0.15 kg ha^{-1} at 15-20 days after land preparation. Pre germinated rice seeds were sown after draining the field and treatment T_3 was applied later at the 3-4 leaf stage of weed. In hand weeded treatment, manual weeding was done at 20 and 45 DAS. In the weedy check (unweeded control) plot, no weed control operation was taken up.

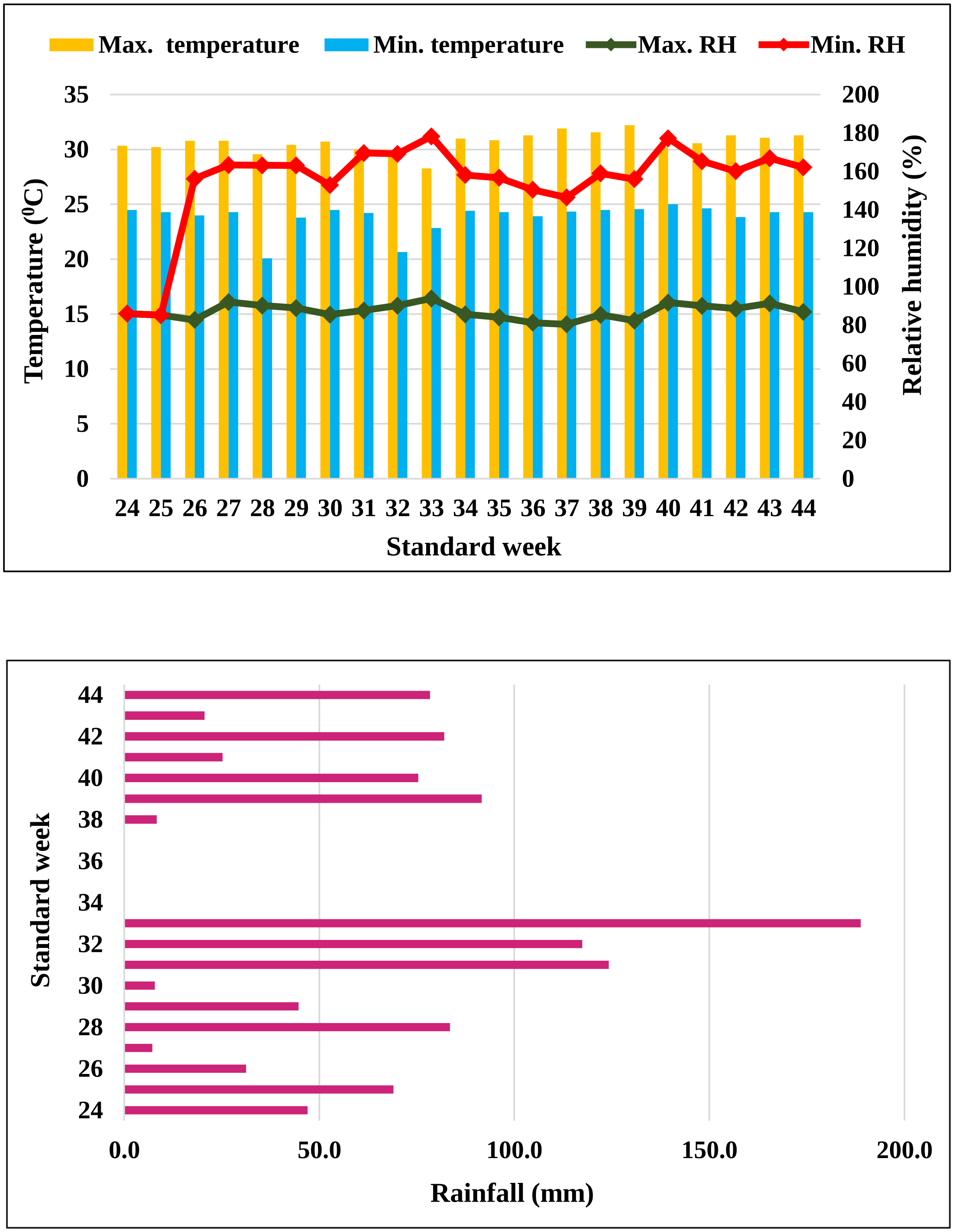
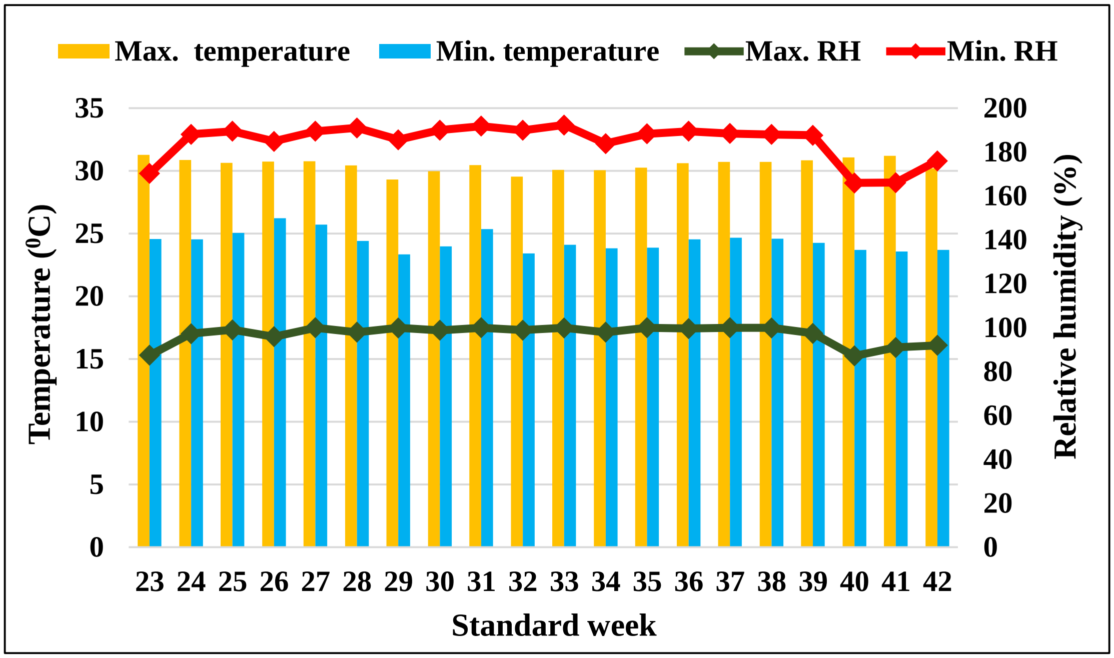


Fig. 1. Weekly weather data during experimental period, *Kharif* 2018



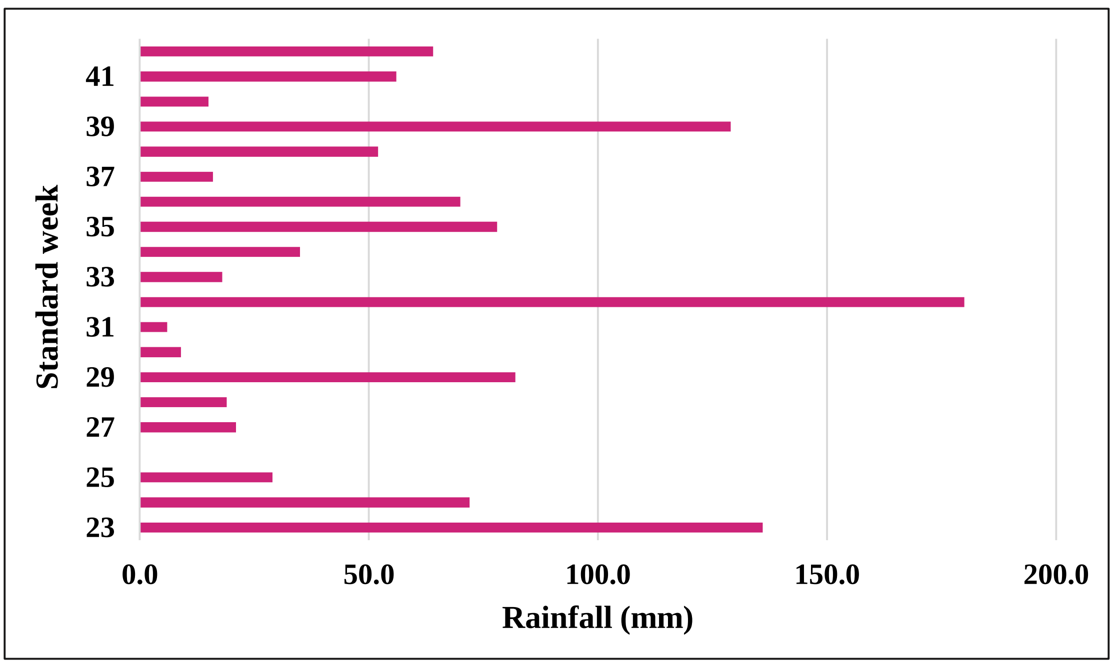


Fig. 2. Weekly weather data during experimental period, *Kharif* 2019

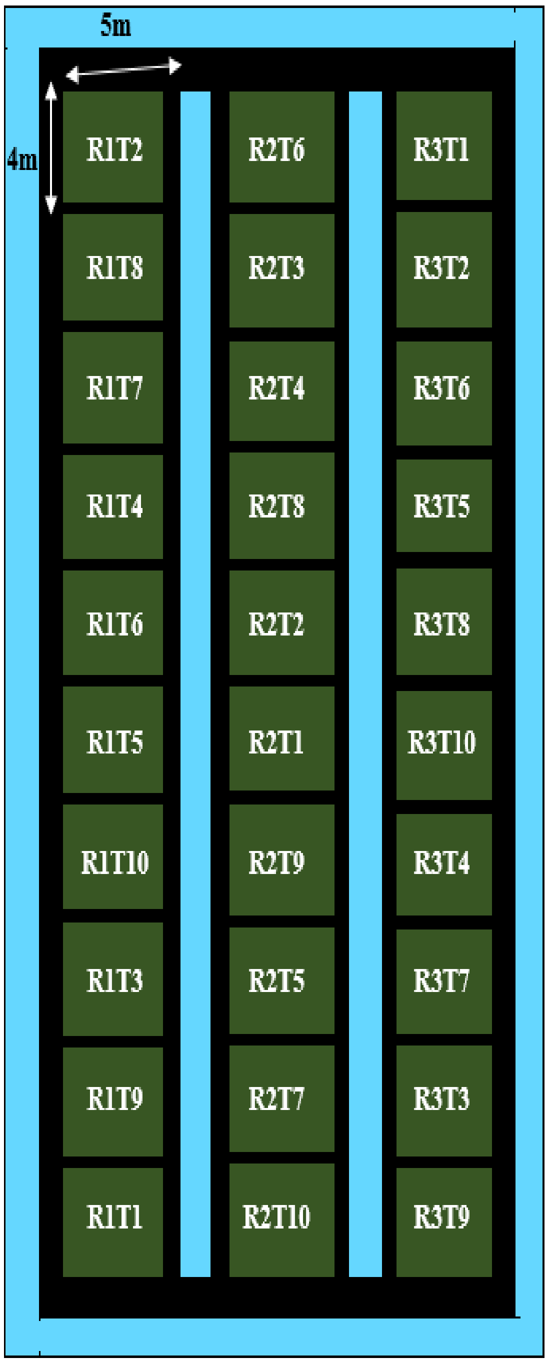


Fig. 3. Layout of the experimental field, *Kharif* 2018

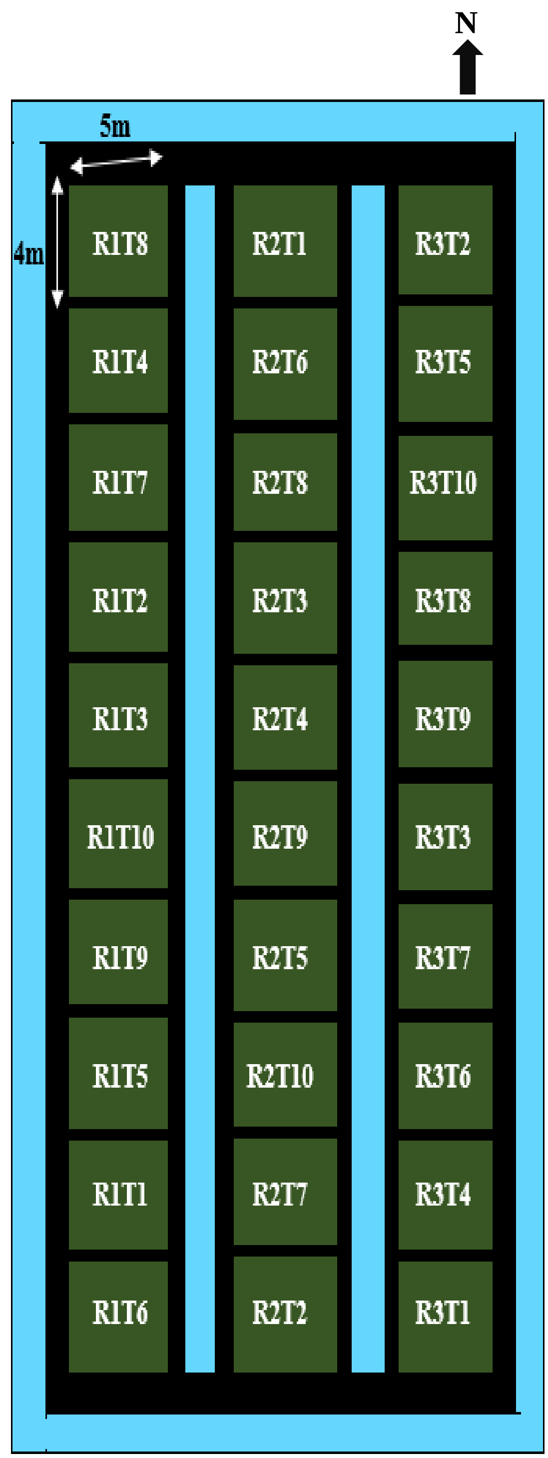


Fig. 4. Layout of the experimental field, *Kharif* 2019

3.3.3.3.6 Plant protection

Timely plant protection measures were taken as per the POP recommendations of KAU (KAU, 2016). Stem borer and leaf folder infestation were noticed during the tillering stage of the crop and one spray of flubendiamide (Fame 480 SC) @ 1 ml 10 L^{-1} was given against it. Incidence of bacterial leaf blight was noticed during both the crop seasons after the floods. A combination of copper oxychloride and K-cycline (3 + 0.5 g L^{-1}) was applied to prevent further infestation and a prophylactic spray of *Pseudomonas fluorescens* @ 20 g L^{-1} was given during 2019. A minor infestation of rice bugs was also noticed during the grain filling stage, against which fenvalerate (Tatafen 10 EC) was applied.

3.3.3.3.7 Harvest

The rice crop was harvested manually when the grains were at the hard dough stage and dry. Each net plot was threshed separately followed by winnowing. Threshing was done mechanically and the produce was cleaned, dried and the grain yield and straw yield were taken and expressed in kg ha^{-1} on a dry weight basis. During the first year, 2018 *Kharif,* in stale seedbed treatment, the crop could be harvested 20 days after all other treatments, but in 2019 *Kharif,* all the fields were harvested simultaneously.

3.3.4 Observations

3.3.4.1 Observations on weeds

3.3.4.1.1 Count of weeds emerged /survived

Species wise weed count of weeds was taken using a 0.5 m x 0.5 m (0.25 m^2) quadrat and categorized into grasses, broad leaf weeds (BLW) and sedges. The quadrat was placed at random, and samples were taken from each plot before treatment application, at 15, 30, 45 days after treatment application (DATA) and were reported as number per square metre (no. m^{-2}).

3.3.4.1.2 Regrowth pattern

The regrowth pattern of the weed was observed 30 days after spraying.

3.3.4.1.3 Dry matter production of weeds

Weed dry weight was recorded at 15, 30, 45 days after treatment application (DATA) by placing a quadrat of 0.5 m x 0.5 m randomly at two sites in each treatment plot. The uprooted weeds were cleaned, air-dried and then oven dried at 80 ± 5^{0}C until a constant weight was attained and the dry weight was recorded in g m^{-2}.

3.3.4.1.4 Nutrient removal

The content and uptake of major nutrients, *viz*., N, P and K at 15, 30, 45 days after treatment application were analyzed by standard procedures (Jackson, 1973). The uptake of N, P and K at 15, 30, 45 days after treatment application was calculated as the product of the content of these nutrients and the dry weight of weeds sampled and expressed in kg ha^{-1}. The total N content of plant samples was determined by the micro kjeldahl digestion and distillation method. The plant sample was digested in a di-acid mixture and the P content was determined by the vanado molybdo phosphoric yellow colour method. The intensity of colour was read using a Spectronic 20 spectrophotometer at 420 nm. Potassium content in the di-acid digest was estimated using a flame photometer.

3.3.4.1.5 Weed Control Efficiency (WCE)

The weed control efficiency was worked out using the formula suggested by Upadhyay and Sivanand (1985).

$$\text{Weed control efficiency, WCE} = \frac{(X - Y)}{X} \times 100$$

where, X designates weed dry matter production in control plot (unweeded control) and Y designates weed dry matter production in selected treatment plot whose WCE has to be computed.

3.3.4.1.6 Weed Index (WI)

The weed index was worked out using the formula suggested by Gill and Vijayakumar (1969).

$$\text{Weed index, WI} = \frac{X - Y}{X}$$

where, X indicates grain yield from the treatment with the least weeds and Y indicates grain yield from the treated plot for which WI has to be worked out.

3.3.4.2 Observations on crop

3.3.4.2.1 Phytotoxicity rating

The treated plots were observed closely, and the **v**isual symptoms of herbicide toxicity on plants were recorded. Phytotoxicity rating of the crop was done on the fourth and seventh day after herbicide application. Symptoms of injury were graded from 0-5 using the toxicity scale suggested by Thomas and Abraham (2007) and given below in Table 4.

Table 4. Scale for rating herbicide phytotoxicity in crop and weeds

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

3.3.4.2.2 Plant height

The height of five plants from each plot was measured from the base of the plant to the tip of the topmost leaf at 30, 60 DAS and harvest.

At harvest, it was measured from the base of the plant to the tip of the longest panicle. The mean height was computed and expressed in centimeters.

3.3.4.2.3 Number of tillers m^{-2}

In each treatment plot, the tiller count was taken from two spots using a quadrat of 0.25 m^2 and was computed as no. m^{-2}.

3.3.4.2.4 Number of panicles m^{-2}

The total number of panicles in a quadrat of 0.25 m^2 was counted from each plot, and the mean was expressed as no. m^{-2}.

3.3.4.2.5 Number of grains per panicle

Both filled and unfilled grains from randomly selected panicles were separated and counted.

3.3.4.2.6 Percentage of filled grains

Grains collected from 10 randomly selected panicles were separated into filled grains and chaff and counted. The average number of filled grains as well as chaff for a single panicle was then found out and percentages were worked out.

3.3.4.2.7 Thousand grain weight

One thousand fully filled, bold grains were counted from the produce of each plot and their weight was recorded in grams.

3.3.4.2.8 Grain yield

Grains from each plot, after winnowing and cleaning, were weighed separately, and recorded the fresh weight. Grains were dried to 13 per cent moisture content, weighed and expressed in kg ha^{-1}.

3.3.4.2.9 Straw yield

The dry weight of straw from the plot area of each treatment was recorded after sun drying for three consecutive days and was expressed in kg ha^{-1}.

3.3.4.2.10 Nutrient uptake at harvest

The content and uptake of major nutrients, *viz*., N, P and K of rice at harvest were analyzed by standard procedures (Jackson, 1973). The total N content of plant samples was determined by the micro kjeldahl digestion and distillation method. The plant sample was digested in a di-acid mixture and the P content was determined by the vanado molybdo phosphoric yellow colour method. The intensity of colour was read using a Spectronic 20 spectrophotometer at 420 nm. Potassium content in the di-acid digest was estimated using a flame photometer. The nutrient uptake of rice at harvest was calculated as the product of nutrient content and the plant's dry weight and expressed in kg ha^{-1}.

3.3.4.2.11 B : C ratio

The prevailing labour charge in the locality, the cost of inputs and extra treatment costs were taken together and gross expenditure was computed and expressed as rupees per hectare. The price of the paddy and that of straw at current local market prices were taken as total receipts for computing gross return and expressed as rupees per hectare. The benefit-cost ratio was worked out by dividing the gross return with the total expenditure per hectare.

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

3.4 SENSITIVITY OF WEED TO HERBICIDE COMBINATIONS USING WHOLE PLANT BIOASSAY TECHNIQUE

3.4.1 Experiment details

The study was conducted by sowing seeds of *L. chinensis* in pots (27 cm diameter and 22 cm height) filled with soil collected from rice fields (the soil was solarized to destroy the soil seed bank). Twenty seeds were placed on the soil surface and allowed to germinate. After one month, 10 seedlings were retained in each pot. The most effective and economical combinations identified from the third experiment were applied to the weed at 4-5 leaf stage. Bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} was identified as the most effective and economical treatment combination. As this treatment was on par with bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}, penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1} and cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}, these combinations were also included in the experiment. The sensitivity of weed to combination herbicides was tested at their lower and normal doses using the whole plant bioassay technique.

Design : Completely randomized design (CRD)

Treatments : 8

Replications : 3

Treatment details

T_1 : bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}

T_2 : bispyribac sodium @ 0.020 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.04 kg ha^{-1}

T_3 : bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}

T_4 : bispyribac sodium @ 0.020 kg ha^{-1} + cyhalofop butyl @ 0.06 kg ha^{-1}

T_5 : penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}

T_6 : penoxsulam + cyhalofop butyl (6% OD) @ 0.10 kg ha^{-1}

T_7 : cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}

T_8 : cyhalofop butyl @ 0.06 kg ha^{-1} + carfentrazone ethyl @ 0.01 kg ha^{-1}

3.4.2 Observations

3.4.2.1 Survival rate

The number of plants that remained unaffected after seven days of treatment application was counted and expressed in percentage.

3.4.2.2 Dry weight

The plants were air dried, placed in paper envelops and oven-dried at 80^0C for 48 hours and the dry weights were then recorded.

3.4.2.3 Scoring of phytotoxicity

The treated plots were observed closely, and the visual symptoms of herbicide toxicity on plants were recorded. The phytotoxicity rating of the weed was done on the fourth and seventh day after herbicide application. Symptoms of injury were graded from 0-5 using the toxicity scale given by Thomas and Abraham (2007).

3.5 ASSESSMENT OF MODE OF ACTION OF TANK MIX HERBICIDE COMBINATIONS

3.5.1 Experiment details

The study was conducted by sowing seeds of *L. chinensis* in pots (27 cm diameter and 22 cm height) filled with soil collected from rice fields (the soil was solarized to destroy the soil seed bank).

Twenty seeds were placed on the soil surface and allowed to germinate. After one month, 10 seedlings were retained in each pot. The experimental design was completely randomized design with 5 replications. The treatments were applied when the weed reached 4-5 leaf stage, which included the application of an ALS inhibitor (bispyribac sodium), ACCase inhibitor (fenoxaprop-p-ethyl) and a combination of ALS and ACCase inhibitor (bispyribac sodium + fenoxaprop-p-ethyl). A control treatment was also maintained. The mode of action of the tank mix herbicide combination was assessed by conducting an amino acid and fatty acid assay.

Design : Completely randomized design (CRD)

Treatments : 4

Replications : 5

Treatment details

T_1 : ALS inhibitor alone (bispyribac sodium @ 0.025 kg ha^{-1})

T_2 : ACCase inhibitor alone (fenoxaprop-p-ethyl @ 0.06 kg ha^{-1})

T_3 : ALS + ACCase inhibitor (bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1})

T_4 : Control

3.5.2 Observations

3.5.2.1 Amino acid content

The amino acid content was estimated using standard procedures (Sadasivam and Manikam, 2007). Total free amino acids were estimated using ninhydrin reagent. Ninhydrin is also chemically known as triketohydrindene hydrate. It reacts with amino acid to give a purple colour complex (Riemann’s purple) with an absorption maximum at

570 nm. Ninhydrin oxidizes the amino acid to aldehyde, releasing carbon dioxide and ammonia. During the course of the reaction, ninhydrin gets reduced to hydridatin. The hydridatin form condenses with Ninhydrin in the presence of ammonia to yield a purple complex.

Tissue sample (1.0 mg) was homogenized in 1mL of phosphate buffer (pH 7.0). It was then centrifuged at 10,000 rpm for 20 minutes. The supernatant was removed, and the pellet was resuspended in 1 mL of phosphate buffer (pH 7.0). It was made upto 4 mL with distilled water and 1 mL of Ninhydrin reagent was added. The contents of the tubes were mixed by vortexing and were placed in a boiling water bath for 15 minutes. The test tubes were cooled in cold water and 1 mL of ethanol was added. After cooling, the absorbance was measured at 570 nm using a UV Visible Spectrophotometer. The concentration of amino acid was calculated using the standard curve for proline.

3.5.2.2 Fatty acid content

The fatty acid content was estimated using standard procedures (Sadasivam and Manikam, 2007). The concentration of triglycerides was estimated using the ERBA Triglycerides kit, Catalogue No - BLT00059 TG 250. To 100 µL of each sample (control, test), standard and distilled water, 1 mL of reagent solution were added. It was mixed well and incubated for 10 minutes at 37°C. After incubation, the absorbance of samples and standards were read at 500 nm against a reagent blank. Fatty acid content was worked out using the formula:

$$\text{Triglycerides (mg dL}^{-1}\text{)} = \frac{\text{Absorbance of the sample} \times \text{Concentration of standard}}{\text{Absorbance of standard}}$$

[Concentration of standard- 200 mg dL^{-1}]

3.6 ASSESSMENT OF DIFFERENTIAL RESPONSE OF GRASS WEEDS TO BISPYRIBAC SODIUM

3.6.1 Experiment details

The study was conducted by sowing 20 seeds of two weeds, *L. chinensis* and *Echinochloa colona* in pots (27 cm diameter and 22 cm height) filled with soil collected from rice fields (the soil was solarized to destroy the soil seed bank). Seeds of both weeds were placed on the soil surface and allowed to germinate. After one month, 10 seedlings of both weeds were retained in each pot. The plants were treated with 50, 100 and 200 per cent field recommended dose (FRD) of bispyribac sodium when they reached 4-5 leaf stage. Three days after treatment with herbicide, the samples were collected and placed on ice packs for analysis.

3.6.2 Observations

3.6.2.1 Amino acid content

Same as in *3.5.2.1*

3.6.2.2 Protein profiling

Protein samples were collected from leaves of all the treatments of both the weeds three days after treatment application and analyzed by Sodium Dodecyl Sulphate - Poly Acrylamide Gel Electrophoresis (SDS PAGE).

STATISTICAL ANALYSIS

The data generated from the experiments was subjected to analysis of variance technique of CRD and RBD using the statistical package WASP (Web Based Agricultural Statistics Software Package) developed by ICAR-GOA, India.

In experiment II, the relationship between germination or emergence (%) and time (T) was identified under various factors, such as light, alternating temperature, salt concentrations, burial depths and moisture conditions. Suitable non-linear regression models were fitted and the best fit model was identified using R. A functional three-parameter sigmoid function was found to be the best fit with an R^2 value of > 0.99. Germination resulting from alternating temperatures and different salt concentrations was modelled as:

$$G = Gmax/ \{1 + e[-(T - T50) / Grate]\}$$

where G is the total germination (%) at time T, Gmax is the maximum germination (%), T50 is the time required for 50% of maximum germination, and Grate indicates the slope.

In the case of experiment III, data on weed count and biomass, 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). Multiple comparisons among treatment means, where the F test was significant (at 5% level) were done with Duncan's Multiple Range Test (DMRT). The pooled analysis was carried out for grain yield, straw yield and B: C ratio by taking the season as a source of variation in addition to replication and treatment.

Results

4. RESULTS

The investigation entitled "Germination ecology and management of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees.] in wet seeded rice" was conducted to study the germination ecology and to formulate a herbicide based management strategy for *L. chinensis* in wet seeed rice (WSR). The data obtained from the experiments are furnished here in tables after subjecting them to appropriate statistical analysis.

4.1 PHYTOSOCIOLOGICAL SURVEY

The surveys were conducted to document the habitat features, composition and distribution of *L. chinensis* in the major rice growing tracts of Kerala *viz.*, Palakkad, *Kole* and Kuttanad, after selecting three severely infested *padasekharam* in each tract. The information from the surveys was used for studying the influence of agro ecological conditions on weed flora. The results are furnished below.

4.1.1 Distribution of weed flora

The species wise count of each weed that existed in the surveyed locations was recorded and based on the data obtained, parameters such as density, frequency, abundance, relative density, relative frequency, relative abundance and summed dominance ratio were worked out.

4.1.1.1 Kuttanad tract

The data on the distribution and dominance of weeds in the Kuttanad tract is depicted in Table 5. A total of 13 weed species were observed in the rice fields, of which four were grass weeds, three were broad leaf weeds (BLWs), five were sedges and one was fern. Grass weeds dominated the Kuttanad ecosystem with a summed dominance ratio (SDR) of 48.41, followed by sedges (27.99), BLWs (16.43) and ferns (7.17).

Out of 13 weed species, *Echinochloa stagnina* was seen to be the most dominant in the surveyed areas of the Kuttanad tract, recorded the highest density, frequency, relative density, relative frequency and SDR, followed by *Sacciolepis interrupta* and *L. chinensis*. *L. chinensis* was found to be dominated in Karukappadam, Mambuzhakari and Ramankari *padasekharams* of the Kutttanad rice tract. The *L. chinensis* population was observed abundant in the field bunds, fields adjacent to the bunds, waterways, marshy areas, waterlogged areas as well as upland areas. The weed was also seen growing profusely along the inner bunds that separate individual fields.

When the weeds were ranked according to the SDR, 7 weeds, *i.e*., *E. stagnina*, *L. chinensis*, *S. interrupta*, *Oryza sativa f. spontanea*, *Monochoria vaginalis*, *Cyperus difformis* and *Fimbristylis miliacea* together had a SDR of 73.09, indicating that more than 70 per cent of the weed flora of Kuttanad rice tracts is constituted by these weeds. In terms of abundance, *S. interrupta*, followed by *E. stagnina* and *L. chinensis* were the most abundant than other weed species.

Echinochloa stagnina (SDR - 14.8), *S. interrupta* (SDR - 13.26) and *L. chinensis* (SDR - 13.05) were the dominant weeds in Kuttanad ecosystem, followed by *C. difformis* (SDR - 8.95) and *F. miliacea* (SDR - 8.47) together accounting for 58.53 per cent of the SDR. These five weeds were present in the majority of the sites surveyed with *E. stagnina* with a frequency of 86.67 per cent, *S. interrupta and L. chinensis* each with a 73.33 per cent, *C. difformis* with 66.67 per cent and *F. miliacea* with a frequency of 60.0 per cent.

Among the BLWs, *M. vaginalis* was the most dominant one, occurring in about 53.33 per cent of the sites surveyed with a SDR of 7.26, followed by *Limnocharis falva* and *Ludwigia hyssopifolia* with SDRs of 4.63 and 4.54, respectively. *C. difformis* was the most dominant sedge, which occurred in 66.67 percent of the fields surveyed, followed by *F. miliacea,* which occurred in 60 per cent of the fields surveyed. *Cyperus haspan*, *Cyperus iria* and *Schoenoplectus juncoides* occurred in limited areas only.

Salvinia molesta was the only fern species present in the Kuttanad rice tract and occupied 40.0 per cent of the area.

4.1.1.2 Kole tract

Table 6 illustrates the information on the distribution and dominance of the weeds in the *Kole* tracts. Altogether 17 weeds were identified in the *Kole* lands, which comprised of seven grass weeds, five BLWs, three sedges, one fern and an aquatic plant. The weed spectrum of *Kole* lands was dominated by grass weeds with SDR of 57.24, followed by BLWs (21.5), sedges (16.81) and ferns (2.98). Infestation of *L. chinensis* was found in almost all *padasekharams* of the *Kole* tract. It was severely infested in the *padasekharams* of Alappad *Kole*, Enamavu *Kole* and Thiruthumthaadu *Kole*.

The weed flora of *Kole* land was found to be dominated by *O. sativa f. spontanea*, *L. chinensis, Echinochloa colona, S. interrupta, Echinochloa stagnina, C. difformis* and *F. miliacea,* which together accounted for a SDR of 64.46. Among these, *O. sativa f. spontanea* was the most dominant weed (SDR - 13.21), occurred in about 86.67 per cent of the fields surveyed, followed by *L. chinensis* (SDR - 12.40), which occurred in about 80 per cent of the areas. *E. colona*, *E. stagnina* and *S. interrupta* were the other three grass species observed with a frequency of 80, 66.7 and 66.7 per cent, respectively in the surveyed locations of the *Kole* tract. *E. colona* and *L. chinensis* were observed to be more frequently occurred (80%). *Echinochloa crus-galli* and *Isachne miliacea* were also present in the surveyed locations, but, their frequency (33.33%) and SDR (2.99 and 3.57 respectively) were much lower.

Monochoria vaginalis was the most dominant BLW (SDR - 5.12) occurred in 60 per cent of the fields surveyed, followed by *Lindernia* sp. (SDR - 5.03) and *Limnocharis flava* (SDR - 4.58). *Ludwigia parviflora* had an important position among the BLW with a frequency of about 60 per cent. *A. philoxeroides* was another important BLW with a wide distribution (frequency - 33.33%) in this ecosystem.

Among the sedges, *C. difformis* was the predominant sedge, having a SDR of 7.11 and occurred in 73.33 per cent of the surveyed areas. *F. miliacea* constituted a major portion of the sedge population with a frequency of 73.33 per cent. *Cyperus iria* was the other sedge that occurred at a lesser frequency of 40.0 per cent with a SDR of 3.03. As in the Kuttanad tract, *S. molesta* was the only fern weed noticed in the surveyed areas of *Kole* lands with a wide distribution (frequency - 33.33%). The presence of *Cabomba furcata* was also noticed in the *Kole* tract with a lower density (0.27 m^{-2}), frequency (6.66%) and SDR (1.30).

4.1.1.3 Palakkad tract

The list of weeds identified in the Palakkad tract during *Kharif* and *Rabi*, 2018 with data on their distribution and dominance are presented in Table 7 and 8, respectively. A total of 15 weed species were observed in the rice fields of Palakkad tract during *Kharif*, of which six were grass weeds, five were BLWs and four were sedges. During *Rabi*, 12 weeds were observed, of which, five were grass weeds, four were BLWs and three were sedges. Grass weeds dominated the weed spectrum of the Palakkad tract during both *Kharif* and *Rabi*, with SDR of 61.18 and 54.3 respectively, followed by BLWs (22.18 and 24.74) and sedges (19.91 and 20.94).

The analysis of the floristic composition of the Palakkad tract during *Kharif* revealed the dominance of weeds like *S. interrupta*, *L. chinensis, E. colona, C. iria*, *I. miliacea* and *L. parviflora* together accounting for a SDR of 64.78, indicating that more than half of the weed problems of this ecosystem are from these weeds. Out of these, *S. interrupta* occupied the top position and was the dominant one with a SDR of 23.60, followed by *L. chinensis* with a SDR of 17.49. However, during the *Rabi* season, *L. chinensis* dominated the ecosystem with a SDR of 19.04 followed by *S. interrupta* (SDR - 14.16). Severe infeststion of *L. chinensis* was found in the Alathur, Chithali and Kavasseri *padasekharams* of the Palakkad rice tract.

Table 5. Distribution and dominance of weed species in surveyed areas of Kuttanad tract

Weed species	Density (no. m^{-2})	Frequency (%)	Abundance	RD (%)	RF (%)	RA (%)	SDR
Grass weeds							
Echinochloa stagnina	14.40	86.67	16.62	18.81	12.38	13.20	14.80
Leptochloa chinensis	12.00	73.33	16.36	15.68	10.47	13.00	13.05
Sacciolepis interrupta	12.26	73.33	16.72	16.02	10.47	13.29	13.26
Oryza sativa f. spontanea	5.07	60.00	8.44	6.62	8.57	6.71	7.30
Broad leaf weeds							
Limnocharis flava	2.40	46.67	5.14	3.14	6.67	4.09	4.63
Ludwigia hyssopifolia	2.40	40.00	6.00	3.14	5.71	4.77	4.54
Monochoria vaginalis	5.07	53.33	9.50	6.62	7.62	7.55	7.26
Sedges							
Cyperus difformis	6.93	66.67	10.40	9.06	9.52	8.26	8.95
Cyperus haspan	2.40	40.00	6.00	3.14	5.71	4.77	4.54
Cyperus iria	1.33	33.33	4.00	1.74	4.76	3.18	3.23
Fimbristylis miliacea	6.40	60.00	10.67	8.36	8.57	8.48	8.47
Schoenoplectus juncoides	1.07	26.67	4.00	1.40	3.81	3.18	2.80
Ferns							
Salvinia molesta	4.80	40.00	12.00	6.27	5.71	9.53	7.17

RD – Relative density; RF – Relative frequency; RA – Relative abundance; SDR – Summed dominance ratio

Table 6. Distribution and dominance of weed species in surveyed areas of *Kole* tract

Weed species	Density (no. m^{-2})	Frequency (%)	Abundance	RD (%)	RF (%)	RA (%)	SDR
Grass weeds							
Echinochloa colona	9.60	80.00	12.00	11.11	8.82	8.55	9.49
Echinochloa crus-galli	1.60	33.33	4.80	1.85	3.68	3.42	2.99
Echinochloa stagnina	5.33	66.67	8.00	6.17	7.35	5.70	6.40
Isachne miliacea	2.13	33.33	6.40	2.47	3.68	4.56	3.57
Leptochloa chinensis	13.87	80.00	17.33	16.05	8.82	12.35	12.40
Sacciolepis interrupta	9.06	66.67	13.60	10.49	7.35	9.69	9.18
Oryza sativa f. spontanea	15.20	86.67	17.53	17.59	9.56	12.50	13.21
Broad leaf weeds							
Alternathera philoxeroides	1.33	33.33	4.00	1.54	3.68	2.85	2.69
Lindernia sp.	3.47	33.33	10.40	4.01	3.68	7.41	5.03
Limnocharis flava	3.20	46.67	6.86	3.70	5.15	4.89	4.58
Ludwigia parviflora	2.40	60.00	4.00	2.78	6.61	2.85	4.08
Monochoria vaginalis	3.73	60.00	6.22	4.32	6.61	4.43	5.12
Sedges							
Cyperus difformis	6.40	73.33	7.40	8.09	6.22	7.24	7.11
Cyperus iria	1.60	40.00	4.00	1.85	4.41	2.85	3.03
Fimbristylis miliacea	5.60	73.33	7.64	6.48	8.08	5.44	6.67
Ferns							
Salvinia molesta	1.60	33.33	4.80	1.85	3.68	3.42	2.98
Others							
Cabomba furcata	0.27	6.66	4.00	0.31	0.74	2.85	1.30

RD – Relative density; RF – Relative frequency; RA – Relative abundance; SDR – Summed dominance ratio

The predominant BLW species observed in the rice fields of the Palakkad tract during *Kharif* consisted of *L. parviflora* (SDR - 4.69) with a frequency of 46.67 per cent, followed by *Lindernia* sp. and *Commelina benghalensis* with SDR of 3.98 and 3.73, respectively. *Cyanotis auxillaris* and *Eclipta alba* were the other two BLW species with a frequency of 26.67 per cent and SDR of 3.26 each. During *Rabi*, *L. parviflora*, *C. benghalensis, M. vaginalis* and *Lindernia* sp. were observed with a frequency of 33.33, 26.67, 20.0 and 20.0 per cent, respectively.

The sedge population was dominated by *C. iria* with a SDR of 6.87 and occurred in 60 per cent of the surveyed areas during *Kharif*. *F. miliacea* and *S. juncoides* were the other sedge species that occurred in about 40 per cent of the fields surveyed, followed by *C. haspan* (frequency - 26.67%), while the density of these weeds was very low, resulting in low SDR. *C. iria, F. miliacea* and *S. juncoides* were the sedges observed during *Rabi* season with a density of 2.13, 1.07 and 0.8 m^{-2}, respectively.

4.1.2 Habitat analysis

In the major rice tracts of Kerala, *i.e.*, Kuttanad, *Kole* and Palakkad, habitat analysis was carried out and expressed in terms of weed vegetation. According to the results of the survey, there were similarities in weed flora among the rice tracts, which are geographically far away from each other. The data of the diversity indices calculated for weed vegetation analysis are presented in Table 9. Appraisal of weed vegetation analysis indices in different rice tracts of Kerala disclosed the highest weed species richness (R) of 17 in the *Kole* tract. The Simpson diversity (D) and Shannon Wiener diversity (H) were the highest in *Kole* followed by Kuttanad, *i.e.*, 0.90 and 2.50 and 0.88 and 2.31, respectively, whereas in the Palakkad tract (*Kharif*), it was 0.80 and 2.09, respectively. This indicated a high degree of supremacy of one species in the Palakkad tract and a greater diversity of weed species in the other two tracts.

Table 7. Distribution and dominance of weed species in surveyed areas of Palakkad tract (*Kharif*)

Weed species	Density (no. m^{-2})	Frequency (%)	Abundance	RD (%)	RF (%)	RA (%)	SDR
Grass weeds							
Echinochloa colona	3.20	80.00	4.00	5.58	11.65	4.02	7.09
Echinochloa crus-galli	1.60	40.00	4.00	2.79	5.83	4.02	4.21
Isachne miliacea	2.13	46.67	4.57	3.72	6.80	4.60	5.04
Ischaemum rugosusm	1.33	26.67	5.00	2.33	3.88	5.03	3.75
Leptochloa chinensis	13.60	80.00	17.00	23.72	11.65	17.10	17.49
Sacciolepis interrupta	20.27	93.33	21.71	35.35	13.59	21.85	23.60
Broad leaf weeds							
Commelina benghalensis	1.33	33.33	4.00	2.33	4.85	4.02	3.73
Cyanotis axillaris	1.07	26.67	4.00	1.86	3.88	4.02	3.26
Eclipta alba	1.07	26.67	4.00	1.86	3.88	4.02	3.26
Lindernia sp.	1.33	20.00	6.67	2.33	2.91	6.71	3.98
Ludwigia parviflora	1.87	46.67	4.00	3.26	6.80	4.02	4.69
Sedges							
Cyperus iria	3.47	60.00	5.78	6.05	8.74	5.81	6.87
Cyperus haspan	1.60	26.67	6.00	2.79	3.88	6.04	4.24
Fimbristylis miliacea	1.87	40.00	4.67	3.26	5.83	4.70	4.59
Schoenoplectus juncoides	1.60	40.00	4.00	2.79	5.83	4.02	4.21

RD – Relative density; RF – Relative frequency; RA – Relative abundance; SDR – Summed dominance ratio

Table 8. Distribution and dominance of weed species in surveyed areas of Palakkad tract (*Rabi*)

Weed species	Density (no. m^{-2})	Frequency (%)	Abundance	RD (%)	RF (%)	RA (%)	SDR
Grass weeds							
Echinochloa colona	1.87	40.00	4.67	8.64	9.84	8.05	8.84
Echinochloa crus-galli	1.07	26.67	4.00	4.94	6.56	6.90	6.13
Isachne miliacea	1.07	26.67	4.00	4.94	6.56	6.90	6.13
Leptochloa chinensis	5.60	73.33	7.64	25.93	18.03	13.17	19.04
Sacciolepis interrupta	3.73	53.33	7.00	17.28	13.11	12.08	14.16
Broad leaf weeds							
Commelina benghalensis	1.07	26.67	4.00	4.94	6.56	6.90	6.13
Lindernia sp.	0.80	20.00	4.00	3.70	4.92	6.90	5.17
Ludwigia parviflora	1.33	33.33	4.00	6.17	8.20	6.90	7.09
Monochoria vaginalis	1.07	20.00	5.33	4.94	4.92	9.20	6.35
Sedges							
Cyperus iria	2.13	40.00	5.33	9.88	9.84	9.20	9.64
Fimbristylis miliacea	1.07	26.67	4.00	4.94	6.56	6.90	6.13
Schoenoplectus juncoides	0.80	20.00	4.00	3.70	4.92	6.90	5.17

RD – Relative density; RF – Relative frequency; RA – Relative abundance; SDR – Summed dominance ratio

With regard to the grass weed flora, the maximum species richness was observed in *Kole* lands (7), followed by Palakkad (6) and Kuttanad (4). For grasses, all the diversity indices displayed discrete variations in the different rice tracts of Kerala. The Simpson diversity index (D), Shannon Wiener diversity index (H) and the Evenness (J) had the lowest values for Palakkad, *i.e.*, 0.65, 1.30 and 1.67, respectively (Table 10). For BLWs, the lowest values for the Simpson diversity index (D), Shannon Wiener diversity index (H) and the Evenness (J) were displayed for the Kuttanad tract, whereas the same were the highest for the Palakkad tract. This was reversed in the case of sedges, in which Kuttanad tract recorded the highest values for all these indices except the Evenness index (J).

4.1.3 Characteristics of *Leptochloa chinensis* ecotypes at flowering

Growth characteristics of *L. chinensis* ecotypes at flowering were also recorded during the survey and are presented in Table 11. There were differences in the growth characteristics across the rice growing tracts and also within the tracts. *L. chinensis* collected from the Alathur *padasekharam* of the Palakkad tract registered the lowest values for all characteristics, and the Mambuzhakari *padasekharam* of the Kuttanad tract recorded the highest values.

The height of *L. chinensis* plants varied from 84.0 to 152.0 cm, with the highest mean value of 137.9 cm from the plants in the Mambuzhakari *padasekharam* of the Kuttanad tract and the lowest (87.9 cm) from the Alathur *padasekharam* of the Palakkad tract. The number of tillers and panicles per plant ranged from 6 to 14 and 3 to 12 respectively, with the highest mean value of 10.4 tillers and 9.3 panicles per plant being recorded at Mambuzhakari *padasekharam*. The data on seed production potential of *L. chinensis* (7400-33,941 seeds per plant) implied it as a prolific seed producer with the highest mean value of 23,469 seeds per plant was recorded from Mambuzhakari *padasekharam* in the Kuttanad tract.

Table 9. Weed vegetation analysis indices in different rice tracts of Kerala

Indices	Kuttanad	*Kole*	Palakkad	
			Kharif	*Rabi*
Species richness (R)	13.0	17.0	15.0	12.0
Simpson diversity (D)	0.88	0.90	0.80	0.86
Shannon-Wiener diversity (H)	2.31	2.50	2.09	2.25
Evenness (J)	2.07	2.03	1.77	2.08

Table 10. Weed vegetation analysis indices for weed groups in different rice tracts of Kerala

Tract	Grasses				Broad leaf weeds				Sedges			
	R	D	H	J	R	D	H	J	R	D	H	J
Kuttanad	4	0.72	1.33	2.20	3	0.61	1.33	2.15	5	0.70	1.36	1.94
Kole	7	0.80	1.74	2.05	5	0.78	1.56	2.23	3	0.59	0.97	2.03
Palakkad (*Kharif*)	6	0.65	1.30	1.67	5	0.79	1.92	2.26	4	0.71	1.33	2.20
Palakkad (*Rabi*)	5	0.71	1.40	2.00	4	0.74	1.37	2.27	3	0.60	1.01	2.11

R – Species richness; D - Simpson diversity index; H - Shannon-Wiener diversity index; J – Evenness index

Table 11. Characteristics of *Leptochloa chinensis* ecotypes at flowering

Location		Plant height (cm)		No. tillers per plant		No. panicles per plant		No. of seeds per plant	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Palakkad	Alathur	87.9 ± 1.0	84.0 - 93.0	6.8 ± 0.2	6 - 8	4.7 ± 0.4	3 -7	12541.7 ± 1723.5	8304.7-17192.3
	Chithali	94.5 ± 1.2	90.0 - 101.0	8.4 ± 0.3	7 - 10	6.0 ± 0.3	4 - 7	12916.9 ± 1809.7	8444.4-18529.4
	Kavasseri	92.2 ± 0.7	89.0 - 97.0	7.8 ± 0.3	7 - 9	5.9 ± 0.5	3 - 8	13002.5 ± 1800.8	8347.8-17500.0
Kole	Alappad	115.7 ± 2.7	103.0 - 130.0	9.6 ± 0.5	7 - 12	7.5 ± 0.5	5 - 10	20348.4 ± 3294.6	12304.3-28363.6
	Enamavu	119.6 ± 2.8	109.8 - 139.7	9.8 ± 0.4	8 - 12	8.5 ± 0.7	6 - 12	18604.6 ± 3580.0	7941.9-31166.6
	Thiruthum thaadu	109.1 ± 2.5	97.5 - 120.2	7.8 ± 0.5	6 - 10	6.5 ± 0.5	4 - 9	19969.8 ± 4109.2	7400.0-33181.8
Kuttanad	Karukappa dam	130.4 ± 3.0	120.9 - 148.0	9.8 ± 0.7	7 - 13	8.6 ± 0.6	6 - 12	22156.3 ± 3038.2	13323.0-31806.4
	Mambuzh akari	137.9 ± 2.3	130.3 - 152.2	10.4 ± 0.7	8 - 14	9.3 ± 0.6	6 - 12	23469.3 ± 3828.4	12301.0-33941.1
	Ramankari	133.6 ± 1.4	122.7 - 137.9	9.6 ± 0.6	7 - 12	8.3 ± 0.6	5 - 11	18884.3 ± 2203.2	12492.3-26832.3

4.1.4 Content of major nutrients in *L. chinensis*

Collected plant samples from each location were analyzed in the laboratory. The data on the status of major nutrients (NPK) in *L. chinensis* from different survey locations is furnished in Table 12. The average N, P and K content in *L. chinensis* varied from 1.03 to 1.64, 0.029 to 0.081 and 1.32 to 3 per cent, respectively. The highest average N, P and K content in *L. chinensis* was recorded from Thiruthumthadu *Kole*, Alappad *Kole* and Ramankari *padasekharam* with 1.64, 0.081 and 3.0 per cent, respectively, whereas, the plants from Kavasseri, Chithali and Mambuzhakari *padasekharam* recorded the lowest N, P and K content of 1.03, 0.029 and 1.32 per cent, respectively.

The N, P and K content in *L. chinensis* samples in the Palakkad tract varied from 1.03 to 1.44, 0.029 to 0.036 and 1.57 to 2.19 per cent, respectively. The highest content of NPK was recorded from the samples collected from Alathur *padasekharam*.

Among the surveyed locations in the *Kole* tract, the average N content in *L. chinensis* was the highest (1.64%) in the samples collected from Thiruthumthadu *Kole*, whereas the P and K content were the highest in the samples from Alappad and Enamavu *Kole, i.e.,* 0.081 and 2.12 per cent, respectively. The NPK content in the plant samples from these locations varied from 1.59 to 1.64, 0.050 to 0.081 and 1.94 to 2.14 per cent.

In the Kuttanad tract, the highest N and K content (1.42 and 3.0%) was registered in the samples collected from Ramankari *padasekharam* and the P content was the highest in the *L. chinensis* plants from Karukappadam with 0.044 per cent. The average nutrient content in *L. chinensis* samples in the Kuttanad tract ranged from 1.10 to 1.42, 0.032 to 0.044 and 1.32 to 3.0 per cent N, P and K, respectively.

4.1.5 Nutrient status of soils

Collected soil samples from each location were analyzed in the laboratory and the data on soil chemical properties of the surveyed locations is provided in Table 13.

The soil pH of all the surveyed locations exhibited acidic property with a pH of less than 7 and varied from 3.84 to 6.46. The soil samples collected from the Kuttanad tract were more acidic (3.84 to 4.41) and the Palakkad soils inclined more towards neutral pH (5.65 to 6.46). Samples collected from the *Kole* tract reclined in an acidic range (5.20 to 5.90). The pH status varied among different locations and the average pH recorded was 6.04, 5.59 and 4.06 in Palakkad, *Kole* and Kuttanad, respectively.

The electrical conductivity (EC) varied from 0.0003 to 0.0105 dS m^{-1} and was the highest for Kuttanad soil (0.0054 dS m^{-1}) and the lowest for Palakkad soil (0.00096 dS m^{-1}). Soil samples collected from the *Kole* tract registered an average EC of 0.0032 dS m^{-1}. Among the different survey locations, Kavasseri in Palakkad tract registered the lowest EC value of 0.0003 dS m^{-1} and the highest (0.0105 dS m^{-1}) was recorded at Ramankari *padasekharam* of Kuttanad tract.

The soil collected from Kuttanad was rich in organic carbon and recorded the highest values in Mambuzhakari *padasekharam* (4.17%), while it was less than one per cent in Palakkad soil and recorded the lowest (0.57%) in Chithali soil. *Kole* soils had a high status of organic carbon and registered the highest content in Enamavu *Kole* (2.21%).

The available soil N content in the surveyed locations varied from 104.53 to 420.0 kg ha^{-1}. Palakkad, *Kole* and Kuttanad tracts recorded an average of 132.71, 222.41 and 335.92 kg N ha^{-1}, respectively. The highest available nitrogen content (420.0 kg ha^{-1}) was recorded at Mambuzhakari *padasekharam* in the Kuttanad tract, followed by Ramankari in the Kuttanad tract (392.89 kg ha^{-1}). Palakkad soil was observed to be low in available N (132.71 kg ha^{-1}). The lowest N content (104.53 kg ha^{-1}) was recorded in the Chithali soils of the Palakkad tract.

The available P content in the soil samples was found to be in the medium range for all the surveyed locations and recorded the highest value of 18.98 kg ha^{-1} in Chithali *padasekharam* of the Palakkad tract.

The lowest value (11.24 kg ha^{-1}) was recoreded in Mambuzhakari *padasekharam* of the Kuttanad tract. The available P content in the *Kole* soils was recorded at an average of 12.94 kg ha^{-1}.

A range of low to high status of available soil K was observed in the surveyed locations and the highest content of 306.6 kg ha^{-1} was recorded in Ramankari *padasekharam* of the Kuttanad tract and the lowest content (89.22 kg ha^{-1}) was recorded in Chithali soils. The available K content in the soils from the same tract even showed variations and ranged from low to high status.

4.2 GERMINATION ECOLOGY

In the present programme, the germination ecology of *L. chinensis* was studied with respect to identification of phonological phases, duration of growth stages, vegetative and reproductive characteristics, incidence of pest and disease and emergence percentage under different ecological conditions and management practices such as field conditions, depth of burial and longevity. Apart from this, attempt was also made to study the biology of *L. chinensis*, including morphological, biometrical and floral characteristics, method of propagation, and the effect of environmental factors such as light, temperature and salinity on germination.

4.2.1 Biology of *L. chinensis*

To understand the biology of *L. chinensis*, 10 plants were randomly selected from the wetland rice fields of Integrated Farming System Research Station (IFSRS), Karamana, and observations on morphological, biometrical and floral characteristics were recorded from germination to maturity. The results are presented in Table 14.

Table 12. Content of major nutrients in *Leptochloa chinensis* from surveyed locations

Location		N (%)	P (%)	K (%)
Palakkad	Alathur	1.44 ± 0.11	0.036 ± 0.008	2.19 ± 0.16
	Chithali	1.21 ± 0.13	0.029 ±0.001	1.57 ± 0.19
	Kavasseri	1.03 ± 0.05	0.032 ± 0.006	1.61 ± 0.09
Kole	Alappad	1.61 ± 0.12	0.081 ± 0.007	2.12 ± 0.08
	Enamavu	1.59 ± 0.12	0.058 ± 0.010	2.14 ± 0.03
	Thiruthumthaadu	1.64 ± 0.07	0.050 ± 0.004	1.94 ± 0.24
Kuttanad	Karukappadam	1.10 ± 0.13	0.044 ± 0.003	2.26 ± 0.56
	Mambuzhakari	1.36 ± 0.15	0.032 ± 0.003	1.32 ± 0.12
	Ramankari	1.42 ± 0.13	0.041 ± 0.001	3.00 ± 0.09

Table 13. Soil chemical properties of surveyed locations

Location		pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Soil moisture level
Palakkad	Alathur	6.01	0.0022	0.88	136.82	18.24	119.63	Saturated
	Chithali	5.65	0.0004	0.57	104.53	18.98	89.22	-do-
	Kavasseri	6.46	0.0003	0.89	156.80	15.11	282.80	-do-
	Average	**6.04**	**0.00096**	**0.78**	**132.71**	**17.44**	**163.88**	
Kole	Alappad	5.20	0.0032	1.59	195.77	12.62	135.71	Submerged
	Enamavu	5.69	0.0044	2.21	247.89	12.61	261.67	-do-
	Thiruthumthaadu	5.90	0.0020	1.23	223.58	13.61	179.10	-do-
	Average	**5.59**	**0.0032**	**1.67**	**222.41**	**12.94**	**192.16**	
Kuttanad	Karukappadam	3.94	0.0042	2.92	194.88	12.24	241.19	Submerged
	Mambuzhakari	4.41	0.0017	4.17	420.00	11.24	218.40	-do-
	Ramankari	3.84	0.0105	3.56	392.89	11.31	306.60	-do-
	Average	**4.06**	**0.0054**	**3.55**	**335.92**	**11.59**	**255.39**	

4.2.1.1 Morphological characters

a) Habit

L. chinensis was observed to be an erect or creeping annual or perennial grass that grows upto 120-150 cm in height. It has slender and heavily tufted branches that bear a multitude of nodes and hollow grooved internodes.

b) Habitat

L. chinensis was commonly seen as associated with wetland rice fields. It was profusely seen on the field bunds, in areas near the bunds, waterways, marshy areas, waterlogged areas as well as upland areas. The *L. chinensis* population was also be observed to grow both under clayey soils of heavy texture and sandy soils of light texture.

c) Leaves

The leaves were observed smoother on the upper surface, green in colour with an alternate arrangement. With a broad and flat petiole, the leaf blade is linear, membraneous, and lanceolated or rounded at the base and sharp at the tip. The midrib, which runs parallel to the leaf blade had a distinct white colour. *L. chinensis* leaves were lighter in colour and had a smoother texture than rice leaves.

d) Inflorescence

The inflorescence was observed as erect, compact open terminal panicle. The main axis was 20 to 50 cm long with numerous spikes like flexous, slender branches arising out of it with pairs of spikelets. Each spikelet carried seeds. The flowering heads were forked and varied from dark green while young to straw coloured at maturity.

e) Seeds

The seed were observed to be numerous, minute with a size of about 1.038-1.112 mm in length and 0.525-0.608 mm in width having a brown colour.

4.2.1.2 Biometric characteristics

Observations recorded to study the biometric characteristics of *L. chinensis* are furnished in Table 14. *L. chinensis* was noticed to be an erect or creeping plant with high tillering ability. The weed had produced about 4 to 10 tillers per plant. A stem (culm), which is cylindrical in shape was observed to emerge laterally from the base of the plant, and had produced numerous nodes (5-8) bearing white fibrous roots. Pubescentary was observed at internodes and a pinkish tinge was seen at the enlarged nodal portion. The growth of the culm was found to cease with the arrival of infloresence. During its life cycle, two to five similar culms were noticed to emerge producing inflorescence. The culms of *L. chinensis* were noticed to be erect, slender and hollow with a circular cross section. At seedling stage, plant height ranged from 15.8 to 21.5 cm, with an average height of 18.65 cm. At the tillering stage, plant height ranged from 20.2 to 35.5 cm, with a mean height of 27.85 cm. At flowering, plant height ranged from 49.08 to 66.3 cm, with a mean height of 58.89 cm. The plant height was maximum at the stage of maturity and ranged from 89.7 to 109.1 cm, with a mean of 99.1 cm. At maturity, the leaf length varied from 30.1 to 34.7 cm, with a mean length of 32.58 cm.

4.2.1.3 Floral characteristics

Floral characteristics of *L. chinensis* were documented and presented in Table 14.

The inflorescence of *L. chinensis* was noted to be an open panicle that appeared terminally from the base of the leaf sheath and had the ability to produce three to seven inflorescences per plant. The length of the panicle ranged from 21.0 to 27.0 with a mean length of 24.0 cm. Each panicle carried numerous ascending slender flexuous primary branches and the number ranged from 50 to 54, with a mean value of 52 primary branches per inflorescence. The length of primary branches varied from 3.0 to 4.2 cm, with an average length of 3.6 cm. Each primary branch of inflorescence produced spikelets at the base which were attached to the pedicel. Numerous tiny brown seeds were observed within each spikelet.

A single spikelet carried four to six flowers which were purplish white in colour, appressed to the primary branches attached by a rachilla. Each plant was observed to produce 8304.76 to 29,857.14 seeds with an average of 16951.25 seeds per inflorescence. The seeds matured from the top to the bottom of the inflorescence and the dehiscence and dispersal of seeds were found to occur from tip to base.

4.2.1.4 Propagation and spread

The study identified seeds as the major method of propagation in *L. chinensis*. Each inflorescence produced numerous seeds which matured at different times. Seeds positioned at the top of the inflorescence matured first, followed by the seeds at the middle and bottom of the panicle. Matured seeds were found to shatter within three to four days and were dispersed by wind and water. The change in the colour of the inflorescence from purple to brown or straw colour and its dehiscence indicated maturity of seeds. Seeds do not show dormancy and germinated quickly.

Leptochloa chinensis was noticed to propagate vegetatively by means of slips. The culm was noted to produce new roots from the nodes and each node gave rise to primary, secondary or tertiary branches, which were stoloniferous with three to six nodes having glabrous, smooth, grooved, striate and hollow internodes. Intercultural operations and mechanical tillage were seemed to aid in the distribution and spread of these rooted clumps and slips.

4.2.2 Phenology of *L. chinensis*

To understand the phenology of *L. chinensis*, observations were recorded from the pot culture experiments continuously during 2018 and 2019 and the results are presented in Table 15. The weed was noticed to develop through five phenological stages, *viz*., emergence, tillering, heading, flowering and maturity, with an average duration of 10.6, 41.5, 73.5, 78.5 and 95 days, respectively.

4.2.2.1 Duration of growth stages

Data on the duration of different growth stages of *L. chinensis* is furnished in Table 15.

The number of days taken for specific growth stages of *L. chinensis* recorded are given below.

a) Days to emergence

In pot experiments, emergence of *L. chinensis* was noticed on the third day and continued upto the 18th day after sowing, with an average of 10.6 days for emergence.

Seeds collected from Kuttanad rice tracts showed emergence from the third day onwards and continued upto the 14th day after sowing (DAS), with an average of 8.6 days for emergence (Table 15). Emergence was noticed at 3.2 DAS of Palakkad, *Kole* and Thiruvananthapuram ecotypes and continued upto 13.2, 18.2 and 16.8 DAS, respectively. The average number of days for germination initiation was 8.2, 10.7 and 10 days respectively for seeds from Palakkad, *Kole* and Thiruvananthapuram. In wet seeded paddy field of IFSRS, Karamana, concomitant emergence of rice and *L. chinensis* was observed.

b) Days to active tillering

The stage between seedling emergence and tillering marks the early vegetative phase. The number of days taken for tillering varied with different ecotypes and ranged from 35 to 48 days, with an average of 41.5 days (Table 15). Palakkad ecotypes showed earliness in tillering compared to *Kole* lands, Kuttanad and Thiruvananthapuram ecotypes and took 38.6, 43.3, 39.2 and 42.0 days respectively for active tillering.

c) Days to heading

The number of days to heading ranged from 67 to 80 days, with an average of 73.5 days, and varied with the ecotypes (Table 15). The ecotypes of Palakkad and Kuttanad took an average of 71.4 and 72.2 days respectively for heading, whereas the ecotypes of *Kole* lands and Thiruvananthapuram required a comparatively higher number of days (74.2 and 75.6 days).

d) Days to flowering

The days to flowering varied from 72 to 85 DAS, with an average of 78.5 days. Flowering in Palakkad ecotypes was noticed on the 74th DAS and extended upto the 79th day, and the average number of days for flowering was found to be 77.2 days (Table 15). From heading, the ecotypes of Palakkad took 6 days to flower, whereas it was 5 days for Kuttanad, *Kole* and Thiruvananthapuram ecotypes.

e) Days to maturity

Yellowing and drying of the leaves followed by drying up of the stems represented the stage of final maturity and the end of life cycle. The average number of days to maturity was found to be 95 days, with a range of 88 to 102 days. The ecotypes of Palakkad, *Kole*, Kuttanad and Thiruvananthapuram took 93.9, 97.2, 94.4 and 99.0 days respectively, to attain maturity. *L. chinensis* was observed to have the ability to grow continuously from its branches that touches the ground and new tillers were found to emerge. This has marked the ability of the plant to grow as a perennial under favourable conditions. Henceforth, the days to attain maturity could not be substantiated. Plants in the pot culture experiments persisted for more than one year when favourable conditions (irrigation) were provided.

4.2.2.2 Vegetative and reproductive characteristics of L. chinensis ecotypes

The vegetative and reproductive characteristics of *L. chinensis* ecotypes of different rice tracts were recorded and presented below in Table 16.

a) Number of tillers per plant

The tiller production capacity of *L. chinensis* ecotypes at maturity is depicted in Table 16. Kuttanad ecotypes produced the maximum number of tillers per plant and ranged from 7.6 to 9.0, with a mean of 8.33 tillers per plant. The tiller production capacity of *Kole* land ecotypes ranged from 7.3 to 8.6 with 8.13 tillers on an average. The plants of Palakkad and Thiruvananthapuram produced 6.5 to 8.9 and 7.3 to 8.6 tillers per plant with a mean value of 7.96 and 8.06 tillers per plant, respectively.

Table 14. Biometric and floral characteristics of *Leptochloa chinensis*

Characters	Range	Average	SEm(±)
Biometric characteristics			
Plant height at seedling stage (cm)	15.8 - 21.5	18.65	0.61
Plant height at tillering stage (cm)	20.2 - 35.5	27.85	1.51
Plant height at flowering (cm)	49.08 - 66.3	58.89	1.55
Plant height at maturity (cm)	89.7 - 109.1	99.10	1.63
No. of tillers per plant	4.0 - 10.0	7.00	0.61
Leaf length (cm)	30.1 - 34.7	32.58	0.16
Floral characteristics			
No. of panicles per plant	3.0 - 7.0	5.20	0.20
Length of panicle (cm)	21.0 - 27.0	24.0	0.59
No. of primary branches of panicle	50.0 - 54.0	52.00	0.42
No. of flowers in a spikelet	4.0 - 6.0	5.00	0.27
No. of seeds per plant	8304.76 - 29857.14	16951.25	2348.53
Thousand seed weight (g)	0.10-0.11	0.105	0.002

Table 15. Phenology of *Leptochloa chinensis* ecotypes in different rice tracts

Growth phase	Eco types / Days required	Palakkad	*Kole*	Kuttanad	Thiruvananthapuram	CV (%)	SEm(±)	Range (in days)	Average (in days)
Emergence	Minimum	3.2	3.2	3.0	3.2	-	-	3 - 18	10.6
	Maximum	13.2	18.2	14.2	16.8	-	-		
	Mean	8.2	10.7	8.6	10.0	25.36	0.61		
Active tillering	Minimum	35.5	41.5	35.5	37.5	-	-	35 - 48	41.5
	Maximum	40.5	46.5	44.0	47.5	-	-		
	Mean	38.6	43.3	39.2	42.0	4.75	0.72		
Heading	Minimum	68.0	71.0	67.0	70.0	-	-	67 - 80	73.5
	Maximum	74.0	76.0	80.0	78.0	-	-		
	Mean	71.4	74.2	72.2	75.6	4.77	0.82		
Flowering	Minimum	74.0	77.0	72.0	76.0	-	-	72 - 85	78.5
	Maximum	79.0	81.0	85.0	83.0	-	-		
	Mean	77.2	79.2	77.4	80.6	7.49	0.36		
Maturity	Minimum	91.5	95.5	87.5	94.0	-	-	88 - 102	95.0
	Maximum	95.5	99.0	101.5	102.0	-	-		
	Mean	93.9	97.2	94.4	99.0	3.38	0.24		

b) Number of panicles per plant

The number of panicles produced by *L. chinensis* ecotypes at maturity was shown in Table 16. The Kuttanad ecotypes generated the maximum number of panicles per plant, with a range of 6.6 to 8.3 panicles per plant and a mean of 7.53 panicles per plant. The number of panicles per plant in the *Kole* and Thiruvananthapuram ecotypes ranged from 5.6 to 7.3 and 6.0 to 7.0, respectively with a mean of 6.53 panicles per plant. The plants of Palakkad produced a comparatively lower number of panicles and ranged from 5.3 to 6.3 with an average of 6.06 panicles per plant.

c) Seed production capacity

The seed production capacity of *L. chinensis* ecotypes under pot culture is depicted in Table 16. The plants of the Kuttanad tract produced the maximum number of seeds per plant and ranged from 7999.13 to 15164.92 with a mean of 11582.02 seeds per plant. The seed production capacity of *Kole* land ecotypes ranged from 7657.45 to 14118.60 with 10888.02 seeds on an average. The seed production potential of Palakkad and Thiruvananthapuram ecotypes was comparatively low and ranged from 6263.95 to 12694.55 and 6433.41 to 14475.17 with a mean of 9479.24 and 10454.29 seeds per plant, respectively.

d) Thousand seed weight

Data on thousand seed weight of *L. chinensis* ecotypes is shown in Table 16. The thousand seed weight recorded was the highest for *Kole* ecotypes and ranged from 0.165 to 0.18 g with a mean of 0.176 g, followed by Kuttanad ecotypes with a mean value of 0.166 g and varied from 0.155 to 0.17 g. The thousand seed weight of Palakkad and Thiruvananthapuram ecotypes ecotypes were comparatively low and ranged from 0.11 to 0.12 and 0.10 to 0.13 g with a mean of 0.115 and 0.116 g, respectively.

Table 16. Vegetative and reproductive characteristics of *Leptochloa chinensis* ecotypes in different rice tracts

Location	No. of tillers per plant		No. of panicles per plant		Seed production capacity per plant		Thousand seed weight (g)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Palakkad	6.5-8.9	7.96	5.3-6.3	6.06	6263.95-12694.55	9479.24	0.11-0.12	0.115
Kole	7.3-8.6	8.13	5.6-7.3	6.53	7657.45-14118.60	10888.02	0.165 - 0.18	0.176
Kuttanad	7.6-9.0	8.33	6.6-8.3	7.53	7999.13-15164.92	11582.02	0.155-0.17	0.166
Thiruvananthapuram	7.3-8.6	8.06	6.0-7.0	6.53	6433.41-14475.17	10454.29	0.10-0.13	0.116
CV (%)	8.66		8.51		29.41		7.14	
SEm(±)	0.14		0.16		636.44		0.004	

4.2.2.3 Incidence of pest and disease

No diseases were observed during the weed growth stage. The incidence of aphid species, *Aphis gossypi*, was noticed at the tillering and grain filling stages. The incidence of spittle bug was also noticed at the base of the leaf sheath at the late tillering stage and reproductive stages of the weed.

4.2.3 Germination studies

4.2.3.1 Effect of light and temperature on germination

Perusal of the data revealed that light was not an absolute requirement for germination in *L. chinensis* seeds. Seeds under dark conditions also germinated and recorded maximum germination of 65 per cent at both 35/25 and 25/15°C (Table 17).

When exposed to alternating temperatures in light/dark, *L. chinensis* seeds germinated at all the tested temperature ranges. The highest germination occurred at 25/15°C (87.2%) in comparison with 70.31 per cent germination at 35/25°C (Fig. 5). Seed germination was found to be higher in the temperature regime of 25/15°C, whereas the temperature regime of 35/25°C had 19 per cent lower germination than 25/15°C. The time to 50 per cent germination in the 25/15°C and 35/25°C temperature regimes was 7.2 and 8.0 days, respectively (Fig. 5).

4.2.3.2 Effect of salinity on germination

Germination of *L. chinensis* was not significantly affected by increasing salt concentrations. A higher germination percentage of atleast 85 per cent was recorded at all the levels of salinity from 0 to 25 mM (Table 18). However, it decreased with a further increase in salt concentration. Even though at 150 mM or greater concentrations of NaCl, more than 40 per cent of the *L. chinensis* seeds germinated. The germination was more than 60 per cent upto a concentration of 100 mM NaCl.

The salt concentration required for 50 per cent inhibition of maximum germination of *L. chinensis* was 150 mM NaCl. Salt stress delayed the onset of seed germination. The time to 50 per cent germination increased from 4 to 11 days when concentrations of NaCl solution were increased from 0 to 200 mM (Fig. 6).

4.2.3.3 Studies on field conditions favourable for emergence

4.2.3.3.1 Emergence percentage

The emergence of *L. chinensis* seedlings was found to be significantly influenced by various moisture regime treatments (Table 19a). A higher percentage of seedling emergence (70%) was observed in pots where moisture conditions were maintained by irrigating on alternate days (T_1) (Table 19b). Seedling emergence at 5 DAS was recorded as 55 per cent in the pots maintained with alternate flooding and draining (T_3). Later, the emerged plants were killed by subsequent dry conditions resulted from drainage and further irrigation could not help in seed germination. Similar results were obtained from pots irrigated to 5 cm depth once every 15 days (T_5). Only 35 per cent of the seeds emerged at 5 DAS, and the emerged plants were completely dried during the latter phase of the treatment with no irrigation for a period of 15 days. No seeds germinated in the pots maintained with continuous flooding (T_2) and also with a thin layer of water (T_4). Flooding did not kill any established seedlings once they emerged.

4.2.3.4 Studies on the effect of depth of burial and means of propagation on weed survival

4.2.3.4.1 Emergence percentage

Seedling emergence of *L. chinensis* was significantly affected by seed burial depth (Table 20a). With increased burial depths, cumulative seedling emergence decreased. Seedling emergence was observed to be greatest (85%) for seeds placed on the soil surface (T_1), and no emergence was observed at burial depths of 2 cm or greater (Table 20b).

Table 17. Effect of light and alternating temperatures on seed germination of *Leptochloa chinensis*

Time (Days after sowing)	Germination (%)			
	Light/Dark		Dark	
	35/25ºC	25/15 ºC	35/25 ºC	25/15 ºC
3	0	0	0	0
6	30	46.25	10	21.25
9	35	50	10	30
12	65	80	65	65
15	65	80	65	65

Table 18. Effect of salinity on seed germination of *Leptochloa chinensis*

Time (Days after sowing)	Germination (%)						
	Salinity (NaCl concentration) (mM)						
	0	25	50	100	150	200	250
3	25	10	0	0	0	0	0
6	75	60	20	10	0	0	0
9	85	80	50	35	20	10	10
12	85	80	65	55	45	40	30
15	85	85	70	65	50	50	45

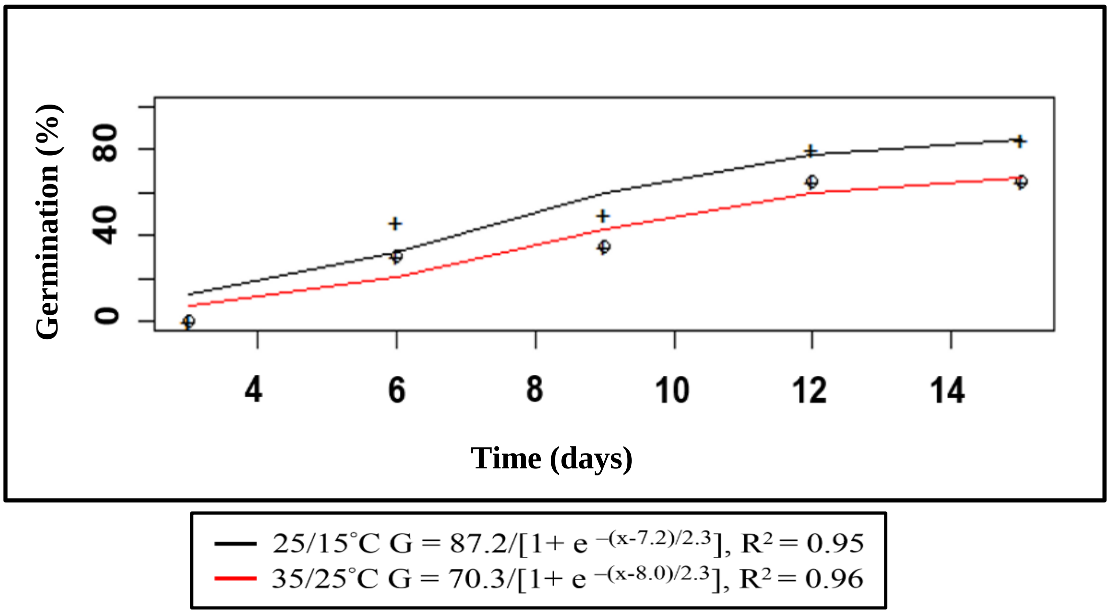


Fig. 5. Influence of alternating temperature regimes (25/15 and 35/25°C) and light/dark conditions on germination of *Leptochloa chinensis*

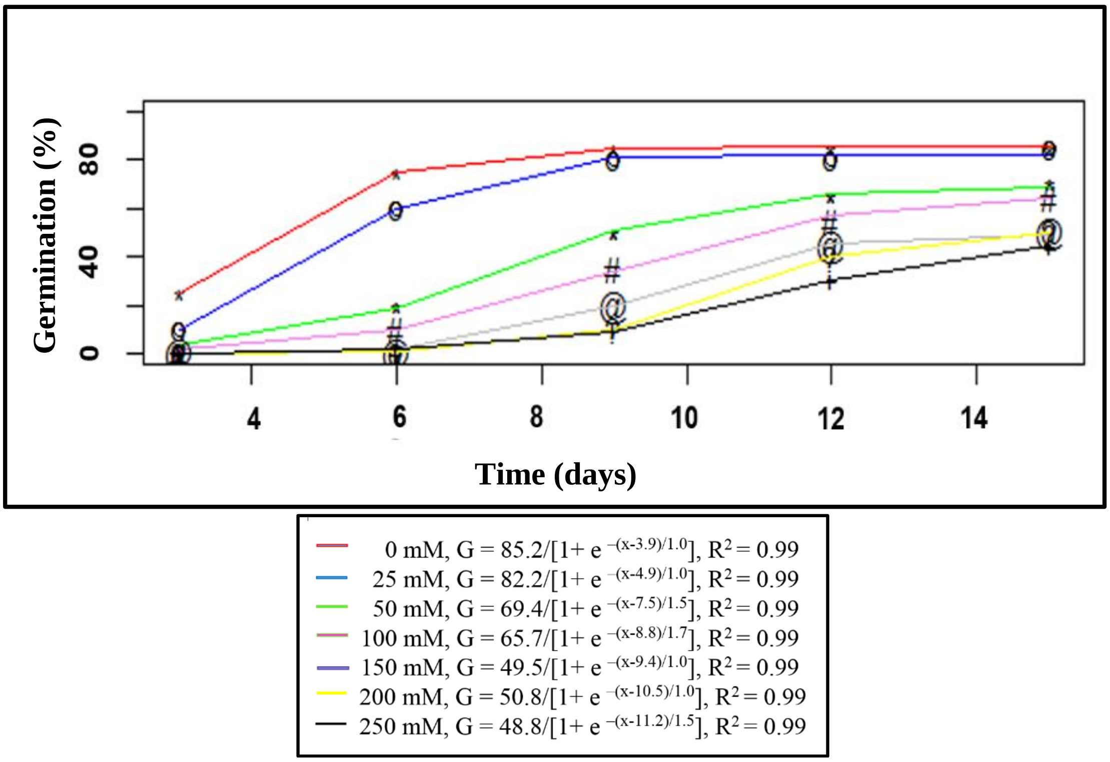


Fig. 6. Influence of salinity levels on germination of *Leptochloa chinensis*

Table 19a. Effect of field conditions on emergence of *Leptochloa chinensis*

Time (days)	Emergence (%)				
	Moisture regimes				
	T1	T2	T3	T4	T5
5	50	0	55	0	35
10	65	0	55	0	0
15	70	0	10	0	0
20	70	0	0	0	0
25	70	0	0	0	0
30	70	0	0	0	0

Table 19b. Effect of field conditions on emergence of *Leptochloa chinensis* at 30 DAS

Treatments		Emergence (%) at 30 DAS
T1	Moist conditions maintained by irrigating on alternate days	56.94 (70.00)
T2	Lowland with continuous flooding	0.65 (0.00)
T3	Lowland conditions with alternate flooding and draining	0.65 (0.00)
T4	Moist conditions with a thin layer of water (3 cm)	0.65 (0.00)
T5	Soil irrigated to 5 cm depth once in 15 days	0.65 (0.00)
SEm±		1.03
CD (0.05)		3.488

Data were arc-sin transformed, actual mean values are given in parentheses.

The surface sown seeds showed germination over a very long period of time, *i.e.*, certain seeds germinated even after 30 days. The slips showed a more pronounced emergence of *L. chinensis* as compared to seeds. Slips placed at the surface resulted in 100 per cent emergence and the time taken for 50 per cent emergence was increased with further increases in burial depth. Despite the increase in time taken for emergence, 100 per cent of slips emerged from a depth of upto 4 cm (Table 20a). The emergence of both seeds and slips was found to be zero at deeper depths beyond 4 cm. The emergence of new flushes was noticed by the slips buried deep (6 and 10 cm) when they were brought back to the surface through soil overturning after 30 days.

4.2.3.5 Studies on seed longevity

The germination of *L. chinensis* seed was found to be negatively influenced by the increase in period of storage (Table 21). The germination percentage was found to be highest during the first month and declined later. The rate of germination reached less than 50 per cent after four months of storage. However, the seeds of *L. chinensis* remained viable up to nine months after harvest, with a declining germination percentage over time. Zero germination was recorded after nine months of seed storage.

4.3 MANAGEMENT OF *L. chinensis* IN WET SEEDED RICE

4.3.1 Observations on weeds

The observations related to floristic composition of weeds, species wise weed count, weed dry matter production, nutrient removal by weeds, weed control efficiency and weed index are presented below.

4.3.1.1 Floristic composition of weeds

The experiments were laid out at IFSRS, Karamana, in sites where, high infestation of *L. chinensis* was reported. Weed species present in the experimental field, collected during first crop season of 2018 and 2019 were identified and categorized into grasses, broad leaf weeds (BLW), sedges and ferns.

Table 20a. Effect of depth of burial and means of propagation on survival of *Leptochloa chinensis*

Time (days)	Burial depth (cm) of soil									
	Seedling emergence from seeds (%)					Sprouting from slips (%)				
	0 cm	2 cm	4 cm	6 cm	10 cm	0 cm	2 cm	4 cm	6 cm	10 cm
3	0	0	0	0	0	0	0	0	0	0
6	45	0	0	0	0	100	0	0	0	0
9	70	0	0	0	0	100	50	0	0	0
12	70	0	0	0	0	100	100	0	0	0
15	80	0	0	0	0	100	100	50	0	0
18	85	0	0	0	0	100	100	50	0	0
21	85	0	0	0	0	100	100	100	0	0

Table 20b. Effect of depth of burial and means of propagation on survival of *Leptochloa chinensis* at 30 DAS

Treatments		Emergence/ sprouting (%) at 30 DAS
T1	Seeds buried at 0 cm depth	67.71 (85.00)
T2	Seeds buried at 2 cm depth	0.65 (0.00)
T3	Seeds buried at 4 cm depth	0.65 (0.00)
T4	Seeds buried at 6 cm depth	0.65 (0.00)
T5	Seeds buried at 10 cm depth	0.65 (0.00)
T6	Slips buried at 0 cm depth	89.35 (100.00)
T7	Slips buried at 2 cm depth	89.35 (100.00)
T8	Slips buried at 4 cm depth	89.35 (100.00)
T9	Slips buried at 6 cm depth	0.65 (0.00)
T10	Slips buried at 10 cm depth	0.65 (0.00)
SEm±		1.21
CD (0.05)		3.592

Data were arc-sin transformed, actual mean values are given in parentheses.

Table 21. Effect of period of storage on germination of *Leptochloa chinensis*

Month	Months from the start of the experiment (MSE)	Germination (%)
March	1 MSE	89
April	2 MSE	85
May	3 MSE	72
June	4 MSE	57
July	5 MSE	34
August	6 MSE	20
September	7 MSE	16
October	8 MSE	9
November	9 MSE	4
December	10 MSE	0
January	11 MSE	0
February	12 MSE	0

The details of the weeds observed in the experimental field are given in Table 22. Fifteen species of weeds were observed in the experimental field all through the growing season during both the years. The grass weeds comprised *L. chinensis, E. colona*, and *I. miliacea.* The major BLWs were *Sphenoclea zeylanica*, *Bergia capensis*, *M. vaginalis*, *L. flava*, *Ludwigia perennis*, *A. philoxeroides* and *Lindernia* sp.. The sedges present were *C. iria*, *C. difformis* and *F. miliacea. Marsilea quadrifolia* was the fern species in the experimental field.Grass weeds were the most dominant species during the whole crop growth phase followed by BLWs, sedges and ferns during both the years.

4.3.1.2 Effect of weed management practices on species wise count of weeds

The data on species wise count of weeds emerged before treatment application during *Kharif* 2018 and 2019 are given in Table 23 and 24, respectively. No significant variation in the initial count of weeds emerged before treatment application was observed durin both the years. During both the years, grass weeds were the dominant followed by BLWs and sedges, occupying 48.90, 38.87 and 10.37 per cent and 42.63, 34.48 and 22.53 per cent, respectively during 2018 and 2019 (Table 25). Among the grass weeds, *L. chinensis* was the predominant species, with the highest count and occupied more than 40 per cent of the grass weed population during both the years followed by *E. colona* and *I. miliacea. S. zeylanica* was the dominant BLW before treatment application during both the years followed by *B. capensis* and *M. vaginalis* during 2018. *L. flava* population was also observed during 2019. The population of sedges was low in the experimental field before treatment application compared to grasses and BLWs.

4.3.1.2.1 Species wise weed count at 15 days after treatment application

The effect of the weed management practices on species wise weed count at 15 days after treatment application (DATA) in WSR during 2018 and 2019 is presented in Table 26 and 27. During both 2018 (Table 26) and 2019 (Table 27), the weed management practices had a considerable impact on the weed count at 15 DATA.

At 15 DATA, grass weeds dominated the unweeded control during both 2018 and 2019 followed by BLWs and sedges, occupied 46.2, 11.95 and 9.24 per cent and 62.3, 25.34 and 12.32 per cent, respectively during 2018 and 2019. Ferns occupied 32.60 per cent in the unweeded control during 2018. *L. chinensis* occupied 56.47 and 64.83 per cent of the total grass weed population, respectively during 2018 and 2019.

The weed management practices had significant influence on *L. chinensis* count at 15 DATA during both 2018 and 2019. At 15 DATA, the count of *L. chinensis* was zero in the treatments bispyribac sodium (BS) @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl (FPE) @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), stale seedbed (SSB) *fb* chemical weeding (T_8) and hand weeding (HW) twice at 20 and 45 DAS (T_{10}) during both the years. The treatment cyhalofop butyl (CB) @ 0.08 kg ha^{-1} + carfentrazone ethyl (CE) @ 0.02 kg ha^{-1} (T_3) also recorded zero population of *L. chinensis* during 2018 whereas, a count of 1.33 plants m^{-2} was observed during 2019. A higher count of 5.33 plants m^{-2} was observed in penoxsulam (PS) + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) during both the years and was the highest among the herbicide combination treatments (T_2, T_3, T_5, T_6 and T_8). Unweeded control (T_9) recorded the highest count of 64 and 78.66 plants m^{-2}, respectively, followed by BS @ 0.025 kg ha^{-1} (T_4) during both the years.

The count of *E. colona* was zero in all the treatments except CB @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1} (T_3), FPE @ 0.06 kg ha^{-1} (T_7) and unweeded control (T_9) at 15 DATA during both 2018 and 2019. The highest count of 37.33 and 29.33 plants m^{-2} was registered in unweeded control, respectively during 2018 and 2019. Among the herbicidal treatments (T_1 to T_8), T_3 and T_7 registered higher count each with 2.66 plants m^{-2} during 2018 and 3 and 4 plants m^{-2}, respectively during 2019.

Application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7) and SSB *fb* chemical weeding (T_8) resulted in 100 per cent control of *I. miliacea* at 15 DATA during both 2018 and 2019. The highest count of 12.00 and 13.33 m^{-2} was observed in unweeded control (T_9), respectively during 2018 and 2019 followed by BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5).

Sphenoclea zeylanica, *B. capensis* and *M. vaginalis* were the major BLWs occurred in the experimental field at 15 DATA during 2018 and 2019. Application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8) registered zero count of *S. zeylanica* and *B. capensis* during both the years. The treatment PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded 100 per cent control of *S. zeylanica* and *B. capensis* during 2018. Against *M. vaginalis*, T_8 recorded complete control at 15 DATA during both the years. The treatments T_2, BS @ 0.025 kg ha^{-1} (T_4), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and T_6 also recorded zero count of *M. vaginalis* and 100 per cent control during 2019.

Sole application of CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) resulted in higher count of *S. zeylanica*, *B. capensis* and *M. vaginalis* during both the years. The tank mix combination of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) was not effective in controlling *M. vaginalis* and resulted in a higher count of 22.66 and 24 m^{-2}, respectively during 2018 and 2019. *L. flava, L. perennis* and *Lindernia* sp. were also observed in the experimental field at 15 DATA during 2019 and a higher count was observed in T_1, T_7 and unweeded control (T_9).

Cyperus iria, *C. difformis* and *F. miliacea* were the sedge species observed at 15 DATA during 2018 and 2019. At 15 DATA, *C. iria* population was observed only in unweeded control (T_9) during both the years. A higher count of *C. difformis* was noted in FPE @ 0.06 kg ha^{-1} (T_7) and CB @ 0.08 kg ha^{-1} (T_1) during both the years. BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) recorded 100 per cent control of *C. difformis* at 15 DATA during both the years. Application of T_1 and T_7 alone was not effective against *F. miliacea.*

4.3.1.2.2 Species wise weed count at 30 days after treatment application

The effect of the weed management practices on weed count at 30 DATA during 2018 and 2019 is furnished in Table 28 and 29.

Table 22. Major weed flora observed in the experimental field

COMMON NAME	SCIENTIFIC NAME	FAMILY	MALAYALAM NAME
GRASSES			
Chinese sprangletop	*Leptochloa chinensis*	Poaceae	*Kuthiravali/Peelikavada*
Jungle rice	*Echinochloa colona*	Poaceae	*Kavada*
Blood grass	*Isachne miliacea*	Poaceae	*Changalipullu/Valari/Naringa*
BROAD LEAF WEEDS			
Goose weed	*Sphenoclea zeylanica*	Sphenocleacea	*Pongolan/Pongati/Pongankala*
Water primrose	*Ludwigia perennis*	Onagraceae	*Neer gramboo/Marakkala*
White water fire	*Bergia capensis*	Elatinaceae	*Neeru paavila*
Pickerel weed	*Monochoria vaginalis*	Pontederiaceae	*Neelolpalam/Kakkappola/Karimkoovalam*
Water cabbage	*Limnocharis flava*	Limnocharitaceae	*Nagappola/Malankoovalam*
Lindernia	*Lindernia* sp.	Linderniaceae	-
Alligator weed	*Alternanthera philoxeroides*	Amaranthaceae	*Vellamkanni/Kozhuppa*
False daisy	*Eclipta alba*	Asteraceae	*Kayyonni*
SEDGES			
Rice flat sedge	*Cyperus iria*	Cyperaceae	*Manjakkora*
Umbrella sedge	*Cyperus difformis*	Cyperaceae	*Thalekkettan*
Globe fringerush	*Fimbrystylis miliacea*	Cyperaceae	*Mangu*
FERN			
Water clove	*Marsilea quadrifolia*	Marsileaceae	*Neeraral/Naalilakodiyan*

Table 23. Count of weeds emerged before treatment application during *Kharif* 2018, no. m^{-2}

Treatments		Weed count								
		Grass weeds			Broad leaf weeds			Sedges		Fern
		L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*B. capensis*	*M. vaginalis*	*Cyperus* spp.	*F. milacea*	*M. quadrifolia*
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	5.09 (26.66)	3.80 (14.66)	2.59 (8.00)	4.13 (22.66)	3.43 (12.00)	4.72 (26.66)	1.17 (1.33)	2.85 (8.00)	1.44 (2.66)
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	6.04 (40.00)	4.73 (22.66)	3.14 (21.33)	4.89 (33.33)	3.60 (13.33)	3.52 (16.00)	2.38 (5.33)	2.38 (6.66)	0.70 (0.00)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	5.64 (32.00)	4.25 (18.66)	0.70 (0.00)	2.12 (5.33)	3.04 (9.33)	3.06 (12.00)	1.17 (1.33)	2.25 (9.33)	1.64 (4.00)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	4.82 (25.33)	3.25 (10.66)	2.45 (8.00)	3.32 (10.66)	2.55 (6.66)	2.85 (8.00)	1.91 (4.00)	1.98 (6.66)	0.70 (0.00)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	3.98 (17.33)	3.37 (12.00)	0.70 (0.00)	4.74 (25.33)	3.25 (10.66)	1.98 (6.66)	2.38 (5.33)	1.64 (4.00)	2.59 (13.33)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	4.19 (20.00)	4.13 (17.33)	4.35 (25.33)	2.69 (14.66)	3.25 (10.66)	2.69 (14.66)	1.91 (4.00)	1.44 (2.66)	0.70 (0.00)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	4.91 (25.33)	3.21 (10.66)	1.17 (1.33)	1.91 (4.00)	2.76 (8.00)	2.59 (13.33)	1.44 (2.66)	2.25 (9.33)	0.70 (0.00)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	5.04 (26.66)	4.31 (18.66)	1.82 (5.33)	6.87 (48.00)	3.15 (10.33)	0.70 (0.00)	2.85 (8.00)	3.03 (9.33)	0.70 (0.00)
T_9	unweeded control	4.78 (24.00)	4.13 (17.33)	4.77 (24.00)	2.38 (6.66)	2.76 (8.00)	3.19 (12.00)	1.17 (1.33)	2.12 (5.33)	0.70 (0.00)
T_{10}	hand weeding twice at 20 and 45 DAS	5.21 (28.00)	4.12 (17.33)	2.25 (9.33)	3.83 (14.66)	3.04 (9.33)	4.80 (26.66)	2.56 (8.00)	3.03 (9.33)	0.70 (0.00)
SEm±		2.36	1.06	2.98	3.67	0.63	3.02	0.75	1.49	1.39
CD (0.05)		-		-	-	-	-	-	-	-

Data were subjected to square root transformation - √x+0.5 and original values are given in parentheses.
DALP – Days after land preparation; DAS – Days after sowing

Table 24. Count of weeds emerged before treatment application during *Kharif* 2019, no. m^{-2}

Treatments		Weed count											
		Grass weeds			Broad leaf weeds						Sedges		Fern
		L. chinensis	*E. colona*	*I. miliacea*	*L. flava*	*M. vaginalis*	*S. zeylanica*	*B. capensis*	*A. philoxe roides*	*E. alba*	*Cyperus* spp.	*F. miliacea*	*M. quadrifolia*
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	3.50 (12.00)	2.85 (8.00)	1.44 (2.66)	1.91 (4.00)	2.85 (8.00)	2.91 (8.00)	2.91 (8.00)	0.70 (0.00)	0.70 (0.00)	2.56 (8.00)	3.12 (9.33)	0.70 (0.00)
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	4.04 (16.00)	2.72 (10.66)	0.70 (0.00)	1.91 (4.00)	2.85 (8.00)	2.38 (5.33)	2.17 (5.33)	0.70 (0.00)	0.70 (0.00)	1.91 (4.00)	3.71 (13.33)	0.70 (0.00)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	3.86 (14.66)	3.50 (12.00)	2.38 (6.66)	2.38 (6.66)	2.38 (5.33)	2.59 (6.66)	2.59 (6.66)	0.70 (0.00)	0.70 (0.00)	2.94 (10.66)	2.56 (8.00)	0.70 (0.00)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	4.76 (22.66)	2.56 (8.00)	1.64 (4.00)	1.82 (5.33)	1.64 (4.00)	1.91 (4.00)	2.85 (8.00)	0.70 (0.00)	0.70 (0.00)	2.38 (6.66)	2.94 (10.66)	0.70 (0.00)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	4.58 (21.33)	3.84 (16.00)	1.44 (2.66)	2.12 (5.33)	2.38 (5.33)	1.91 (4.00)	2.17 (5.33)	1.44 (2.66)	0.70 (0.00)	2.38 (6.66)	2.59 (8.00)	0.70 (0.00)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	4.35 (18.66)	4.19 (17.33)	2.38 (6.66)	1.91 (4.00)	2.85 (8.00)	3.23 (10.66)	3.12 (9.33)	0.70 (0.00)	0.70 (0.00)	2.25 (9.33)	2.85 (10.66)	1.44 (2.66)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.83 (14.66)	2.92 (10.66)	0.70 (0.00)	1.64 (2.66)	1.91 (4.00)	1.91 (4.00)	2.38 (6.66)	0.70 (0.00)	0.70 (0.00)	2.59 (6.66)	2.76 (9.33)	0.70 (0.00)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	2.94 (10.66)	3.88 (14.66)	1.44 (2.66)	0.70 (0.00)	2.38 (5.33)	3.50 (12.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.71 (9.33)	2.38 (6.66)	0.70 (0.00)
T_9	unweeded control	4.33 (18.66)	2.38 (6.66)	1.91 (4.00)	3.66 (14.66)	3.12 (9.33)	2.12 (5.33)	1.91 (4.00)	1.44 (2.66)	1.44 (2.66)	1.17 (1.33)	3.29 (10.66)	0.70 (0.00)
T_{10}	hand weeding twice at 20 and 45 DAS	4.64 (21.33)	4.51 (20.00)	1.91 (4.00)	3.67 (13.33)	2.38 (5.33)	2.65 (6.66)	2.85 (8.00)	2.38 (6.66)	0.70 (0.00)	3.50 (12.00)	3.50 (12.00)	0.70 (0.00)
SEm±		1.24	1.45	0.81	1.23	0.65	0.79	0.76	0.58	0.26	1.33	1.13	0.26
CD (0.05)		-	-	-	-	-	-	-	-	-	-	-	-

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.
DALP – Days after land preparation; DAS – Days after sowing

Table 25. Count of total weeds emerged before treatment application during *Kharif* 2018 and 2019, no. m^{-2}

Treatments		Weed count							
		2018				2019			
		Grasses	BLW	Sedges	Fern	Grasses	BLW	Sedges	Fern
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	6.99 (49.33)	7.78 (61.33)	3.03 (9.33)	1.44 (2.66)	4.70 (22.66)	5.26 (28.00)	4.18 (17.33)	0.70 (0.00)
T_2	penoxsulam +cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	8.77 (84.00)	7.80 (62.66)	3.41 (12.00)	0.70 (0.00)	5.08 (26.66)	4.68 (22.66)	4.18 (17.33)	0.70 (0.00)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	7.10 (50.66)	4.91 (26.66)	2.72 (10.66)	1.64 (4.00)	5.70 (33.33)	5.00 (25.33)	3.78 (18.66)	0.70 (0.00)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	6.46 (44.00)	5.02 (25.33)	2.85 (10.66)	0.70 (0.00)	5.67 (34.66)	4.47 (21.33)	3.66 (17.33)	0.70 (0.00)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	5.32 (29.33)	6.38 (42.66)	3.03 (9.33)	2.59 (13.33)	6.31 (40.00)	4.66 (22.66)	3.39 (14.66)	0.70 (0.00)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	7.51 (62.66)	6.05 (40.00)	2.29 (6.66)	0.70 (0.00)	6.49 (42.66)	5.58 (32.00)	3.89 (20.00)	1.44 (2.66)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	6.09 (37.33)	4.56 (25.33)	2.98 (12.00)	0.70 (0.00)	4.98 (25.33)	4.06 (17.33)	4.04 (16.00)	0.70 (0.00)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	7.11 (50.66)	7.55 (58.33)	4.19 (17.33)	0.70 (0.00)	5.28 (28.00)	4.12 (17.33)	3.99 (16.00)	0.70 (0.00)
T_9	unweeded control	8.08 (65.33)	4.95 (26.66)	2.29 (6.66)	0.70 (0.00)	5.37 (29.33)	6.06 (38.66)	3.45 (12.00)	0.70 (0.00)
T_{10}	hand weeding twice at 20 and 45 DAS	7.25 (54.66)	7.00 (50.66)	4.05 (17.33)	0.70 (0.00)	6.72 (45.33)	6.30 (40.00)	4.93 (24.00)	0.70 (0.00)
SEm±		4.81	4.10	1.67	1.39	2.15	2.19	1.76	0.26
CD (0.05)		-	-	-	-	-	-	-	-

Data were subjected to square root transformation - √x+0.5 and original values are given in parentheses.
BLW – Broad leaf weeds; DALP – Days after land preparation; DAS – Days after sowing

Table 26. Effect of weed management practices on weed count at 15 days after treatment application during *Kharif* 2018, no. m^{-2}

Treatments	Weed count										
	Grass weeds			Broad leaf weeds				Sedges			Fern
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*B. capensis*	*M. vaginalis*	*L perennis*	*C. iria*	*C. difformis*	*F. miliacea*	*M. quadrifolia*
T_1	1.17 (1.33)	0.70 (0.00)	1.17 (1.33)	5.75 (40.00)	5.42 (29.33)	4.64 (21.33)	0.70 (0.00)	0.70 (0.00)	2.92 (10.66)	3.20 (10.66)	2.65 (6.66)
T_2	2.12 (5.33)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	1.44 (2.66)	0.70 (0.00)	0.70 (0.00)
T_3	0.70 (0.00)	1.64 (2.66)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	4.76 (22.66)	0.70 (0.00)	0.70 (0.00)	1.44 (2.66)	1.76 (2.66)	1.17 (1.33)
T_4	6.50 (44.00)	0.70 (0.00)	1.64 (2.66)	0.70 (0.00)	1.17 (1.33)	1.91 (4.00)	1.34 (1.33)	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	0.70 (0.00)
T_5	1.64 (2.66)	0.70 (0.00)	1.64 (2.66)	1.17 (1.33)	1.44 (2.66)	1.64 (2.66)	1.34 (1.33)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	1.17 (1.33)
T_6	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_7	0.70 (0.00)	1.64 (2.66)	0.70 (0.00)	3.53 (13.33)	2.37 (10.66)	5.53 (30.66)	0.70 (0.00)	0.70 (0.00)	3.39 (12.00)	1.76 (2.66)	2.91 (8.00)
T_8	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_9	7.94 (64.00)	6.12 (37.33)	3.53 (12.00)	3.71 (13.33)	2.38 (5.33)	3.12 (9.33)	1.34 (1.33)	1.34 (1.33)	1.17 (1.33)	4.52 (20.00)	8.96 (80.00)
T_{10}	0.70 (0.00)	0.70 (0.00)	1.64 (2.66)	1.17 (1.33)	0.70 (0.00)	1.64 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)
SEm±.	0.54	0.25	0.42	0.66	0.63	0.45	0.07	0.02	0.58	0.21	0.29
CD (0.05)	1.617	0.724	1.252	1.964	1.898	1.341	0.193	0.116	1.745	0.657	0.885

Data were subjected to square root transformation - √x+0.5 and original values are given in parentheses.

Table 27. Effect of weed management practices on weed count at 15 days after treatment application during *Kharif* 2019, no. m^{-2}

Treatments	Weed count											
	Grass weeds			Broad leaf weeds						Sedges		
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*B. capensis*	*M. vaginalis*	*L. flava*	*L. perennis*	*Lindernia* sp.	*C. iria*	*C. difformis*	*F. miliacea*
T_1	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	4.80 (22.66)	4.80 (22.66)	2.67 (6.66)	2.91 (8.00)	2.91 (8.00)	0.70 (0.00)	0.70 (0.00)	3.89 (14.66)	4.52 (20.00)
T_2	2.41 (5.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	0.70 (0.00)	3.13 (9.33)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	0.70 (0.00)
T_3	1.34 (1.33)	2.12 (4.00)	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	4.94 (24.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	1.34 (1.33)
T_4	6.03 (36.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.67 (6.66)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.64 (2.66)	0.70 (0.00)
T_5	1.76 (2.66)	0.70 (0.00)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.77 (2.66)	0.70 (0.00)
T_6	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_7	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	4.79 (22.66)	5.92 (34.66)	4.67 (21.33)	2.65 (6.66)	2.12 (4.00)	3.53 (12.00)	0.70 (0.00)	3.33 (10.66)	4.52 (20.00)
T_8	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_9	8.88 (78.66)	5.45 (29.33)	3.70 (13.33)	3.53 (12.00)	3.89 (14.66)	2.90 (8.00)	2.84 (12.00)	1.76 (2.66)	0.70 (0.00)	1.34 (1.33)	2.41 (5.33)	4.20 (17.33)
T_{10}	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	1.34 (1.33)	1.34 (1.33)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
SEm±	0.12	0.05	0.08	0.10	0.08	0.09	0.51	0.06	0.04	0.02	0.17	0.09
CD (0.05)	0.372	0.151	0.265	0.335	0.244	0.247	1.536	0.212	0.097	0.116	0.527	0.287

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.

Grass weeds still continued as the dominant category of weed in unweeded control, comprised 66.66 and 67.75 per cent of the total weed population, respectively during 2018 and 2019 at 30 DATA followed by BLWs and sedges, occupied 21.26 and 12.1 per cent and 20.09 and 12.15 per cent, respectively. Out of the total grass weed population, *L. chinensis* encompassed 67.0 and 61.37 per cent, respectively during 2018 and 2019.

Hand weeding twice at 20 and 45 DAS (T_{10}) recorded the lowest count of *L. chinensis* (1.33 plants m^{-2}) during 2018 (Table 28) and was followed by FPE @ 0.06 kg ha^{-1} (T_7). Among the herbicidal treatments (T_1 to T_8), T_7 registered the lowest count of 2.66 plants m^{-2} during 2018 and was followed by CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8), with 4 plants m^{-2}. During 2019 also, T_7 registered the lowest count of *L. chinensis* (1.33 plants m^{-2}) and was found to be statistically on par with T_6 and T_{10} (Table 29). BS @ 0.025 kg ha^{-1} (T_4) recorded the highest count of *L. chinensis* among the herbicidal treatments with 80 and 58.66 plants m^{-2}, respectively during 2018 and 2019.

Echinochloa colona was not present in the treatments PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and HW twice at 20 and 45 DAS (T_{10}) at 30 DATA during both the years. A count of zero was also recorded in BS @ 0.025 kg ha^{-1} (T_4) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) during 2018 and in the treatment SSB *fb* chemical weeding (T_8) during 2019. Tank mix combination of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) recorded the highest count of *E. colona* during 2018 and was on par with unweeded control (T_9), recorded a count of 6.66 and 5.33 plants m^{-2}, respectively. Both T_7 and T_3 registered higher counts of *E.colona* at plants m^{-2} among the herbicidal treatments (T_1 to T_8) during 2019.

The count of *I. miliacea* was found to increase in all the treatments at 30 DATA compared to 15 DATA. At 30 DATA, unweeded control (T_9) recorded the highest count of *I. miliacea* and HW twice at 20 and 45 DAS (T_{10}) recorded the lowest count of zero during both the years.

Among the herbicidal treatments (T_1 to T_8), FPE @ 0.06 kg ha^{-1} (T_7) effectively controlled *I. miliacea* at 30 DATA and recorded the lowest count (1.33 and 0 m^{-2}, respectively during 2018 and 2019), while, the control was poor with the sole application of CB @ 0.08 kg ha^{-1} (T_1) and BS @ 0.025 kg ha^{-1} (T_4). Application of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) was also found to be less effective against *I. miliacea*.

Sphenoclea zeylanica, B. capensis, M. vaginalis, L. flava, L. perennis and *Lindernia* sp. were the BLWs observed at 30 DATA. Application of BS @ 0.025 kg ha^{-1} (T_4), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and HW twice at 20 and 45 DAS (T_{10}) ensured better control of *S. zeylanica, B. capensis* and *M. vaginalis* at 30 DATA. A higher count of *M. vaginalis* was observed in CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) and SSB *fb* chemical weeding (T_8) during both the years at 30 DATA. The treatments CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) recorded the lowest control of these weeds during both the years. A higher count of *L. perennis* was observed in T_2 (10.66 m^{-2}) and T_7 (13.33 m^{-2}) among the herbicidal treatments (T_1 to T_8) during 2019.

Ready mix combination of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and HW twice at 20 and 45 DAS (T_{10}) registered complete control of *C. iria, C. difformis* and *F. miliacea* at 30 DATA during both the years. BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) also recorded zero count of *C. iria, C. difformis* and *F. miliacea* during 2019.

4.3.1.2.3 Species wise weed count at 45 days after treatment application

The effect of the weed management practices on species wise weed count at 45 DATA in WSR during 2018 and 2019 is documented in Table 30 and 31. At 45 DATA also, grass weeds dominated the weed spectrum in unweeded control with 87.40 and 75.0 per cent of the total weed population, respectively during 2018 and 2019 followed by BLWs, comprised of 10.23 and 25.0 per cent, respectively. *L. chinensis* dominated the grass weed spectrum in unweeded control during both the years and engrossed 81.08 and 56.41 per cent, respectively during 2018 and 2019.

Fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} (T_7) recorded the lowest count of *L. chinensis* (4 plants m^{-2}) during both the years and was significantly superior to rest of the treatments during 2018. However CB @ 0.08 kg ha^{-1} (T_1), CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8) with average count of 5.33 m^{-2} was statistically on par with T_7 during 2019. The highest count of *L. chinensis* was noticed in unweeded control (120 and 88 plants m^{-2}, respectively during 2018 and 2019), followed by BS @ 0.025 kg ha^{-1} (T_4) with 81.33 and 64 plants m^{-2}, respectively.

The count of *E. colona* was zero in ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) during 2018 and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) during 2019. Unweeded control (T_9) recorded the highest count (12 m^{-2}) of *E.colona* during 2018 and was on par with CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) with 8 plants m^{-2}. During 2019, T_3 recorded the highest count of *E. colona* amongst the herbicidal treatments and was on par with FPE @ 0.06 kg ha^{-1} (T_7) and CB @ 0.08 kg ha^{-1} (T_1), recorded a count of 5.33, 4 and 2.66 m^{-2}, respectively.

At 45 DATA, the count of *I. miliacea* was found to be increased in all the treatments compared to 30 DATA. During both the years, application of FPE @ 0.06 kg ha^{-1} (T_7) and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) resulted in lower count of 1.33 and 2.66 m^{-2} and 5.33 and 6.66 m^{-2}, respectively during 2018 and 2019. Hand weeding twice at 20 and 45 DAS (T_{10}) with 1.33 m^{-2} was on par to T_7 and T_6 during both the years. CB @ 0.08 kg ha^{-1} (T_5) recorded the highest count of *I. miliacea* with 45 plants m^{-2} during 2018.

Sphenoclea zeylanica, B. capensis, M. vaginalis, L. flava, L. perennis and *Lindernia* sp. were the BLWs noted at 45 DATA. Application of BS @ 0.025 kg ha^{-1} (T_4) recorded zero count of *S. zeylanica, B. capensis, M. vaginalis* and *L. flava* and ensured 100 per cent control at 45 DATA during both the years. It was observed that the tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) resulted in lower count of *S. zeylanica*, *B. capensis, M. vaginalis, L. flava, L. perennis* and *Lindernia* sp., registered a count of 2.66, 1.33, 1.33, 2.66, 2.66 and zero, respectively during 2018 and ensured 100 per cent control during 2019.

Application of SSB *fb* chemical weeding (T_8), FPE @ 0.06 kg ha^{-1} (T_7) and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) couldn't control *M. vaginalis* during both the years and recorded higher counts of 17.33, 5.33 and 5.33 m^{-2} during 2018 and 26.66, 25.33 and 36 plants m^{-2} during 2019. Among the herbicide combinations (T_2, T_3, T_5, T_6 and T_8), a higher count of *L. perennis* was observed in ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), recorded 8 and 9.33 m^{-2}, respectively during 2018 and 2019. At 45 DATA, the population of *L. flava* under T_8 was the highest among the herbicidal combinations and recorded a count of 8 and 10.66 m^{-2}, respectively 2018 and 2019.

Application of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), BS @ 0.025 kg ha^{-1} (T_4), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and HW twice at 20 and 45 DAS (T_{10}) recorded zero count of *C. iria, C. difformis* and *F. miliacea* at 45 DATA and obtained complete control during both 2018 and 2019. BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) also recorded 100 per cent control of these sedges during 2019. CB @ 0.08 kg ha^{-1} (T_1) and SSB *fb* chemical weeding (T_8) registered higher count of *C .iria* during both the years with 17.33 and 34.66 plants m^{-2} during 2018 and 8 plants m^{-2} in each during 2019. The population of *C. difformis* was reduced towards the later stage of the crops in all the treatments during both the years.

4.3.1.3 Effect of weed management practices on total weed count

The effect of weed management practices on total weed count of grass weeds, BLWs and sedges at different stages of crop growth was statistically analysed and presented in Table 32 to 34.

4.3.1.3.1 Effect of weed management practices on weed count at 15 DATA

Weed management practices had a significant effect on the total count of grass weeds, BLWs and sedges at 15 DATA during both 2018 and 2019 and the data is furnished in Table 32.

Table 28. Effect of weed management practices on weed count at 30 days after treatment application during *Kharif* 2018, no. m^{-2}

Treatments	Weed count											
	Grass weeds			Broad leaf weeds						Sedges		
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*B. capensis*	*M. vaginalis*	*L. flava*	*L. perennis*	*Lindernia* sp.	*C. difformis*	*C. iria*	*F. miliacea*
T_1	2.27 (5.33)	1.77 (2.66)	1.76 (2.66)	2.67 (6.66)	2.38 (5.33)	2.40 (5.33)	2.91 (8.00)	2.12 (4.00)	0.70 (0.00)	1.34 (1.33)	1.17 (1.33)	2.12 (4.00)
T_2	3.05 (9.33)	0.70 (0.00)	2.12 (4.00)	1.34 (1.33)	1.64 (2.66)	1.34 (1.33)	0.70 (0.00)	1.77 (2.66)	2.12 (4.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_3	2.00 (4.00)	2.66 (6.66)	1.17 (1.33)	2.67 (6.66)	2.38 (5.33)	2.91 (8.00)	1.77 (2.66)	1.34 (1.33)	2.40 (5.33)	1.77 (2.66)	0.70 (0.00)	1.77 (2.66)
T_4	8.94 (80.00)	0.70 (0.00)	1.76 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.12 (4.00)	1.34 (1.33)	2.38 (5.33)	0.70 (0.00)	1.34 (1.33)
T_5	2.57 (6.66)	0.70 (0.00)	1.64 (2.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.91 (4.00)	1.17 (1.33)	0.70 (0.00)	1.34 (1.33)	0.70 (0.00)	1.34 (1.33)
T_6	2.00 (4.00)	0.70 (0.00)	1.34 (1.33)	1.34 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.46 (1.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_7	1.62 (2.66)	2.12 (4.00)	1.17 (1.33)	2.67 (6.66)	2.11 (4.00)	2.40 (5.33)	2.12 (4.00)	1.91 (4.00)	2.67 (6.66)	3.53 (12.00)	0.70 (0.00)	3.53 (12.00)
T_8	2.00 (4.00)	1.76 (2.66)	1.76 (2.66)	1.76 (2.66)	0.70 (0.00)	2.67 (6.66)	2.12 (4.00)	0.70 (0.00)	2.91 (8.00)	0.70 (0.00)	5.20 (26.66)	6.96 (48.00)
T_9	10.19 (104.00)	2.40 (5.33)	6.75 (45.33)	5.56 (30.66)	3.12 (9.33)	2.40 (5.33)	2.12 (4.00)	0.70 (0.00)	0.70 (0.00)	3.53 (12.00)	1.91 (4.00)	3.53 (12.00)
T_{10}	1.13 (1.33)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.12 (4.00)	1.76 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
SEm±	0.10	0.09	0.28	0.15	0.20	0.09	0.20	0.25	0.08	0.10	0.24	0.06
CD (0.05)	0.338	0.281	0.847	0.468	0.592	0.240	0.608	0.756	0.262	0.311	0.744	0.177

Data were subjected to square root transformation - √x+0.5 and original values are given in parentheses.

Table 29. Effect of weed management practices on weed count at 30 days after treatment application during *Kharif* 2019, no. m^{-2}

Treatments	Weed count											
	Grass weeds			Broad leaf weeds						Sedges		
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*M. vaginalis*	*L. flava*	*L. perennis*	*Lindernia* sp.	*B. capensis*	*C. iria*	*C. difformis*	*F. miliacea*
T_1	2.12 (4.00)	1.34 (1.33)	2.41 (5.33)	5.07 (25.33)	3.71 (13.33)	4.04 (16.00)	2.41 (5.33)	5.07 (25.33)	3.88 (14.66)	3.33 (10.66)	2.41 (5.33)	6.56 (42.66)
T_2	2.85 (8.00)	0.70 (0.00)	2.12 (4.00)	1.34 (1.33)	0.70 (0.00)	0.70 (0.00)	3.33 (10.66)	3.88 (14.66)	2.91 (8.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_3	2.12 (4.00)	1.91 (4.00)	2.12 (4.00)	2.40 (5.33)	4.52 (20.00)	2.91 (8.00)	0.70 (0.00)	2.91 (8.00)	3.53 (12.00)	3.33 (10.66)	2.12 (4.00)	3.13 (9.33)
T_4	7.69 (58.66)	1.34 (1.33)	3.33 (10.66)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	5.46 (29.33)	0.70 (0.00)	0.70 (0.00)	1.91 (4.00)	0.70 (0.00)
T_5	2.65 (6.66)	1.34 (1.33)	3.52 (12.00)	1.34 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	5.07 (25.33)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_6	1.64 (2.66)	0.70 (0.00)	2.41 (5.33)	1.77 (2.66)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	5.07 (25.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_7	1.17 (1.33)	2.12 (4.00)	0.70 (0.00)	6.34 (42.66)	2.67 (6.66)	3.33 (10.66)	3.69 (13.33)	8.09 (65.33)	6.24 (38.66)	1.34 (1.33)	3.71 (13.33)	7.24 (52.00)
T_8	2.12 (4.00)	0.70 (0.00)	2.40 (5.33)	0.70 (0.00)	5.06 (25.33)	3.13 (9.33)	0.70 (0.00)	1.76 (2.66)	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	3.70 (13.33)
T_9	10.91 (118.66)	7.05 (49.33)	5.08 (25.33)	3.86 (14.66)	2.40 (5.33)	1.76 (2.66)	3.51 (12.00)	4.01 (16.00)	2.67 (6.66)	3.53 (12.00)	1.76 (2.66)	4.52 (20.00)
T_{10}	1.76 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
SEm±-	0.28	0.21	0.08	0.39	0.10	0.10	0.14	0.20	0.13	0.05	0.20	0.10
CD (0.05)	0.835	0.667	0.255	1.186	0.317	0.329	0.450	0.629	0.389	0.173	0.613	0.335

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.

Table 30. Effect of weed management practices on weed count at 45 days after treatment application during *Kharif* 2018, no. m^{-2}

Treatments	Weed count												
	Grass weeds			Broad leaf weeds						Sedges			Fern
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*B. capensis*	*M. vaginalis*	*L. flava*	*L. perennis*	*Lindernia* sp.	*C. iria*	*C. difformis*	*F. miliacea*	*M. quadrifolia*
T_1	3.05 (9.33)	2.38 (5.33)	4.94 (24.00)	3.52 (12.00)	3.71 (13.33)	0.70 (0.00)	4.49 (21.33)	4.49 (21.33)	0.70 (0.00)	3.60 (17.33)	0.70 (0.00)	4.04 (16.00)	1.91 (4.00)
T_2	4.15 (17.33)	0.70 (0.00)	3.53 (12.00)	2.67 (6.66)	2.67 (6.66)	1.17 (1.33)	1.34 (1.33)	2.91 (8.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_3	3.44 (12.00)	2.91 (8.00)	4.80 (22.66)	1.34 (1.33)	0.70 (0.00)	2.12 (5.33)	1.34 (1.33)	1.17 (1.33)	1.17 (1.33)	4.52 (28.00)	1.34 (1.33)	2.56 (8.00)	2.56 (8.00)
T_4	9.01 (81.33)	2.12 (4.00)	2.91 (8.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.38 (5.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_5	3.05 (9.33)	1.76 (2.66)	6.76 (45.33)	2.91 (8.00)	3.32 (10.66)	0.70 (0.00)	2.12 (4.00)	0.70 (0.00)	4.19 (17.33)	0.70 (0.00)	1.34 (1.33)	3.86 (20.00)	5.66 (45.33)
T_6	2.57 (6.66)	1.17 (1.33)	1.64 (2.66)	1.77 (2.66)	1.34 (1.33)	1.17 (1.33)	1.64 (2.66)	1.64 (2.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	5.93 (36.00)
T_7	2.00 (4.00)	2.65 (6.66)	1.17 (1.33)	1.73 (2.66)	1.34 (1.33)	2.12 (5.33)	4.66 (21.33)	3.19 (13.33)	3.12 (9.33)	0.70 (0.00)	2.91 (8.00)	0.70 (0.00)	2.56 (8.00)
T_8	3.05 (9.33)	2.38 (5.33)	2.41 (5.33)	1.34 (1.33)	2.12 (4.00)	4.21 (17.33)	2.12 (8.00)	0.70 (0.00)	3.19 (13.33)	5.91 (34.66)	0.70 (0.00)	8.31 (69.33)	0.70 (0.00)
T_9	10.95 (120.00)	3.53 (12.00)	4.05 (16.00)	2.91 (8.00)	2.40 (5.33)	2.12 (4.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.12 (4.00)
T_{10}	3.05 (9.33)	1.34 (1.33)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	3.12 (9.33)	4.80 (22.66)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)
SEm±-	0.11	0.22	0.27	0.11	0.12	0.40	0.54	0.55	0.50	0.76	0.05	0.66	1.00
CD (0.05)	0.337	0.669	0.837	0.379	0.377	1.194	1.617	1.656	1.504	2.260	0.161	1.987	2.977

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.

Table 31. Effect of weed management practices on weed count at 45 days after treatment application during *Kharif* 2019, no. m^{-2}

Treatments	Weed count											
	Grass weeds			Broad leaf weeds						Sedges		
	L. chinensis	*E. colona*	*I. miliacea*	*S. zeylanica*	*M. vaginalis*	*L. flava*	*L. perennis*	*Lindernia* sp.	*B. capensis*	*C. iria*	*C. difformis*	*F. miliacea*
T_1	2.17 (5.33)	1.76 (2.66)	3.50 (12.00)	5.31 (33.33)	4.37 (18.66)	3.32 (12.00)	2.76 (9.33)	3.66 (17.33)	5.24 (38.66)	2.59 (8.00)	0.70 (0.00)	4.69 (22.66)
T_2	3.71 (13.33)	1.34 (1.33)	4.98 (25.33)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)	3.12 (9.33)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_3	2.38 (5.33)	2.38 (5.33)	3.45 (12.00)	1.44 (2.66)	5.66 (36.00)	1.44 (2.66)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)	1.17 (1.33)	1.34 (1.33)	0.70 (0.00)
T_4	8.01 (64.00)	1.17 (1.33)	4.98 (25.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_5	2.91 (8.00)	1.34 (1.33)	3.86 (14.66)	0.70 (0.00)	0.70 (0.00)	1.17 (1.33)	1.17 (1.33)	1.64 (4.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_6	2.41 (5.33)	0.70 (0.00)	2.38 (5.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_7	2.12 (4.00)	2.12 (4.00)	2.65 (6.66)	3.18 (10.66)	4.18 (25.33)	2.65 (6.66)	2.65 (6.66)	3.39 (14.66)	7.37 (56.00)	1.64 (4.00)	0.70 (0.00)	3.06 (9.33)
T_8	2.38 (5.33)	0.70 (0.00)	4.33 (18.66)	0.70 (0.00)	5.08 (26.66)	2.94 (10.66)	1.44 (2.66)	0.70 (0.00)	0.70 (0.00)	2.85 (8.00)	0.70 (0.00)	4.21 (17.33)
T_9	9.39 (88.00)	5.55 (30.66)	6.02 (37.33)	2.59 (9.33)	0.70 (0.00)	3.23 (10.66)	2.85 (8.00)	0.70 (0.00)	3.30 (24.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_{10}	2.91 (8.00)	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	2.12 (5.33)	0.70 (0.00)	0.70 (0.00)	1.34 (1.33)
SEm±	0.31	0.21	0.51	0.73	0.80	0.60	0.47	0.69	1.12	0.43	0.02	0.26
CD (0.05)	0.938	0.664	1.525	2.181	2.387	1.793	1.414	2.067	3.351	1.310	0.116	0.805

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.

At 15 DATA, application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8) resulted in zero count of grass weeds and were found to be best in controlling grass weeds during both the years. Among the herbicide combinations (T_2, T_3, T_5, T_6 and T_8), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) recorded higher count of grass weeds during both the years and was statistically on par with BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3), with 6.66, 5.33 and 4 m^{-2} during 2018 and 5.33 m^{-2} each during 2019. Sole application of CB @ 0.08 kg ha^{-1} (T_1) resulted in lower grass weed count compared to its tank mix combinations with BS @ 0.025 kg ha^{-1} (T_5) or CE @ 0.02 kg ha^{-1} (T_3) during both 2018 and 2019. The highest count of grass weed was observed in unweeded control (T_9) during both the years, followed by BS @ 0.025 kg ha^{-1} (T_4), respectively recorded 113.33 and 46.66 m^{-2} and 121.33 and 36 plants m^{-2} during 2018 and 2019.

Stale seedbed *fb* chemical weeding (T_8) recorded zero count of BLWs at 15 DATA during both the years. Application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) resulted in lower count of BLWs with 1.33 and 2.66 m^{-2}, respectively during 2018 and 2019. The treatment BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) also resulted in zero count of BLWs during 2019, but a count of 8 plants m^{-2} was noted in the treatment during 2018. Application of CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) registered higher count of BLWs, recorded 90.66 and 54.66 m^{-2} and 68 and 101.33 m^{-2}, respectively during 2018 and 2019, and were statistically higher than unweeded control (T_9).

Similar to the grass weeds, sedges were also effectively controlled by the tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8), resulted in zero count at 15 DATA during both the years. Zero count of sedges was also observed in HW twice at 20 and 45 DAS (T_{10}) during both the years. Among the herbicidal treatments (T_1 to T_8), CB @ 0.08 kg ha^{-1} (T_1) registered the highest count of sedges and was on par with FPE @ 0.06 kg ha^{-1} (T_7) during both the years, recorded 21.33 and 14.66 m^{-2} and 34.66 and 30.66 m^{-2}, respectively during 2018 and 2019.

Sole application of BS @ 0.025 kg ha^{-1} (T_4) and FPE @ 0.06 kg ha^{-1} (T_7) recorded higher count of sedges compared to the tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), where complete control of sedges was achieved.

4.3.1.3.2 Effect of weed management practices on weed count at 30 DATA

Table 33 contains data on the weed count in WSR at 30 DATA in 2018 and 2019. During both years, weed control strategies had a considerable impact on the total count of grass weeds, BLWs and sedges at 30 DATA.

Hand weeding twice at 20 and 45 DAS (T_{10}) recorded the lowest count of grass weeds during both the years, recorded 1.33 and 2.66 m^{-2} respectively during 2018 and 2019. This was followed by BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and FPE @ 0.06 kg ha^{-1} (T_7) during 2018 with 5.33 and 8 plants m^{-2}, respectively. However, T_7 was statistically comparable to T_{10} during 2019, recorded 5.33 plants m^{-2}. CB @ 0.08 kg ha^{-1} (T_1), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) recorded on par values in grass weed count during both the years with 10.66, 13.33 and 12 m^{-2} and 10.66, 12 and 12 plants m^{-2}, respectively during 2018 and 2019. Unweeded control (T_9) recorded the highest count of grass weeds during both the years followed by BS @ 0.025 kg ha^{-1} (T_4), recorded 154.66 and 82.66 m^{-2} during 2018 and 193 and 70.66 m^{-2} during 2019.

Among the herbicidal treatments (T_1 to T_8), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) recorded the lowest count of BLWs during both the years and was on par with BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and BS @ 0.025 kg ha^{-1} (T_4) with 3, 5.33 and 5.33 m^{-2} and 29.33, 29.33 and 32 plants m^{-2}, respectively during 2018 and 2019. Among the herbicide combination treatments (T_2, T_3, T_5, T_6 and T_8), CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) and SSB *fb* chemical weeding (T_8) recorded higher count of BLWs during both the years at 30 DATA. BLWs was found to be the highest in unweeded control (T_9) with 49.33 m^{-2} during 2018 whereas, FPE @ 0.06 kg ha^{-1} (T_7) recorded the highest count (177.33 m^{-2}) during 2019.

Sedge population was absent with HW twice at 20 and 45 DAS (T_{10}), ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) during both the years and resulted in 100 per cent control. Tank mix combination of BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) also recorded zero count of sedges during 2019. Compared to the sole application of CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7), its tank mix combination with BS @ 0.025 kg ha^{-1} resulted in lower count of sedges. SSB *fb* chemical weeding (T_8) registered the highest count of sedges (74.66 m^{-2}) during 2018 and was significantly higher to all other treatments.

4.3.1.3.3 Effect of weed management practices on weed count at 45 DATA

The data regarding weed count at 45 DATA during 2018 and 2019 is documented in Table 34. Weed management practices had a significant effect on the total count of grass weeds, BLWs and sedges at 45 DATA during both the years.

In general, the population of grass weeds was found to be increasing in all the treatments from 15 to 45 DATA during both the years. Among the herbicidal treatments (T_1 to T_8), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) registered the lowest count of grass weeds (10.66 m^{-2}) during both the years and was on par with FPE @ 0.06 kg ha^{-1} (T_7), which recorded 12 and 14.66 plants m^{-2}, respectively during 2018 and 2019. T_6 and T_7 was statistically comparable with HW twice at 20 and 45 DAS (T_{10}) with 12 and 9.33 plants m^{-2}, respectively during 2018 and 2019. The highest count of grass weeds was observed in unweeded control (T_9) during both the years followed by BS @ 0.025 kg ha^{-1} (T_4), recorded 148 and 93.33 m^{-2} and 156 and 90.66 m^{-2}, respectively during 2018 and 2019.

Application of CB @ 0.08 kg ha^{-1} (T_1) recorded lower count of grass weeds compared to its tank mix application with CE @ 0.02 kg ha^{-1} (T_3) or BS @ 0.025 kg ha^{-1} (T_5) during both the years, even though recorded statistically comparable grass weed count during 2019 (Table 34). The population of grass weeds under SSB *fb* chemical weeding (T_8) was found to be increasing from 15 to 45 DATA and recorded a count of 20 and 24 m^{-2}, respectively during 2018 and 2019 at 45 DATA.

Broad leaf weed count was noticed the highest in CB @ 0.08 kg ha^{-1} (T_1) treated plots during both the years and was on par with FPE @ 0.06 kg ha^{-1} (T_7), recorded 38.66 and 12 plants m^{-2} and 20 and 14.66 m^{-2}, respectively during 2018 and 2019. Application of BS @ 0.025 kg ha^{-1} (T_4) and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) registered zero count of BLWs during 2019.

The highest count of sedges (104.0 and 30.66 m^{-2}) was recorded in SSB *fb* chemical weeding (T_8) during 2018 and CB @ 0.08 kg ha^{-1} (T_1) during 2019. Among the herbicidal treatments (T_1 to T_8), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), BS @ 0.025 kg ha^{-1} (T_4) and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) recorded zero count of sedges during both the years and ensured 100 per cent control. Tank mix combination of BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) also recorded 100 per cent control of sedges during 2019. During both the years, unweeded control (T_9) recorded zero count of sedges at 45 DATA.

4.3.1.4 Regrowth pattern, if any, at 30 days after spraying

No regrowth was observed at 30 days after spraying of herbicides.

4.3.1.5 Dry matter production of weeds

The influence of weed management practices on dry matter production (DMP) of weeds at 15, 30 and 45 DATA during 2018 and 2019 are presented in Table 35. Perusal of data at 15, 30 and 45 DATA during both the years indicated that the weed management practices had significant effect on total weed dry matter production.

Observations of data at 15 DATA revealed that the treatment SSB *fb* chemical weeding (T_8) recorded zero DMP during both the years. This was followed by HW twice at 20 and 45 DAS (T_{10}), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) , PS + CB @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) during 2018, recorded 16.40, 18.80, 23.93 and 29.66 kg ha^{-1}, respectively. However during 2019, T_{10} and T_6 were found to be on par with T_8 and recorded a DMP of 5.50 and 4.67 kg ha^{-1}, respectively.

Table 32. Effect of weed management practices on weed count at 15 days after treatment application, no. m^{-2}

Treatments		Weed count					
		2018			2019		
		Grass weeds	Broad leaf weeds	Sedges	Grass weeds	Broad leaf weeds	Sedges
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	1.64 (2.66)	9.35 (90.66)	4.46 (21.33)	1.77 (2.66)	8.27 (68.00)	5.92 (34.66)
T_2	penoxsulam +cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	2.38 (6.66)	1.17 (1.33)	1.44 (2.66)	2.41 (5.33)	3.71 (13.33)	1.34 (1.33)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	1.91 (4.00)	4.76 (22.66)	2.31 (5.33)	2.41 (5.33)	5.33 (28.00)	1.77 (2.66)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	6.70 (46.66)	2.51 (6.66)	2.12 (4.00)	6.03 (36.00)	2.87 (8.00)	1.64 (2.66)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	2.12 (5.33)	2.77 (8.00)	1.17 (1.33)	2.41 (5.33)	0.70 (0.00)	1.77 (2.66)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.70 (0.00)	1.17 (1.33)	0.70 (0.00)	0.70 (0.00)	1.77 (2.66)	0.70 (0.00)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	1.64 (2.66)	7.40 (54.66)	3.82 (14.66)	2.12 (4.00)	10.08 (101.33)	5.58 (30.66)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)	0.70 (0.00)
T_9	unweeded control	10.60 (113.33)	5.45 (29.33)	4.80 (22.66)	11.03 (121.33)	6.95 (49.33)	4.93 (24.00)
T_{10}	hand weeding twice at 20 and 45 DAS	1.64 (2.66)	1.91 (4.00)	0.70 (0.00)	1.34 (1.33)	2.65 (6.66)	0.70 (0.00)
SEm±		0.67	0.64	0.49	0.09	0.30	0.18
CD (0.05)		2.011	1.902	1.477	0.266	0.906	0.544

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.
DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

Table 33. Effect of weed management practices on weed count at 30 days after treatment application, no. m^{-2}

Treatments		Weed count					
		2018			2019		
		Grass weeds	Broad leaf weeds	Sedges	Grass weeds	Broad leaf weeds	Sedges
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	3.25 (10.66)	5.40 (29.33)	2.65 (6.66)	3.26 (10.66)	9.99 (100.00)	7.68 (58.66)
T_2	penoxsulam +cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	3.65 (13.33)	3.43 (12.00)	0.70 (0.00)	3.43 (12.00)	5.88 (34.66)	0.70 (0.00)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	3.44 (12.00)	5.41 (29.33)	2.40 (5.33)	3.43 (12.00)	7.30 (53.33)	4.94 (24.00)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	9.09 (82.66)	2.30 (5.33)	2.65 (6.66)	8.40 (70.66)	5.65 (32.00)	1.91 (4.00)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	2.97 (9.00)	2.27 (5.33)	1.77 (2.66)	4.45 (20.00)	5.41 (29.33)	0.70 (0.00)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	2.30 (5.33)	1.71 (3.00)	0.70 (0.00)	2.79 (8.00)	5.41 (29.33)	0.70 (0.00)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	2.81 (8.00)	5.51 (30.66)	4.94 (24.00)	2.27 (5.33)	13.28 (177.33)	8.19 (66.66)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	3.05 (9.33)	4.65 (21.66)	8.66 (74.66)	3.05 (9.33)	6.09 (37.33)	4.21 (17.33)
T_9	unweeded control	12.43 (154.66)	7.01 (49.33)	5.32 (28.00)	13.90 (193.00)	7.54 (57.33)	5.92 (34.66)
T_{10}	hand weeding twice at 20 and 45 DAS	1.13 (1.33)	2.81 (8.00)	0.70 (0.00)	1.60 (2.66)	1.13 (1.33)	0.70 (0.00)
SEm±		0.14	0.23	0.13	0.24	0.31	0.21
CD (0.05)		0.439	0.689	0.392	0.729	0.931	0.664

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.
DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

Table 34. Effect of weed management practices on weed count at 45 days after treatment application, no. m^{-2}

Treatments		Weed count					
		2018			2019		
		Grass weeds	Broad leaf weeds	Sedges	Grass weeds	Broad leaf weeds	Sedges
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	6.21 (38.66)	8.24 (68.00)	5.58 (33.33)	4.47 (20.00)	11.13 (129.33)	5.56 (30.66)
T_2	penoxsulam +cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	5.41 (29.33)	5.02 (25.33)	0.70 (0.00)	6.27 (40.00)	3.50 (12.00)	0.70 (0.00)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	6.53 (42.66)	2.92 (10.66)	5.33 (37.33)	4.70 (22.66)	6.15 (42.66)	1.66 (2.66)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	9.66 (93.33)	2.27 (5.33)	0.70 (0.00)	9.46 (90.66)	0.70 (0.00)	0.70 (0.00)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	7.56 (57.33)	6.32 (40.00)	4.21 (21.33)	4.86 (24.00)	2.29 (6.66)	0.70 (0.00)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.24 (10.66)	3.15 (10.66)	0.70 (0.00)	3.21 (10.66)	0.70 (0.00)	0.70 (0.00)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.43 (12.00)	7.23 (53.33)	2.91 (8.00)	3.82 (14.66)	10.82 (120.00)	3.53 (13.33)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	4.46 (20.00)	6.54 (44.00)	10.21 (104.00)	4.88 (24.00)	6.25 (40.00)	5.07 (25.33)
T_9	unweeded control	12.16 (148.00)	4.16 (17.33)	0.70 (0.00)	12.46 (156.00)	6.76 (52.00)	0.70 (0.00)
T_{10}	hand weeding twice at 20 and 45 DAS	3.45 (12.00)	5.65 (32.00)	0.70 (0.00)	3.04 (9.33)	2.12 (5.33)	1.34 (1.33)
SEm±		0.18	0.54	0.92	0.43	0.96	0.32
CD (0.05)		0.564	1.610	2.730	1.281	2.861	0.986

Data were subjected to square root transformation - √x+0.5 and original values are given in parentheses.
DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

Unweeded control (T_9) registered the highest total DMP of weeds at 15 DATA during both the years with a mean value of 333.66 and 374.83 kg ha^{-1}, respectively during 2018 and 2019 (Table 35).

At 30 DATA, the weed DMP increased to the tune of five times in unweeded control during both the crop years and recorded a DMP of 1876.10 and 1978.26 kg ha^{-1}, respectively during 2018 and 2019. During 2018, the lowest DMP was observed in T_{10} (28.61 kg ha^{-1}) and was on par to T_6 with a mean value of 29.70 kg ha^{-1}. T_{10} recorded the lowest DMP during 2019 (26.60 kg ha^{-1}) and was statistically comparable to T_6 and T_2 with a mean DMP of 39.43 and 56.56 kg ha^{-1}, respectively.

Critical appraisal of data at 45 DATA indicated that the treatment T_{10} recorded the lowest mean DMP of 117.54 kg ha^{-1} and 118.66 kg ha^{-1}, respectively during 2018 and 2019. This was followed by T_6, T_5 and T_2 during 2018 with a DMP of 222.45, 283.96 and 287.20 kg ha^{-1}, respectively. However, during 2019, T_6 and T_5 with 127 and 224.08 kg ha^{-1}, respectively was on par with T_{10}. There was an increase in weed DMP in most of the herbicide treatments at 45 DATA. However, in unweeded control, DMP was less at 45 DATA than at 30 DATA during both years and recorded 1850.90 and 1492.20 kg ha^{-1}, respectively during 2018 and 2019.

4.3.1.6 Dry matter production of L. chinensis

The data on dry matter production (DMP) of *L. chinensis* during 2018 and 2019 are presented in Table 36. During both the years, the DMP of *L. chinensis* was increased from 15 to 45 DATA in all the treatments and unweeded control recorded the highest DMP at all stages of observation.

At 15 DATA, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) were free of *L. chinensis* and recorded zero DMP during both the years. CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded zero DMP of *L. chinensis* during 2018. The treatments CB @ 0.08 kg ha^{-1} (T_1) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) were statistically on par with the treatments recorded zero DMP of *L. chinensis* during both the years and acquired 1.68 and 2.57 kg ha^{-1} and 1.99 and 2.48 kg ha^{-1}, respectively during 2018 and 2019. PS + CB @ 0.15 kg ha^{-1} (T_2) with 1.56 kg ha^{-1} was also on par to all other treatments except T_4 and T_9 during 2019. The highest DMP of *L. chinensis* (74.09 kg ha^{-1}) was registered in unweeded control (T_9) during 2018 (Table 36) and was found to be on par with BS @ 0.025 kg ha^{-1} (T_4) with 41.35 kg ha^{-1}. During 2019 also, T_9 recorded the highest DMP of 121.34 kg ha^{-1}, which was followed by T_4 with 47.21 kg ha^{-1}.

Critical appraisal of data at 30 DATA showed that among the herbicidal treatments (T_1 to T_8), T_7 registered the lowest *L. chinensis* DMP of 8.90 and 4.41 kg ha^{-1}, respectively during 2018 and 2019, and was statistically comparable with T_{10}, T_6 and T_8 during both the years, recorded 6.32, 13.90 and 14.02 kg ha^{-1} and 9.21, 7.90 and 10.72 kg ha^{-1}, respectively during 2018 and 2019. T_9 recorded the highest DMP of 240.78 and 374.55 kg ha^{-1}, respectively during 2018 and 2019 and was on par with T_4 with 170.77 kg ha^{-1}during 2019.

At 45 DATA, the DMP of *L. chinensis* in unweeded control (T_9) has increased to three fold compared to 30 DATA and recorded the highest DMP of 826.13 and 855.04 kg ha^{-1}, followed by T_4 with 519.87 and 446.26 kg ha^{-1}, respectively during 2018 and 2019. During both the years, FPE @ 0.06 kg ha^{-1} (T_7) treated plots registered the lowest *L. chinensis* DMP of 23.91 and 30.15 kg ha^{-1}, respectively during 2018 and 2019 and was on par with T_{10}, T_6, T_8, T_5 and T_1 during both the years.

4.3.1.7 Nutrient removal by weeds

Nutrient removal by weeds at 15, 30 and 45 DATA was significantly influenced by the weed management treatments. At all stages of observation the highest nutrient removal was recorded in unweeded control. The data were statistically analysed and presented in the Table 37 to 39.

4.3.1.7.1 Nitrogen removal by weeds

Nitrogen (N) removal by weeds was significantly influenced by weed management treatments during both the crop years (Table 37).

Critical appraisal of data at 15 DATA revealed that SSB *fb* chemical weeding (T_8)) recorded the lowest N removal (zero) by weeds during both 2018 and 2019 and was statistically on par with HW twice at 20 and 45 DAS (T_{10}), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) during both the years, recorded 0.20, 0.21, 0.282 and 0.401kg ha^{-1} and 0.14, 0.13, 0.15 and 0.19 kg ha^{-1}, respectively during 2018 and 2019. The highest N removal of 5.70 and 9.52 kg ha^{-1} by weeds was noted in unweeded control (T_9), respectively during 2018 and 2019.

At 30 DATA, T_{10} registered the lowest values of N removal of 0.44 and 0.46 kg ha^{-1} and was found to be statistically on par with T_6, T_2 and T_5 during both the years, recorded 0.48, 1.15 and 1.40 kg ha^{-1} and 0.87, 1.24 and 2.17 kg ha^{-1}, respectively during 2018 and 2019. The highest N removal was observed in T_9 with 19.39 and 24.55 kg ha^{-1}, respectively during 2018 and 2019.

At 45 DATA, T_{10} recorded the least N removal of 2.36 and 1.79 kg ha^{-1}, respectively during 2018 and 2019. Among the herbicidal treatments (T_1 to T_8), lower removal of 4.11, 4.37 and 5.09 kg ha^{-1} and 1.81, 3.58 and 4.38 kg ha^{-1} was noticed, respectively in T_6, T_5 and T_2 during 2018 and 2019 and was statistically comparable with T_{10} during both the years. The highest values of N removal was observed in T_9 with 33.87 and 21.58 kg ha^{-1}, respectively during 2018 and 2019.

4.3.1.7.2 Phosphorus removal by weeds

The phosphorus (P) removal by weeds followed almost a similar trend to that of nitrogen (Table 38). P removal was in the range of 0 to 0.81 kg ha^{-1} at 15 DATA during 2018 and 0 to 0.96 kg ha^{-1} during 2019, 0.21 to 4.85 kg ha^{-1} at 30 DATA during 2018 and 0.04 to 4.71 kg ha^{-1} during 2019, while at 45 DATA, it ranged from 0.77 to 4.77 kg ha^{-1} during 2018 and 0.24 to 4.41 kg ha^{-1} during 2019.

Table 35. Effect of weed management practices on total weed dry matter production, kg ha^{-1}

Treatments		Dry matter production					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	9.29 (86.00)	25.01 (626.60)	39.03 (1524.30)	7.79 (60.40)	24.56 (604.87)	35.09 (1241.79)
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	4.93 (23.93)	8.45 (73.06)	16.76 (287.20)	2.70 (7.10)	7.51 (56.56)	15.74 (249.92)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	8.55 (72.80)	20.61 (425.51)	30.01 (905.02)	6.75 (45.53)	17.49 (306.56)	27.11 (740.38)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	8.56 (73.86)	17.88 (320.73)	26.52 (704.43)	7.28 (55.91)	14.65 (219.46)	23.99 (584.24)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	5.23 (29.66)	9.21 (85.06)	16.82 (283.96)	2.85 (7.70)	9.53 (91.63)	14.96 (224.08)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.93 (18.80)	5.41 (29.70)	14.73 (222.45)	2.16 (4.67)	6.26 (39.43)	11.30 (127.92)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	8.81 (78.80)	24.71 (612.73)	37.57 (1411.78)	7.41 (55.94)	21.08 (448.61)	33.60 (1137.06)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.70 (0.00)	16.13 (261.13)	27.01 (730.50)	0.70 (0.00)	15.40 (238.06)	26.05 (684.26)
T_9	unweeded control	18.06 (333.66)	43.15 (1867.10)	43.00 (1850.90)	19.34 (374.83)	44.24 (1978.26)	38.59 (1492.20)
T_{10}	hand weeding twice at 20 and 45 DAS	4.02 (16.40)	5.31 (28.61)	10.83 (117.54)	2.44 (5.50)	5.13 (26.60)	10.88 (118.66)
SEm±		0.69	0.72	1.04	0.61	1.32	1.52
CD (0.05)		2.062	2.159	3.096	1.832	3.948	4.520

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.
DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

Table 36. Effect of weed management practices on dry matter production of *Leptochloa chinensis*, kg ha^{-1}

Treatments		Dry matter production					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	1.25 (1.68)	4.12 (17.45)	6.71 (44.74)	1.32 (1.99)	3.80 (13.96)	6.86 (47.30)
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	2.64 (6.69)	6.19 (38.58)	9.41 (88.45)	1.56 (2.48)	5.46 (33.16)	8.91 (80.15)
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.70 (0.00)	4.91 (24.34)	7.85 (61.22)	1.21 (1.48)	3.26 (13.83)	6.88 (47.39)
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	6.46 (41.35)	13.77 (189.94)	22.72 (519.87)	5.86 (47.21)	12.46 (170.77)	21.08 (446.28)
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	1.62 (2.57)	4.86 (24.78)	6.57 (42.76)	1.60 (2.48)	4.31 (18.56)	6.92 (48.85)
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.70 (0.00)	3.69 (13.90)	5.64 (31.47)	0.70 (0.00)	2.57 (7.90)	5.98 (36.43)
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.70 (0.00)	2.96 (8.90)	4.94 (23.91)	0.70 (0.00)	1.70 (4.41)	5.49 (30.15)
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.70 (0.00)	3.71 (14.02)	6.53 (42.28)	0.70 (0.00)	2.92 (10.72)	6.49 (42.63)
T_9	unweeded control	8.51 (74.09)	15.51 (240.7)	28.72 (826.13)	10.68 (121.34)	17.95 (374.55)	29.23 (855.04)
T_{10}	hand weeding twice at 20 and 45 DAS	0.70 (0.00)	2.43 (6.32)	5.51 (41.84)	0.70 (0.00)	2.23 (9.21)	6.20 (39.44)
SEm±-		0.43	0.31	0.90	1.00	2.10	0.98
CD (0.05)		1.281	0.929	2.688	2.989	6.263	2.932

Data were subjected to square root transformation - $\sqrt{x+0.5}$ and original values are given in parentheses.

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

The data during both the years at 15 DATA indicated that SSB *fb* chemical weeding (T_8) recorded the lowest removal (zero) of P. Ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and HW twice at 20 and 45 DAS (T_{10}) was found to be on par with T_8 during both years.

Critical appraisal of data revealed that the treatment T_{10} recorded the lowest P removal of 0.21 and 0.04 kg ha^{-1} at 30 DATA and 0.77 and 0.24 kg ha^{-1} at 45 DATA, respectively during 2018 and 2019. It was on par with T_6, T_2 and T_5 with 0.22, 0.59 and 0.671 kg ha^{-1} and 0.09, 0.18 and 0.32 kg ha^{-1} at 30 DATA and 0.82, 1.39 and 1.51 kg ha^{-1} and 0.28, 1.02 and 0.83 kg ha^{-1} at 45 DATA, respectively during 2018 and 2019. Unweeded control (T_9) registered the highest P removal of 0.81 and 0.96 kg ha^{-1} at 15 DATA, 4.85 and 4.71 kg ha^{-1} at 30 DATA and 4.79 and 4.41 kg ha^{-1} at 45 DATA, respectively during 2018 and 2019.

4.3.1.7.3 Potassium removal by weeds

Potassium **(**K) removal by weeds at 15, 30 and 45 DATA during 2018 and 2019 was significantly influenced by the weed management treatments (Table 39).

Unweeded control (T_9) recorded the highest K removal and was statistically higher to other treatments at all stages of observations during both the years. The K removal in T_9 increased from 9.80 to 66.46 kg ha^{-1} at 15 to 45 DATA during 2018. During 2019, this was increased from 10.09 to 69.44 kg ha^{-1} at 15 to 45 DATA.

Similar to N and P removal, SSB *fb* chemical weeding (T_8) recorded zero K removal during both the years at 15 DATA. HW twice at 20 and 45 DAS (T_{10}), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) was found to be on par with T_8 during both years and correspondingly recorded 0.40, 0.51, 0.65 and 0.82 kg ha^{-1} and 0.12, 0.09, 0.23 and 0.23 kg ha^{-1} during 2018 and 2019.

The data corresponding to K removal at 30 DATA showed a similar trend as that of N removal at 30 DATA during both the years.

The treatment T_{10} recorded the lowest K removal of 0.38 and 0.53 kg ha^{-1} and was statistically comparable with T_6, T_2, T_5 and T_8 during both the years with 0.73, 1.75, 1.81 and 3.57 kg ha^{-1} during 2018 and 0.91, 1.51, 2.14 and 7.11 kg ha^{-1} during 2019. BS @ 0.025 kg ha^{-1} (T_4) registered 6.24 kg ha^{-1} was also on par to T_{10} during 2019.

At 45 DATA, there was considerable increase in K removal by weeds in all the treatments over 15 and 30 DATA. Among the herbicidal treatments (T_1 to T_8), T_6 recorded the lowest K removal of 5.68 and 3.09 kg ha^{-1}, respectively during 2018 and 2019 at 45 DATA and was on par with $T_{10,}$ T_5 and T_2 during both the years.

4.3.1.8 Nutrient removal by L. chinensis

The tables 40, 41 and 42, respectively shows the N, P, and K removal by *L. chinensis* during 2018 and 2019. The lower dry matter production during 15 DATA resulted in the lower nutrient removal by *L. chinensis* compared to 30 DATA and 45 DATA.

4.3.1.8.1 Nitrogen removal

Nitrogen (N) removal by *L. chinensis* was significantly influenced by weed management practices during both the crop years (Table 40).

Perusal of data on the effect of weed management practices on N removal at 15 DATA revealed that BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) recorded zero removal during both 2018 and 2019. The treatment CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded zero N removal during 2018. Among the herbicidal treatments (T_1 to T_8), T_7 recorded the lowest N removal of 0.209 and 0.063 kg ha^{-1} and 0.651 and 0.697 kg ha^{-1}, correspondingly at 30 and 45 DATA during 2018 and 2019. It was found to be statistically comparable with all other treatments except T_4 and $T_{9,}$ at 45 DATA during both the years.

Table 37. Effect of weed management practices on nitrogen removal by weeds, kg ha^{-1}

Treatments		N removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	1.32	9.11	29.85	2.04	8.66	20.70
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.28	1.15	5.09	0.15	1.24	4.38
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.87	7.35	18.13	1.17	6.15	12.59
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	0.88	5.66	10.65	1.48	4.88	6.33
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.40	1.40	4.37	0.19	2.17	3.58
T_6	bispyribac sodium @ 0.025 kg ha^{-1} +fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.21	0.48	4.11	0.13	0.87	1.81
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.96	9.00	24.49	1.93	6.72	19.41
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.00	4.42	15.62	0.00	4.89	11.83
T_9	unweeded control	5.70	19.39	33.87	9.52	24.55	21.58
T_{10}	hand weeding twice at 20 and 45 DAS	0.20	0.44	2.36	0.14	0.46	1.79
SEm±		0.31	1.07	2.09	0.51	1.27	1.44
CD (0.05)		0.942	3.288	6.402	0.889	3.219	4.203

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing.

Table 38. Effect of weed management practices on phosphorus removal by weeds, kg ha^{-1}

Treatments		P removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	0.40	2.08	3.56	0.69	2.76	3.52
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.07	0.59	1.39	0.05	0.18	1.02
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.21	1.82	2.93	0.52	1.17	2.77
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	0.37	1.15	2.59	0.55	0.64	1.16
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.07	0.67	1.51	0.07	0.32	0.83
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.05	0.22	0.82	0.03	0.09	0.28
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.39	1.91	3.34	0.65	1.63	2.92
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.00	1.12	2.77	0.00	0.86	2.42
T_9	unweeded control	0.81	4.85	4.79	0.96	4.71	4.41
T_{10}	hand weeding twice at 20 and 45 DAS	0.03	0.21	0.77	0.03	0.04	0.24
SEm±		0.05	0.25	0.31	0.07	0.27	0.31
CD (0.05)		0.298	0.975	2.452	0.374	0.816	1.994

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing.

Table 39. Effect of weed management practices on potassium removal by weeds, kg ha^{-1}

Treatments		K removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	2.84	13.47	46.91	2.55	12.90	43.36
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.65	1.75	7.80	0.23	1.51	6.75
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	2.08	10.75	28.20	1.89	8.23	24.10
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	2.38	6.08	18.34	2.00	6.24	12.94
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.82	1.81	8.26	0.23	2.14	5.45
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.51	0.73	5.68	0.09	0.91	3.09
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	2.50	12.98	42.38	2.01	11.54	43.34
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.00	3.57	25.18	0.00	7.11	21.27
T_9	unweeded control	9.80	30.05	66.46	10.09	39.65	69.44
T_{10}	hand weeding twice at 20 and 45 DAS	0.40	0.38	3.34	0.12	0.53	2.99
SEm±		0.53	1.64	3.77	0.55	2.31	4.14
CD (0.05)		1.959	3.601	8.494	1.481	12.173	15.708

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing.

Leptochloa chinensis present in unweeded control (T_9) resulted in significantly higher N removal of 1.286, 7.368, 18.484 kg ha^{-1} and 3.052, 9.766 and 19.055 kg ha^{-1}, correspondingly at 15, 30 and 45 DATA, during 2018 and 2019. It was followed by BS @ 0.025 kg ha^{-1} (T_4) at 15, 30 and 45 DATA during both the years with N removal of 0.416, 4.045 and 10.579 kg ha^{-1} and 1.240, 3.957 and 9.428 kg ha^{-1}, respectively during 2018 and 2019. Among the herbicide combination treatments (T_2, T_3, T_5, T_6 and T_8), the highest N removal by *L. chinensis* was noticed in PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) at all stages of observation during both the years, recorded 0.073, 1.109 and 2.375 kg ha^{-1} and 0.065, 0.97 and 2.055 kg ha^{-1}, respectively at 15, 30 and 45 DATA during 2018 and 2019. However, it was on par to all other treatments except T_9 and T_4 at all stages.

4.3.1.8.2 Phosphorus removal

The phosphorus (P) removal by *L. chinensis* followed almost a similar trend as that of nitrogen (Table 41). P removal was in the range of 0 to 0.378 kg ha^{-1} and 0 to 0.504 kg ha^{-1} at 15 DATA, 0.016 to 0.0745 kg ha^{-1} and 0.016 to 0.797 kg ha^{-1} at 30 DATA and 0.021 to 1.479 kg ha^{-1} and 0.017 to 1.432 kg ha^{-1} at 45 DATA, respectively during 2018 and 2019.

Critical appraisal of data at 15 DATA revealed that the P removal was zero in BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) during both the years. The treatment CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded zero P removal during 2018.

The highest P removal by *L. chinensis* was noted in unweeded control (T_9) with 0.378 and 0.504 kg ha^{-1}, 0.745 and 0.797 kg ha^{-1} and 1.479 and 1.432 kg ha^{-1}, correspondingly at 15, 30 and 45 DATA during 2018 and 2019. Among the herbicidal treatments (T_1 to T_8), T_7 recorded the lowest P removal by *L. chinensis* at 30 and 45 DATA and was on par with allother treatments except T_9 and T_4 during 2018.

4.3.1.8.3 Potassium removal

Potassium (K) removal by *L. chinensis* at 15, 30 and 45 DATA during 2018 and 2019 was significantly influenced by the weed management practices (Table 42). K removal in unweeded control (T_9) increased from 2.172 kg ha^{-1} at 15 DATA to 10.352 kg ha^{-1} and 29.738 kg ha^{-1} correspondingly at 30 and 45 DATA during 2018, whereas during 2019, this was increased from 3.348 kg ha^{-1} at 15 DATA to 19.622 kg ha^{-1} at 30 DATA and 39.878 kg ha^{-1} at 45 DATA.

Similar to N and P removal, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) recorded zero removal of K at 15 DATA during both the years. CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded zero removal of K during 2018.

The data corresponding to removal of K at 30 DATA showed a similar trend as that of N and P removal at 30 DATA during both years. The treatment FPE @ 0.06 kg ha^{-1} (T_7) recorded the lowest K removal among the herbicidal treatments (T_1 to T_8) during both the years at 30 and 45 DATA and was on par with all other treatments except T_9 and BS @ 0.025 kg ha^{-1} (T_4) at 45 DATA. T_9 registered the highest K removal at all stages and recorded 2.172, 10.352 and 29.738 kg ha^{-1} and 3.348, 19.622 and 39.878 kg ha^{-1}, correspondingly at 15, 30 and 45 DATA during 2018 and 2019. It was followed by T_4 during both the years with a K removal of 1.345 and 1.741 kg ha^{-1} at 15 DATA, 5.498 and 4.708 kg ha^{-1} at 30 DATA and 13.535 and 9.853 kg ha^{-1} at 45 DATA, respectively during 2018 and 2019. At 45 DATA, there was considerable increase in K removal by *L. chinensis* in all the weed management treatments over 15 and 30 DATA.

4.3.1.9 Weed control efficiency

Weed control efficiency (WCE) gives an idea of the effectiveness of an applied herbicide. It is the percentage reduction in population or dry weight of weeds due to application of herbicides compared to unweeded control. The data on WCE at different stages are presented in Table 43. WCE was significantly influenced by the weed management practices at 15, 30 and 45 DATA during both the years.

Table 40. Effect of weed management practices on nitrogen removal by *Leptochloa chinensis*, kg ha^{-1}

Treatments		N removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	0.026	0.430	1.327	0.038	0.364	1.103
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.073	1.109	2.375	0.065	0.917	2.055
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.000	0.617	1.655	0.038	0.344	1.133
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	0.416	4.045	10.579	1.240	3.957	9.428
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.040	0.659	1.287	0.054	0.475	1.331
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.306	0.885	0.000	0.156	0.740
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.209	0.650	0.000	0.063	0.697
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.000	0.329	1.262	0.000	0.219	0.987
T_9	unweeded control	1.286	7.368	18.484	3.052	9.766	19.055
T_{10}	hand weeding twice at 20 and 45 DAS	0.000	0.152	1.210	0.000	0.181	0.833
SEm±		0.075	0.420	0.591	0.202	1.703	1.072
CD (0.05)		0.332	1.058	1.750	1.074	5.069	2.312

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing.

Table 41. Effect of weed management practices on phosphorus removal by *Leptochloa chinensis*, kg ha^{-1}

Treatments		P removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	0.001	0.039	0.073	0.006	0.017	0.061
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.024	0.098	0.139	0.015	0.030	0.121
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.000	0.058	0.075	0.004	0.016	0.070
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	0.214	0.357	0.806	0.211	0.234	0.636
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.005	0.062	0.041	0.008	0.018	0.075
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.023	0.013	0.000	0.008	0.014
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.022	0.008	0.000	0.006	0.009
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.000	0.025	0.025	0.000	0.013	0.050
T_9	unweeded control	0.378	0.745	1.479	0.504	0.797	1.432
T_{10}	hand weeding twice at 20 and 45 DAS	0.000	0.016	0.021	0.000	0.016	0.017
SEm±		0.027	0.004	0.082	0.036	0.054	0.141
CD (0.05)		0.145	0.153	0.168	0.200	0.404	0.282

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

Table 42. Effect of weed management practices on potassium removal by *Leptochloa chinensis*, kg ha^{-1}

Treatments		K removal					
		2018			2019		
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	0.063	0.547	1.361	0.077	0.520	1.358
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.259	1.296	3.057	0.177	0.861	2.424
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.000	0.840	1.962	0.067	0.505	1.744
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	1.345	5.498	13.535	1.741	4.708	9.853
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.062	0.897	1.347	0.099	0.586	2.279
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.295	0.805	0.000	0.198	1.016
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.000	0.222	0.587	0.000	0.184	0.892
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	0.000	0.357	1.237	0.000	0.320	1.343
T_9	unweeded control	2.172	10.352	29.738	3.348	19.622	39.878
T_{10}	hand weeding twice at 20 and 45 DAS	0.000	0.169	1.191	0.000	0.284	1.244
SEm±-		0.140	0.153	1.681	0.231	1.455	0.660
CD (0.05)		0.529	0.454	4.204	1.387	11.244	1.965

DATA - Days after treatment application; DALP - Days after land preparation; DAS - Days after sowing

At 15 DATA, the highest WCE of 100 per cent was observed with SSB *fb* chemical weeding (T_8) during both the years. HW twice at 20 and 45 DAS (T_{10}) and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) were found to be on par with T_8 during both the years and recorded 95.08 and 94.36 per cent and 98.52 and 98.74 per cent, respectively during 2018 and 2019. PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) were also statistically comparable with T_8, T_6 and T_{10} during 2019, recorded 98.10 and 97.94 per cent, respectively. CB @ 0.08 kg ha^{-1} (T_1), FPE @ 0.06 kg ha^{-1} (T_7), CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) and BS @ 0.025 kg ha^{-1} (T_4) were statistically comparable and recorded lower WCE during both the years at 15 DATA.

At 30 DATA, T_{10} recorded the highest WCE of 98.46 and 98.65 per cent, respectively during 2018 and 2019 and was noticed on par with T_6, T_2 and T_5 during both the years, disclosed 98.40 and 96.08 and 95.44 per cent and 98.0, 97.13 and 95.36 per cent, respectively during 2018 and 2019. The lowest WCE of 66.43 and 69.42 per cent was recorded in T_1, correspondingly during 2018 and 2019 and was on par to T_7 with 67.17 and 77.31 per cent, respectively.

Critical appraisal of data at 45 DATA displayed that T_{10} recorded the highest WCE of 93.64 and 92.04 per cent, respectively during 2018 and 2019 and was statistically on par with T_6 during both the years with 87.97 and 91.42 per cent, respectively. The treatments T_5 and T_2 were also statistically comparable with T_{10} and T_6 during 2019, recorded 84.97 and 83.24 per cent, respectively. T_1 registered the lowest WCE and obtained only 17.64 and 20.21 per cent control, respectively during 2018 and 2019. It was statistically comparable to T_7 with 23.72 and 23.79 per cent efficiency and significantly lower to all other treatments. Among tank mix application of herbicides (T_3, T_5, T_6 and T_8), T_3 recorded lower WCE of 51.10 and 50.37 per cent, respectively during 2018 and 2019, and was statistically on par with T_8 during 2019.

Pooled data of WCE at 15, 30 and 45 DATA revealed that T_8 recorded 100 per cent weed control at 15 DATA. The treatments T_{10} and T_6 were found to be statistically on par with T_8 and realized 96.80 and 96.55 per cent WCE, respectively during 15 DATA.

At 30 DATA, the highest WCE of 98.56 per cent was registered by T_{10} and was statistically comparable with T_{6}, T_2 and T_5 with 98.20, 96.61 and 95.40 per cent efficiency, respectively. Critical appraisal of data at 45 DATA indicated that T_{10} recorded the highest WCE of 92.84 per cent and the herbicide combination treatments T_6 and T_5 were statistically on par to T_{10}, acquired 89.70 and 84.81 per cent weed control. T_1 recorded the lowest WCE at all stages with 79.05, 67.92 and 18.92 per cent control, respectively at 15, 30 and 45 DATA. Among the herbicide combinations (T_2, T_3, T_5, T6 and T8), T_3 recorded lower WCE compared to all other combinations and recorded 50.73 per cent weed control at 45 DATA.

4.3.1.10 Control efficiency of L. chinensis

The data on control efficiency (CE) of *L. chinensis* at different stages during 2018 and 2019 are depicted in Table 44. CE was significantly influenced by the weed management practices at 15, 30 and 45 DATA during both the years.

At 15 DATA, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7), SSB *fb* chemical weeding (T_8) and HW twice at 20 and 45 DAS (T_{10}) realized 100 per cent control of *L. chinensis* during both the years. CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) also recorded 100 per cent CE during 2018. The lowest control efficiency of 44.17 and 61.08 per cent was recorded in BS @ 0.025 kg ha^{-1} (T_4), respectively during 2018 and 2019. All treatments, except T_4 and T_9 were statistically comparable with those treatments recorded 100 per cent CE during 2019.

Critical appraisal of data at 30 DATA revealed that T_7 registered the highest control efficiency of *L. chinensis* among the herbicidal treatments (T_1 to T_8) during both the years and recorded 96.29 and 98.82 per cent, respectively during 2018 and 2019. However, it was found to be on par with T_6, T_8 and T_{10}, during both the years, with 94.24, 94.17 and 97.37 per cent and 97.88, 97.54 and 97.13 per cent, during 2018 and 2019. All other treatments except T_4 and T_9 recorded statistically on par values in CE of *L. chinensis* during 2019. T_4 recorded the lowest CE of 22.96 and 54.40 per cent, respectively during 2018 and 2019 among the management practices.

The treatment T_5 recorded lower CE of *L. chinensis* compared to T_1 during both the years, correspondingly recorded 89.70 and 92.75 per cent and 95.04 and 96.27 per cent during 2018 and 2019.

At 45 DATA, T_7 recorded the highest CE of *L. chinensis* during both the years with 97.10 and 96.47 per cent, respectively during 2018 and 2019. However, all other weed management treatments except T_2 and T_4 were statistically on par with T_7 during both the years and ranged from 92.58 to 96.18 and 94.28 to 95.73 per cent, respectively during 2018 and 2019. T_4 recorded the lowest efficiency of controlling *L. chinensis* during both the years with 37.07 and 47.80 per cent respectively, during 2018 and 2019.

Pooled data revealed that the treatments T_6, T_7, T_8 and T_{10} were efficient in managing *L. chinensis* and recorded 100 per cent CE at 15 DATA. At 30 and 45 DATA, the highest CE was obtained in T_7 with 97.55 and 96.78 per cent, respectively. All other treatments except T_4 was statistically on par to each other at 15 and 30 DATA. T_4 recorded the lowest CE of 52.63, 38.68 and 42.43 per cent respectively at 15, 30 and 45 DATA. T_2 recorded lower CE of *L. chinensis* among the herbicide combinations (T_2, T_3, T_5, T_6 and T_8) at 45 DATA, which was comparable to unweeded control, even though was statistically on par to other combination treatments at 15 and 30 DATA.

4.3.1.11 Weed index

Weed index (WI) is a parameter to describe the extent of yield loss occurred due to weed infestation in comparison with weed free plots. Weed management practices exerted significant influence on weed index during 2018 and 2019 (Table 45). HW twice at 20 and 45 DAS (T_{10}) was considered as the weed free plot for calculating the weed index, since it recorded the minimum weeds and highest grain yield among the treatments during both the years.

Bispyribac sodium @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) recorded the lowest WI value of 3.26 during 2018 and was on par with PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and SSB *fb* chemical weeding (T_8) with WI values of 7.67, 11.33 and 18.29, respectively. Unweeded control (T_9) recorded significantly higher weed index value of 56.77 compared to other treatments, followed by FPE @ 0.06 kg ha^{-1} (T_7) and CB @ 0.08 kg ha^{-1} (T_1) (34.96 and 33.69, respectively) during 2018.

Among the herbicidal treatments (T_1 to T_8), T_6 recorded the lowest WI of 2.93 during 2019, which was on par with T_2, T_5 and T_8. T_1 recorded higher WI of 60.29 among the herbicidal treatments and was statistically on par with T_9, where the highest yield reduction of 63.13 per cent was noticed, followed by T_7 with WI of 42.96 during 2019.

Season long weed competition in unweeded control caused 56.77 per cent reduction in yield during 2018 and the extent of yield reduction in 2019 was 63.13 per cent. Critical analysis of the pooled data showed a reduction in grain yield to the tune of 59.95 per cent to uncontrolled weed competition in T_9, whereas the minimum reduction in grain yield (3.09%) was resulted from tank mix application of T_6. However, this was statistically comparable to the obtained weed index of 7.83, 8.60 and 15.77 correspondingly through the application of T_2, T_5 and T_8.

It is evident from the data that combined application of various herbicides recommended for grasses, BLWs and sedges resulted in statistically comparable weed index values. The combined application of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) was an exception, where weed index values were higher (25.32 during 2018 and 23.05 during 2019) and were on par with BS @ 0.025 kg ha^{-1} (T_4) during both years (23.59 and 23.22, respectively).

Table 43. Effect of weed management practices on weed control efficiency, %

Treatments		WCE						Pooled WCE		
		2018			2019			15 DATA	30 DATA	45 DATA
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA			
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	74.22	66.43	17.64	83.88	69.42	20.21	79.05	67.92	18.92
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	92.82	96.08	84.47	98.10	97.13	83.24	95.46	96.61	83.86
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	78.17	77.20	51.10	87.84	84.50	50.37	83.01	80.85	50.73
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	77.85	82.82	61.93	85.07	88.90	60.84	81.46	85.86	61.39
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	91.10	95.44	84.65	97.94	95.36	84.97	94.52	95.40	84.81
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	94.36	98.40	87.97	98.74	98.00	91.42	96.55	98.20	89.70
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	76.37	67.17	23.72	85.06	77.31	23.79	80.72	72.24	23.75
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	100.00	86.01	60.53	100.00	87.96	54.14	100.00	86.98	57.33
T_9	unweeded control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_{10}	hand weeding twice at 20 and 45 DAS	95.08	98.46	93.64	98.52	98.65	92.04	96.80	98.56	92.84
SEm±		1.94	1.18	2.43	1.89	1.51	5.73	1.32	1.21	2.92
CD (0.05)		5.783	3.518	7.234	5.617	4.482	17.049	3.938	3.614	8.692

WCE - Weed control efficiency; DATA - Days after treatment application; DAS - Days after sowing; DALP - Days after land preparation

Table 44. Effect of weed management practices on control efficiency of *Leptochloa chinensis*, %

Treatments		Control Efficiency						Pooled CE (%)		
		2018			2019			15 DATA	30 DATA	45 DATA
		15 DATA	30 DATA	45 DATA	15 DATA	30 DATA	45 DATA			
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	97.72	92.75	94.58	98.35	96.27	94.46	98.04	94.51	94.52
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	90.94	83.97	89.29	97.95	91.14	90.62	94.44	87.56	89.95
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	100.00	89.88	92.58	98.77	96.30	94.45	99.38	93.09	93.52
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	44.17	22.96	37.07	61.08	54.40	47.80	52.63	38.68	42.43
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	96.51	89.70	94.82	97.95	95.04	94.28	97.23	92.37	94.55
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	100.00	94.24	96.18	100.00	97.88	95.73	100.00	96.06	95.96
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	100.00	96.29	97.10	100.00	98.82	96.47	100.00	97.55	96.78
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP+ T_3	100.00	94.17	94.88	100.00	97.13	95.01	100.00	95.65	94.94
T_9	unweeded control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T_{10}	hand weeding twice at 20 and 45 DAS	100.00	97.37	94.93	100.00	97.54	95.38	100.00	97.45	95.16
SEm±		1.18	1.17	2.51	6.14	6.84	1.79	3.23	3.57	1.26
CD (0.05)		3.523	3.496	7.484	18.249	20.325	5.333	9.611	10.634	3.751

CE - Control efficiency; DATA - Days after treatment application; DAS - Days after sowing; DALP - Days after land preparation

Table 45. Effect of weed management practices on weed index

Treatments		Weed Index		Pooled Weed Index
		2018	2019	
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	33.69	60.29	46.99
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	7.67	7.98	7.83
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	25.32	23.05	24.19
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	23.59	23.22	23.41
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	11.33	5.87	8.60
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.26	2.93	3.09
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	34.96	42.96	38.96
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	18.29	13.26	15.77
T_9	unweeded control	56.77	63.13	59.95
T_{10}	hand weeding twice at 20 and 45 DAS	0.00	0.00	0.00
SEm±.		3.45	4.27	3.71
CD (0.05)		18.031	13.444	13.262

DAS - Days after sowing; DALP - Days after land preparation

4.3.2 Observations on crop

4.3.2.1 Visual symptoms of phytotoxicity

Visual symptoms of phytotoxicity and the degree of toxicity were scored during both 2018 and 2019 at four and seven days after spraying (Table 46) to assess whether the applied herbicides had any toxicity in rice plants. Phytotoxicity symptoms were graded on a visual scale of 0-5 as per Abraham and Thomas (2007), where 0 indicated no phytotoxicity and 5 indicated complete destruction of crops (Table 4).

Among various herbicidal treatments, CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), FPE @ 0.06 kg ha^{-1} (T_7) and SSB *fb* chemical weeding (T_8) resulted in severe injury on crop at 4th day after spraying (DASP) and recorded a score of 3 during both the years. However, the crop in T_6 and T_7 recouped at 7th DASP and registered a score of 1 and 2, respectively during 2018 and 2019. The treatments comprised of CE *i.e.*, T_3 and T_8 exhibited brownish discolouration with white halo on leaves and leaf sheath. However, the symptom alleviated to small brown spots by seven days. Treatments involving FPE (T_6 and T_7) caused phytotoxic symptoms on rice in the form of white streaks on leaves.

All herbicides showed phytotoxic effect on weeds both at three and seven DASP. The scoring ranged from three to five, indicating good control to complete control. Application of FPE caused phytotoxic symptoms on weeds in the form of purple blotches on leaves and the growing portion of the grass weeds.

4.3.2.2 Height of plants at 30, 60 DAS and at harvest

Data regarding the influence of various weed management practices on plant height at 30 DAS, 60 DAS and at harvest were analysed statistically and are given in Table 47. At 30 DAS, the plant height was not statistically influenced by weed management practices during both the years and the average plant height ranged from 43.0 to 53.0 cm and 49.36 to 57.43 cm, respectively during 2018 and 2019.

Critical appraisal of data at 60 DAS indicated that BS @ 0.025 kg ha^{-1} (T_4) recorded the maximum plant height of 87.33 and 86.18 cm, respectively during 2018 and 2019 and was statistically on par with CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3), HW twice at 20 and 45 DAS (T_{10}), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and SSB *fb* chemical weeding (T_8) during 2018. Unweeded control recorded significantly lower plant height of 69.00 and 62.05 cm, respectively during 2018 and 2019. All other treatments were found to be statistically comparable with each other and were significantly superior to unweeded control during 2019 at 60 DAS.

At harvest, considerable difference in plant height was observed in response to weed management practices during both the years. During 2018, T_4 recorded the maximum plant height with mean value of 100.16 cm and was found be statistically on par with T_3, T_6, T_8, T_2, T_7, T_{10} and T_5, correspondingly recorded 99.33, 98.33, 97.33, 96.77, 96.77, 95.54 and 92.79 cm. During 2019, T_8 recorded the maximum plant height of 104.88 cm and was found to be on par with T_5, T_2, T_6 and T_3 with 104.44, 102.77, 102.44 and 101.60 cm. The shortest plant was observed in unweeded control (T_9) with 86.66 and 88.91 cm in 2018 and 2019.

4.3.2.3 Number of tillers m^{-2}

Tillering capacity reflects the ability of the plant to make use of space, light and nutrition effectively and it finally contributes to yield. The data regarding number of tillers m^{-2} at harvest during both years are depicted in Table 47.

At harvest, the highest number of tillers m^{-2} (336.00) was recorded in BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) during 2018, which was statistically on par with BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), BS @ 0.025 kg ha^{-1} (T_4) and HW twice at 20 and 45 DAS (T_{10}). Unweeded control (T_9) recorded the lowest number of tillers (202.66 m^{-2}) during 2018 followed by CB @ 0.08 kg ha^{-1} (T_1), CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) and FPE @ 0.06 kg ha^{-1} (T_7) with average tiller number of 249.33, 285.33 and 289.33 m^{-2}, respectively.

Tiller production was the highest in the treatment T_6 during 2019 (336.00 m^{-2}) and was found to be statistically comparable with T_5, T_{10}, T_2, T_8 and T_4, congruently recorded 330.66, 330.66, 328.0, 322.66 and 321.33 tillers m^{-2}. Unweeded control (T_9) recorded the lowest number of tillers (197.33 m^{-2}) during 2019 followed by T_1 (265.33 m^{-2}) and T_7 (270.66 m^{-2}).

Among the herbicide combination treatments (T_2, T_3, T_5, T_6 and T_8), T_3 recorded significantly lower tiller number m^{-2} of 285.33 and 302.66, respectively during 2018 and 2019, and was statistically comparable with T_7 during 2018. T_4 recorded statistically comparable tiller number with herbicide combination treatments during both the years.

4.3.2.4 Number of panicles m^{-2}

The effect of various treatments on number of panicles (productive tillers) m^{-2} is presented in Table 48.

The highest number of panicles m^{-2} of 304.00 was recorded in HW twice at 20 and 45 DAS (T_{10}) and PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) during 2018 and registered an average of 307.6 and 306.6 panicles m^{-2}, respectively during 2019. This was statistically comparable with BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), SSB *fb* chemical weeding (T_8), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5), BS @ 0.025 kg ha^{-1} (T_4) and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) with average number of 301.33, 274.66, 272.0, 264.0 and 254.66 panicles m^{-2}, respectively during 2018. T_6 and T_5 with 304 and 276 panicles m^{-2} were statistically comparable to T_{10} and T_2 during 2019.

Panicle count was the least in unweeded control during both years (100.00 and 104.00 m^{-2} respectively), followed by CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) during both years. Among the tank mix treatments (T_3, T_5, T_6 and T_8), CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) recorded the lowest number of panicles m^{-2} during 2019, while its combination with SSB *fb* chemical weeding (T_8) was statistically on par with all other treatments including herbicide combinations.

Table 46. Visual symptoms of phytotoxicity on 4th and 7th day after spraying

Treatments		2018				2019			
		4th DASP		7th DASP		4th DASP		7th DASP	
		Score on crop	Score on weeds	Score on crop	Score on weeds	Score on crop	Score on weeds	Score on crop	Score on weeds
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	0	3	0	3	0	3	0	3
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0	4	1	4	0	4	0	4
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	3	3	3	3	3	3	3	3
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	0	4	0	4	0	3	0	4
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0	4	0	5	0	5	0	5
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3	5	1	5	3	4	1	5
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3	4	2	3	3	4	2	3
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP+T_3	3	4	3	3	3	3	3	3
T_9	unweeded control	0	0	0	0	0	0	0	0
T_{10}	hand weeding twice at 20 and 45 DAS	0	0	0	0	0	0	0	0

DASP - Days after spraying; DALP - Days after land preparation; DAS - Days after sowing

Table 47. Effect of weed management practices on plant height and number of tillers m^{-2}

Treatments		Plant height (cm)						No. of tillers m^{-2}	
		2018			2019			2018	2019
		30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest		
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	47.46	78.83	90.99	55.83	83.11	98.66	249.33	265.33
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	44.99	81.66	96.77	54.83	82.88	102.77	316.00	328.00
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	48.33	87.00	99.33	53.31	81.41	101.60	285.33	302.66
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	44.73	87.33	100.16	52.88	86.18	100.00	314.66	321.33
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	47.20	82.33	92.79	55.80	85.38	104.44	336.00	330.66
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	44.19	81.66	98.33	53.14	83.76	102.44	318.66	336.00
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	44.66	79.99	96.77	57.43	80.50	95.22	289.33	270.66
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	43.00	83.66	97.33	49.36	82.21	104.88	302.66	322.66
T_9	unweeded control	53.00	69.00	86.66	52.85	62.05	88.91	202.66	197.33
T_{10}	hand weeding twice at 20 and 45 DAS	50.60	85.33	95.54	55.56	82.16	99.11	313.33	330.66
SEm±		0.79	1.04	1.00	0.55	1.35	0.91	7.27	8.07
CD (0.05)		-	5.434	7.615	-	7.061	3.876	23.520	24.632

DAS - Days after sowing; DALP - Days after land preparation

4.3.2.5 Number of grains per panicle

The data on influence of weed management practices on number of grains per panicle were statistically analysed and presented in Table 48. The number of grains per panicle ranged from 96.33 to 133.33 during 2018 and 106.00 to 176.00 during 2019.

The highest number of 133.66 grains per panicle was recorded in PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) during 2018 and was found to be statistically comparable with HW twice at 20 and 45 DAS (T_{10}), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5), BS @ 0.025 kg ha^{-1} (T_4) and SSB *fb* chemical weeding (T_8) with 133.33, 132.66, 131.66, 120.66 and 116.33 grains per panicle, respectively.

During 2019, the highest number of grains per panicle of 176.00 was noted in T_6 and was comparable with T_{10}, T_5, T_4, T_2 and $T_{3,}$ correspondingly recorded 170.33, 170.0, 167.66, 162.66 and 161.0 grains per panicle. Unweeded control plot (T_9) registered 96.33 and 106.00 grains per panicle, respectively during 2018 and 2019, recorded the lowest number of grains per panicle during both years.

. *4.3.2.6 Percentage of filled grains*

The data on percentage of filled grains was statistically evaluated and are presented in Table 48.

The percentage of filled grains ranged from 44.24 to 71.73 during 2018 and 53.42 to 79.14 during 2019. Hand weeding twice at 20 and 45 DAS (T_{10}) recorded the highest percentage of filled grains, 71.73 and 79.14, respectively during 2018 and 2019. BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), penoxsulam + CB (6% OD) @ 0.15 kg ha^{-1} (T_2), SSB *fb* chemical weeding (T_8), BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) and BS @ 0.025 kg ha^{-1} (T_4) were on par with T_{10} during both the years with 71.66, 68.22, 66.43, 63.07 and 61.08 per cent and 76.11, 77.83, 67.68, 72.62 and 69.43 per cent, respectively during 2018 and 2019.

Unweeded control (T_9) recorded the lowest filled grain percentage of 44.24 and 53.42, respectively during 2018 and 2019 and was statistically on par with CB @ 0.08 kg ha^{-1} (T_1) with 52.87 and 60.16 per cent, respectively during 2018 and 2019. CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) and FPE @ 0.06 kg ha^{-1} (T_7) with 64.23 and 65.04 per cent were also statistically comparable to T_1 and T_3 during 2019.

4.3.2.7 Thousand grain weight

The influence of weed management practices on thousand grain weight is shown in Table 48. There was no significant difference among treatments with respect to thousand grain weight (test weight) of seeds during both years and ranged from 22.2 to 24.5 during 2018 and 22.3 to 25.6 during 2019.

4.3.2.8 Grain yield

Perusal of the data on influence of weed management practices on grain yield during 2018 and 2019 were statistically evaluated and furnished in Table 49. Grain yield was significantly influenced by weed management treatments during both the years. All the tested herbicides and its combinations (T_1 to T_8) improved the grain yield compared to unweeded control during both the years.

Hand weeding twice at 20 and 45 DAS (T_{10}) recorded the highest grain yield of 4.93 and 5.47 t ha^{-1}, respectively during 2018 and 2019. BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) were found to be on par with T_{10} during both the years with a grain yield of 4.76, 4.55 and 4.37 t ha^{-1} and 5.30, 5.03 and 5.14 t ha^{-1}, respectively during 2018 and 2019. SSB *fb* chemical weeding (T_8) with 4.74 t ha^{-1} was also statistically comparable with T_{10}, T_6, T_5 and T_2 during 2019. Among the herbicidal treatments (T_1 to T_8), the lowest grain yield of 3.20 and 2.17 t ha^{-1} was obtained in FPE @ 0.06 kg ha^{-1} (T_7) and CB @ 0.08 kg ha^{-1} (T_1), respectively during 2018 and 2019. Grain yield reported in unweeded control was 2.13 and 2.01 t ha^{-1}, respectively during 2018 and 2019. However, the yield in T_9 was ststistically comparable with T_1 during 2019 with 2.17 t ha^{-1}.

Table 48. Effect of weed management practices on yield components

Treatments		No. of panicles m^{-2}		No. of grains per panicle		Percentage of filled grains		Thousand grain weight (g)	
		2018	2019	2018	2019	2018	2019	2018	2019
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	224.00	210.66	114.00	139.00	52.87	60.16	24.3	24.0
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	304.00	306.66	133.66	162.66	68.22	77.83	24.5	24.5
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	254.66	240.00	111.66	161.00	58.35	64.23	24.1	22.8
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	264.00	258.66	120.66	167.66	61.08	69.43	24.5	22.5
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	272.00	276.00	131.66	170.00	63.07	72.60	23.9	22.3
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	301.33	304.00	132.66	176.00	71.66	76.11	22.2	24.0
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	213.33	228.00	114.00	151.33	57.90	65.04	23.8	25.6
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	274.66	258.66	116.33	145.00	66.43	67.68	23.6	24.3
T_9	unweeded control	100.00	104.00	96.33	106.00	44.24	53.42	22.9	23.0
T_{10}	hand weeding twice at 20 and 45 DAS	304.00	307.60	133.33	170.33	71.73	79.14	23.5	23.3
SEm±		12.05	11.47	2.75	4.23	1.95	1.80	0.25	0.30
CD (0.05)		58.161	46.600	17.941	22.463	13.308	12.389	-	-

DALP - Days after land preparation; DAS - Days after sowing

The data on grain yield obtained during 2018 and 2019 were pooled, evaluated statistically and the data is presented in Table 49. Weed management practices had significant influence on pooled grain yield and T_{10} recorded the highest grain yield of 5.20 t ha^{-1}, which was on par with the grain yield registered in the herbicide combination treatments T_6, T_2 and T_5, recorded 5.03, 4.79 and 4.76 t ha^{-1}, respectively. Among the herbicide combination treatments (T_2, T_3, T_5, T_6 and T_8), the lowest pooled grain yield of 3.95 t ha^{-1} was obtained in T_3. T_9 recorded the lowest pooled grain yield of 2.07 t ha^{-1}.

4.3.2.9 Straw yield

Data on straw yield of 2018 and 2019 and the pooled mean as influenced weed management practices were statistically analysed and furnished in Table 49. Straw yield was significantly influenced by weed management practices during both the years. All the tested herbicides and the herbicide combinations were observed to improved the straw yield compared to unweeded control during both the years.

During 2018, straw yield followed the same trend as of grain yield. The highest straw yield of 6.84 t ha^{-1} was recorded in HW twice at 20 and 45 DAS (T_{10}) which was found to be statistically on par with BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) with a straw yield of 6.12 and 6.06 t ha^{-1}. Tank mix application of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (T_3) recorded comparatively lower straw yield (4.99 t ha^{-1}) than all other treatments with herbicide combinations (T_2, T_3, T_5, T_6 and T_8). Amongst the herbicidal treatments applied, CB @ 0.08 kg ha^{-1} (T_1) registered the lowest straw yield of 4.51 t ha^{-1} and was statistically on par with and FPE @ 0.06 kg ha^{-1} (T_7) and unweeded control (T_9), recorded 4.52 and 3.88 t ha^{-1}, respectively.

During 2019, the highest straw yield of 6.79 t ha^{-1} was obtained in T_{10} as in 2018. The treatments T_6, T_2 and T_5 were found to be statistically on par with T_{10}, correspondingly recorded 6.37, 6.27 and 6.09 t ha^{-1}. The lowest straw yield of 3.58 t ha^{-1} among the herbicidal treatments (T_1 to T_8) was obtained in T_1, which was on par with T_9 and T_7, respectively recorded 3.42 and 4.30 t ha^{-1}.

Among the various weed management practices adopted, T_{10} recorded significantly higher pooled straw yield of 6.82 t ha^{-1}. Application of T_6 resulted in the highest pooled straw yield of 6.25 t ha^{-1} among the herbicidal treatments (T_1 to T_8) and was found to be on par with T_2 and T_5 with 6.18 and 6.00 t ha^{-1}, respectively. Among the herbicidal treatments, the lowest pooled straw yield was obtained in T_1 (4.06 t ha^{-1}), which was statistically on par with T_9 and T_7 with 3.66 and 4.41 t ha^{-1}, respectively.

4.3.2.10 Total dry matter production

The data on effect of weed management practices on total dry matter production (DMP) in WSR at harvest is represented in Table 50.

Analysis of data revealed that HW twice at 20 and 45 DAS (T_{10}) recorded the highest DMP of 9465.76 and 10,156.60 kg ha^{-1}, respectively during 2018 and 2019. Herbicide combination treatments BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) were on par to T_{10} during both the years with 8736.79, 8578.88 and 8304.21 kg ha^{-1} and 9573.33, 8920.33, and 9177.66 kg ha^{-1}, respectively during 2018 and 2019. Among the various weed management practices tried, CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) resulted in lower DMP of 4429.46 and 4582.54 kg ha^{-1} and 4083.13 and 5082.86 kg ha^{-1}, respectively during 2018 and 2019.

Perusal of the data on pooled DMP also showed that T_{10} recoreded the highest DMP (9811.183 kg ha^{-1}) and was found to be on par to T_6, T_2 and T_5 with 9155.06, 8749.60 and 8740.94 kg ha^{-1}, respectively. Unweeded control (T_9) recorded the lowest total DMP (3547.53 kg ha^{-1}), which was on par with $T_{1,}$ recorded 4256.30 kg ha^{-1}.

4.3.2.11 Harvest index

From the data obtained for grain and straw yield, harvest index (HI) was calculated separately for 2018 and 2019, analysed statistically and presented along with the pooled data in Table 50.

Table 49. Effect of weed management practices on grain yield and straw yield, t ha^{-1}

Treatments		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Pooled yield (t ha^{-1})	
		2018	2019	2018	2019	Grain	Straw
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	3.26	2.17	4.51	3.58	2.72	4.06
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	4.55	5.03	6.06	6.27	4.79	6.18
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	3.68	4.20	4.99	5.65	3.95	5.33
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	3.76	4.19	5.64	5.26	3.98	5.45
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	4.37	5.14	5.92	6.09	4.76	6.00
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	4.76	5.30	6.12	6.37	5.03	6.25
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.20	3.12	4.52	4.30	3.16	4.41
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	4.02	4.74	5.52	5.89	4.38	5.72
T_9	unweeded control	2.13	2.01	3.88	3.42	2.07	3.66
T_{10}	hand weeding twice at 20 and 45 DAS	4.93	5.47	6.84	6.79	5.20	6.82
SEm±		0.17	0.23	0.17	0.22	0.19	0.18
CD (0.05)		0.881	0.911	0.843	0.755	0.700	0.533

DALP - Days after land preparation; DAS - Days after sowing

Table 50. Effect of weed management practices on total dry matter production and harvest index

Treatments		Total DMP ($kg\ ha^{-1}$) 2018	Total DMP ($kg\ ha^{-1}$) 2019	Pooled DMP ($kg\ ha^{-1}$)	Harvest Index 2018	Harvest Index 2019	Pooled Harvest Index
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	4429.46	4083.13	4256.30	0.42	0.38	0.39
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	8578.88	8920.33	8749.60	0.42	0.44	0.44
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	6431.40	7516.33	6973.86	0.41	0.43	0.42
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	7012.28	7277.13	7144.71	0.40	0.44	0.43
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	8304.21	9177.66	8740.94	0.43	0.45	0.45
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	8736.79	9573.33	9155.06	0.43	0.45	0.44
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	4582.54	5082.86	4832.70	0.42	0.42	0.42
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	7192.73	7866.46	7529.60	0.43	0.45	0.44
T_9	unweeded control	3513.13	3581.93	3547.53	0.36	0.37	0.37
T_{10}	hand weeding twice at 20 and 45 DAS	9465.76	10156.00	9811.18	0.41	0.45	0.43
SEm±		384.18	425.54	397.43	0.004	0.001	0.002
CD (0.05)		1436.983	1318.226	1144.330	0.036	0.046	0.037

DMP - Dry matter production; DALP - Days after land preparation; DAS - Days after sowing

Weed management practices had significant influence on HI under wet seeded condition during both the years. The highest HI of 0.43 was recorded in BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5), BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and SSB *fb* chemical weeding (T_8) during 2018 and was statistically similar with all other treatments except unweeded control (T_9), recorded the lowest HI of 0.35. During 2019, the treatments T_5, T_6, T_8 and T_{10} registered the highest HI of 0.45 and was statistically on par with all other treatments except T_1 and T_9. A lower HI of 0.37 and 0.38, respectively was obtained in T_9 and T_1.

The data on pooled HI indicated that the treatment T_5 registered the highest HI of 0.45. However, the treatment was found to be on par with all other treatments except T_9 and T_1, which recorded the lowest HI of 0.37 and 0.39, respectively.

4.3.2.12 NPK uptake by the crop at harvest

The data on nutrient uptake by crop at harvest during both years are presented in Tables 51 to 53.

4.3.2.12.1 Nitrogen uptake

The data regarding the nitrogen (N) uptake by grain and straw and total nitrogen uptake by the crop at harvest are depicted in Table 51. Weed management treatments had significant influence on the N uptake by grains at harvest. The N uptake by grains ranged from 26.81 to 96.01 kg ha^{-1} during 2018 and 20.09 to 92.74 kg ha^{-1} during 2019.

Critical analysis of data regarding N uptake by grains revealed that HW twice at 20 and 45 DAS (T_{10}) recorded the highest uptake during both the years with 96.01 and 92.74 kg ha^{-1}, respectively during 2018 and 2019. However, the herbicide combinations BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) were on par with T_{10} during 2018 and recorded 81.55, 77.46 and 76.20 kg ha^{-1}, respectively. T6 with 79.35 kg ha^{-1} was found to be on par to T_{10} during 2019 also.

Among the herbicidal treatments (T_1 to T_8), CB @ 0.08 kg ha^{-1} (T_1) recorded the lowest N uptake by grains during both the years, recorded 44.52 and 32.41 kg ha^{-1}, respectively during 2018 and 2019 and was found to be on par with unweeded control with 26.81 and 20.09 kg ha^{-1}, respectively.

The N uptake by straw ranged from 23.77 to 66.67 kg ha^{-1} during 2018 and 14.12 to 71.87 kg ha^{-1} during 2019. T_{10} recorded the highest uptake during both the years (66.67 and 71.87 kg ha^{-1}, respectively during 2018 and 2019) and was found to be on par with T_6, T_2 and T_5, recorded 65.98, 63.28 and 60.48 kg ha^{-1}, respectively during 2018. Application of T_1 and T_7 recorded lower N uptake by straw, registered 25.70 and 32.79 kg ha^{-1} and 17.80 and 18.77 kg ha^{-1}, respectively during 2018 and 2019, which were statistically on par with T_9 during both years, recorded 23.77 and 14.12 kg ha^{-1}, respectively.

Weed management treatments did have a significant influence on the total N uptake by crop at harvest. In the case of total N uptake, T_{10} recorded the highest uptake of 162.68 and 164.62 kg ha^{-1} respectively during 2018 and 2019, which was on par with $T_{6,}$ T_2 and T_5 during 2018, recorded 147.54, 140.74 and 136.68 kg ha^{-1}. Unweeded control (T_9) recorded the lowest total N uptake during both years (50.58 and 34.21 kg ha^{-1}, respectively) and was found to be statistically on par with T_1 during both 2018 and 2019, recorded 70.22 and 50.21 kg ha^{-1}, respectively.

4.3.2.12.2 Phosphorus uptake

The data pertaining phosphorus (P) uptake by grain and straw and total phosphorus uptake are presented in Table 52. P uptake was significantly influenced by weed management treatments at harvest during 2018 and 2019. Phosphorus uptake by grains ranged from 2.90 to 8.97 kg ha^{-1} during 2018 and 2.38 to 9.50 kg ha^{-1} during 2019.

Critical analysis of data regarding P uptake by grains revealed that HW twice at 20 and 45 DAS (T_{10}) recorded the highest uptake during both the years (8.97 and 9.50 kg ha^{-1}, respectively). This was found to be on par with herbicide combination treatments BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6), PS + CB (6% OD) @ 0.15

kg ha^{-1} (T_2) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (T_5) during both the years, recorded 8.28, 7.61 and 7.10 kg ha^{-1} and 8.29, 7.42 and 8.11 kg ha^{-1}, respectively during 2018 and 2019. Among the herbicidal treatments (T_1 to T_8), CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) recorded lower P uptake by grain during both the years and was statistically comparable with unweeded control (T_9), recorded 3.61, 3.96 and 2.90 kg ha^{-1} and 2.73, 3.01 and 2.38 kg ha^{-1}, respectively during 2018 and 2019.

Phosphorus uptake by straw ranged from 1.60 to 6.36 kg ha^{-1} during 2018 and 1.08 to 6.14 kg ha^{-1} during 2019. The herbicide combination treatments T_6 and T_2 resulted in higher uptake of 5.97 and 5.55 kg ha^{-1} and 5.82 and 4.79 kg ha^{-1}, respectively during 2018 and 2019, which were statistically comparable to T_{10} (6.36 and 6.14 kg ha^{-1}, respectively) during both the years. Among the herbicidal treatments (T_1 to T_8), T_1 resulted in lower P uptake by straw of 1.93 and 2.04 kg ha^{-1}, respectively during 2018 and 2019 and was found to be statistically on par with T_9 during both years, recorded 1.60 and 1.08 kg ha^{-1}, respectively.

Weed management practices significantly improved the total P uptake by the crops at harvest during both the years compared to unweeded control. A higher uptake of P was obtained in herbicide combination treatments T_6, T_2 and T_5, recorded on par values of 14.25, 13.16 and 11.83 kg ha^{-1} and 14.11, 12.22 and 12.54 kg ha^{-1}, respectively during 2018 and 2019. These treatments were found to be statistically comparable with T_{10}, which recorded the highest total uptake of 15.33 and 15.64 kg ha^{-1}, respectively during 2018 and 2019. Application of T_1 and T_7 resulted in lower P uptake during both the years and was statistically comparable with T_9, recorded 5.55, 7.66 and 4.50 kg ha^{-1} and 4.78, 5.67 and 3.47 kg ha^{-1}, respectively during 2018 and 2019.

4.3.2.12.3 Potassium uptake

Potassium (K) uptake by rice also followed the same trend as N uptake. K uptake was expressively influenced by weed management treatments during both years.

The data on the K uptake by grains, straw and total K uptake at harvest are given in Table 53. K uptake ranged from 7.34 to 38.44 kg ha^{-1} by grains and 31.72 to 133.99 kg ha^{-1} by straw during 2018 and 6.01 to 21.85 kg ha^{-1} by grains and 31.02 to 150.41 kg ha^{-1} by straw during 2019.

At harvest, the highest K uptake of 38.44 and 21.85 kg ha^{-1} by grains was noted in HW twice at 20 and 45 DAS (T_{10}), respectively during 2018 and 2019. The herbicide combination treatments BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) and PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) were found to be statistically comparable with T_{10} during both the years and recorded 33.39 and 30.65 kg ha^{-1} and 20.24 and 18.57 kg ha^{-1}, respectively during 2018 and 2019. A lower K uptake by grains of 9.71 and 10.81 kg ha^{-1} and 9.09 and 9.22 kg ha^{-1}, respectively was recorded in CB @ 0.08 kg ha^{-1} (T_1) and FPE @ 0.06 kg ha^{-1} (T_7) during 2018 and 2019, which were statistically comparable with unweeded control (T_9), recorded 7.34 and 6.01 kg ha^{-1}, respectively.

The K uptake by straw ranged from 31.72 to 133.99 kg ha^{-1} during 2018 and 31.02 to 150.41 kg ha^{-1} during 2019. Among the herbicidal treatments (T_1 to T_8), T_6 resulted in the highest K uptake of 120.32 and 127.60 kg ha^{-1}, respectively during 2018 and 2019, which was statistically on par to T_2 and T_5 and also with T_{10}, recorded 117.31, 116.08 and 133.99 kg ha^{-1}, respectively during 2018. T_9 recorded the lowest K uptake during both the years and was statistically comparable with T_1 and T_7, recorded 31.72, 51.12 and 56.18 kg ha^{-1} and 47.53, 49.99 and 31.02 kg ha^{-1}, respectively during 2018 and 2019.

Weed management treatments significantly enhanced the total K uptake by the crops during both the years. T_{10} recorded the highest uptake of 172.44 and 172.26 kg ha^{-1}, respectively during 2018 and 2019. This was on par with T_6, T_2 and T_5, recorded 153.52, 147.97 and 142.42 kg ha^{-1}, respectively during 2018. The lowest K uptake was recorded in T_9 during both years and was on par to the herbicidal treatments (T_1 to T_8) T_1 and T_7 during both years, recorded 60.84 and 67.00 kg ha^{-1} and 56.62 and 59.21 kg ha^{-1}, respectively during 2018 and 2019. Among tank mix applications (T_3, T_5, T_6 and T_8), T_3 recorde lower K uptake with 90.51 and 108.60 kg ha^{-1}, respectively during 2018 and 2019.

Table 51. Effect of weed management practices on nitrogen uptake at harvest, kg ha^{-1}

Treatments		N uptake					
		2018			2019		
		Grains	Straw	Total	Grains	Straw	Total
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	44.52	25.70	70.22	32.41	17.80	50.21
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	77.46	63.28	140.74	65.05	44.70	109.75
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	61.77	45.44	107.22	52.45	29.88	82.33
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	66.62	47.01	113.64	44.27	24.62	68.89
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	76.20	60.48	136.68	69.45	41.72	111.17
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	81.55	65.98	147.54	79.35	57.96	137.31
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	48.65	32.79	81.44	42.57	18.77	61.34
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	67.48	47.38	114.88	54.40	32.43	86.84
T_9	unweeded control	26.81	23.77	50.58	20.09	14.12	34.21
T_{10}	hand weeding twice at 20 and 45 DAS	96.01	66.67	162.68	92.74	71.87	164.62
SEm±-		3.99	3.26	11.42	4.01	3.51	7.27
CD (0.05)		21.331	16.960	29.393	17.388	13.898	25.269

DALP - Days after land preparation; DAS - Days after sowing

Table 52. Effect of weed management practices on phosphorus uptake at harvest, kg ha^{-1}

Treatments		P uptake					
		2018			2019		
		Grains	Straw	Total	Grains	Straw	Total
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	3.61	1.93	5.55	2.73	2.04	4.78
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	7.61	5.55	13.16	7.42	4.79	12.22
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	5.48	3.96	9.44	5.62	3.53	9.16
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	5.52	4.08	9.61	5.00	3.04	8.04
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	7.10	4.73	11.83	8.11	4.42	12.54
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	8.28	5.97	14.25	8.29	5.82	14.11
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	3.96	3.70	7.66	3.01	2.65	5.67
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	5.96	4.29	10.25	6.05	3.74	9.79
T_9	unweeded control	2.90	1.60	4.50	2.38	1.08	3.47
T_{10}	hand weeding twice at 20 and 45 DAS	8.97	6.36	15.33	9.50	6.14	15.64
SEm±		0.64	0.49	1.13	0.79	0.50	0.81
CD (0.05)		2.238	1.817	3.639	3.517	1.493	3.987

DALP - Days after land preparation; DAS - Days after sowing

Table 53. Effect of weed management practices on potassium uptake at harvest, kg ha^{-1}

Treatments		K uptake					
		2018			2019		
		Grains	Straw	Total	Grains	Straw	Total
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	9.71	51.12	60.84	9.09	47.53	56.62
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	30.65	117.31	147.97	18.57	120.91	139.48
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	20.75	69.76	90.51	13.97	94.63	108.60
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	22.67	87.76	110.43	13.24	93.96	107.22
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	26.34	116.08	142.42	19.46	118.58	138.04
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	33.39	120.32	153.52	20.24	127.60	147.84
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	10.81	56.18	67.00	9.22	49.99	59.21
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15 - 20 DALP + T_3	25.77	92.33	118.10	17.95	93.07	110.76
T_9	unweeded control	7.34	31.72	39.07	6.01	31.02	37.04
T_{10}	hand weeding twice at 20 and 45 DAS	38.44	133.99	172.44	21.85	150.41	172.26
SEm±		4.00	6.49	8.39	1.01	7.17	9.91
CD (0.05)		11.899	26.722	34.020	3.926	24.383	29.463

DALP - Days after land preparation; DAS - Days after sowing

4.3.2.13 Economics of cultivation

The influence of weed management practices on the economics (benefit: cost ratio) of WSR cultivation was computed and the results obtained during 2018 and 2019 are presented in Table 54. From the results, it was evident that weed management practices had a significant influence on the benefit: cost ratio (B: C ratio) of WSR cultivation during both the years.

In the present study, the highest gross returns of ₹ 1,39,956 and 1,54,486 ha^{-1} were obtained in HW twice at 20 and 45 DAS (T_{10}), respectively during 2018 and 2019. Among the herbicidal treatments, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} recorded the highest gross returns of ₹ 1,34,640 and 1,49,471 ha^{-1}, respectively during 2018 and 2019 followed by PS + CB (6% OD) @ 0.15 kg ha^{-1} (₹ 1,28,910 and 1,42,080 ha^{-1}) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (₹ 1,23,913 and 1,44,870 ha^{-1}). However, the treatment BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) recorded the highest net income of ₹ 56,241 and 71,072 ha^{-1} and B: C ratio of 1.72 and 1.91, respectively during 2018 and 2019 followed by PS + CB (6% OD) @ 0.15 kg ha^{-1} with net income of ₹ 50,410 and 63,580 ha^{-1} and B: C ratio of 1.64 and 1.81, respectively. HW twice at 20 and 45 DAS (T_{10}) grasped a B: C ratio of 1.13 and 1.25, respectively during 2018 and 2019.

The pooled data revealed that the tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) registered maximum net returns per hectare (₹ 63,657 ha^{-1}) and B:C ratio (1.81) followed by ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) (₹ 56,995 ha^{-1} and 1.73).

Table 54. Effect of weed management practices on economics of cultivation

Treatments		Cost of cultivation (Rs ha^{-1})	2018			2019			Pooled Net returns (₹ ha^{-1})	Pooled BCR
			Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	BCR	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	BCR		
T_1	cyhalofop butyl @ 0.08 kg ha^{-1}	76491	92533	16041	1.21	62179	-14312	0.81	864	1.01
T_2	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	78500	128910	50410	1.64	14208	63580	1.81	56995	1.73
T_3	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	77000	104356	27355	1.36	119053	42052	1.55	34704	1.45
T_4	bispyribac sodium @ 0.025 kg ha^{-1}	76856	107160	30303	1.39	118396	41539	1.54	35921	1.47
T_5	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	78347	123913	45565	1.58	144870	66522	1.85	56044	1.72
T_6	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	78398	134640	56241	1.72	149471	71072	1.91	63657	1.81
T_7	fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	76542	90926	14383	1.19	88546	12003	1.16	13193	1.17
T_8	stale seedbed *fb* glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 DALP + T_3	85577	114063	28485	1.33	133876	48298	1.56	38391	1.45
T_9	unweeded control	75000	61393	-13607	0.82	57696	-17304	0.77	-15455	0.79
T_{10}	hand weeding twice at 20 and 45 DAS	123000	139956	16956	1.13	154486	31486	1.25	24221	1.19

BCR - Benefic cost ratio; DALP - Days after land preparation; DAS - Days after sowing

4.4 SENSITIVITY OF WEED TO HERBICIDE COMBINATIONS USING WHOLE PLANT BIOASSAY TECHNIQUE

The sensitivity of *L. chinensis* to herbicide combinations was tested at their lower doses using whole plant bioassay technique after identifying the most effective and economic combinations from the third experiment. The best combinations identified were BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1}, PS + CB @ 0.15 kg ha^{-1} and CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1}. For a comparison, effect of field recommended doses (FRD) were also included. The results of the experiment are presented below.

4.4.1 Survival rate

The data regarding the effect of herbicide combinations on survival rate of *L. chinensis* is documented in Table 55. All the tested herbicide combinations, *i.e.*, BS + FPE, BS + CB, PS + CB (6% OD) and CE + CE at FRD *i.e.*, T_1, T_3, T_5 and T_7 recorded the least survival (0%) of *L. chinensis.*

The lower dose of BS + FPE @ 0.020 + 0.04 kg ha^{-1} (T_2) recorded the least survival (0%) of *L. chinensis* whereas, BS + CB @ 0.020 + 0.06 kg ha^{-1} (T_4), CB + CE @ 0.06 + 0.01 kg ha^{-1} (T_8) and PS + CB @ 0.10 kg ha^{-1} (T_6) registered 26.66, 30.0 and 86.66 per cent survival, respectively.

4.4.2 Dry weight

The results pertaining to the effect of herbicide combinations on dry weight of *L. chinensis* are documented in Table 55. The dry weight of plants was found to increase with decrease in concentration of all the herbicide combinations. Application of BS @ 0.020 kg ha^{-1} + FPE @ 0.04 kg ha^{-1} (T_2) registered the lowest dry weight of *L. chinensis* (0.031 g $plant^{-1}$) and was significantly effective among the lower doses tested. The highest weed dry weight (0.097 g $plant^{-1}$) was recorded in PS + CB (6% OD) @ 0.10 kg ha^{-1} (T_6).

4.4.3 Phytotoxicity scoring

Phytotoxicity scoring of herbicide combinations on *L. chinensis* was also carried out under the experiment and the data are furnished in Table 56. All the herbicide combinations showed phytotoxic effect on *L. chinensis* at FRD (T_1, T_3, T_5 and T_7) and recorded a score of five, both at four and seven days after spraying (DASP). Among the lower dose of combinations tested, BS @ 0.020 kg ha^{-1} + FPE @ 0.04 kg ha^{-1} (T_2) recorded a score of five and completely killed the plants by the 4^{th} DASP. Application of BS @ 0.020 kg ha^{-1} + CB @ 0.06 kg ha^{-1} (T_4) and CB @ 0.06 kg ha^{-1} + CE @ 0.01 kg ha^{-1} (T_8) registered a score of three and four at 4^{th} and 7^{th} DASP, respectively. The combination of PS + CB (6% OD) @ 0.10 kg ha^{-1} (T_6) showed no toxicity symptoms on 4^{th} DASP and marked a score of only one at 7^{th} DASP.

4.5 ASSESSMENT OF MODE OF ACTION OF TANK MIX HERBICIDE COMBINATIONS

The mode of action of tank mix herbicide combination on *L. chinensis* was assessed by conducting amino acid and fatty acid assay and the data pertaining to the study are represented in Table 57.

4.5.1 Amino acid content

The amino acid content in *L. chinensis* was found to be the highest (0.2904 mg mL^{-1}) in T_1 *i.e.*, BS @ 0.025 kg ha^{-1}. However, application of herbicide combination BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_3) resulted in lower amino acid content (0.1775 mg mL^{-1}) in *L. chinensis* compared to T_1.

4.5.2 Fatty acid content

The results showed that application of FPE @ 0.06 kg ha^{-1} (T_2) resulted in the lowest fatty acid content in *L. chinensis* (127.36 mg dL^{-1}). A higher fatty acid content of 132.33 mg dL^{-1} was observed in the treatment BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_3) compared to T_2. Application of BS @ 0.025 kg ha^{-1} (T_1) registered the highest fatty acid content of 193.65 mg dL^{-1} in *L. chinensis* among the treatments.

Table 55. Effect of herbicide combinations on survival rate and dry weight of *Leptochloa chinensis*

Treatments		Survival rate* (%)	Dry weight (g per plant)
T_1	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	0.90 (0.00)	0.028
T_2	bispyribac sodium @ 0.020 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.04 kg ha^{-1}	0.90 (0.00)	0.031
T_3	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	0.90 (0.00)	0.031
T_4	bispyribac sodium @ 0.020 kg ha^{-1} + cyhalofop butyl @ 0.06 kg ha^{-1}	30.99 (26.66)	0.053
T_5	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	0.90 (0.00)	0.030
T_6	penoxsulam + cyhalofop butyl (6% OD) @ 0.10 kg ha^{-1}	72.49 (86.66)	0.097
T_7	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	0.90 (0.00)	0.030
T_8	cyhalofop butyl @ 0.06 kg ha^{-1} + carfentrazone ethyl @ 0.01 kg ha^{-1}	33.21 (30.00)	0.089
SEm±		6.05	0.006
CD (0.05)		10.178	0.004

*Data were arc-sin transformed, actual mean values are given in parentheses.

Table 56. Phytotoxicity scoring of herbicide combinations on *Leptochloa chinensis*

Treatments		Score	
		4^{th} day after spraying	7^{th} day after spraying
T_1	bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}	5	5
T_2	bispyribac sodium @ 0.020 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.04 kg ha^{-1}	5	5
T_3	bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}	5	5
T_4	bispyribac sodium @ 0.020 kg ha^{-1} + cyhalofop butyl @ 0.06 kg ha^{-1}	3	4
T_5	penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}	5	5
T_6	penoxsulam + cyhalofop butyl (6% OD) @ 0.10 kg ha^{-1}	0	1
T_7	cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}	5	5
T_8	cyhalofop butyl @ 0.06 kg ha^{-1} + carfentrazone ethyl @ 0.01 kg ha^{-1}	3	4

Table 57. Effect of tank mix herbicide combinations on amino acid and fatty acid content of *Leptochloa chinensis*

Treatments		Amino acid content (mg mL^{-1})	Fatty acid content (mg dL^{-1})
T_1	ALS inhibitor alone (bispyribac sodium @ 0.025 kg ha^{-1})	0.2904	193.65
T_2	ACCase inhibitor alone (fenoxaprop-p-ethyl @ 0.06 kg ha^{-1})	0.1532	127.36
T_3	ALS + ACCase inhibitor (bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1})	0.1775	132.33
T_4	Control	0.2085	119.48
SEm±		0.011	0.70
CD (0.05)		0.016	2.110

4.6 ASSESSMENT OF DIFFERENTIAL RESPONSE OF GRASS WEEDS TO BISPYRIBAC SODIUM

In the experiment, the response of two grass weeds *i.e.*, *L. chinensis* and *E. colona* to varying concentrations of bispyribac sodium was investigated by estimating the amino acid content, protein content, number of proteins expressed and molecular weight of total proteins in each treatment.

4.6.1 Amino acid content

Data regarding the effect of different doses of BS on the amino acid content of *L. chinensis* and *E. colona* were furnished in Table 58. The data revealed no significant variation in amino acid content with increasing dose of the herbicide, BS (0.0125, 0.025 and 0.05 kg ha^{-1}). The highest content of amino acid (0.3440 mg mL^{-1}) was observed in *L. chinensis* at 50 per cent field recommended dose of BS (@0.0125 kg ha^{-1}). It was found to be statistically comparable with its higher doses of 100 and 200 per cent FRD with an amino acid content of 0.2904 and 0.3234 mg mL^{-1}, respectively. However, the amino acid content was found to be higher in all the bispyribac treated plants compared to control and was significantly different from non-treated control.

In *E. colona*, the amino acid content was observed to decrease with herbicide application, compared to control. Among the different doses tested, the lowest amino acid content was recorded in 200 per cent FRD (@ 0.05 kg ha^{-1}) followed by 100 per cent FRD (@ 0.025 kg ha^{-1}) and 50 per cent FRD (@ 0.0125 kg ha^{-1}) with an amino acid content of 0.0627, 0.1520 and 0.2437 mg mL^{-1} respectively. The amino acid content of *E. colona* decreased with increased concentration of BS.

Critical appraisal of the data identified higher content of amino acid in *L. chinensis* compared to *E. colona,* irrespective of the concentration of BS. The amino acid content in *E. colona* was 0.2437 mg mL^{-1} with the 50 per cent FRD (@ 0.0125 kg ha^{-1}) of BS whereas, it was 0.3440 mg mL^{-1} in *L. chinensis.* At 100 per cent FRD, the amino acid content was 0.1520 and 0.2904 mg mL^{-1} and at 200 per cent FRD, it was 0.0627 and 0.3234 mg mL^{-1} respectively in *E. colona* and *L. chinensis.*

4.6.2 Protein profiling

Data pertaining to the protein content, total number of proteins expressed and the molecular weight of total proteins obtained from SDS PAGE analysis are presented in Table 58. Differential expressions of proteins were observed in *L. chinensis* and *E. colona* with varying concentrations of BS from lower to higher concentrations. Variations in the protein content was observed in both *L. chinensis* and *E. colona* but, the protein content of *L. chinensis* was not statistically influenced by the application of BS. Statistically significant reduction was not observed in the protein content, number of proteins expressed and the molecular weight of proteins in *L. chinensis* with the application of BS from lower to higher concentration.

In *E. colona*, the protein content and molecular weight of total proteins were found to decrease with BS application compared to control. The number of proteins expressed, molecular weight of proteins and the protein content diminished with increasing concentration of BS. The lowest protein content of 0.1009 mg mL^{-1} was registered at 200 per cent FRD in *E. colona*. This was statistically comparable with 100 per cent FRD with a protein content of 0.1420 mg mL^{-1}. The highest protein content (0.4599 mg mL^{-1}) and molecular weight of total proteins (622.27 kDa) were registered in control without any herbicide application. Among various concentrations, application of BS at 50 per cent FRD recorded the highest protein content (0.2061 mg mL^{-1}) and molecular weight of total proteins (377.3 kDa) in *E. colona*. In general, higher molecular weight of total proteins was observed in *L. chinensis* compared to *E. colona* in herbicide treated plants (Plate 1 and 2).

A total of seven proteins were expressed in both *L. chinensis* and *E. colona* at 50 per cent FRD of BS. As the concentration increased from 50 to 200 per cent FRD, the total number of proteins expressed in *E. colona* was found to decrease from seven to three whereas it decreased to six at 100 per cent FRD and then increased to eight at 200 per cent FRD in the case of *L. chinensis.*

Table 58. Differential response of *Leptochloa chinensis* and *Echinochlo colona* to different doses of bispyribac sodium

Concentration	Amino acid content (mg mL^{-1})		Protein content (mg mL^{-1})		No. of proteins expressed		Molecular weight of total proteins (kDa)	
	L. chinensis	*E. colona*	*L. chinensis*	*E. colona*	*L. chinensis*	*E. colona*	*L. chinensis*	*E. colona*
bispyribac sodium @ 0.0125 kg ha^{-1} (50% *FRD)	0.3440	0.2437	0.5401	0.2061	7	7	639.86	377.3
bispyribac sodium @ 0.025 kg ha^{-1} (100% FRD)	0.2904	0.1520	0.4762	0.1420	6	4	460.76	248.82
bispyribac sodium @ 0.05 kg ha^{-1} (200% FRD)	0.3234	0.0627	0.4827	0.1009	8	3	629.06	107.84
Control (no herbicide)	0.2085	0.3604	0.5021	0.4599	8	6	610.86	622.27
SEm±	0.011	0.025	0.009	0.037	-	-	-	-
CD (0.05)	0.037	0.018	-	0.059	-	-	-	-

(*FRD – Field recommended dose)

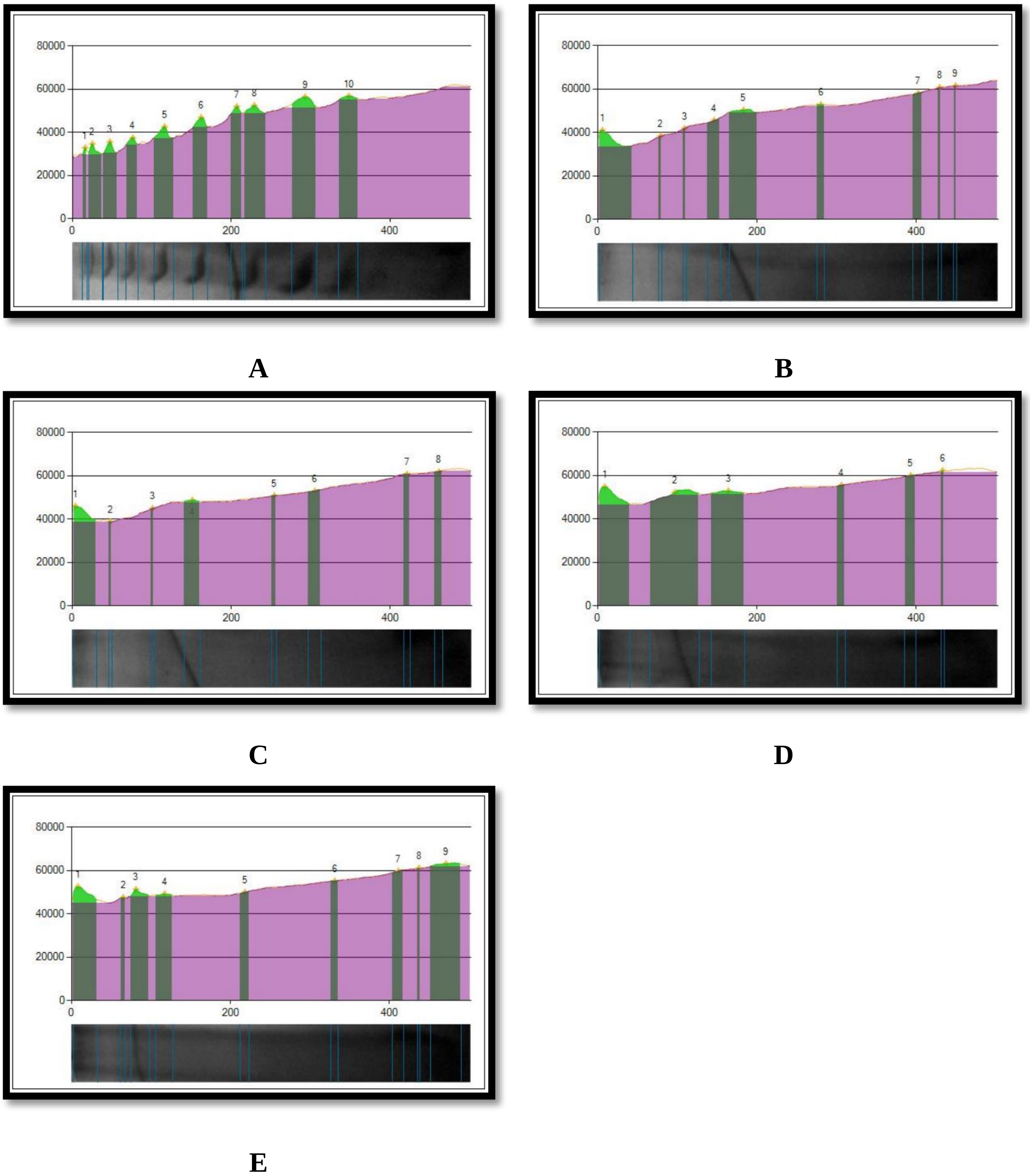
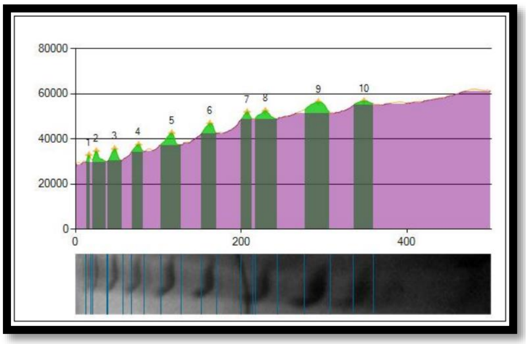
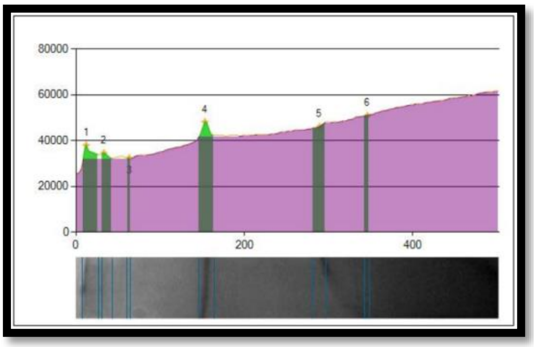


Plate 1. Protein profiling by SDS PAGE (*Leptochloa chinensis*)

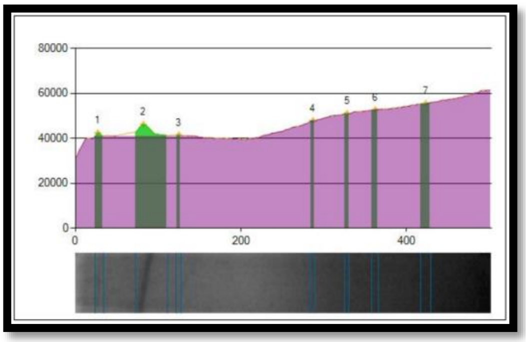
A - Marker
B - Control
C - bispyribac sodium @ 0.0125 kg ha^{-1} (50% FRD)
D - bispyribac sodium @ 0.025 kg ha^{-1} (100% FRD)
E - bispyribac sodium @ 0.05 kg ha^{-1} (200% FRD)



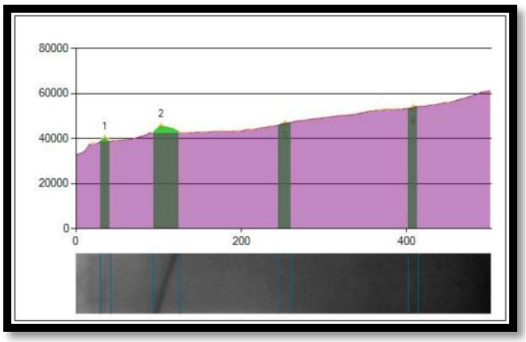
A



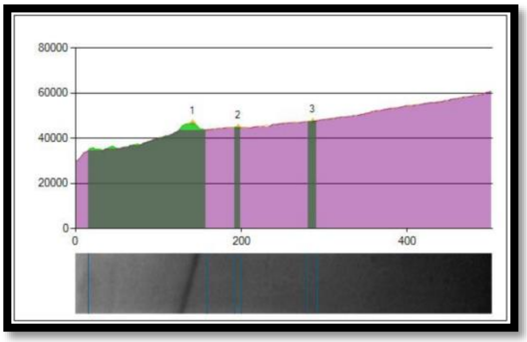
B



C



D



E

Plate 2. Protein profiling by SDS PAGE (*Echinochloa colona*)

A - Marker
B - Control
C - bispyribac sodium @ 0.0125 kg ha^{-1} (50% FRD)
D - bispyribac sodium @ 0.025 kg ha^{-1} (100% FRD)
E - bispyribac sodium @ 0.05 kg ha^{-1} (200% FRD)

Discussion

5. DISCUSSION

Weeds exist as a critical constraint in wet seeded rice (WSR) and chemical weed control could be one of the possible economic alternatives to manage the complex weed flora. However, repeated and non-judicious use of the same herbicide or herbicides having similar mode of action may lead to shift in weed flora, development of herbicide resistance and build-up of herbicide load in the environment. *Leptochloa chinensis* is one such weed which has become problematic in direct seeded rice (DSR) due to the continuous use of bispyribac sodium, a popular herbicide among the farmers for broad spectrum weed control in rice. Its continuous use to control *Echinochloa* sp. has led to the dominance of *L. chinensis* for which it was ineffective. To overcome the problem, tank mix application of compatible herbicides is a viable economic option. Studies focused on germination ecology, biology and growth requirements of the weed are essential for formulating an integrated management strategy. Hence, the present study on “Germination ecology and management of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees.] in wet seeded rice” was carried out. The results of the data obtained from the field and laboratory experiments reported in the previous chapter are discussed below with supporting literature.

5.1 PHYTOSOCIOLOGICAL SURVEY

A phytosociological survey is a group of ecological evaluation methods aimed to provide a comprehensive overview of both the composition and distribution of plant species in a given plant community (Concenco *et al*., 2013). Phytosociological surveys are valuable tools for understanding the dynamics of weed species and their interactions in agricultural fields. Differences between weed populations can influence the competitive nature of weed species and might affect their response to chemical or cultural control strategies. Weed populations which are continuously associated with specific agricultural systems might evolve phenological patterns which optimize survival within the most favourable growing areas (Barret, 1983).

Several population indices are being used as fundamental requisites to investigate the structure of each community and the relationships that exist between them. The selection of appropriate indices is essential when assessing a weed community (Travlos *et al*., 2018). Variations in crop management are likely to serve as weed community filters, removing or limiting species that lack specified features or combinations of traits (Storkey *et al*., 2010). In the study, density, frequency, abundance, relative density, relative frequency, relative abundance and summed dominance ratio of each weed species in each tract were analysed.

Density measures the number of target species per given area, while relative density articulates the numerical strength of a target species in relation to the total number of individuals of all the species encountered (Travlos *et al*., 2018). Frequency is an important variable for documenting and comparing changes in plant communities over time (Bonham, 2013). Frequency represents the presence or absence of a species, as well as the extent to which it is distributed across a community, and is generally expressed as a percentage (Booth *et al*., 2003). The degree of distribution of target species with respect to the total count of all species in the sampling unit is indicated by relative frequency. The number of individuals on the same sample plot is represented by species abundance (Kent, 2012) and is defined as the measure of the number or frequency of individuals of the same species. The Summed Dominance Ratio (SDR) reflects how well a species may expand and dominate in a given region. The higher the SDR value, the greater a species dominance (Firmansyah and Pusparani, 2019).

5.1.1. Distribution of weed flora

Kuttanad**,** the rice bowl of Kerala, basically lies 0.5 to 2.0 m below MSL and is open to continuous submergence and inundation all through the monsoon. Rice is grown in Kuttanad by pumping out water and those weeds which are tolerant of water stagnation can flourish and become the dominant ones. The survey was undertaken in the Kuttanad region from July to September, 2018, when rice was planted as a *Kharif* crop, and during November to March, 2018-19 in the *Puncha* season (late *Rabi*), as a summer crop.

In general, the population of many weeds, especially broad leaf weeds (BLWs), was less during *Kharif* compared to the *Puncha* season. This might be because of the devastating floods of 2018, which destroyed the crop at 55-60 DAS, along with the emerged weeds in the cropped field.

In the Kuttanad rice fields, a total of 13 weeds were observed during the survey (Plate 3) and of these, *Echinochloa stagnina*, *Sacciolepis interrupta* and *L. chinensis* registered higher density, frequency and abundance. The *L. chinensis* population was observed to be inhabited in both upland and lowland situations, either in cropped fields, bunds, uncultivated lands or along waterways (Plate 4). When *L. chinensis* is prevalent in water channels, it is subject to quick spread through moving water or irrigation water. Profuse growth of the weed was observed along the inner bunds separating individual fields in the polder (Plate 5). When *L. chinensis* grows on bunds, it usually remains undisturbed and could lead the plant to produce a higher number of seeds. *L. chinensis*, which was not a major weed during the 2000-2010 period in Kuttanad, has been identified as one of the major weed with higher density (12 No. m^{-2}), frequency (73.33%), abundance (16.36), relative density (15.68%), relative frequency (10.47%), relative abundance (13.0) and summed dominance ratio (13.05) in the present survey, which indicated its invasive potential (Plate 6). The dominance of *L. chinensis* could be attributed to its ability to tolerate and flourish under water stagnation and the spread of seeds produced by plants on bunds through flood water or water ways. Kathiresan (2004) opined that *L. chinensis* is an invasive alien weed in rice and its invasiveness is allied with its high seed production potential (Chin, 2001). The dominance of *E. stagnina, S. interrupta* and *L. chinensis* signified its high adaptability to waterlogged conditions. The survey conducted by Vidya (2003) pointed out that *E. stagnina* and *Sacciolepis* sp., were the major grass weeds in the *Kayal* lands of Kuttanad.

The survey revealed the predominance of grass weeds in the weed spectrum of Kuttanad (Fig. 7), together constituting SDR of 48.41 per cent. Studies conducted by Rani (2020) also observed the dominance of grass weeds in Kuttanad with SDR of 62.2.

Echinochloa stagnina

Leptochloa chinensis

Sacciolepis interrupta

Oryza sativa f. spontanea

Ludwigia hyssopifolia

Limnocharis flava

Monochoria vaginalis

Cyperus iria

Cyperus difformis

Cyperus haspan

Fimbristylis miliacea

Schoenoplectus juncoides

Salvinia molesta

Plate 3. Weed spectrum of Kuttanad tract

Cropped field

Bunds

Uplands

Stream banks

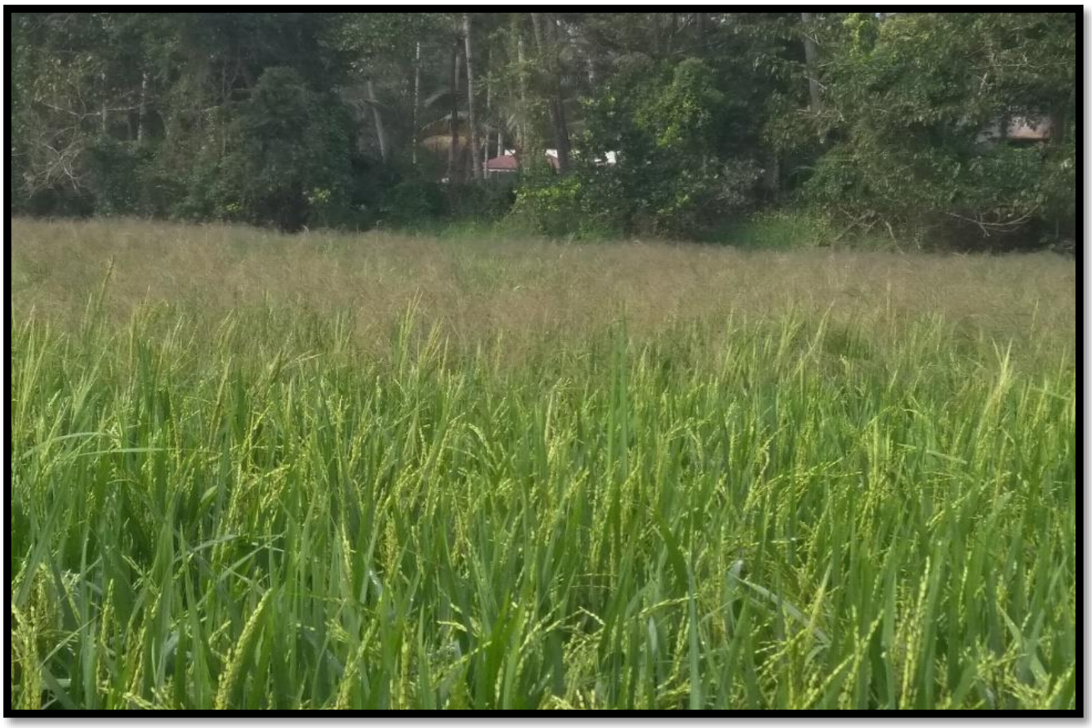
Uncultivated uplands

Irrigation channels

Plate 4. Habitat of *Leptochloa chinensis*

Plate 5. Abundance of *Leptochloa chinensis* in bunds separating field polders

A



B

Plate 6. Abundance of *Leptochloa chinensis* in rice fields
(A) Kuttanad (B) *Kole*

Sedges were the second dominant group of weeds noticed in the surveyed fields of Kuttanad, with a combined SDR of 27.99, constituting one-third population of weeds. The major sedges observed in the Kuttanad rice fields were *Cyperus difformis, Cyperus haspan, Cyperus iria, Fimbristylis miliacea* and *Schoenoplectus juncoides.* Among these, *C. difformis* was the dominant and was observed in high abundance (10.40) with SDR of 8.95. Raj *et al*. (2013) observed *F. miliacea, C. difformis, C. iria* and *Schenoplectus pungens* as the major sedges in Kuttanad.

The population of BLWs was lower in Kuttanad compared to grass weeds and sedges (Fig. 7). The BLWs observed were *Monochoria vaginalis, Limnocharis flava* and *Ludwigia hyssopifolia*. During the survey, *M. vaginalis* was seen abundantly in Kuttanad with 53.33 per cent frequency and 7.55 per cent relative abundance. The population was observed to be not affected by the floods, showing its ability to flourish under waterlogged conditions. Studies conducted by Juraimi *et al*. (2012) reported an increase in the population of *M. vaginalis* under deep flooding and the preference of *M. vaginalis* for water stagnation.

In the *Kole* region, rice is cultivated under wetland situation and two crops are taken (monsoon crop during September to December and summer crop during November to May). Those weeds that thrive under waterlogged conditions are the dominant ones in *Kole* lands, as in Kuttanad. The phytosociological survey in the *Kole* lands was done during the *Puncha* (summer) season.

Annual grass weeds dominated the weed spectrum in the *Kole* lands (Fig. 7) and *Oryza sativa f. spontanea,* being the major weed, followed by *L. chinensis, Echinochloa colona, S. interrupta* and *E. stagnina* (Plate 7). The dominance of *O. sativa f. spontanea* (SDR - 13.21) could be due to its persistent soil seed bank in the tract. It was closely followed by *L. chinensis* with SDR of 12.40 and exhibited high abundance (17.33). This indicated its high adaptability to the *Kole* ecosystem due to its ability to tolerate and flourish under water stagnation coupled with its prolific seed production and vegetative mode of reproduction.

Studies conducted by Vidya (2003) identified *E. statgnina, Echinochloa crus-galli, E. colona, S. interrupta*, *Echinochloa glabrescens* and *Oryza rufipogan* as the major grass weeds in the *Kole* lands of Kerala. As reported by Srinivasan (2012), *O. rufipogon, Ischaemum rugosum, E. crus-galli, Cynodon dactylon* and *S. interrupta* were the major grass weeds found in the *Kole* lands. During the study periods of 2003 to 2012, *L. chinensis* was not even present in the *Kole* fields. However, the current survey, which was undertaken after a period of six years, identified *L. chinensis* as the second dominant weed in the *Kole* lands, with higher values in all weed indices. The possible reason for the entry of the weed to this tract might be through the import of contaminated paddy straw carrying the remnanats of the weed with its panicle and seed from the neighbouring states. It could be inferred that, in the coming years, *L. chinensis* may become the dominant weed in the *Kole* lands, considering its abundance (Plate 6).

Monochoria vaginalis occurred in 60 per cent of the fields surveyed and was the dominant BLW with SDR of 5.12, closely followed by *Lindernia* sp. (SDR - 5.03) and *L. flava* (SDR - 4.58). This might be because of the preference of these weeds to waterlogged conditions. Moody and Drost (1983) reported that the occurrence of *M. vaginalis* is strongly related to the moisture content of the soil and it needs saturated soil for germination. *Lindernia* sp. was reported as an aquatic annual found in rice fields, river beds and other moist and muddy habitats by Swapna *et al*. (2011).

Sedges, being an important part of the weed spectrum in the *Kole* region, occurred with more frequency compared to BLws in the surveyed areas. *C. difformis* and *F. miliacea* constituted 89.55 per cent of the sedge population in the *Kole* fields, with a frequency of 73.33 per cent. As reported by Mounisha (2020), *Cyperus* spp. and *F. miliacea* were the major sedges in *Kole* lands.

Palakkad is a major rice growing belt in Kerala where, rice is grown mostly as a semi-dry crop in the *Kharif* season. It is dry sown immediately after the receipt of pre monsoon showers during May. The crop is raised as a rainfed upland crop for the first 30 to 50 days, until the field gets flooded due to the southwest monsoon, during June-July. However, it is either transplanted or wet sown in the puddled soil

Echinochloa colona

Echinochloa crus-galli

Isachne miliacea

Leptochloa chinensis

Oryza sativa f. spontanea

Sacciolepis interrupta

Echinochloa stagnina

Limnocharis flava

Ludwigia parviflora

Plate 7. Weed spectrum of *Kole* tract

Contd..

Monochoria vaginalis

Alternanthera philoxeroides

***Lindernia* sp.**

Cyperus difformis

Fimbristylis miliacea

Cyperus iria

Salvinia molesta

Cabomba furcata

in the *Rabi* season (October to January), utilizing the irrigation water. The survey was conducted during *Kharif* 2018 and 2019 (July to September) and in *Rabi* 2018-19 (December to February).

From the survey, it was evident that annual grass weeds dominated the weed spectrum of the Palakkad rice tract during *Kharif* (Fig. 7), which constituted SDR of 61.18, followed by BLWs (SDR - 22.18) and sedges (SDR - 19.91). The dominance of grass species in the *Kharif* season could be attributed to the higher seedling emergence due to the absence of water and morphological similarity to rice.

Among the grass weeds, *S. interrupta* dominated the weed spectrum of the Palakkad region during *Kharif* with SDR of 23.60. *L. chinensis* was the second most dominant weed (SDR - 17.49) in the Palakkad tract and was observed both in semi dry systems and in puddled wet sown/transplanted systems. The higher abundance, density and frequency of *L. chinensis* in the semi dry system indicated its adaptability across fluctuating soil moisture and soil temperature. The result is in conformity with the findings of Rani (2020), who reported that among the 15 weed species observed in the Palakkad tract, *S. interrupta* recorded the highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio, followed by *Leptochloa* sp. Studies conducted by Abraham *et al.* (1993) also presented *S. interrupta* as a weed typically associated with the dry sown *Kharif* rice in the Palakkad region of Kerala. The higher SDR of *S. interrupta* and *L. chinensis* could be attributed to their morphological similarities with rice crop, which allows them to escape the hand weeding practices during the initial stages.

As reported by Vidya (2003), *S. interrupta, Isachne miliacea, O. rufipogon, C. iria* and *Ludwigia parviflora* were the dominant weeds in the Palakkad tract during *Kharif* and *L. chinensis* was not a major weed, recorded low frequency (4.5%) and very low relative importance value (RIV) of 1.73. It was reported as a major weed only in the black soils of Chittoor during *Kharif* and *Rabi* seasons, with a higher plant density of more than five plants m^{-2} and a RIV of 16.8 during *Kharif* and 12.8 during *Rabi*. However, the present survey, which was conducted after a span of 15 years, showed a shift in the weed flora in the paddy fields of Palakkad during the *Kharif* season. During the present survey, *S. interrupta* remained as the most dominant grass weed however, the tract showed the dominance of *L. chinensis* over the period (Plate 8). The study revealed the dominance of *L. chinensis* from 4.5 per cent of the total area during 2003 to more than 70 per cent of the total area during 2018. This indicated the invasive potential of *L. chinensis* under wider environmental conditions existing in dry and wet systems of rice cultivation in Palakkad.

Echinochloa colona and *I. miliacea* were the other two grass weeds observed in the Palakkad tract (Plate.9). The predominance of *E. colona* clearly indicated it as a weed of upland conditions. *E. colona* preferred dry upland conditions and this explains its occurrence in the semi-dry crop in the Palakkad tract during the first season. Thomas and Abraham (1998) reported the predominance of grass weeds in the semi dry system and rated *S. interrupta, I. miliacea, E. colona* and *E. crus-galli* as the major weeds in semi dry rice culture in Kerala.

Unlike in Kuttanad and *Kole*, BLWs were the second dominant category of weeds identified in the Palakkad tract, with SDR of 22.18. However, the density, abundance, frequency, relative density, relative frequency, relative abundance and SDR were found to be lower for the individual weeds under this category compared to sedges. Among the BLWs, *L. parviflora* registered higher density of 1.87 m^{-2} with SDR of 4.69 and was observed in 46.67 per cent of the surveyed areas. *M. vaginalis* was not recorded from the surveyed areas of the Palakkad tract but was observed in higher densities in Kuttanad and *Kole*. This might be attributed to its distinct preference for moist and flooded conditions that provide an ideal environment to prosper.

Salvinia molesta was also not observed in the Palakkad tract. On the other hand, it was noticed as a major weed in Kuttanad and the *Kole* lands. As *S. molesta* is a floating weed and flowing or stagnant water is essential for its survival, it explicates its absence in the Palakkad tract, where the weed does not get a chance to proliferate.

A

B

Plate 8. Abundance of *Leptochloa chinensis* in rice fields (A) Palakkad (B) Karamana

Echinochloa colona

Echinochloa crus-galli

Leptochloa chinensis

Isachne miliacea

Ischaemum rugosum

Sacciolepis interrupta

Cyanotis axillaris

Eclipta alba

Ludwigia parviflora

Monochoria vaginalis

Commelina benghalensis

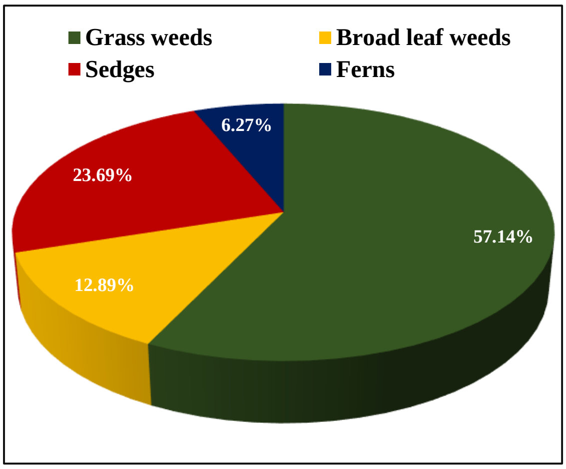
Cyperus haspan

Cyperus iria

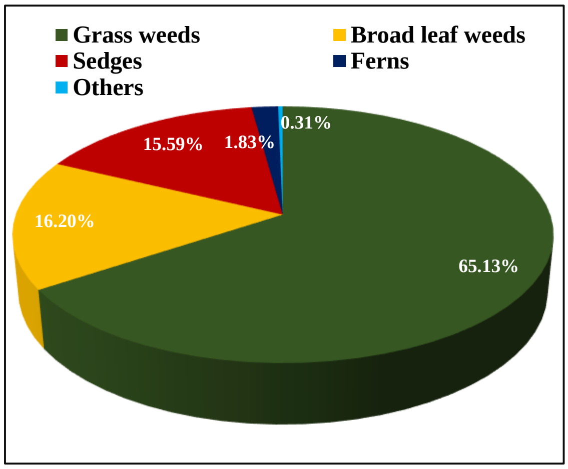
Fimbristylis miliacea

Schoenoplectus juncoides

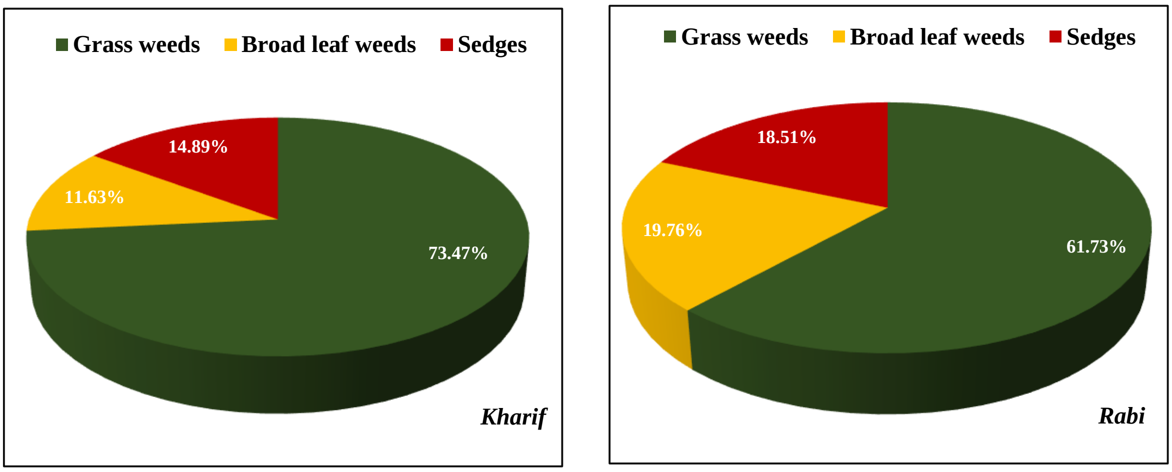
Plate 9. Weed spectrum of Palakkad tract



A



B



C

Fig. 7. Weed composition of surveyed locations in (A) Kuttanad (B) *Kole* and (C) Palakkad

5.1.2 Habitat analysis

Weeds are quite dynamic in nature. The adaptability of weeds to a particular ecosystem is the key factor facilitating their successful establishment and determines the habitat. Habitat adaptability has become an increasingly effective indication of weed expansion risk on a worldwide scale (Crossman *et al*., 2011; Richter *et al*., 2013). The ability of a weed to grow and dominate a living space is mainly determined by vegetation analysis. Dominance generally determines whether weeds are important or not (Firmansyah and Pusparani, 2019). An understanding of the similarities or dissimilarities between different regions, seasons or methods of cultivation will be helpful in identifying the conditions, which might favour or prevent the proliferation of a particular weed. In the study, weed vegetation analyses were done by using the Simpson's diversity index (D), Shannon Wiener diversity index (H) and the Evenness index (J).

The Simpson's diversity index (D) indicates the diversity of the flora and as the value of D increases, diversity increases and dominance decreases. The low value of Simpson's diversity index (D) in Palakkad during *Kharif* could be attributed to the dominance of *S. interrupta* (SDR - 23.60) compared to other weeds. This was also indicated by the lowest evenness index (1.77) for the Palakkad region. The Simpson's diversity index (D) value was the highest in the *Kole* region with the highest number of species (17), as more than one species had relatively higher densities. Along with *O. sativa f. spontanea, L. chinensis, E. colona* and *S. interrupta* co-dominated the *Kole* lands. In Kuttanad paddy fields, *E. stagnina, L. chinensis* and *S. interrupta* were the co-dominant weeds.

The lowest value (2.09) for the Shannon Wiener diversity index (H) was obtained in the Palakkad tract, followed by Kuttanad (2.31). A decrease in the value of the Shannon Wiener diversity index (H) indicates an increase in the magnitude of environmental stress favouring the dominance of a few adapted species of plants, which are often referred to as opportunistic species (Osborne *et al.,* 1976). The extreme high acidity of Kuttanad soils and the stressed environmental conditions of Palakkad tracts during the *Kharif* season might be the reason for the low species diversity in these regions compared to the *Kole* lands, which had the highest species richness (17) and the highest value (2.50) for the Shannon Wiener diversity index (H).

The evenness index value was the highest (2.07) in the Kuttanad region and the lowest (1.77) in the Palakkad tract during *Kharif*. When all the species have almost the same number of individuals, the evenness index indicates a maximum value as the environment is equally favourable for all the weeds, resulting in high species diversity. When environmental stress occurs, only a few adapted species are favoured, the population of which will dominate over other species. This condition resulted in a low evenness index in the Palakkad tract during *Kharif*. The unfavourable soil conditions during semi dry rice cultivation led to the dominance of *S. interrupta* and resulted in a low evenness index of 1.77. Even though five species of grass weeds were recorded in the Kuttanad tract, there was no distinct difference in the densities of the three weeds and so co-dominated, resulting in a higher evenness index compared to the other two tracts.

5.1.3 Growth characteristics and nutrient content in *Leptochloa chinensis* as influenced by soil conditions

Soil pH has a noteworthy influence on the growth of weed species. Weeds can take full advantage of the soil moisture and nutrients in acidic soils to proliferate and set seeds, contributing to the soil weed seed bank. In general, Palakkad soils had a higher pH and Kuttanad soils registered the lowest pH. The extreme variations in pH might have limited the number of weeds adaptable to the ecosystem. This could be evident from the lowest value (2.09) for the Shannon Wiener diversity index (H) obtained in the Palakkad tract followed by Kuttanad (2.31). The extreme acidity of Kuttanad soils might be the reason for the low species diversity in the region.

Across the locations surveyed where *L. chinensis* was a dominant weed, the pH varied from 3.84 to 6.46, indicating extremely acidic to slightly acidic soil conditions, and the OC and NPK content also extended from low to high status.

In general, *L. chinensis* ecotypes of the Kuttanad rice growing region showed greater growth characteristics compared to the *Kole* and Palakkad regions (Table 11). The extreme acidity of Kuttanad soils did not inhibit the germination and growth of *L. chinensis* but acidity might have favoured seed germination and growth, as seen by its superior growth characteristics.

The higher OC content in the Kuttanad soil ranged between 2.92 to 4.17 per cent and the higher K content (218.4-306.6 kg ha^{-1}), contributed by straw recycling, might also be the reason for the robust growth of *L. chinensis* in the Kuttanad region. The phosphorus content was found to be the highest in plants collected from *Kole* lands and might be attributed to the higher content of phosphorus in *Kole* land soils.

Earlier, the presence of *L. chinensis* was reported only in the alkaline soils of the Chittoor taluk of Palakkad. However, now the weed has spread to almost all the soil types, irrespective of the soil chemical properties. This indicated its wider adaptability to an extremely wide range of soil conditions that prevailed in the different rice growing areas of Kerala and points out that soil nutrient status is not a determinant of *L. chinensis* occurrence.

Soil moisture status has an intense impact on shaping the weed flora of a specific region. Only those weeds that are able to grow and establish themselves under the specific moisture conditions will be dominant. The soil moisture level was saturated for all the surveyed locations in the Palakkad tract, whereas it was under submerged conditions for the *Kole* and Kuttanad regions. The presence and dominance of *L. chinensis* in both saturated and submerged conditions highlight the invasive potential of this weed and the possibility of it becoming a threat to all rice growing ecosystems in the near future.

5.2. GERMINATION ECOLOGY

Understanding the weed germination ecology, emergence dynamics, and growth requirements is important for managing the infestation of various weed species as well as formulating effective management strategies.

The lack of understanding of the reasons for weed species' infestation and dominance is a key impediment to developing long-term management techniques in crop ecosystems. Knowledge of the seed biology and floristic relationships of a species might be utilized to determine specific management techniques for that species (Bhowmik, 1997).

An acquaintance of the behaviour of *L. chinensis* in relation to environmental factors and common weed management practices will bring a comprehensive outlook on how to holistically and efficiently manage the weed. Data obtained from the biology, phenology and germination ecology studies of *L. chinensis* is discussed in this section.

5.2.1 Biology of *L. chinensis*

Weed biology refers to the biological attributes that may be associated with survival and dispersal of species (Bhowmik, 1993) and is related to the study of weeds in relation to their geographic distribution, habitat, growth and population dynamics of weed species and communities (Rao, 2000). Knowledge of weed biology provides vital information on the emergence dynamics, mode of propagation, competitiveness and critical stages of weed management and, in turn, will help reinforce the management approaches.

During the field investigation, the weed was observed to grow under flooded or upland conditions and along the water channels, bunds and in the cropped rice field. It was found growing profusely on the field bunds, and after flowering there was a clear distinction between the bunds and the field areas. It was also seen growing near the bunds, waterways, marshy areas, waterlogged areas, as well as upland. The prevalence of *L. chinensis* in bunds promotes prolific seed production, and the water channels facilitate rapid spread through water.

Galinato *et al*. (1999) reported that *L. chinensis* has the ability to grow in both flooded and upland conditions, which makes it a widespread and abundant weed in rice and many other crops. The *L. chinensis* population was also observed to inhabit both heavy textured clayey soils and light textured sandy soils. The adaptation to thrive and grow under diverse situations aids in season long persistence and infestation of the weed in the field.

Leptochloa chinensis was observed to be an erect or creeping annual or perennial grass that can grow upto a height of 1.2 to 1.5 m (Plate 10). Chauhan and Johnson (2008) opined that even though *L. chinensis* is an annual species, it can be perennial when suitable growing conditions exist.

Soerjani *et al*. (1987) also reported that *L. chinensis* is a slender tufted grass that grows to a height of upto 1.2 m. The leaves are light green in colour and glabrous, which are smoother in texture compared to the leaves of the rice plant. The close resemblance of *L. chinensis* and rice seedlings at the early stages of crop growth causes difficulty in differentiating them under DSR. The light green colour and softer texture of the leaves could be a practical way to distinguish the weed from the crop. Yield reduction due to weed infestation is more challenging in WSR due to similarities in age (Umkhulzum *et al*., 2019) and morphological characteristics (Moody, 1989) of grass weeds and rice seedlings. The maximum plant height was noticed at the stage of maturity and ranged from 89.7 to 109.1 cm.

The inflorescence of *L. chinensis* is an open panicle that appears terminally from the base of the leaf sheath, and each plant has the ability to produce 4 to 10 inflorescences (Plate 11). Each panicle bears numerous ascending slender flexuous primary branches and each such primary branch produces spikelets and numerous tiny brown seeds (Plate 12). Each plant was observed to produce 8304.76 to 29857.14 seeds with an average of 16951.25 seeds per plant and the thousand seed weight ranged from 0.10 to 0.11g. Holm *et al*. (1977) also reported that each inflorescence of *L. chinensis* has the potential to produce hundreds of seeds and an individual plant may have numerous inflorescences. According to Manidool (1992) and Chin (2001), the invasiveness of *L. chinensis* is due to its high seed production potential.

In a single inflorescence, the seeds matured at different intervals starting from the tip to the base (Plate 13 and 14). This temporal difference in seed maturation allows the weed to germinate at different conditions and seasons.

Leptochloa chinensis

A plant of *Leptochloa chinensis* showing tufted branches and panicles

Stoloniferous branches under upland

Stoloniferous branches under flooded condition

Plate 10. Growth habit of *Leptochloa chinensis*

Leaf

Seeds

Inflorescence

Slips

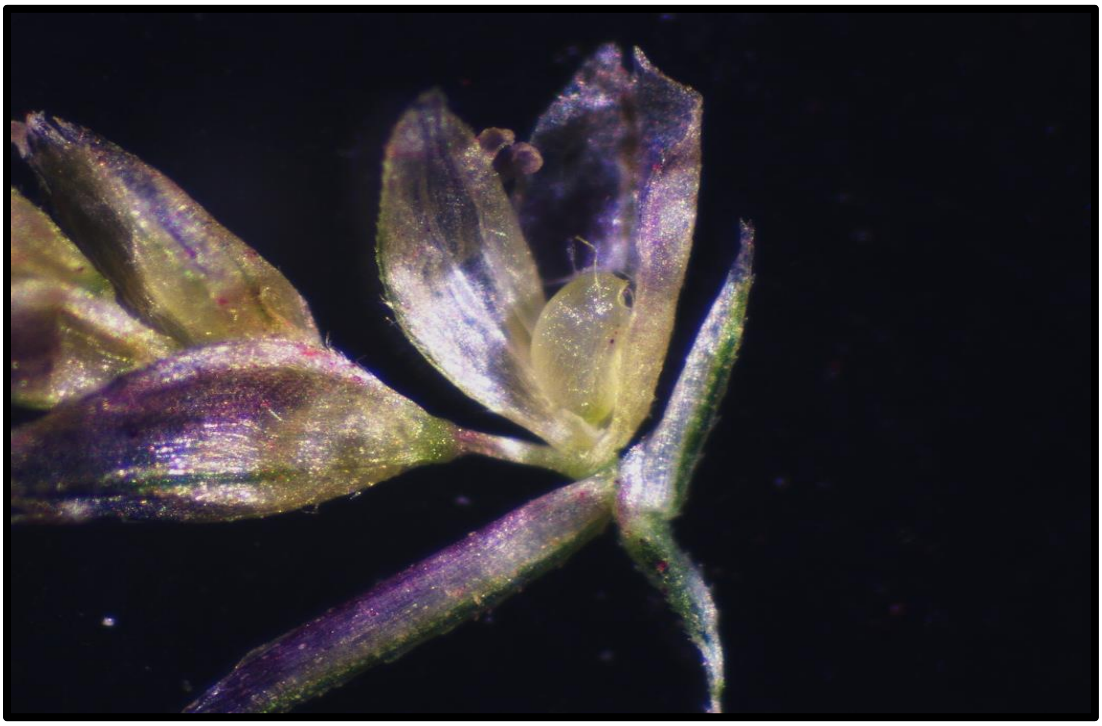
Plate 11. Morphological characters of *Leptochloa chinensis*

The shattering was found to occur from the tip to the base of the panicle, and wind and water aided in the dispersal of *L. chinensis* seeds. The higher abundance of the plants in field bunds indicates that bunds become a critical habitat for *L. chinensis,* dispersing finer seeds to adjacent fields through the water channel. *L. chinensis* is propagated sexually by seeds and asexually (vegetative reproduction) by root slips (Plate 11). The capability to propagate by multiple means is an indicator of the persistent and competitive nature of the weed and marks the problematic scenario under field conditions.

Holm *et al*. (1977) also reported the seed and vegetative mode of propagation by division of clumps or rootstocks of *L. chinensis* following cultivation or ploughing during land preparation.

5.2.2 Studies on phenology

In pot studies on phenology, *L. chinensis* was noticed to develop through five phenological stages in its life cycle (Plate 15). These included emergence, tillering, heading, flowering and maturity. The period after seed germination (from seedling emergence) to active tillering represented the vegetative stage (35-48 days) and was observed by the development of leaves and tillers along with a steady increase in the height of the plants. Germination of the weed started on the third day and continued upto 18.2 days after sowing (DAS). This temporal difference in germination could make the weed present throughout the cropping season (persistent) depending on the weed seed bank and become problematic under field conditions. Tillering was completed within 30 to 33 days and the number of tillers per plant ranged from six to nine with an average of 7.5 tillers per plant. The reproductive stage started with panicle initiation followed by flowering and covered panicle development, booting, heading and flowering, which was completed within 72 to 83 DAS. Heading commenced at 67 to 80 days. The number of panicles per plant ranged from five to eight and an average of 6.5 panicles was observed per plant. The cessation of flowering marked the beginning of the ripening stage and the plants attained maturity at 88 to 102 days, with an average of 95 DAS.



A

B

Plate 12. Microscopic view of *Leptochloa chinensis*
(A) Flower (4X magnification) (B) Seed (8X magnification)

A B C D

Plate 13. Microscopic view of (A) Spikelet with glumes; Spikelet from (B) bottom (C) middle (D) top position of inflorescence (2.5X magnification)

Plate 14. Maturity of seeds within the inflorescence (Microscopic view) : Seeds from (A) bottom (B) middle (C) top (2X magnification)

Among the ecotypes, plants from Palakkad had the shortest duration (93.9 days) along with the *Kole* ecotypes (94.4 days), which would be due to the favourable climatic conditions preferably higher temperature that prevailed at the time of seed maturity. The Kuttanad ecotypes exhibited greater vegetative and reproductive characteristics of *L. chinensis*. The average seed production per plant ranged from 9479.24 to 11582.02, with the highest being registered from Kuttanad ecotypes and the lowest from Palakkad ecotypes. Seed development is strongly regulated by various environmental factors such as temperature, photoperiod, water availability and nutrient supply (Donohue, 2009). Previous studies have reported that seeds which develop at a higher temperature or with shorter days are mostly less dormant (Gutterman, 2000; Donohue, 2009).

5.2.3 Germination studies

Various environmental factors such as light, temperature, salinity, moisture and cultural practices like depth of seed burial influence weed seed germination (Chauhan and Johnson, 2008; Chauhan and Johnson, 2010). Effective control of weeds could be attained with a better understanding of the factors that impede or encourage weed seed germination (Chauhan, 2012).

5.2.3.1 Effect of light and temperature on germination

Light is an important ecological aspect of germination. Seeds should be present on or near the soil surface for those weed species that need light for germination (Kettenring *et al*., 2006). Species preferring light for germination would be more ubiquitous in continuous no-till systems where a substantial quantity of weed seeds are resting on the surface and exposed to light (Batlla and Benech-Arnold, 2014).

In the laboratory studies conducted, it was observed that light stimulated the seed germination of *L. chinensis* by 23 per cent (Fig. 8). Higher germination was attained in the presence of light, signifying that light favours germination of *L. chinensis*. The stimulated germination under light indicated the need of seed burial to deeper depths by tillage in heavily infested areas.

Seedling stage

Seedling stage

Tillering stage

Tillering stage

Heading stage

Flowering stage

Maturity stage

Maturity stage

Plate 15. Growth phases of *Leptochloa chinensis*

Cousens *et al*. (1993) also observed that weed species preferring light for germination could become problematic in no-till or reduced-till systems. In the study, 65 per cent of *L. chinensis* seeds did germinate in the dark, suggesting that germination was not adversely affected by dark conditions. The absence of light to stimulate germination leaves a fraction of *L. chinensis* seeds ungerminated in the soil seed banks. Under field conditions, these seeds may remain dormant when buried deeply and re-infest the area when brought back to or near the soil surface.

Even though, light stimulated the seed germination of *L. chinensis*, the seeds kept under dark conditions too germinated which pointed out the fact that light is not an absolute requirement for germination. This would be the plausible reason for the continued emergence of *L. chinensis* over a span of 15 days from the shallow weed seed bank within 2 cm of the soil surface. It is evident that weed seed bank in the shallow depths remaining under dark in paddy fields also could contribute to potential weed population. The results find ample support from the findings of Benvenuti *et al*. (2004), who reported that 20 per cent of *L. chinensis* seeds germinated in the dark. However, studies conducted by Chauhan and Johnson (2008) found that *L. chinensis* had an absolute light requirement for germination and suggested that the differential response of *L. chinensis* to light could be due to the polymorphic nature.

Leptochloa chinensis seeds germinated at all the tested temperature regimes (25/15°C and 35/25°C). A maximum cumulative germination of 87.2 per cent was registered when seeds were exposed to 25/15°C under light/dark conditions (Fig. 5). Many researchers authenticated temperature as a vital factor for inducing weed seed germination (Burke *et al*., 2003; Chauhan and Johnson, 2010). The time to 50 per cent germination in the 25/15°C and 35/25°C temperature regimes was 7.2 and 8.0 days, respectively. The study indicated that *L. chinensis* seeds germinated irrespective of the atmospheric temperature regimes and was favoured throughout the season. This could be the reason for the similar occurrence of *L. chinensis* during the *Kharif* and *Rabi* seasons in Kerala. Higher germination immediately after attaining maturity revealed that adoption of stale seedbed (SSB) with deep ploughing for incorporation or shallow ploughing for control of surface sown seeds could be done to deplete the soil seed bank. The studies conducted by Benvenuti *et al*. (2004) on the Italian population and Chauhan and Johnson (2008) on the Philippine population of *L. chinensis* also reported high germination immediately after seed harvest.

The light requirement for seed germination may vary with changes in temperature. In the study, germination of *L. chinensis* seeds under complete darkness might be facilitated by the alternating temperature regimes. As reported by Benvenuti *et al*. (2004), the fluctuation in temperature improves the germination of *L. chinensis* seeds in the absence of light.

Fluctuations in temperature led to an increase in dark germination, indicating that this could satisfy the Pfr requirement for seed germination (Benvenuti *et al*., 2004). Although light is not required for all species to germinate, it can help to alleviate the factors that prevent germination when the incubating temperature is higher than ideal (Aud and Ferraz, 2012). Moreover, such a phenomenon was earlier observed for light sensitive species (Benvenuti *et al*., 2001). The improved response to fluctuating temperatures and higher temperature levels might be the cause of *L. chinensis* emergence on bare ground where the greatest diurnal fluctuations could happen (Chauhan and Johnson, 2008).

5.2.3.2 Effect of salinity on germination

Salinity is considered as one of the major constraints in crop production and more areas are gradually becoming salt affected due to climate change. Only certain crops can be successfully grown in salt affected areas, and rice is one among them. Salt affected areas are characterized by distinctive weed flora. Information on the effect of salt stress on weed germination could help to predict the invasive potential of *L. chinensis* in such areas.

In the present study, *L. chinensis* was found less sensitive to salinity stress and was not affected by increasing salt concentrations. This could validate the high abundance of *L. chinensis* in Kuttanad and *Kole*, where saline water intrusion occurs. The salt concentration required to inhibit maximum germination by 50 per cent was 150 mM NaCl (Fig. 6).

Similar results of increased germination at high salt concentrations, even at 250 mM NaCl, were also reported for *E. glabrescens* (Opena *et al*., 2014) and *Mimosa invisa* (Chauhan and Johnson, 2010). In the study conducted by Chauhan and Johnson (2008) on *L. chinensis*, no seeds germinated at 150 mM or greater concentrations of NaCl, and the salt concentration required for 50 per cent inhibition of maximum germination was 50 mM NaCl. It was observed that subjecting seeds to salt stress delayed the onset of germination and the time to 50 per cent germination increased with increasing salt concentration from 0 to 250 mM. The longevity of *L. chinensis* seeds in saline conditions is still unclear and needs further investigation.

The results suggested that seeds of *L. chinensis* could germinate at high salt concentrations, indicating its tolerance to salinity and potential to become a major weed in saline soils in future. Hence, crop cultivation practices in such regions could be affected not only by salinity but also by competition with the weed species.

5.2.3.3 Studies on field conditions favourable for emergence

Irrigation is an important cultural operation as far as weed management is concerned. Early flooding is futile in WSR as the aerobic conditions required to grow rice also allow weeds to establish. The potential of water management options, especially flooding, as a component of integrated weed management strategies could be enhanced if the response of *L. chinensis* to various practices were better understood.

In the pot study, continuous flooding for a period of 30 days and maintaining a thin layer of water (3 cm) appeared to be the most effective tactic for reducing the emergence of *L. chinensis* (Fig. 9), when seeds were placed on the soil surface. Maintaining soil moisture with a thin layer of water by irrigating every day could not provide a favourable condition for germination and resulted in zero emergence. Flooding to a depth of 2 cm reduced seedling emergence of *L. chinensis* by 72 per cent when the soil had been flooded continuously for 28 days (Chauhan and Johnson, 2008).

According to Chauhan and Johnson (2010), the alteration in physical, chemical, or biological characteristics of submerged soils is responsible for the reduced weed emergence and dry matter in flooded soils. Reduced oxygen levels, accumulation of carbon-di-oxide and toxic gaseous products resulting from anaerobic decomposition and manifestation of reduced forms of chemical radicals and gases such as methane, nitrogen, nitrogen oxides, and sulphides may all contribute to weed growth inhibition in flooded soils (Smith and Fox, 1973). It is also conceivable that the weed seeds' depth sensing mechanisms are associated to the amplitude of temperature variations (Pons, 1982). Lower germination of seeds under flooding might be a result of smaller temperature fluctuations in deeper water (Chauhan and Johnson, 2010).

In the pots where alternate flooding and draining and irrigation to a depth of 5 cm once in every 15 days was practiced, 55 and 35 per cent seedling emergence was noticed at 5 DAS. Alternate flooding and draining commenced with draining the field 2 DAS and during this period, seeds started germinating. The germinated seedlings survived the flooding done later for 5 days. However, the late emerged seedlings got dried up during the second draining, though they survived during the period of flooding. The presence of residual water in the puddled soil might be responsible for the initial germination of *L. chinensis* seeds. Flooding to a depth of 2 cm reduced seedling emergence of *L. chinensis* by 26 per cent when the soil had been intermittently flooded for 2 of 7 days for 28 days (Chauhan and Johnson, 2008).

In the study, irrigation on alternate days provided a condition similar to field capacity and favoured the germination of *L. chinensis.* This demonstrated that aerobic moist soil alternating with short term moisture stress could trigger their germination. This might be the reason for the successful establishment and colonization of the weed in WSR, where aerobic moist soil provides a favourable niche for establishment. Chauhan and Abhugo (2013) reported that field capacity favours the germination of *L. chinensis*. In the present scenario of impending water crisis and drought, *L. chinensis* could become more problematic in WSR.

A study conducted by Awan *et al*. (2015) reported that aerobic conditions increased the growth and growth parameters of *L. chinensis* compared to saturated conditions.

In the pot study, *L. chinensis* seeds were found to have emerged even after 30 days when flooding was withdrawn, indicating the ability of this weed to wait for favourable conditions to establish and thrive. It was observed that once *L. chinensis* seedlings had emerged, flooding later would not reduce their shoot growth. Similar results have been reported for some sedges and BLWs (Chauhan and Johnson, 2009b). The small size of *L. chinensis* seeds makes seedling emergence a crucial point, so that seeds can rapidly reach normoxic conditions at the soil surface (Benvenuti *et al*., 2004).

5.2.3.4 Studies on the effect of depth of burial and means of propagation on weed survival

The emergence of *L. chinensis* was maximum from the seeds present on the soil surface and no seeds emerged from a depth of 2 cm or more. The reduced seed reserves due to smaller seed size (1.038-1.112 mm in length and 0.525-0.608 mm in width) with the thousand seed weight of 0.10 to 0.18 g might be the reason for poor emergence from higher depths. Benvenuti *et al*. (2004) elucidated the poor emergence of *L. chinensis* to reduced seed reserves from deep soil layers known as fatal germination. Larger seeds with more carbohydrate reserves can emerge from deeper burial depths (Baskin and Baskin, 1998), whereas small seeded species like *L. chinensis* may not have enough reserves to support seedling emergence from deeper depths (Chauhan and Johnson, 2010).

Absence of light at greater depths might also be responsible for the reduced seedling emergence from deep buried seeds. Light penetration is largely restricted to the first few millimetres of the soil and seeds buried more than two mm below the soil surface generally receive less than one per cent of incident light (Woolley and Stoller, 1978), which is not adequate to trigger germination (Egley, 1986). On top of this, reduced seedling emergence with an increase in burial depth could be due to hypoxia and low rates of gaseous diffusion and the presence of carbon-di-oxide deriving from soil biological activity (Benvenuti and Macchia, 1995; Benvenuti, 2003). Even though the burial depth response varies among species, it is very common for seeds of most weed species to germinate when they are positioned on the soil surface (Chauhan and Johnson, 2010). Since thermal fluctuation is a known germination stimulator, decreasing thermal fluctuation as burial depth increases may result in reduced seedling emergence (Roberts and Totterdell, 1981). Similar results were reported by Chauhan and Johnson (2008) for *L. chinensis*, in which no seedlings emerged from a burial depth of 0.5 cm or more. In contrast, seedlings of the Italian population emerged from seeds buried upto 5 cm (Benvenuti *et al*., 2004).

In pot experiments, slips reported pronounced emergence compared to seeds with 100 per cent emergence from a depth of upto 4 cm. New flushes emerged from the slips buried deep (6 and 10 cm) when they were brought back to the surface after 30 days, indicating that slips can remain viable for a month even though buried deep and can serve as a major propagule under unfavourable conditions. This is suggestive of the fact that weed can establish even in the absence of seeds. In the field, tillage after land preparation could bring back slips to the surface, and could help in establishment of the weed. The presence of varying stages of the weed propagule in the same field can help the weed escape from herbicide application and can become more problematic.

The results of our study suggest that no-till or shallow tillage, as well as practises that achieve shallow burial of weed seeds and slips, would increase the emergence of *L. chinensis* in field conditions. Under no-till or conservation agriculture practises, the majority of weed seeds remain on or near the soil surface after crop planting, albeit they may be more susceptible to quicker desiccation and insect predation (Chauhan *et al*., 2012). As *L. chinensis* cannot emerge beyond a depth of 2 cm, initial deep tillage operations that bury weed seeds and slips beyond their maximum depth of emergence could manage the build-up of seed banks on the soil surface and limit the germination of this weed.

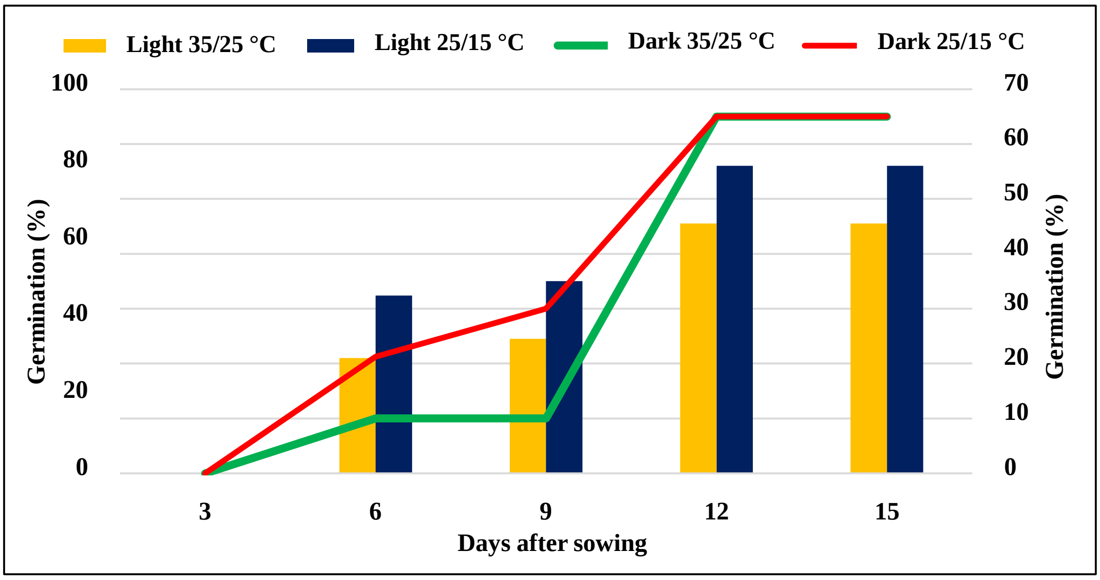


Fig. 8. Influence of alternating temperature regimes (25/15 and 35/25°C) and light/dark and dark conditions on germination of *Leptochloa chinensis*

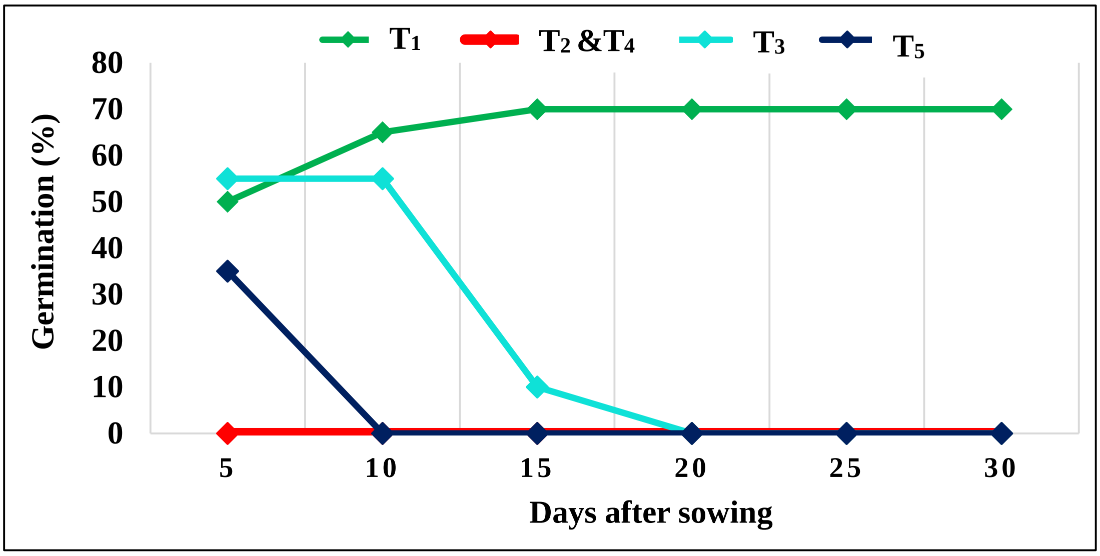


Fig. 9. Influence of field conditions on emergence of *Leptochloa chinensis*

Further tillage operations, however, must be shallow to avoid taking the buried seeds and slips back to the soil surface.

5.2.3.5 Studies on seed longevity

Seed longevity is defined as the viability of seeds following dry storage (storability) and hence describes the whole seed life span (Rajjou and Debeaujon, 2008). The germination of *L. chinensis* seed was found to be negatively influenced by the increase in storage period (Fig. 10). As time passed, the germinability of the seeds was found to decline, and they germinated till nine months of storage. A decrease in germination and viability with seed age was also reported by Jiménez-Vázquez *et al*. (2021). A higher longevity period of nine months for the small sized seeds of *L. chinensis* might be due to the low seed dormancy. Nguyen *et al*. (2012) identified a negative association between seed dormancy and seed longevity, with deep dormancy being linked with low storability and shallow dormancy with high storability. Furthermore, studies conducted by Schutte *et al*. (2008) among the individuals of *Ambrosia trifida* populations observed an inverse relationship between seed size and seed longevity. The longevity of seeds combined with the huge quantity of seeds produced emphasized the persistence nature of *L. chinensis.*

5.3 MANAGEMENT OF *L. chinensis* IN WET SEEDED RICE

Leptochloa chinensis is a grass weed which has emerged as a problem weed in the major rice growing regions of Kerala with the continued usage of broad spectrum herbicide bispyribac sodium for the management of *Echinochloa* sp (Jacob, 2014). Despite concerns about weed shifts, herbicide resistance and environmental trade-offs, use of chemical herbicides has become an inevitable practice in WSR due to the enormous and extensive population of weeds, coupled with the paucity and high cost of labour for manual weeding. Tank mixing of appropriate herbicide formulations is a potential economic approach for dealing with weed shift, herbicide resistance and for broad spectrum management of weeds. Herbicide mixes will help to avoid the resistance problem and weed population shifts that are always a concern while using a single herbicide (Duary *et al*., 2015).

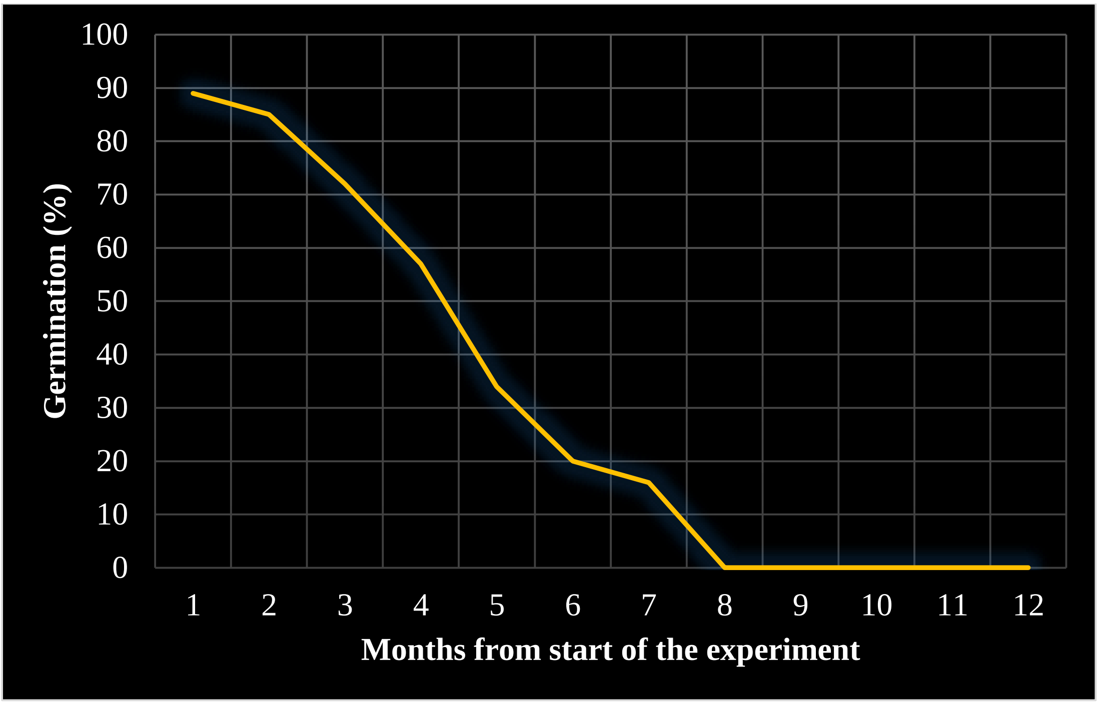


Fig. 10. Germination of *Leptochloa chinensis* as influenced by period of storage

The effectiveness of herbicides and tank mix or ready mix combinations in controlling *L. chinensis* in WSR was investigated in the study.

5.3.1 Observations on weeds

5.3.1.1 Floristic composition of weeds

As far as weed flora is concerned, there was considerable diversity in the weed species that infested the experimental area. Fifteen species of weeds were observed in the WSR (Plate 18) where the species diversity was found to be higher in BLWs (8) as compared to grass weeds (3), sedges (3) and fern (1). Diversity in weed flora in WSR cultivation has been documented earlier by Jacob (2014), Umkhulzum (2018) and Reddy (2020). The major grass weeds were *L. chinensis*, *E. colona* and *I. miliacea.* Broad leaf weeds comprised of *Sphenoclea zeylanica*, *Bergia capensis*, *M. vaginalis*, *L. flava*, *Ludwigia perennis, Alternanthera philoxeroides* and *Lindernia* sp.. The sedges present were *C. iria*, *C. difformis* and *F. miliacea. Marsilea quadrifolia* was the only fern that infested the experimental field. As reported by Reddy (2020), *L. chinensis*, *E. colona, I. rugosum S. zeylanica, L. parviflora, B. capensis, Lindernia rotundifolia*, *M. vaginalis*, *F. miliacea, C. difformis* and *C. iria* were the major weeds infesting WSR. Hussain *et al*. (2008) and Rathika and Ramesh (2019) documented *E. colona*, *L. chinensis*, *E. crus-galli*, *C. iria*, *F. miliacea*, *L. parviflora* and *Eclipta alba* as the major weeds in DSR.

5.3.1.2 Effect of weed management practices on species wise count of weeds

Weed count per unit area is one of the most important quantitative parameters used for appraising the effectiveness of weed management practices. Critical assessment of the relative proportion of weeds before and after treatment application revealed that grass weeds were the most dominant weed flora in WSR during the both years, followed by BLWs and sedges. Grass weed population showed an ascending trend occupying 48.9 and 42.3 per cent of the weed spectra during initial phase and peaked at 87.40 and 75 per cent towards 60 DAS (Fig. 11 to 14). The dominance of grass weeds in WSR could be attributed to its persistent non dormant weed seed bank and favourable soil conditions in wet seeding.

Plate 16. General view of the experimental field during 2018

Plate 17. General view of the experimental field during 2019

Leptochloa chinensis

Echinochloa colona

Isachne miliacea

Sphenoclea zeylanica

Bergia capensis

Monochoria vaginalis

Limocharis flava

Ludwigia perennis

Alternanthera philoxeroides

Lindernia sp.

Eclipta alba

Cyperus difformis

Cyperus iria

Fimbristylis miliacea

Marsilea quadrifolia

Plate 18. Weed flora associated with the crop in experimental field

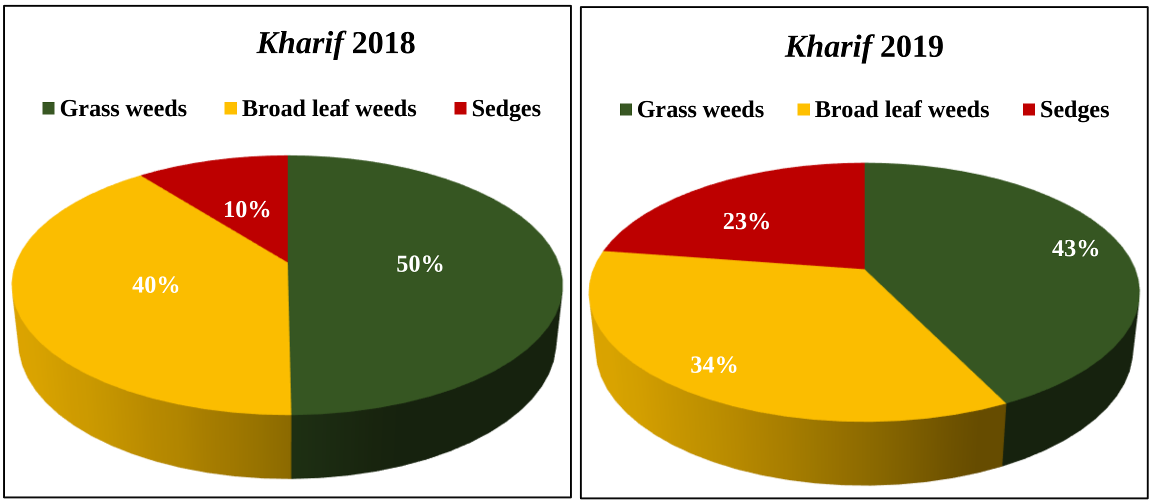


Fig. 11. Weed spectrum before treatment application

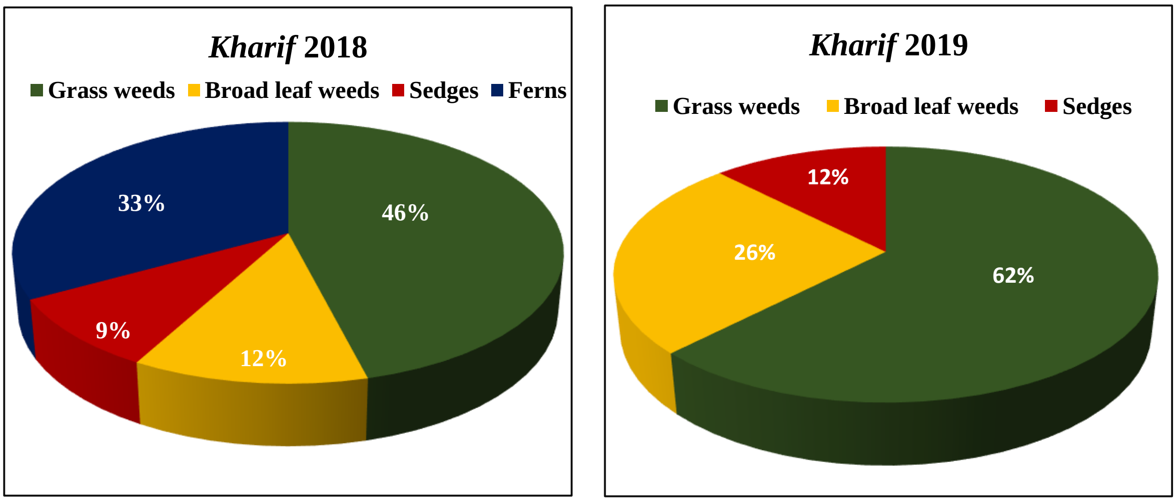


Fig. 12. Weed spectrum in unweeded control at 15 days after treatment application

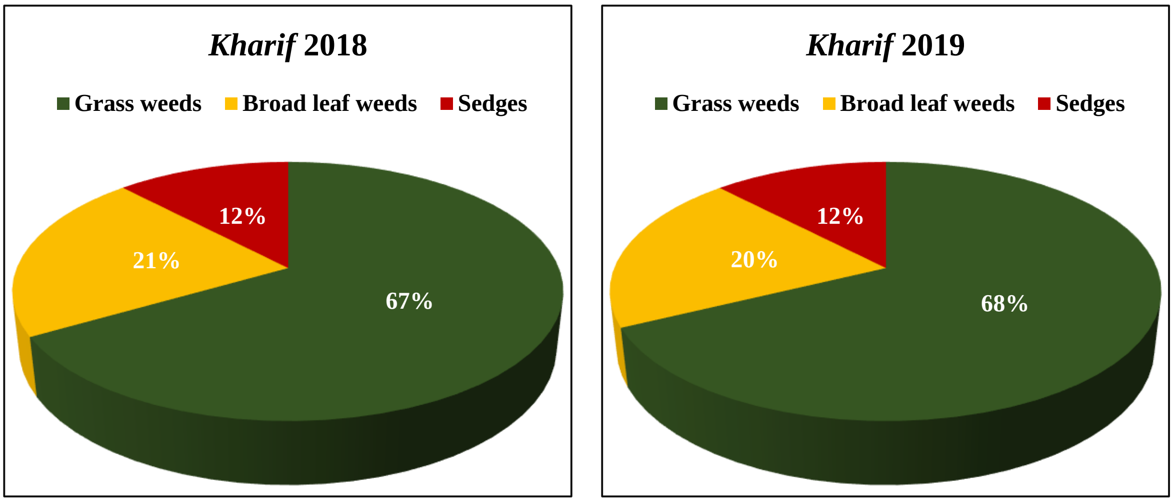


Fig. 13. Weed spectrum in unweeded control at 30 days after treatment application

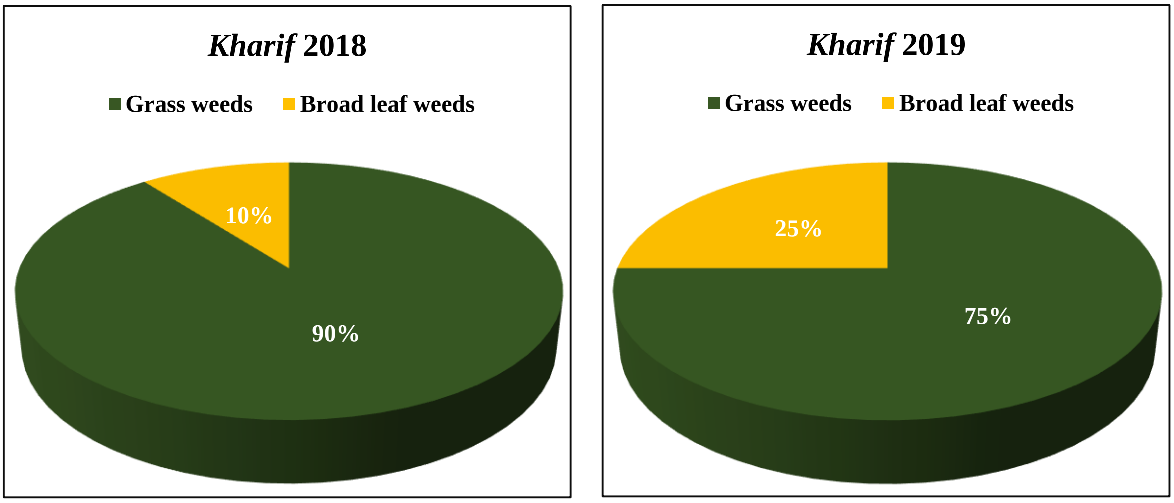


Fig. 14. Weed spectrum in unweeded control at 45 days after treatment application

Poaceae is reported as the most important weed family with more than 80 species of weeds in rice (Smith, 1981). Rani (2020) also reported a higher proportion of grass weeds compared to BLWs and sedges in DSR. According to Ravisankar *et al.* (2008), grass weeds constituted 51.5 per cent of the total weed population in WSR. Kumar and Ladha (2011) reported the shift of weed flora towards more difficult to control and competitive grass weeds and sedges under direct seeding.

Among the weeds, *L. chinensis* was the dominant one throughout the crop growth period in WSR and occupied more than 40 per cent of the grass weed population before treatment application (Fig. 15). Several other researchers also reported the dominance of *L. chinensis* in DSR. Earlier *E. colona* was the most dominant grass weed in the fields. In the present study, dominance of *L. chinensis* continued during the cropping period and surpassed *E. colona* and constituted more than 50 per cent of the total grass weed population (Fig. 16 to 18). The interaction between favourable soil condition and management practices might have resulted in the dominance of *L. chinensis* in wet seeding. Singh *et al.* (2008) reported that *L. chinensis* became more dominant than *E. colona* in DSR. Chauhan *et al.* (2015) also reported *L. chinensis* as one of the most predominant weeds prevalent in the districts of Phuoc Thoi, Thoi Lai and Co Do in the Mekong Delta region of Vietnam, where direct seeding had been practiced. IRRI (2020a) categorized *L. chinensis* under the twelve most troublesome weeds in Asian rice fields and also as one among the dirty dozen weeds.

Among the herbicidal treatments, fenoxaprop-p-ethyl (FPE) @ 0.06 kg ha^{-1} recorded the least count of *L. chinensis* at all stages and was found to be on par with hand weeding twice (HW) at 20 and 45 DAS and bispyribac sodium (BS) @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (Fig. 19). The application of FPE @ 0.06 kg ha^{-1} reduced the *L. chinensis* count by 100, 98.15 and 96.05 per cent compared to the unweeded control, respectively at 15, 30 and 45 DATA. Compared to unweeded control, HW twice at 20 and 45 DAS and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} resulted in 100 per cent reduction of *L. chinensis* at 15 DATA and caused 98.23 and 96.95 per cent and 91.56 and 94.19 per cent reductions at 30 and 45 DATA, respectively.

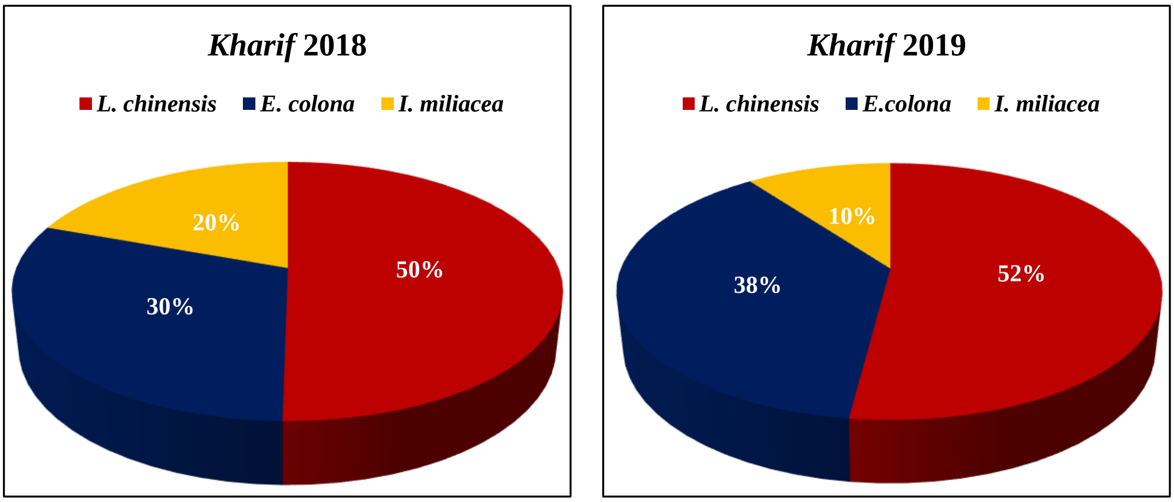


Fig. 15. Grass weed spectrum before treatment application

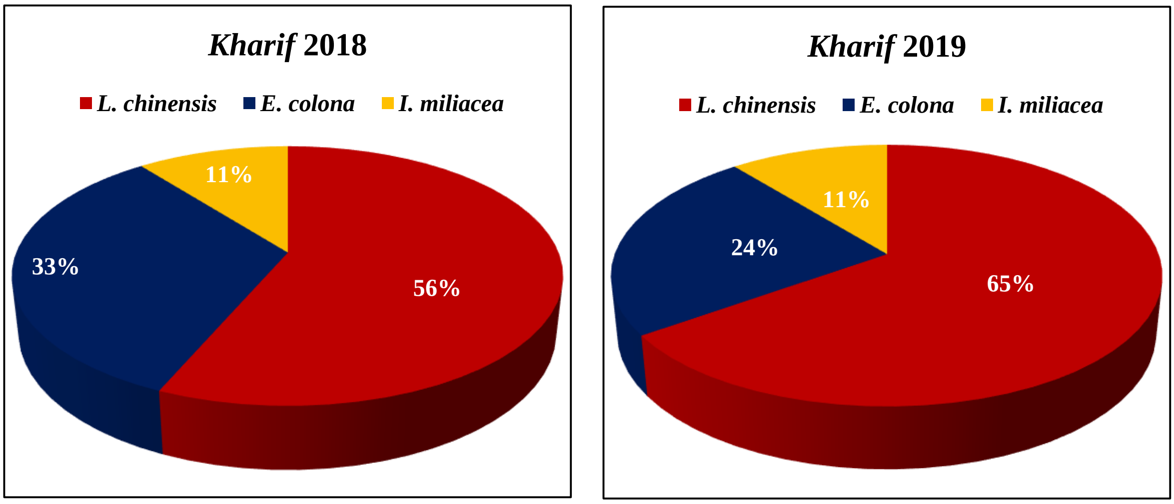


Fig. 16. Grass weed spectrum in unweeded control at 15 days after treatment application

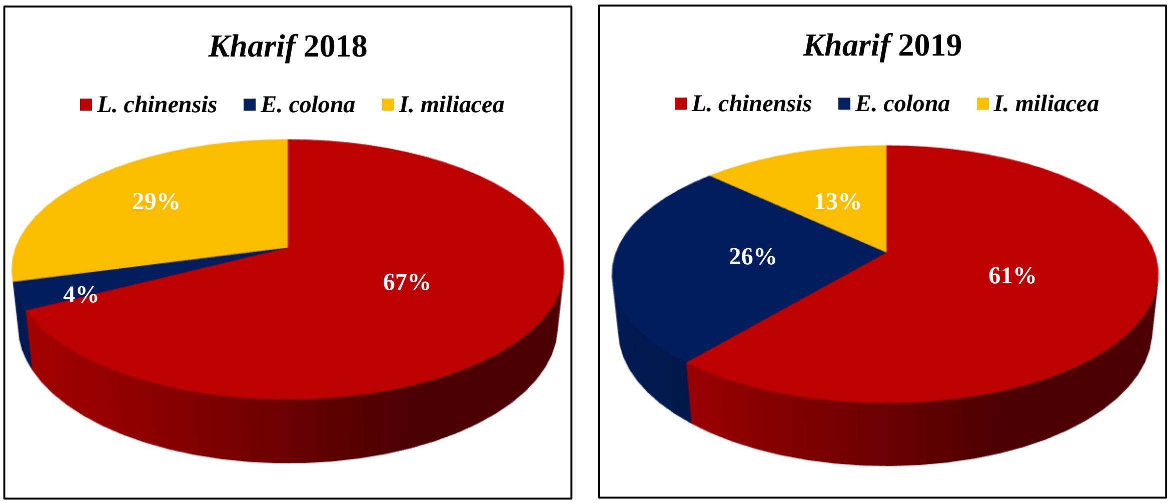


Fig. 17. Grass weed spectrum in unweeded control at 30 days after treatment application

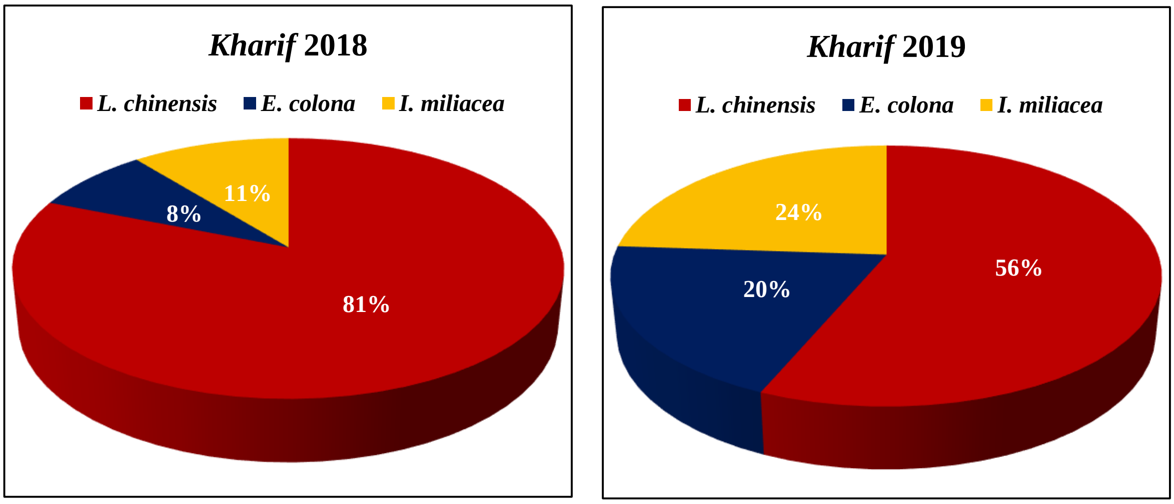


Fig. 18. Grass weed spectrum in unweeded control at 45 days after treatment application

The result was confirmed by the findings of Pratap *et al*. (2016), who reported that sole application of FPE @ 60 g ha^{-1} caused significant reduction in the density of *L. chinensis* at 30 DAS, which was found to be on par with HW twice at 20 and 40 DAS. Jacob (2014) also found that FPE was the most effective herbicide against *L. chinensis* for achieving 100 per cent control at 30 and 60 DAS.

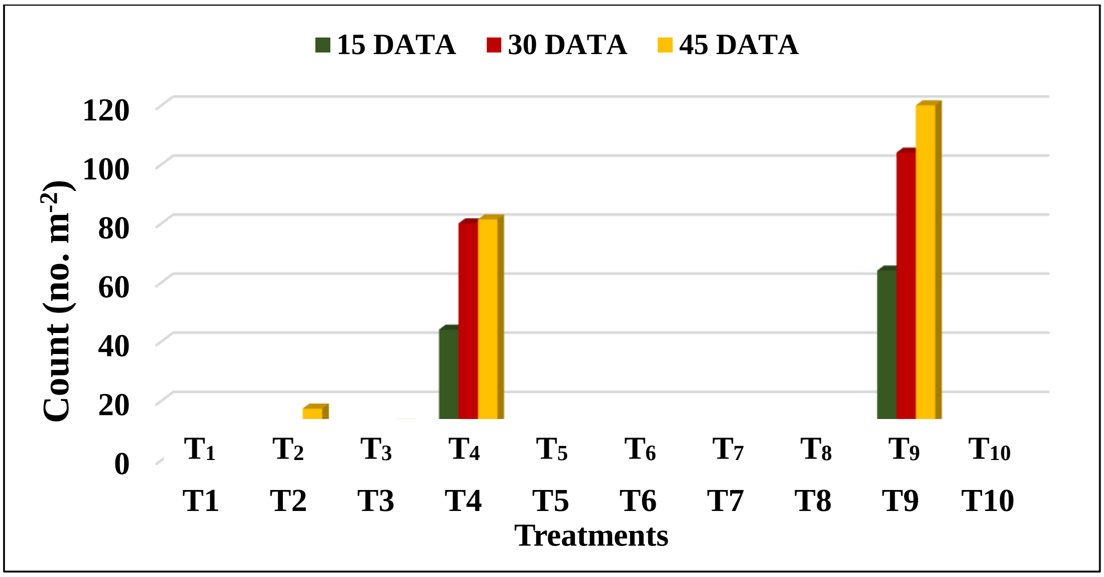
As evident from the data on weed count, application of cyhalofop butyl (CB) @ 0.08 kg ha^{-1} and its tank mix combination with carfentrazone ethyl (CE) @ 0.02 kg ha^{-1} were effective in controlling *L. chinensis* at initial crop growth stages, resulting in lower counts. According to Abeysekera and Wickrama (2004), CB 100% EC applied at 7-10 DAS recorded excellent control (90-94%) over *L. chinensis* resulted in the lowest population and dry weight. Jacob (2014) reported CB as the next best herbicide to FPE in controlling grass weeds including *L. chinensis*. The tank mix combination of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} brought about 75 per cent reduction in *L. chinensis* count compared to sole application of CB @ 0.08 kg ha^{-1} in the early stages of crop growth, which indicated the synergistic effect of the combination in managing *L. chinensis*.

Stale seedbed (SSB) *fb* chemical weeding was effective in controlling the germination and establishment of *L. chinensis* in the early stages of crop (Fig. 19). The control obtained in SSB is due to the destroyal of weed seeds in the top soil layers which germinated during staling operation and its subsequent destroyal on application of glyphosate followed by CB and CE spraying. The control might be because of the stimulated germination of the seeds accumulated on the surface. Application of glyphosate completely killed the established weeds, whereas the simultaneous application of oxyfluorfen inhibited the germination and establishment of new weeds from the soil seed bank by its pre-emergence action. Chauhan and Johnson (2008) also suggested that the soil seed bank of *L. chinensis* could be depleted by SSB strategies before crop establishment, as there is a low amount of primary dormancy in the seeds indicated by the high germination (95%) immediately after maturity. Jiang (1989) testified that oxyfluorfen at 0.1 kg ha^{-1} gave 90-100 per cent control of *L. chinensis*.

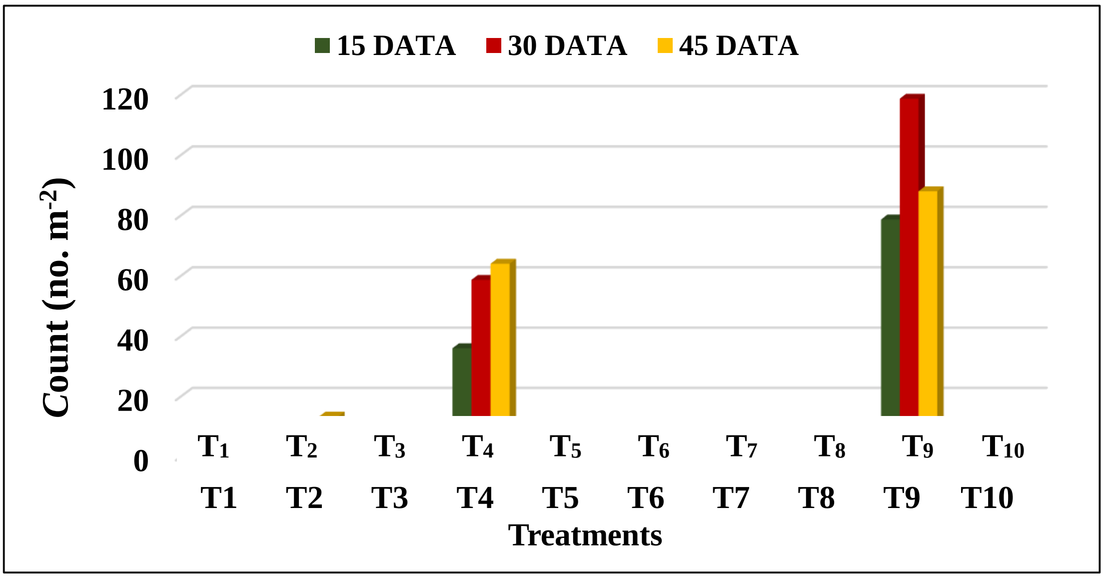
According to Jose *et al*. (2013), oxyfluorfen's contact and residual activity destroyed weed seeds in the top layer of soil, reduced initial crop weed competition and standing water prevented further seed germination.

Application of BS alone @ 0.025 kg ha^{-1} was found not effective in controlling *L. chinensis* throughout the crop growth period. Several researchers reported the inefficiency of BS against *L. chinensis* (Gopal *et al*., 2010; Chauhan and Abugho, 2012; and Atheena, 2016). On the other hand, its combination with FPE @ 0.06 kg ha^{-1} or CB @ 0.08 kg ha^{-1} resulted in corresponding reduction of 91.67-100.0 and 87.5-93.95 per cent of the *L. chinensis* population. Wang *et al*. (2000) reported that BS when applied with thiobencarb or FPE was effective against *L. chinensis*. Mahajan and Chauhan (2015) also reported improved control of aerobic grass weed, *L. chinensis* with the tank mix application of FPE and BS. Acetolactate synthase (ALS) is the main target of herbicides and BS prevented biosynthesis of branched chain amino acids by inhibition of ALS, but its activity was low in *L. chinensis* and it was recommended that 10% BS be applied with thiobencarb or FPE, especially controlled *L. chinensis* (Wang *et al*., 2000).

Among the herbicide combinations, penoxsulam (PS) + CB (6% OD) @ 0.15 kg ha^{-1} butyl could not give satisfactory control of *L. chinensis* during both years and recorded the highest persistent number of *L. chinensis* among the combinations. The possible reason for the observation might be the sandy clay loam texture of the soil with 61.7 per cent sand, 9.3 per cent silt and 28.1 per cent clay. This is in consonance with the findings of Prakash *et al*. (2017) wherein the ready mix formulation of PS + CB recorded higher total weed dry weight compared to other combinations, in a sandy loam texture. Verma *et al*. (2017) also reported that PS + CB @ 120 g a.i. ha^{-1} did not give satisfactory control of grass weeds, BLWs and sedges after 10 days of herbicide application, where the soil texture was sandy loam. On the other hand, studies conducted by Lap *et al*. (2013), Pratap *et al.* (2016), Raj (2016) and Yadav *et al*. (2018) realized complete control of *L. chinensis* with PS + CB combination. Control of *L. chinensis* with this combination performed better in soils dominated by clay (either clayey, clay loam, or silty clay loam) compared to sand.



A



B

Fig. 19. Effect of weed management practices on count of *Leptochloa chinensis*, *Kharif* 2018 (A) *Kharif* 2019 (B)

Application of CB @ 0.08 kg ha^{-1}, PS + CB (6% OD) @ 0.15 kg ha^{-1}, BS @ 0.025 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} and SSB *fb* chemical weeding resulted in 100 per cent control of *E. colona* at 15 DATA during both years. This result was in line with the findings of Lap *et al*. (2013), who reported that the aryloxyphenoxy propionate rice herbicide, CB was effective against *Echinochloa* spp. and both the active ingredients in the ready mix combination of PS + CB provided excellent control of *Echinochloa* spp.. Post emergence application (PoE) of CB at 80 g ha^{-1} was found effective in controlling *E. colona* (Choubey *et al.*, 2001). Scott (2003) also found CB as a very effective herbicide against barnyard grass. Walia *et al*. (2008) indicated the effectiveness of PoE application of BS @ 0.025 kg ha^{-1} against *E. colona.*

Application of FPE @ 0.06 kg ha^{-1} was not effective in controlling *E. colona* and resulted in a higher count irrespective of the crop growth period. Bhullar *et al*. (2016) also reported the ineffectiveness of FPE in managing *E. colona* still, it significantly reduced the density of *L. chinensis*. Conversely, its tank mix combination with BS @ 0.025 kg ha^{-1} resulted in lower count of *E. colona* with 100 per cent reduction at 15 and 30 DATA and 97.5 per cent at 45 DATA. Compared to the sole application of FPE @ 0.06 kg ha^{-1} and BS @ 0.025 kg ha^{-1}, the tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} resulted in a decreased count of *E. colona* at all stages. It is apparent that the combination had a synergistic effect in managing *E. colona* as tank mix and might be the reason for lower population in combination spray compared to sole application. On the contrary, the tank mix combination of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} resulted in 63.40 and 41.73 per cent increase in *E. colona* count compared to the sole application of CB @ 0.08 kg ha^{-1}, respectively at 30 and 45 DATA, and recorded higher populations at all stages of observation. This is suggestive of an antagonistic effect of the herbicide combination in managing *E. colona.* Several studies authenticated the antagonistic effect of CB in various combinations like with broad leaf herbicides against barnyard grass (*E. crus-galli*) by Branson *et al.* (2002) and with 2,4-D amine or acifluorfen by Scott (2003).

Fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} and the tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} were effective in controlling *I. miliacea* at all stages during both years as evident from the lower weed count. This result is in agreement with the findings of Suada (2015) and Renjan (2018). Compared to the weedy check, FPE recorded significantly lower dry weight of *I. miliacea* (Renjan and George, 2018). SSB *fb* chemical weeding achieved complete control of *I. miliacea* at early stages of crop growth. The non-traditional rice herbicide glyphosate gave excellent control of *I. miliacea* and no regrowth was observed after two weeks (Suada, 2015). The control of *I. miliacea* was poor with the sole application of CB @ 0.08 kg ha^{-1} and its combinations with CE @ 0.02 kg ha^{-1} or BS @ 0.025 kg ha^{-1} during later stages of the crop. The ready mix combination of PS + CB (6% OD) @ 0.15 kg ha^{-1} and the sole application of BS @ 0.025 kg ha^{-1} were less effective against *I. miliacea* compared to FPE @ 0.06 kg ha^{-1} and its combination with BS @ 0.025 kg ha^{-1}. Suada (2015) reported that BS and PS could provide initial control of *I. miliacea*, whereas regrowth was seen after two weeks.

The dominant BLWs observed in the experimental field were *S. zeylanica* and *B. capensis*, which were effectively controlled by BS @ 0.025 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, PS + CB (6% OD) @ 0.15 kg ha^{-1} and SSB *fb* chemical weeding. According to Raj *et al*. (2013), BS 10 SC (30 g ha^{-1}) was found to be very effective against *S. zeylanica*. PS + CB premix at 1.0 L ha^{-1} provided excellent control of *S. zeylanica* when applied at 0-14 days after planting (Lap *et al*., 2013).

Another BLW observed in the experimental field during both years was *M. vaginalis*. Its population was found to be high during initial stages of the crop in unweeded control and a gradual decrease in population was observed towards later stages. Under submerged conditions, majority of *M. vaginalis* seedlings emerged within a short span of time, the peak germination being between 15 to 25 days (Noda and Eguchi, 1965). During both years, SSB *fb* chemical weeding achieved complete control of *M. vaginalis* at 15 DATA. However, the treatment failed to produce satisfactory control of *M. vaginalis* at 30 and 45 DATA during both years and resulted in a higher population.

The enhanced germination of *M. vaginalis* on flooding favoured its proliferation during staling followed by flooding. Tank mix application of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} had no effect on *M. vaginalis* and resulted in a higher population at all stages. The result find ample support from the findings of Atheena (2016), where, in a comparison of tank mixing and sequential application of CB and CE, tank mixing was ineffective on *M. vaginalis,* and follow up application of CE resulted in a lower population.

Penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}, BS @ 0.025 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} ensured more than 60 per cent control of *M. vaginalis* at all stages during both years. The population reduction was correspondingly extended to 95.84, 75, 77.86 and 95.25 per cent, and 95.84, 100, 100 and 100 per cent, respectively at 15 and 30 DATA. The PS + CB premix at 1.0 L ha^{-1} provided excellent control (95 to 100%) of *M. vaginalis* when applied 4 to 18 DAP in Philippines and Vietnam (Lap *et al*., 2013). Atheena (2016) also reported the effectiveness of BS in controlling *M. vaginalis.*

During 2018, *L. flava* appeared in the experimental field only after 15 DATA, whereas in 2019 it was present from the beginning. *L. flava* was completely controlled by the herbicide combinations PS + CB (6% OD) @ 0.15 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} at 15 and 30 DATA. BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} was very effective in managing *L. flava* and realized 100 per cent control throughout the crop period. Application of BS @ 0.025 kg ha^{-1} resulted in 75.04 per cent reduction of *L. flava* at 15 DATA and complete control at 30 and 45 DATA. Nishan (2012) reported that BS @ 30 g a.i. ha^{-1} was effective in controlling *L. flava* and was on par with metsulfuron methyl + chlorimuron ethyl @ 6 g a.i. ha^{-1}. Tank mix combination of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} and SSB *fb* chemical weeding also achieved cent per cent control at 15 DATA but failed to maintain the same level of control at 30 DATA and later.

During both years, CB @ 0.08 kg ha^{-1} and FPE @ 0.06 kg ha^{-1} registered a higher population of BLWs (*S. zeylanica, B. capensis, M. vaginalis* and *L. flava*) as they are known grass killers. Ampong-Nyarko and De Datta (1991) reported that

M. vaginalis is resistant to FPE. As reported by Atheena (2016), CB alone registered higher count of *M. vaginalis.*

Cyperus iria, *C. difformis* and *F. miliacea* were the sedges observed in WSR during the crop growth period. The population of these sedges was low in the experimental field compared to grass weeds and BLWs before treatment application. All the weed management practices ensured cent per cent control of *C. iria* at 15 DATA. PS + CB (6% OD) @ 0.15 kg ha^{-1}, BS @ 0.025 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} and HW twice at 20 and 45 DAS resulted in zero count of *C. iria* at all stages of observation. However, CB @ 0.08 kg ha^{-1} and CB @ 0.08 kg ha^{-1} + @ 0.02 kg ha^{-1} though showed 100 per cent control at initial stages of crop growth failed to maintain better WCE later. This could be due to the short term contact action CE @ 0.02 kg ha^{-1}.

Stale seedbed *fb* chemical weeding provided complete control of all the sedges during the initial stage. Chauhan and Johnson (2010) discoursed that *C. iria*, *C. difformis* and *F. miliacea* were relatively more susceptible to the SSB technique owing to their low seed dormancy and the inability to emerge from a depth greater than 1 cm. Jiang (1989) reported that oxyfluorfen at 0.1 kg ha^{-1} offered 90-100 per cent control of *C. iria*.

Application of PS + CB (6% OD) @ 0.15 kg ha^{-1} and BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} were found to be effective in controlling *C. difformis, C. iria* and *F. miliacea* at all stages during both years. Lap *et al.* (2013) reported that PS + CB premix at 1.0 L ha^{-1} (10 + 50 g a.i. L^{-1}) provided very good control of above mentioned sedge species when applied at 0-14, 4-14 and 0-18 DAP, respectively and was on par with premix at 1.25 or 1.5 L ha^{-1}. According to Pal and Banerjee (2007) and Singh *et al.* (2009), PS was effective against *C. difformis.*

Sole application of BS @ 0.025 kg ha^{-1} and its tank mix combination with CB @ 0.08 kg ha^{-1} were effective in controlling *F. miliacea* during 2019. However, the control was effective upto 15 DATA during 2018. Similar results were obtained by Prashanth *et al*. (2015).

Application of CB @ 0.08 kg ha^{-1} and FPE @ 0.06 kg ha^{-1} alone was not effective in managing *C. difformis* and *F. miliacea* and resulted in higher count at all stages. The result was corroborated by the findings of Jacob (2014), who found that CB and FPE were ineffective against *Cyperus* spp. and *F. miliacea.* However, the tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} attained higher control efficiency than the individual herbicides and resulted in 100 per cent control of *C. difformis* and *F. miliacea.* It is apparent that tank mixes have modified properties and perform better than its alone application suggesting the synergistic effect of the combinations in managing *C. difformis* and *F. miliacea*.

5.3.1.3 Effect of weed management treatments on total weed count

Among the weed management practices, tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} registered the least count of grass weeds at all stages and registered 100, 96.89 and 92.97 per cent reduction in weed count over unweeded control at 15, 30 and 45 DATA in WSR (Fig. 20, 21 and 22, respectively). The lower count of grass weeds could be attributed to the combined efficiency of the mix in broad spectrum control of grass weeds. FPE @ 0.06 kg ha^{-1} was also effective against grass weeds, with 97.17, 94.32 and 91.24 per cent reduction over unweeded control, respectively, at 15, 30 and 45 DATA. Kuah and Salehuddin (1988) found that FPE had the potential to control grass weeds in DSR. Dixit and Varshney (2008) and Jacob *et al*. (2014) also reported the effectiveness of FPE at 60 g ha^{-1} for controlling grass weeds in DSR. Application of FPE at 56.25 g ha^{-1} 10 DAT effectively controlled *E. colona, E. crus-galli, L. chinensis* and *I. rugosum* (Singh *et al.,* 2004). BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} registered lower count of grass weeds compared to the their sole application and could be considered as an additive selection for control of grass weeds.

The application of CB @ 0.08 kg ha^{-1} resulted in very good control of grass weeds in WSR compared to the application of broad spectrum herbicide, BS @ 0.025 kg ha^{-1}. Saini (2003) reported CB at 100 g ha^{-1} as PoE application for annual grass weeds in WSR. The higher population of grass weeds in BS @ 0.025 kg ha^{-1} could be ascribed to the higher count of *L. chinensis.* This indicated the inefficiency of BS in managing *L. chinensis,* even though effective against grass weeds. The highest count of *L. chinensis* was observed with the application of BS 10% SC (Abeysekera and Wickrama, 2004). In contrast, the tank mix of BS @ 0.025 kg ha^{-1} with FPE @ 0.06 kg ha^{-1} or CB @ 0.06 kg ha^{-1} brought about 35-50 and 11-40 per cent reduction in *L. chinensis* population, respectively.

The sole application of CB @ 0.08 kg ha^{-1} provided better control of grass weeds compared to its tank mix combination with BS @ 0.025 kg ha^{-1} and CE @ 0.02 kg ha^{-1}, which recorded reduction of 50.09, 28.26 and 24.61 per cent and 36.03, 11.16 and 10.56 per cent, correspondingly at 15, 30 and 45 DATA. The higher count of grass weeds obtained in PS + CB (6% OD) @ 0.15 kg ha^{-1} was contributed from the uncontrolled *L. chinensis* population.

In the experimental site, which was dominated by grass weeds, the number of BLWs was generally low. Application of BS @ 0.025 kg ha^{-1} was found to be effective in regulating BLWs during both the years. The efficiency of BS in controlling BLWs resulted in the lowest count under the treatment. According to Raj *et al*. (2013), BS 10 SC (30 g ha^{-1}) was found to be very effective against BLWs such as *M. vaginalis, L. perennis* and *S. zeylanica*. A lower count of BLWs was observed under the tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, which recorded a reduction of 73.39 and 26.02 per cent, respectively, at 15 and 30 DATA, compared to the sole application of BS @ 0.025 kg ha^{-1}. This might be due to the synergistic effect contributed by FPE towards BS in managing BLWs, even though FPE is known to be a grass killer. Application of the ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} was also effective in controlling BLWs except for *L. perennis.* Application of CB @ 0.08 kg ha^{-1} and FPE @ 0.06 kg ha^{-1} were not able to control BLWs as these are grass herbicides. PoE application of CB was ineffective in controlling BLWs (Saini *et al*., 2001; Kiran and Subramanyan, 2010).

Stale seedbed *fb* chemical weeding resulted in the lowest BLW count at the early stages of the crop. Staling stimulated the emergence of BLWs which are mostly seed propagated and multiple modes of action maximized the efficiency of chemical weeding.

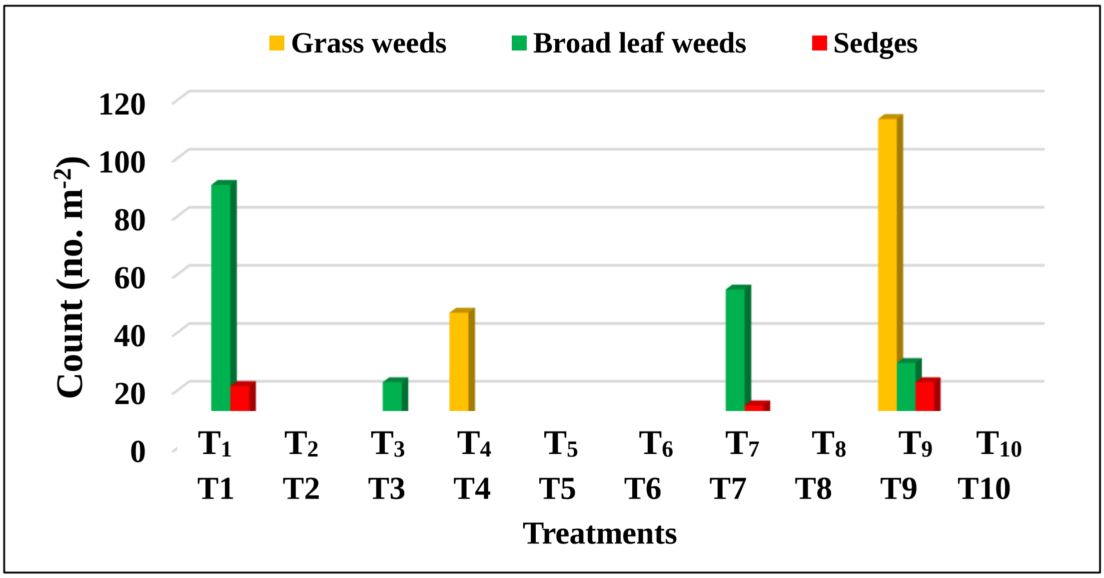
In DSR, the SSB technique combined with the application of a non-selective herbicide was shown to be more effective than mechanical weeding in reducing weeds (Renu *et al*., 2000). However, the treatment failed to maintain control in the later stages due to excessive aggregation of *M. vaginalis* and *L. flava* under flooding.

Though PS + CB (6% OD) @ 0.15 kg ha^{-1} was efficient in controlling a wide range of BLWs, it was found ineffective against *L. perennis* in WSR. This accords for the reports of Menon *et al*. (2016).

Tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} resulted in lower sedge count at all stages of observation. Application of PS + CB (6% OD) @ 0.15 kg ha^{-1} and BS @ 0.025 kg ha^{-1} resulted in better control of sedges, correspondingly recording 91.35 and 85.62 per cent and 100 and 82.33 per cent reduction, respectively at 15 and 30 DATA. Singh *et al.* (2016) observed PS + CB as an effective herbicide for controlling sedges in transplanted rice. BS 10% SC at 35 g ha^{-1} (15 DAT) was found effective against *C. difformis, C. iria* and *Fimbristylis woodrowii* with higher weed control efficiency (82%) in transplanted rice (Prashanth *et al*., 2015).

Hand weeding twice at 20 and 45 DAS recorded lower count of weeds and realized 98.27, 98.88 and 92.95 per cent and 86.42, 90.73 and 46.15 per cent reduction of grass weeds and BLWs over unweeded control at 15, 30 and 45 DATA. HW twice at 20 and 45 DAS reduced the sedge population by 100 per cent compared to the unweeded control at 15 and 30 DATA. This result was corroborated by the findings of Mubeen *et al*. (2014), who opined that HW reduced the density of weeds by 90 per cent, particularly grass weeds. However in the study, no sedges were detected in the unweeded control towards the end of the crop. This could be due to early completion of their growth and life cycle.

Unweeded control resulted in greater weed count at all stages of crop growth. However, the data revealed a downward trend in weed count towards the later stages. The decline can be ascribed to early completion of life cycle of certain weeds and suppression of late emerged weeds by other competing ones.



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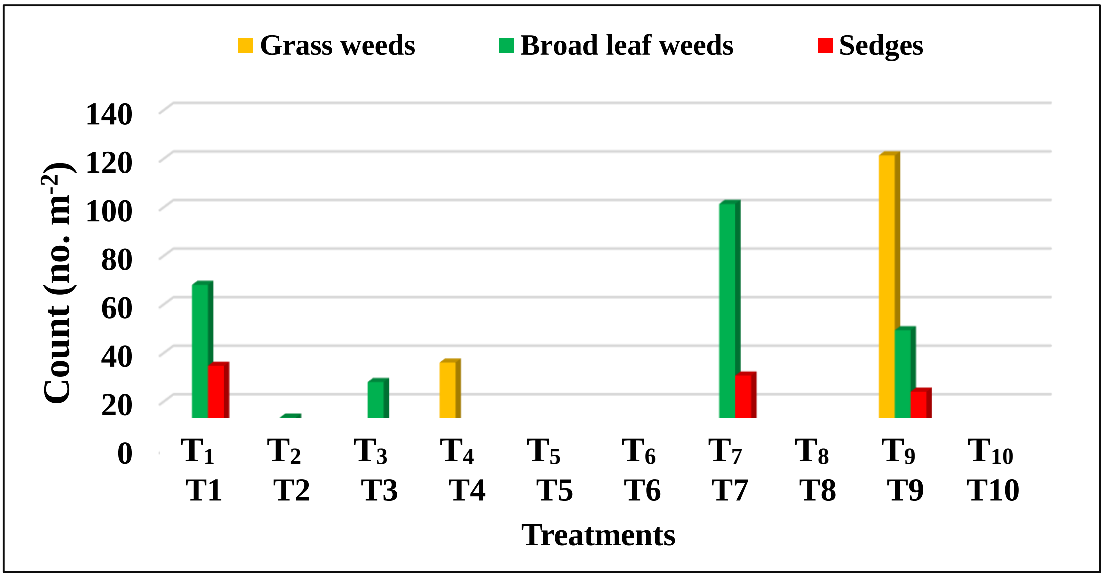
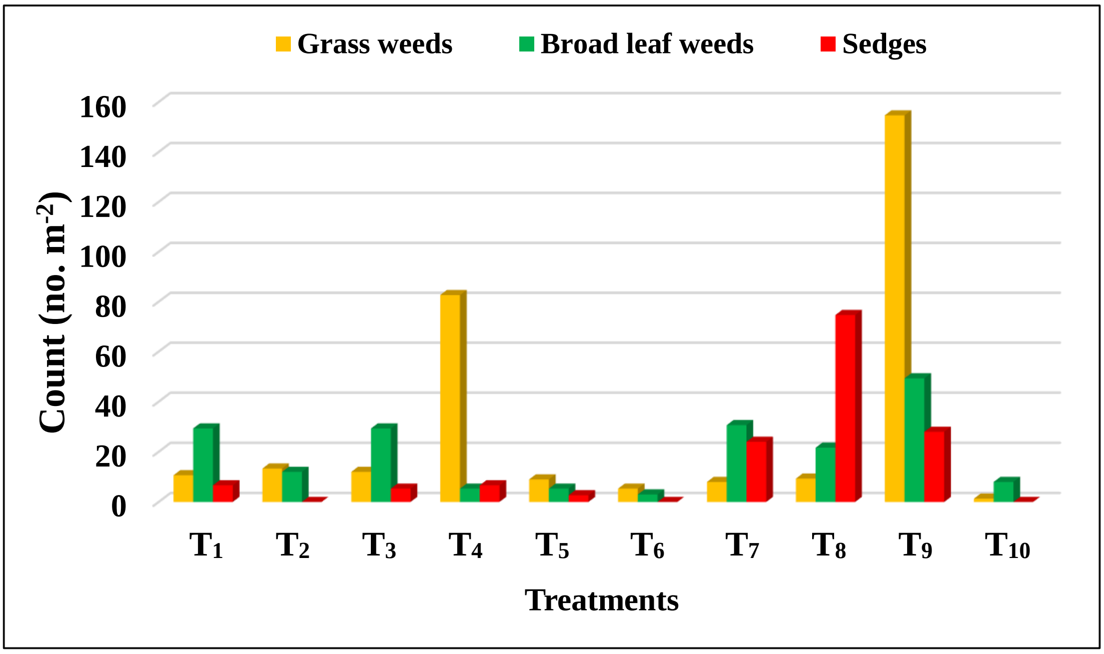


B

Fig. 20. Effect of weed management practices on weed count at 15 days after treatment application, *Kharif* 2018 (A) *Kharif* 2019 (B)



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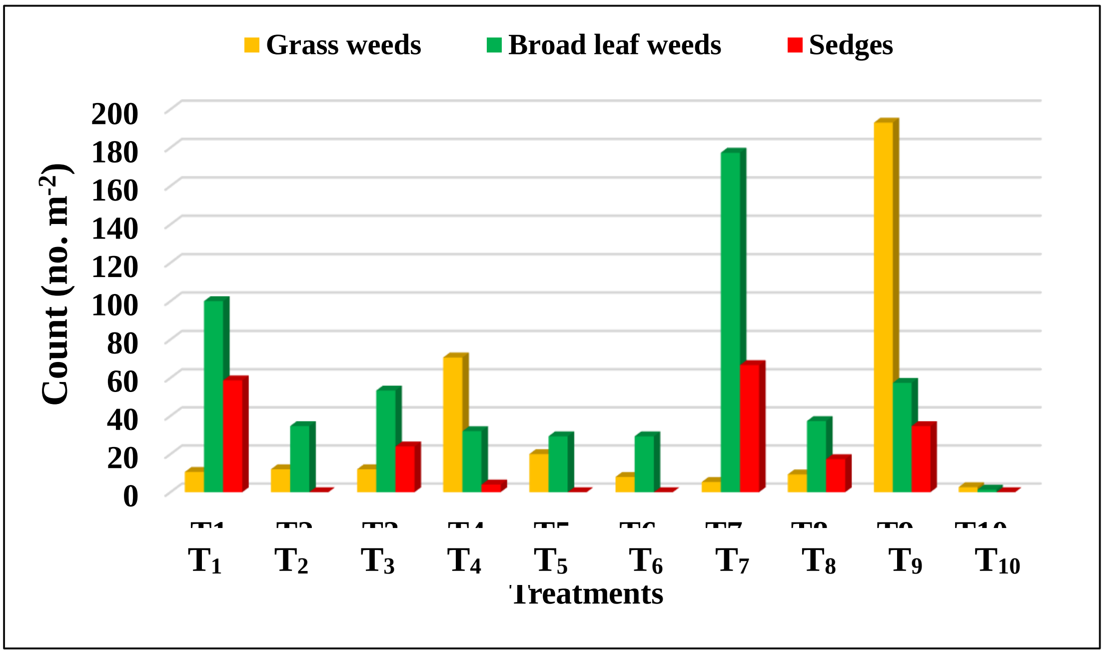
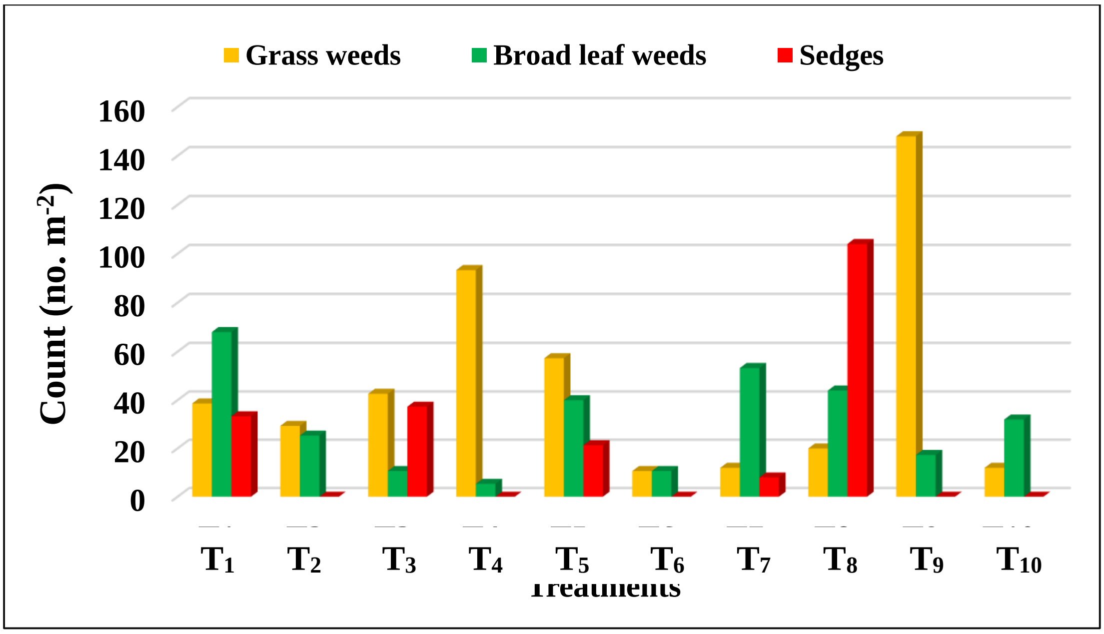
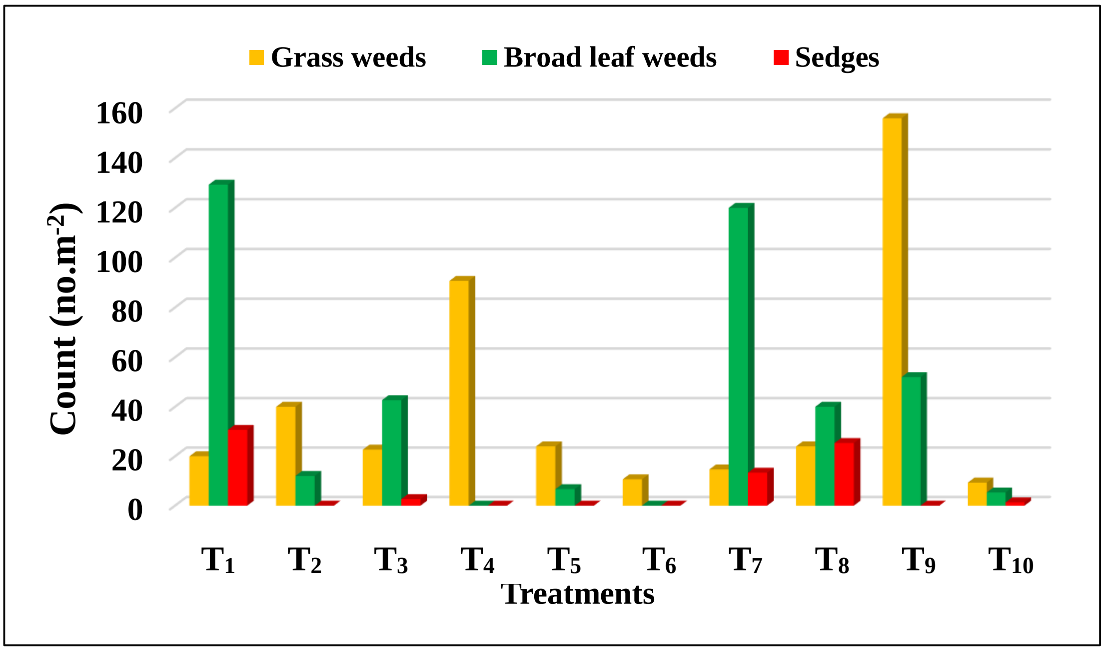


B

Fig. 21. Effect of weed management practices on weed count at 30 days after treatment application, *Kharif* 2018 (A) *Kharif* 2019 (B)



A



B

Fig. 22. Effect of weed management practices on weed count at 45 days after treatment application, *Kharif* 2018 (A) *Kharif* 2019 (B)

5.3.1.4 Effect of weed management treatments on weed dry matter production

Perusal of the data revealed that treatments had significant effect on total weed dry matter production (DMP) at 15, 30 and 45 DATA during 2018 and 2019. Among weed control treatments, tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} registered the least weed DMP, which was significantly lower than their sole application. At 15, 30 and 45 DATA, the combination reduced weed DMP by 83.09, 83.89 and 96.55 per cent, 86.38, 93.18 and 98.20 per cent and 73.26, 86.49 and 89.70 per cent, respectively, when compared to BS @ 0.025 kg ha^{-1}, FPE @ 0.06 kg ha^{-1} and unweeded control (Fig. 23). The synergistic effect of the herbicide combinations would be the plausible reason for the lower DMP. BS @ 0.025 kg ha^{-1} provided effective control of grass weeds, BLWs and sedges, but its ineffectiveness on the aerobic grass *L. chinensis* resulted in large weed DMP. Abeysekera and Wickrama (2004), Jacob (2014) and Atheena (2016) also observed the inefficiency of BS in controlling *L. chinensis.* However, when BS @ 0.025 kg ha^{-1} was combined with FPE @ 0.06 kg ha^{-1} or CB @ 0.08 kg ha^{-1}, the DMP of *L. chinensis* was reduced by 100, 94.02 and 92.89 per cent and 94.26, 88.04 and 92.89 per cent at 15, 30 and 45 DATA, respectively (Fig. 24). Wang *et al*. (2000) and Mahajan and Chauhan (2015) also reported the effectiveness of BS against *L. chinensis* when applied with FPE.

Stale seedbed *fb* chemical weeding at 15 DATA registered zero weed DMP upto 33-35 DAS. However, weed DMP accrued at later stages, which might be attributed to the lower efficiency of PoE CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} in managing late emerged *M. vaginalis* and *L. flava*.

Though PS + CB (6% OD) @ 0.15 kg ha^{-1} was effective in managing a complex spectrum of weeds, DMP at 30 DATA was higher, which could be attributed to its lower efficacy in managing *L. chinensis* in sandy clay loam. This is consistent with the findings of Prakash *et al*. (2017) and Verma *et al*. (2017), where higher total weed dry weight was recorded in sandy loam soil. This ready mix combination showed variable results under different soil texture and needs further investigation.

Amongst the herbicidal treatments, weed DMP was the highest in CB @ 0.08 kg ha^{-1}, followed by FPE @ 0.06 kg ha^{-1} and BS @ 0.025 kg ha^{-1}, where sole application was adopted. Weed DMP was found to increase by 1.6-6.5 times in the plots that received applications of single herbicides compared to the plots with tank mix or ready mix applications. As an exception, CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} resulted in higher weed DMP at later stages and statistically comparable to that of BS. This was due to the inability of the combination to manage *M. vaginalis* and *F. miliacea.* The inability of BS to control *L. chinensis* and the efficacy of FPE and CB to control *L. chinensis* signified the need of herbicide combinations for managing complex weed flora in WSR.

Hand weeding twice at 20 and 45 DAS reduced weed DMP by 96.80, 98.56 and 92.84 per cent compared to unweeded control at 15, 30 and 45 DATA. This result was supported by the findings of Mukharjee and Maity (2011), where HW at the critical growth stages of the crop resulted in lower weed dry weight. There was an increase in weed DMP in most of the herbicidal treatments at 45 DATA and the *L. chinensis* DMP had increased to three-fold at 45 DATA over 30 DATA. The weed DMP in the unweeded control was increased five-fold (Fig. 25), from 15 to 30 DATA. However, it was less at 45 DATA than at 30 DATA during both years. The reduction in DMP per unit area towards the later stages might be caused by the decreased count of weeds in unweeded control.

5.3.1.5 Effect of weed management practices on nutrient removal by weeds

Nutrient removal is a function of total DMP and nutrient content, and it reflects the competitive capacity of weeds, which limits the availability of nutrients to the crop, instigating yield reduction.

Nutrient removal by weeds was statistically influenced by weed management practices. Nutrient removal closely matched the trend of weed DMP. Removal of N, P and K by weeds was noticed more in unweeded control irrespective of the crop growth stage and depleted 27.72, 4.61 and 67.95 kg of N, P and K per hectare at 45 DATA (Fig. 26). This could be attributed to the higher DMP of weeds.

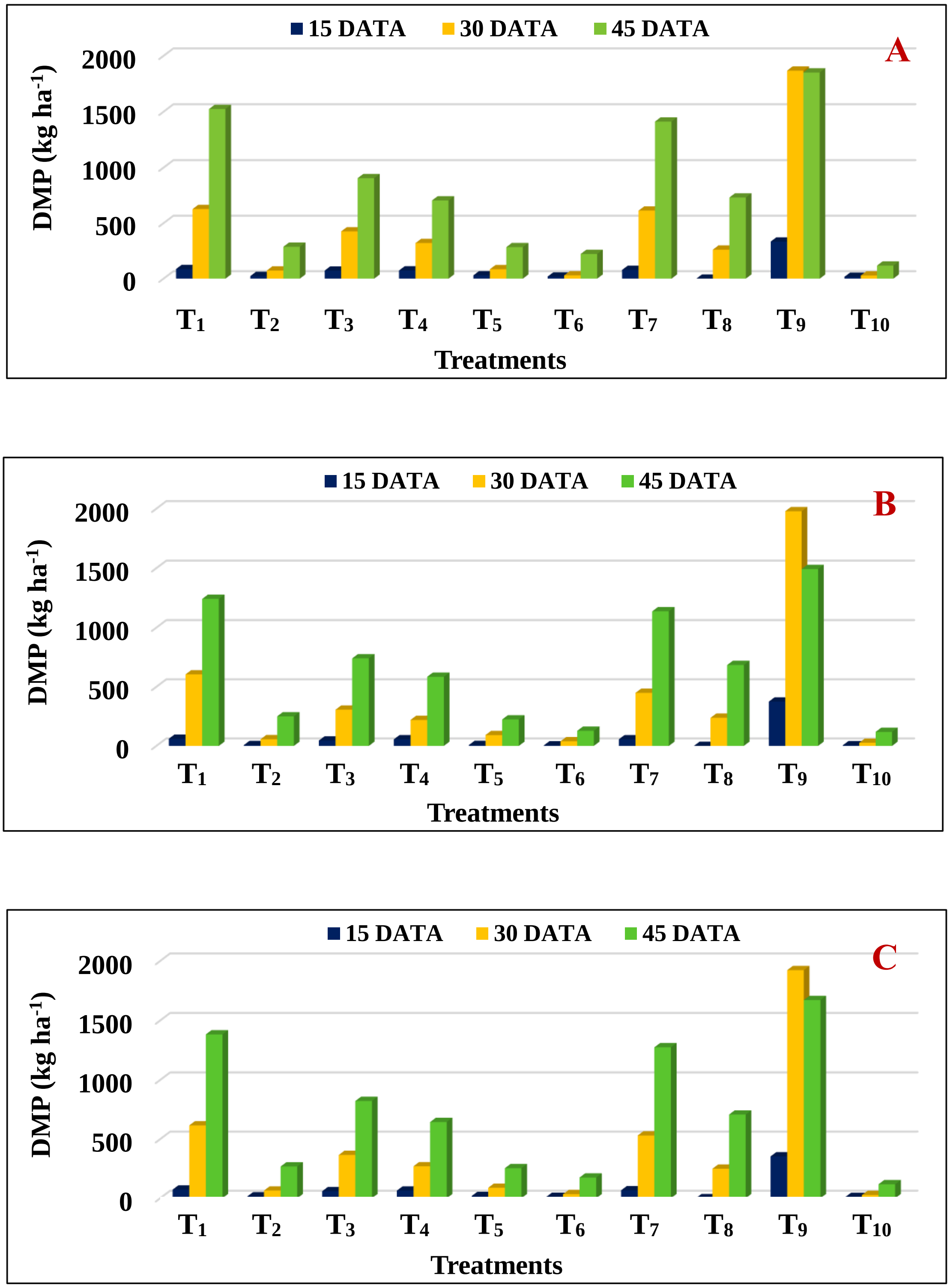


Fig. 23. Effect of weed management practices on weed dry matter production, *Kharif* 2018 (A) *Kharif* 2019 (B) Pooled (C)

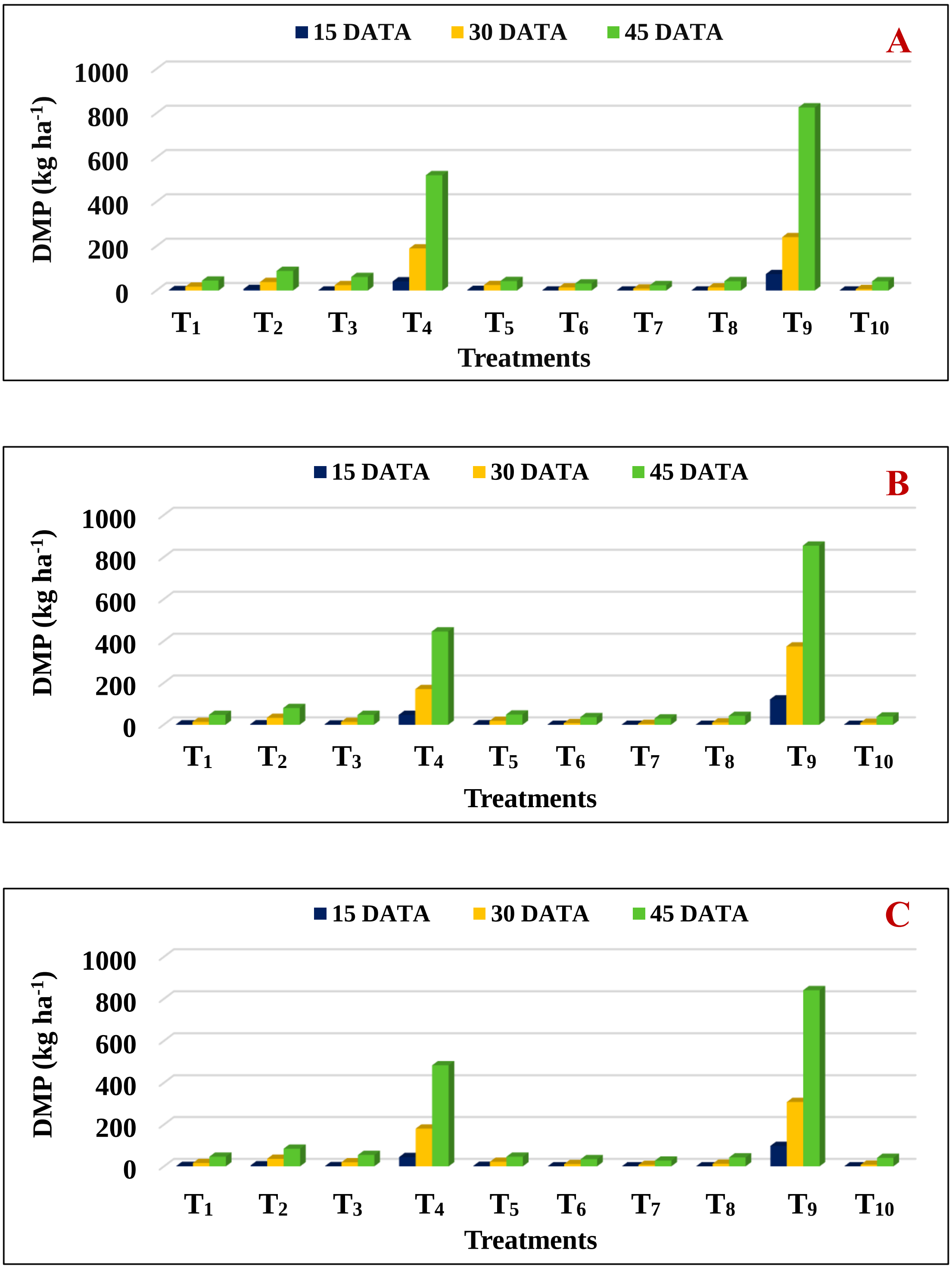


Fig. 24. Effect of weed management practices on dry matter production of *Leptochloa chinensis, Kharif* 2018 (A) *Kharif* 2019 (B) Pooled (C)

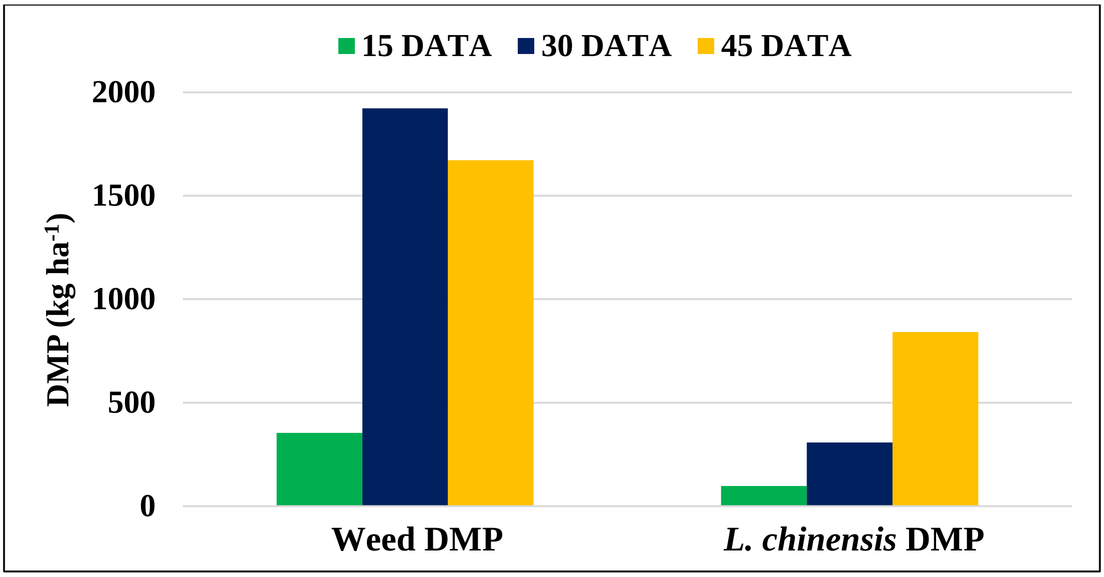


Fig. 25. Weed dry matter production in unweeded control at 15, 30 and 45 days after treatment application (pooled)

Similar results were also reported by Jacob (2014) and Reddy (2020). As per Ramamoorthy (1991), when weeds were allowed to compete with rice, they washed out 25.8 kg N, 3.65 kg P_2O_5 and 21.83 kg K_2O.

The removal of NPK was the least (zero) in the SSB *fb* chemical weeding at 15 DATA. However, the treatment failed to continue the trend due to the increased population of weeds and higher DMP by weeds, especially BLWs and sedges.

The hand weeded treatment, tank mix combination of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} and ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} registered the lowest values of nutrient removal. When compared to unweeded control, these treatments correspondingly reduced N, P, and K removal by 92.35, 89.72, 85.22 and 82.31 per cent, 89.15, 88.28, 74.74 and 73.90 per cent, and 95.33, 93.49, 89.85 and 89.23 per cent. This might be due to the efficient control of broad spectrum of weeds, which resulted in low weed DMP and hence low nutrient removal. Among the herbicide combinations, CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} registered the highest removal of major nutrients, which might be attributed to the inefficiency of the treatment to control *M. vaginalis* as indicated by its increased population and higher weed DMP.

In WSR, *L. chinensis* removed 18.76, 1.46 and 34.81 kg N, P and K per hectare under unweeded conditions at 45 DATA (Fig. 27). Higher nutrient removal by *L. chinensis* irrespective of the growth stages was contributed by the increased DMP. Singh and Dash (1988) had cited the positive correlation between N uptake and weed dry weight. NPK removal by *L. chinensis* also followed the trend of DMP by the weed. As reported by Reddy (2000), *L. chinensis* removed 16.5 kg N, 3.5 kg P and 25.8 kg K per hectare from weedy check. Unweeded control was followed by BS @ 0.025 kg ha^{-1} with nutrient removal of 10.0, 0.72 and 11.69 kg N, P and K per hectare. This also revealed the inefficiency of the herbicide to manage *L. chinensis.*

The lowest nutrient removal by *L. chinensis* was noticed in the plots treated with FPE @ 0.06 kg ha^{-1} and its tank mix combination with BS @ 0.025 kg ha^{-1}, resulting in 96.40, 98.94 and 97.89 per cent and 95.66, 98.73 and 97.37 per cent reduction in N, P and K removal, respectively, over unweeded control. The efficient control of *L. chinensis* by these treatments abridged the nutrient removal owing to the lower DMP. Even though the ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} was efficient in managing the broad spectrum of weeds, its inefficiency in sandy clay loam texture to control *L. chinensis* had led to a higher nutrient removal.

5.3.1.6 Effect of weed management practices on weed control efficiency and weed index

Weed control efficiency (WCE) measures the relative performance of weed management practices over weedy check (unweeded control).

Among the weed management practices, higher WCE of 96.80, 98.56 and 92.84 per cent were recorded in HW twice at 20 and 45 DAS, respectively at 15, 30 and 45 DATA. In WSR, tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} was equally effective as HW twice at 20 and 45 DAS with WCE of 96.55, 98.20 and 89.70 per cent, respectively at 15, 30 and 45 DATA (Fig. 28). This might be possible because of the efficient management of a broad spectrum of weeds by the combined action of herbicides with different mode of action. Similar results were described by Blouin *et al*. (2010), who found that mixtures of ALS inhibitor herbicides with FPE at optimum doses enabled greater weed control in rice.

Tank mix application of BS @ 0.025 kg ha^{-1} with FPE @ 0.06 kg ha^{-1} or CB @ 0.08 kg ha^{-1}, as well as ready mix combination of PS + CB (6% OD) @ 0.15 kg ha^{-1} showed superior weed control than sole applications of these herbicides. WCE with sole application of herbicides ranged from 79.05 to 81.46, 67.92 to 85.86 and 18.92 to 61.39 per cent, respectively at 15, 30 and 45 DATA, while, in herbicide combinations, it ranged from 83.01 to 100, 80.85 to 98.20 and 50.73 to 89.70 per cent, respectively. These results suggested that tank mixing of BS @ 0.025 kg ha^{-1} with FPE @ 0.06 kg ha^{-1} or CB @ 0.08 kg ha^{-1} and ready mix application of PS + CB (6% OD) @ 0.15 kg ha^{-1} might have a synergistic effect for broad spectrum weed control as total weed biomass was lower than the plots received sole application of herbicides and hence resulted in higher WCE. The effect was more pronounced when BS @

0.025 kg ha^{-1} was mixed with FPE @ 0.06 kg ha^{-1} and provided excellent broad spectrum weed control.

At 15 DATA, SSB *fb* chemical weeding resulted in the highest WCE of 100 per cent. This could be due to hardly any weed dry matter accumulation in the early stages. Herbicide combinations improved WCE by 26.79 to 33.87 per cent over alone application of BS where, sole application could register only 61.39 per cent at 45 DATA. With *L. chinensis* as major weed, the data on WCE (52.63, 38.68 and 42.43 per cent, respectively at 15, 30 and 45 DATA) distinctively revealed the ineffectiveness of BS.

At 15, 30 and 45 DATA, sole application of FPE @ 0.06 kg ha^{-1} had the highest WCE of 100, 97.55 and 96.78 per cent against *L. chinensis* (Fig. 29). FPE @ 0.06 kg ha^{-1} and CB @ 0.08 kg ha^{-1} exhibited the lowest total weed control among the treatments due to its inefficient control of BLWs and sedges. Conversely, the tank mix application of CB @ 0.08 kg ha^{-1} or FPE @ 0.06 kg ha^{-1} with BS @ 0.025 kg ha^{-1} improved the control of *E. colona, M. vaginalis*, *C. iria* and *F. miliacea* as compared to sole application and in turn enhanced the WCE in herbicide combinations. Bhullar *et al*. (2016) earlier reported the synergistic effect of tank mixture of FPE and ethoxysulfuron at higher doses of FPE (67 and 83 g ha^{-1}). This indicated the need of herbicide combinations for broad spectrum weed control in WSR.

The weed index (WI) denotes the reduction in yield due to weed competition in different weed control treatments over HW, which represents a completely weed free situation. Taking HW twice as control, the yield loss in WSR was estimated to be 59.95 per cent due to uncontrolled weed competition, while tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} resulted in minimum reduction of 3.09 per cent (Fig. 30). This is consistent with findings of Reddy (2020), who reported that weeds cause 59.75 per cent yield loss in WSR. Several studies authenticated that weeds reduced yield by 53 per cent (Ramzan, 2003); 61 per cent (Maity and Mukherjee, 2008); 64-66 per cent (Mukherjee *et al*., 2008) and 46 per cent (Arunvenkatesh and Velayatham, 2010) in WSR.

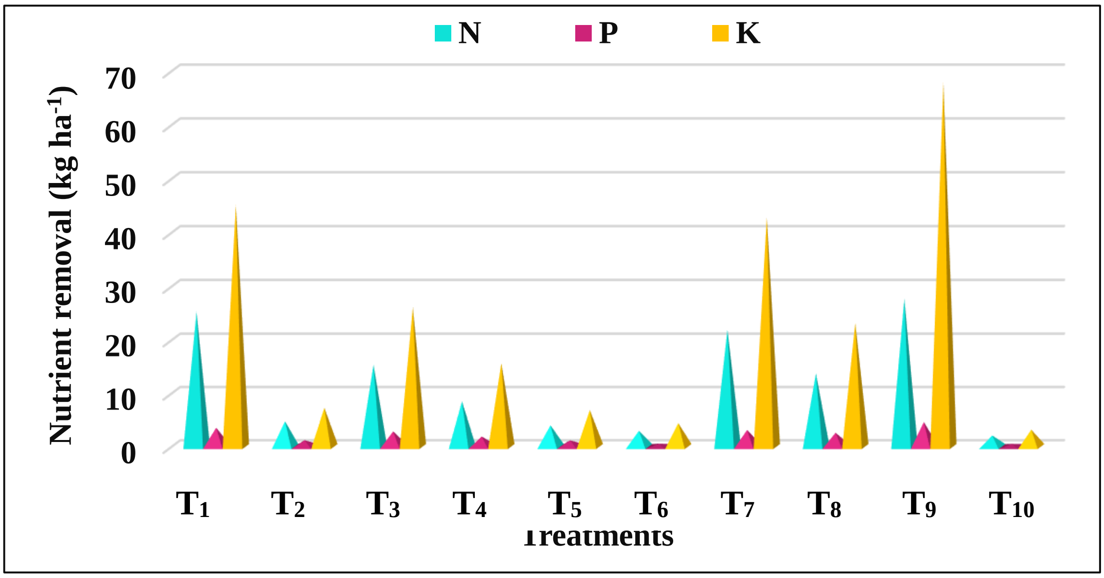


Fig. 26. Effect of weed management practices on nutrient removal by weeds at 45 days after treatment application (pooled)

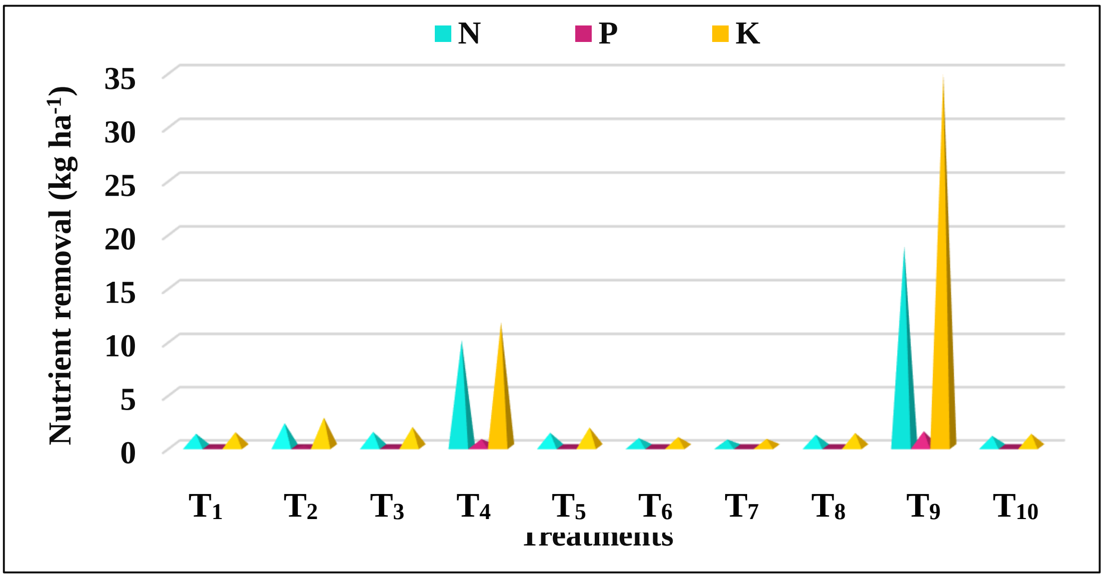


Fig. 27. Effect of weed management practices on nutrient removal by *Leptochloa chinensis* at 45 days after treatment application (pooled)

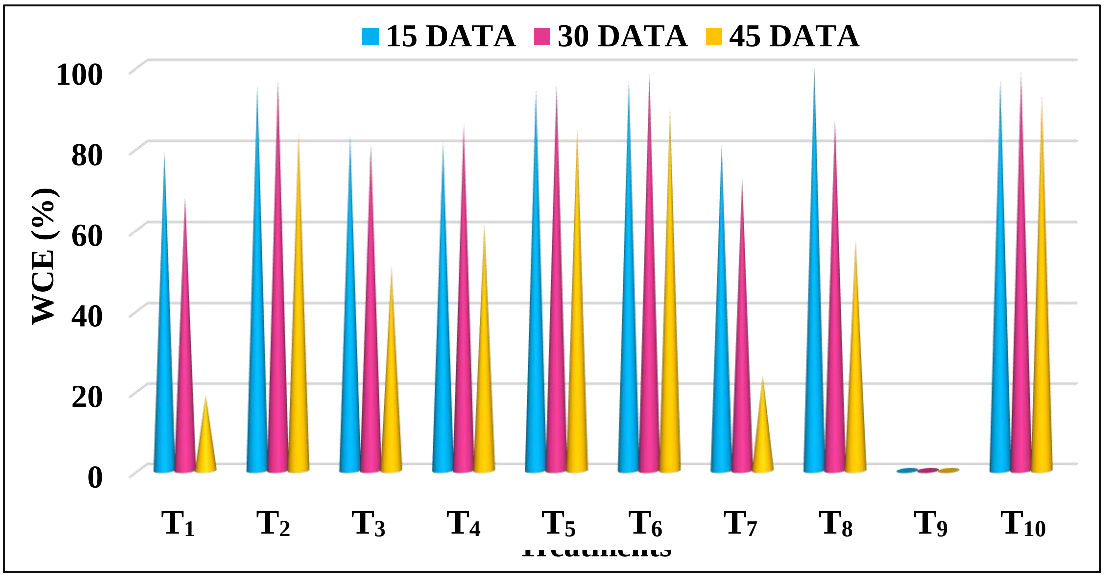


Fig. 28. Effect of weed management practices on weed control efficiency (pooled)

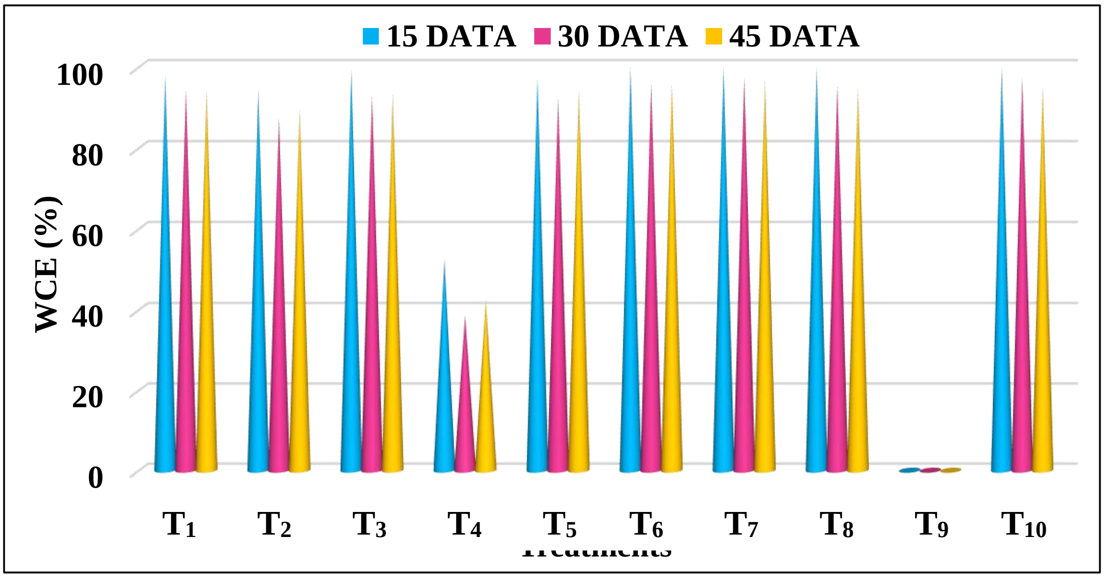


Fig. 29. Effect of weed management practices on control efficiency of *Leptochloa chinensis* (pooled)

Combined application of herbicides recommended for grass weeds, BLWs and sedges resulted in comparable WI values. The lower WI was registered in BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (3.09), PS + CB (6% OD) @ 0.15 kg ha^{-1} (7.83) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (8.60). This indicated the efficacy of herbicide combinations in enhancing competitiveness of the plant and ensuring better crop yield compared to its sole application.

5.3.2 Observations on crop

5.3.2.1 Phytotoxicity scoring

Most of the herbicides used recently are safer to crops as they are selective in nature. However, some can cause biochemical or physiological modifications in crops and may lead to the development of phytotoxic symptoms based on the active ingredient present. In the experiment, as some of the herbicides were tank mixed, chances of herbicide interaction are valid and chemical changes may occur which can cause phytotoxicity, particularly, as they are applied in early stages of crop growth.

Application of FPE @ 0.06 kg ha^{-1} and CE @ 0.02 kg ha^{-1} exhibited phytotoxic symptoms on rice at four and seven days after spraying (DASP). In FPE treated plots, rice plants showed white streaks on leaves, but later diminished within 7 DASP. Chauhan and Abugho (2012) and Shen *et al*. (2017) also observed a phytotoxic effect on rice plants with the application of FPE. Tank mix application of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} resulted in brownish discolouration on leaves and leaf sheath with a white halo and showed very severe injury on rice seedlings from the 2nd day onwards. However, the symptoms and severity were reduced to small brown spots by the 7th day. Langaro *et al*. (2016) opined that the physiology of rice plants is modified by the application of herbicides and the elicited responses to oxidative stress were more prominent with the application of CE. Atheena (2016) also reported a similar effect of CB + CE on rice. Application of CB @ 0.08 kg ha^{-1}, BS @ 0.025 kg ha^{-1} and PS + CB (6% OD) @ 0.15 kg ha^{-1} did not show any visual phytotoxic symptoms on rice plants. CB applied to rice plants did not show any visual phytotoxicity symptoms (Abeysekera and Wickrama, 2004).

Yadav *et al*. (2009) noted that there was no phytotoxicity for BS on rice. Lap *et al*. (2013) reported that application of PS + CB did not cause any phytotoxic symptoms in rice upto five times the specified use rate (300 g ha^{-1}).

All the herbicidal treatments imposed phytotoxic symptoms on weeds, and the incidence, severity and the effectiveness varied based on the active ingredient present in the herbicide formulation. In general, BLWs and dicot weeds exhibited more prominent symptoms where the apical buds of the weeds were severely affected. BLWs displayed severe phytotoxic symptoms with the tank mix application of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} which indicated that the efficiency of CE that selectively kills BLWs does not decrease even if tank mixed with CB. Yellowing of foliage and subsequent wilting and drying were the common symptoms observed in weeds treated with the ready mix combination of PS + CB (6% OD) @ 0.15 kg ha^{-1}.

5.3.2.2 Effect of weed management treatments on growth and yield parameters of rice

Growth of the plant is characterized by plant height, number of tillers and DMP. In the study, no significant difference in plant height was observed among the treatments at 30 DAS. The growth of plants under the treatments that showed phytotoxic symptoms too recovered within one week after application and did not influence their further growth.

All the herbicidal treatments resulted in taller plants with higher tiller production compared to unweeded control during both the years in WSR. The application of herbicides lowered weed competition at an early growth phase with better access of resources, leading to increase in height compared to unweeded control, where severe weed infestation was observed. Less crop weed competition during the early and critical stages of crop growth would result in superior crop growth and a competitive advantage in resource use (Reddy, 2020). Unweeded control resulted 6.61-14.36 per cent reduction in plant height in WSR. The significantly lower plant height recorded in unweeded control during both years might be attributed to the severe competition offered by the weeds, which resulted in poor resource use efficiency and inferior growth attributes. A reduction in height of rice plant due to competitive stress in unweeded check was reported by Jayasree (1987) and Sreedevi *et al*. (2009). Sahu (2016) reported a reduction in plant height of 14.25 per cent in unweeded control under direct seeded lowland conditions. The comparatively lower plant height in SSB *fb* chemical weeding at the initial stages might be due to the delay in germination caused by the application of oxyfluorfen, which gets adsorbed on to the organic matter in the soil. The strong adsorption of oxyfluorfen in the top soil layers (0-2 cm) and organic matter was earlier reported by Ying (1999) and Devi *et al*. (2015).

Due to severe weed competition, the number of tillers and panicles m^{-2} in the unweeded control was reduced by 37.72 and 66.64 per cent, respectively compared to HW twice at 20 and 45 DAS. Herbicide combinations resulted in 31.88 to 40 per cent and 58.69 to 66.58 per cent increase in tiller and panicle production per unit area, respectively as compared to unweeded control. BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1}, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, PS + CB (6% OD) @ 0.15 kg ha^{-1}, SSB *fb* chemical weeding correspondingly resulted in 40, 38.83, 37.84, 35.94 and 31.88 per cent and 62.77, 66.29, 66.58, 61.69 and 58.69 per cent increase in number of tillers and panicles m^{-2}.

Weed management practices had significant influence on the total DMP of crops. Application of herbicide combinations, either tank mix or ready mix, with the exception of CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1}, resulted in an increased crop DMP of 32.71 per cent compared to the sole application of herbicides. This might be due to the better control of weeds in these treatments owing to the reduced competition for resources such as space, light and nutrients. The crop's DMP is determined by the plant's ability to photosynthesize, which is dependent on leaf area, nutrient uptake, and favourable environmental conditions (De Datta, 1981). Lower crop DMP in CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} could be attributed to increased weed competition out of the antagonistic response and failure in controlling many weeds.

Cyhalofop butyl @ 0.08 kg ha^{-1}

Penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}

Cyhalofop butyl + carfentrazone ethyl @ 0.08 + 0.02 kg ha^{-1}

Bispyribac sodium @ 0.025 kg ha^{-1}

Bispyribac sodium + cyhalofop butyl @ 0.025 + 0.08 kg ha^{-1}

Bispyribac sodium + fenoxaprop-p-ethyl @ 0.025 + 0.06 kg ha^{-1}

Fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}

Plate 19. Phytotoxic effect of herbicides and herbicide combinations on *Leptochloa chinensis* at 7 days after spraying

The maximum grain yield (5.20 t ha^{-1}) was attained by HW twice at 20 and 45 DAS, with the highest WCE at all stages, and recorded 60.19 per cent increase in grain yield over unweeded control in WSR. Herbicidal treatments enhanced grain yield by 23.89-58.84 per cent compared to the unweeded control. Herbicide combinations of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, PS + CB (6% OD) @ 0.15 kg ha^{-1} and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} produced superior yield attributes and grain yield (5.03, 4.79 and 4.76 t ha^{-1}, respectively), which were statistically similar to the hand weeded weed free check. These treatments increased grain yield by 58.84, 56.78, and 56.51 per cent, respectively over the unweeded control. This could be due to the greater yield attributes associated with improved WCE. Grain yield is the ultimate result of the yield attributing characters like number of panicles m^{-2}, grains per panicle, fertility percentage and thousand grain weight (Kayvan e*t al*., 2007).

Among the treatments with herbicide combinations, the lowest grain yield was obtained in plots treated with CB @ 0.08 kg ha^{-1} + CE @ 0.02 kg ha^{-1} (3.95 t ha^{-1}), resulted from the lower crop DMP and yield attributes. Sole application of CB @ 0.08 kg ha^{-1} and FPE @ 0.06 kg ha^{-1} marked significantly inferior grain yield (2.72 and 3.16 t ha^{-1}) and higher WI (46.99 and 38.96) among the herbicidal treatments. Severe weed infestation caused by inefficient control of BLWs and sedges, as well as increased nutrient loss by weeds, resulted in lower crop yield.

Unweeded control recorded the least values in yield attributes, grain yield and straw yield with the highest WI of 59.95 per cent. Season long weed competition in the unweeded control reduced grain yield by 56.77 and 63.13 per cent, respectively, in WSR during 2018 and 2019, compared to the treatment with highest grain yield. The heavy and unhampered infestation of weeds contributed to very severe competition and inopportune exploitation of growth factors, which might have resulted in lower yields and yield attributes in unweeded control. The result is in conformity with the findings of Mohan *et al*. (2010) and Kachroo and Bayaza (2011) in WSR. Reddy (2020) also reported a grain yield reduction of 59.03 per cent in weedy check in WSR.

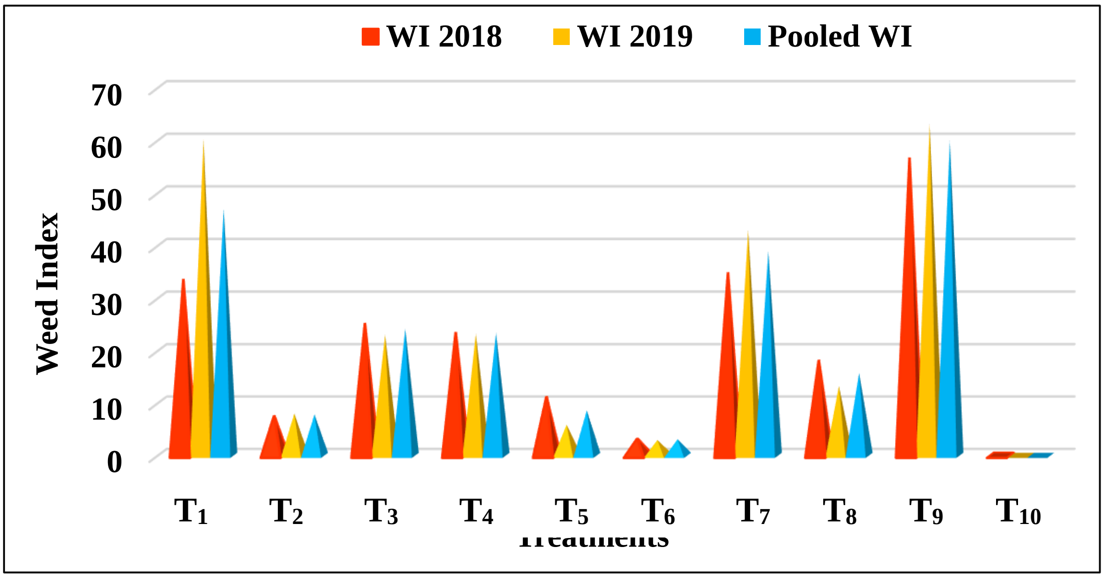


Fig. 30. Effect of weed management practices on weed index

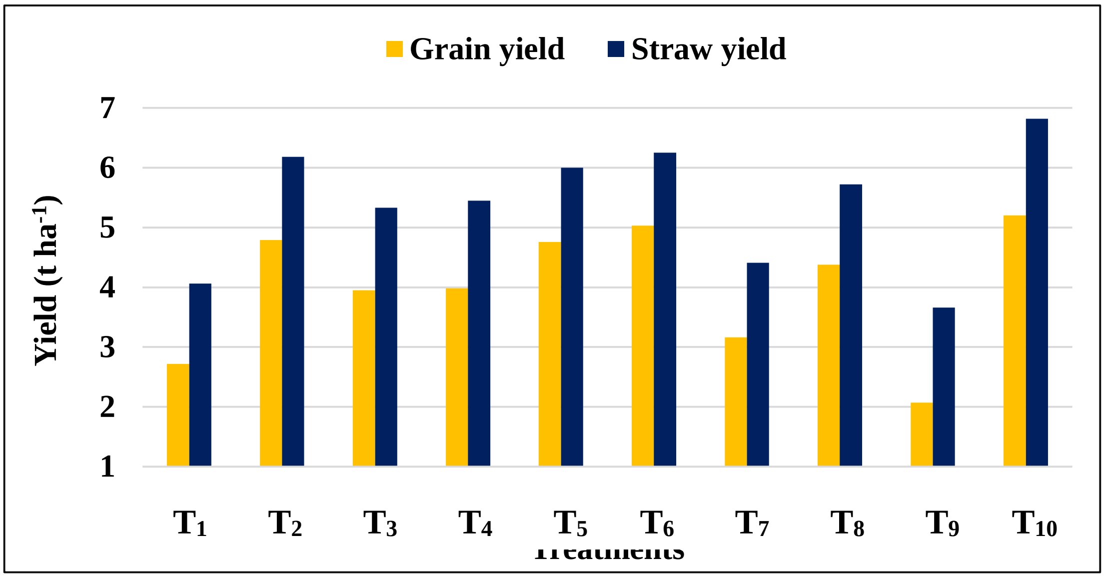


Fig. 31. Effect of weed management practices on pooled grain yield and straw yield

Higher straw yield was recorded in the hand weeded treatment (6.82 t ha^{-1}) and was on par with the herbicide combination treatments BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (6.25 t ha^{-1}), PS + CB (6% OD) @ 0.15 kg ha^{-1} (6.18 t ha^{-1}) and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} (6.00 t ha^{-1}). In comparison to unweeded control, these treatments increased straw yield by 46.33, 41.44, 40.77 and 39.0 per cent, respectively (Fig. 31). This could be ascribed to the increased tiller production as a result of improved crop stand and reduced competition. The unweeded control generated lower straw yield (3.66 t ha^{-1}) and lower harvest index. The reduced tiller count and poor crop stand might have resulted in decreased straw output in the unweeded control. In WSR, Reddy (2020) reported 39.14 per cent reduction in straw yield in the unweeded control.

Herbicide combinations produced higher grain yields than single herbicide applications, increasing grain yield by 16-28 per cent compared to sole application of BS and 56-59 per cent compared to unweeded control (Fig. 31). Higher yield attributes and yield in herbicide combinations compared to sole application during both years due to enhanced control of complex weed flora, could be leading to lower crop-weed competition. Rice plants in vigorous stands have an edge over weeds, which leads to greater growth, allometry, yield components, and, ultimately, increased yield.

5.3.2.3 Effect of weed management practices on nutrient uptake of crop

Nutrient uptake of the crop is a function of grain yield, straw yield and its nutrient content. The N, P and K uptake of both grains and straw was the highest in HW twice at 20 and 45 DAS. The decreased crop-weed competition at all stages of plant growth provided a favourable growing condition for the crop in the hand weeded plot and might have resulted in higher uptake of nutrients. Among the herbicidal treatments, BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1}, PS + CB (6% OD) @ 0.15 kg ha^{-1} and BS @ 0.025 kg ha^{-1} + CB @ 0.08 kg ha^{-1} recorded higher WCE and the highest nutrient uptake of the crop. This was due to better crop growth parameters resulting from the least weed count and weed DMP.

Higher grain and straw yields realized in these treatments were due to broad spectrum weed control, which resulted in higher WCE and less nutrient depletion by weeds, and therefore, greater nutrient uptake of the crop. This consequently increased the supply of carbohydrates to the plant organs, which might have resulted in higher DMP. Nanjappa and Krishnamurthy (1980) testified an inverse relationship between nutrient uptake of rice crops and nutrient depletion by weeds.

Crop nutrient uptake was the lowest in unweeded control, which documented 42.39, 3.99 and 38.05 kg N, P, and K per hectare, respectively (Fig. 32). Rigorous weed infestation might have curtailed the nutrient recovery by crops in unweeded control. The results are in close proximity with the findings of Sanjay *et al*. (2006), Menon (2012) and Reddy (2020).

5.3.2.4 Economics of cultivation

In the present study, the highest net returns (₹ 63, 657 ha^{-1}) and B:C ratio (1.81) were obtained in BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (Fig. 33). The higher economic benefit may be due to the low cultivation costs, which were offset by lower herbicide costs and higher grain and straw yields. Even though, FPE registered better control of *L. chinensis* in WSR, this herbicide alone could not deliver proficient weed management under field conditions because of the presence of complex weed flora and hence resulted in a lower B:C ratio. Even though, HW resulted in high gross returns, it was less remunerative compared to herbicide combinations due to the high cost involved in manual weeding. When compared to herbicidal management, manual weeding was less profitable and practicing manual weeding all over the season is a losing concern (Mahajan *et al*., 2009; Sunil *et al*., 2011; Reddy, 2020). Thus, for management of *L. chinensis* dominated rice fields under wet seeding, a tank mix combination of BS + FPE @ 0.025 + 0.06 kg ha^{-1} proved to be a feasible option as the returns obtained per rupee spent was 1.81.

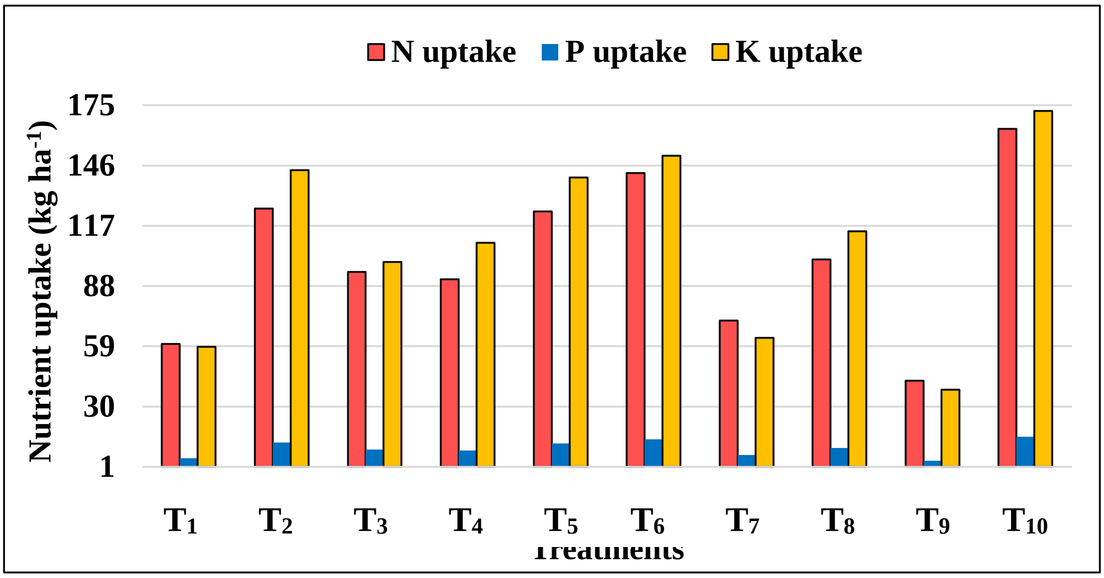


Fig. 32. Effect of weed management practices on nutrient uptake of the crop

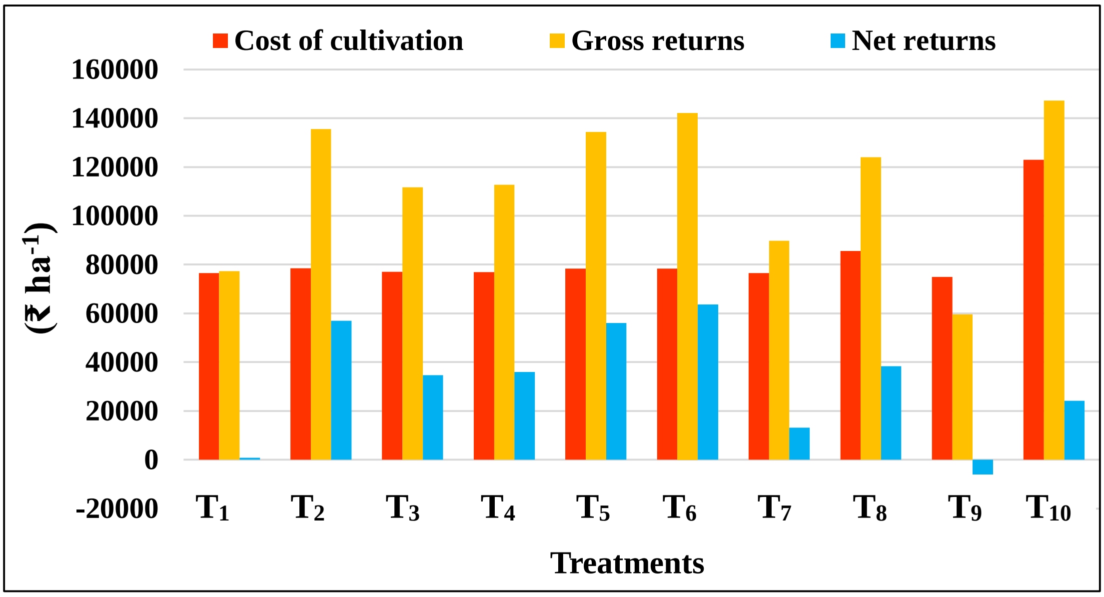


Fig. 33. Effect of weed management practices on economics of cultivation (pooled)

5.4 SENSITIVITY OF WEED TO HERBICIDE COMBINATIONS USING WHOLE PLANT BIOASSAY TECHNIQUE

Use of herbicide combinations is one of the recent strategies adopted in broad spectrum weed control for combating weed flora shifts and preventing or delaying development of herbicide resistance weeds. It would be more plausible if herbicide combinations could lower the dose or rate of the individual herbicides without compromising the broad spectrum weed control efficiency, thus reducing the herbicidal load. Herbicide combinations will help to avoid the resistance problem and weed population shifts that are always a concern with constant use of single herbicides (Duary *et al*., 2015). As part of the programme, the efficacy of herbicide combinations at lower doses was studied against *L. chinensis*, and the results are discussed below.

Application of BS + FPE, *i.e*., @ 0.020 + 0.04 kg ha^{-1} recorded the lowest survival (0%) of *L. chinensis* and verified a score of five at both four and seven days after spraying (DASP) with complete destruction of *L. chinensis*. This indicated that the herbicide combination is effective at its still lower dose. When ACCase inhibitor herbicides are used in conjunction with ALS inhibitors at far lower than labelled rates, the combined action outperforms the individual components (Mahajan and Chauhan, 2015).

Lower doses of BS + CB and CB + CE were also effective in managing *L. chinensis* and the phytotoxicity scoring ranged from three to four at four and seven DASP, respectively, indicating good to complete control. PS + CB @ 0.10 kg ha^{-1} resulted in 86.66 per cent survival of *L. chinensis*, indicating its incompetence in managing *L. chinensis* at lower doses. The study indicated the possibility of reducing the doses of individual herbicides when used as components of herbicide combinations, thus reducing the herbicidal load, which need to be evaluated for field performance. The combination of ALS inhibitor herbicide (BS) with ACCase inhibitor (FPE) performed better in managing *L. chinensis* even at their lower dose (0.020 + 0.04 kg ha^{-1}).

5.5 ASSESSMENT OF MODE OF ACTION OF TANK MIX HERBICIDE COMBINATIONS

Testing the comparative efficiency of herbicide tank mix applications is critical for standardizing the effective dose for herbicide combinations. Though information on the mode of action of individual herbicides is available, the mode of action of herbicide combinations for effective weed management is not yet explored. In the experiment, an attempt was made to study the mode of action of the tank mix herbicide combination on *L. chinensis* by conducting fatty acid and amino acid assays. This information would help in identifying the pathway that gets inhibited when the herbicides are applied in combination.

The fatty acid content in *L. chinensis* was the lowest in plants treated with FPE @ 0.06 kg ha^{-1} (127.36 mg dL^{-1}). FPE is an Acetyl Coenzyme-A Carboxylase (ACCase) inhibiting herbicide, which inhibits the fatty acid synthesis in grasses. The lowest fatty acid content was recorded in plants treated with FPE @ 0.06 kg ha^{-1} endorsing its efficiency in managing *L. chinensis.* Higher weed control efficiency of FPE on *L. chinensis* could be validated based on the above result. However, its combination with BS @ 0.025 kg ha^{-1} recorded increase in fatty acid content, substantiating the lower efficiency of the combination in managing *L. chinensis* compared to its sole application.

Despite the fact that BS is a broad spectrum herbicide capable of inhibiting amino acid synthesis, the highest amino acid content in *L. chinensis* treated with this herbicide proved its inefficiency in managing *L. chinensis*. However, the amino acid content was lower in *L. chinensis* treated with BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} signifying the need for combining FPE for superior weed control.

It could be deducted that the effect of combining an ALS inhibitor (BS) with an ACCase inhibitor (FPE) manifested on *L. chinensis,* as lowered amino acid content, leading to superior weed control efficiency with this combination. The study confirmed that the ALS and ACCase inhibitor could provide better control of *L. chinensis* compared to the application of an ALS inhibitor alone.

5.6 ASSESSMENT OF DIFFERENTIAL RESPONSE OF GRASS WEEDS TO BISPYRIBAC SODIUM

Weeds in crop fields come in a wide range of types and categories, with some belonging to the same family while others are distinct. Information on the response of weeds to various herbicides is essential to develop effective management techniques as components of integrated weed management systems. Bispyribac sodium, chemically, sodium 2, 6-bis [(4, 6-dimethoxy-2-pyrimidinyl) oxy] benzoate, is a popular rice herbicide recommended against a wide range of weeds, including grasses, BLWs and sedges. However, previous studies revealed that BS is ineffective against *L. chinensis,* which is a major grass weed in WSR, thus preventing broad spectrum weed control. As BS is effective for other grass weeds, including *E. colona,* but not for *L. chinensis,* despite the fact that they both belong to Poaceae family, the possibility of differential response is valid. The programme aimed to assess the differential response of grass weeds to BS and the results are discussed below.

Varying concentrations of BS were applied to *L. chinensis* and *E. colona*, and the differential response was evaluated using amino acid content estimation and protein profiling by SDS PAGE. ALS is one of the main targets of herbicides, and BS is an ALS (also referred to as acetohydroxyacid synthase) inhibiting herbicide that prevents the biosynthesis of branched-chain amino acids (isoleucine, leucine, and valine). As a result, the amino acid content in the plants got reduced with the application of BS.

As evident from the on par values, the amino acid content of *L. chinensis* was not affected by the increasing concentration of BS. The amino acid content was higher in the *L. chinensis* plants treated with BS compared to control without herbicide spray. This pointed out the non-inhibitory effect of BS on *L. chinensis*, irrespective of the herbicide concentration. On the other hand, the increase in concentration of BS influenced the amino acid content of *E. colona.* As the concentration of BS increased, the amino acid content was found to decrease in *E. colona.*

The amino acid content in *E. colona* decreased by 32.38, 57.82 and 82.60 per cent, respectively at 50, 100 and 200 per cent FRD of BS compared to control. However, in *L. chinensis*, amino acid content increased by 39.38, 28.20 and 35.52 per cent at 50, 100 and 200 per cent FRD (Fig. 34). The study implied that BS was ineffective in inhibiting amino acid synthesis in *L. chinensis,* as evident from the higher amino acid content compared to *E. colona.*

Among the varying concentrations of BS, 100 per cent FRD resulted in lower protein content, molecular weight of total proteins and number of proteins expressed in *L. chinensis* compared to its higher and lower concentrations. There was also a reduction in protein content, molecular weight of total proteins and number of proteins expressed in *L. chinensis* at 100 per cent FRD of BS compared to control, which was not observed at 50 and 200 per cent FRD. This suggested that increasing the concentration of BS did not have much effect on *L. chinensis.*

The parameters analysed to assess the differential response of grass weeds to BS registered a higher value in *L. chinensis* unlike *E. colona* regardless of the concentration. The differential response of the grass weeds, *Echinochloa crus-galli* and *E. colona* to BS was earlier reported by Riar *et al*. (2012) and Khedr *et al*. (2018). The poor performance of BS could be attributed to its lowered efficiency in inhibiting the biochemical process related to amino acid and protein synthesis in *L. chinensis*. The study confirmed the differential expression of amino acids and proteins in *L. chinensis* and *E. colona,* even though they belong to the same group "*chloa*" meaning grass and the same family Poaceae.

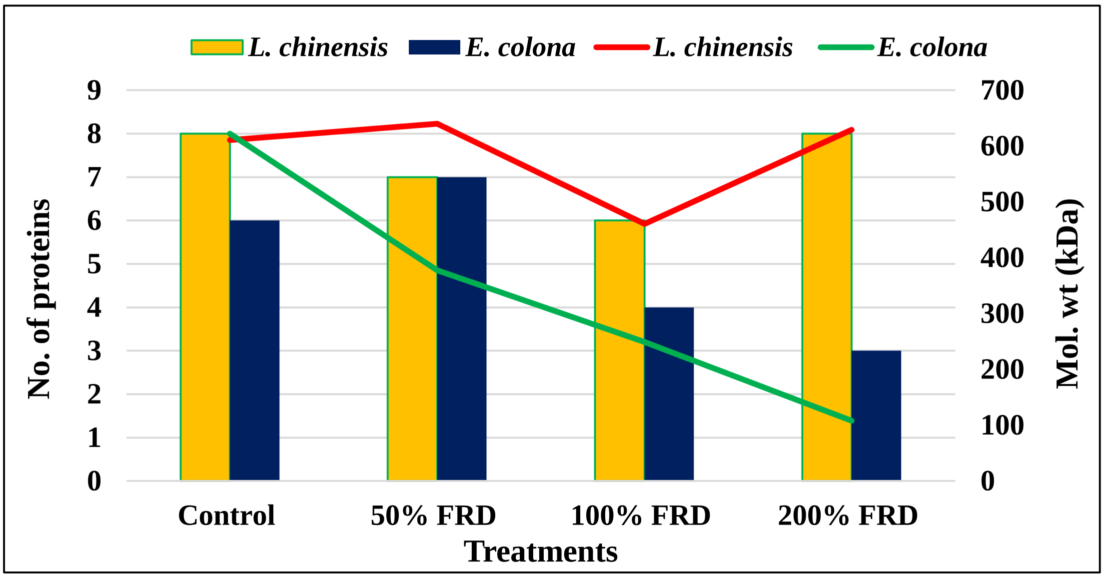


Fig. 34. Effect of bispyribac sodium on number of proteins expressed and molecular weight of total proteins in *Leptochloa chinensis* and *Echinochloa colona*

Summary

6. SUMMARY

An investigation entitled 'Germination ecology and management of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees.] in wet seeded rice' was undertaken at College of Agriculture, Vellayani during 2017-2020. The main objectives were to study the habitat features and distribution of *L. chinensis* in major rice tracts of Kerala; to study the germination ecology of *L. chinensis* under varying conditions; to study the bio-efficacy and mode of action of tank mix combinations of novel herbicides for the management of *L. chinensis*; to study the sensitivity of *L. chinensis* to herbicide combinations. The work is summarized as six experiments.

The phytosociological survey was conducted to document the habitat, composition and distribution of *L. chinensis* in different rice tracts of Kerala *viz*., Palakkad, *Kole* and Kuttanad after selecting three severely infested *padasekharams* in each tract during 2018 and 2019. The germination ecology was studied with respect to biology of *L. chinensis,* identification of phenological phases, duration of growth stages including morphological, biometrical and floral characteristics, method of propagation, vegetative and reproductive characteristics, effect of depth of burial and field conditions on emergence percentage, seed longevity and incidence of pest and diseases.

In order to develop an effective and economic management strategy with special reference to *L. chinensis* in wet seeded rice (WSR), studies were conducted at Integrated Farming System Research Station, Karamana. The treatments were T_1: cyhalofop butyl @ 0.08 kg ha^{-1}, T_2: penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}, T_3: cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}, T_4: bispyribac sodium @ 0.025 kg ha^{-1}, T_5: bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}, T_6: bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}, T_7: fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}, T_8: stale seedbed followed by (*fb*) glyphosate @ 0.8 kg ha^{-1} + oxyfluorfen @ 0.15 kg ha^{-1} at 15-20 days after land preparation *fb* cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1}, T_9: unweeded control and T_{10}: hand weeding twice at 20 and 45 days after sowing (DAS).

The sensitivity of *L. chinensis* to herbicide combinations was tested at the field recommended dose (FRD) and its lower doses using whole plant bioassay technique after identifying best combinations from the management studies. The treatments included T_1: bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}, T_2: bispyribac sodium @ 0.020 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.04 kg ha^{-1}, T_3: bispyribac sodium @ 0.025 kg ha^{-1} + cyhalofop butyl @ 0.08 kg ha^{-1}, T_4: bispyribac sodium @ 0.020 kg ha^{-1} + cyhalofop butyl @ 0.06 kg ha^{-1}, T_5: penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}, T_6: penoxsulam + cyhalofop butyl (6% OD) @ 0.10 kg ha^{-1}, T_7: cyhalofop butyl @ 0.08 kg ha^{-1} + carfentrazone ethyl @ 0.02 kg ha^{-1} and T_8: cyhalofop butyl @ 0.06 kg ha^{-1} + carfentrazone ethyl @ 0.01 kg ha^{-1}.

The mode of action of the tank mix herbicide combination was assessed by conducting amino acid and fatty acid assay and the treatments were T_1: ALS inhibitor alone (bispyribac sodium @ 0.025 kg ha^{-1}), T_2: ACCase inhibitor alone (fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}), T_3: ALS + ACCase inhibitor (bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}) and T_4: Control.

To assess the differential response of grass weeds to bispyribac sodium, *L. chinensis* and *Echinochloa colona* were treated with 50, 100 and 200 per cent FRD of bispyribac sodium when they reached 4-5 leaf stage. The samples were subjected to amino acid estimation three days after treatment application and protein profiling using SDS PAGE. The salient findings of the above experiments are summarized in this chapter.

EXPERIMENT I - PHYTOSOCIOLOGICAL SURVEY

- *Leptochloa chinensis* was found to occur in all the major rice growing tracts of Kerala irrespective of the soil chemical properties and its population was observed to inhabit both upland and lowland situations, either in cropped fields, bunds or along waterways.

- A total of 13 weeds were observed during the survey in Kuttanad region and of these, *Echinochloa stagnina*, *Sacciolepis interrupta* and *L. chinensis* registered higher density, frequency and abundance.
- Annual grass weeds dominated the weed spectrum in the *Kole* lands and *L. chinensis* was the second most abundant (17.33) weed with SDR of 12.40.
- *Leptochloa chinensis* was the second most dominant weed (SDR - 17.49) in the Palakkad tract during *Kharif* and was observed both in semi dry systems and in puddled wet sown/transplanted systems.
- Appraisal of weed vegetation analysis indices in different rice tracts of Kerala disclosed the highest weed species richness (17), Simpson diversity (0.90) and Shannon Wiener diversity (2.50) in the *Kole* tract and the lowest in the Palakkad tract.
- The plant height, number of tillers and panicles per plant of *L. chinensis* varied from 84.0 to 152.0 cm, 6 to 14 and 3 to 12, respectively, with the highest mean value of 137.9 cm, 10.4 tillers and 9.3 panicles per plant being recorded at Mambuzhakari *padasekharam* of the Kuttanad tract.
- *Leptochloa chinensis* is a prolific seed producer and its seed production potential varied from 7400-33,941 seeds per plant.
- The average N, P and K content in *L. chinensis* varied from 1.03 to 1.64, 0.029 to 0.081 and 1.32 to 3 per cent, respectively.

EXPERIMENT II - GERMINATION ECOLOGY

- The weed was noticed to develop through five phenological stages, *viz*., emergence, tillering, heading, flowering and maturity, with an average duration of 10.6, 41.5, 73.5, 78.5 and 95 days, respectively.
- The emergence of *L. chinensis* was noticed on the third day and continued upto the 18th DAS.
- In pot experiments, Kuttanad ecotypes produced the maximum number of tillers and panicles with a mean of 8.33 tillers, 7.53 panicles and 11582.02 seeds per plant.

- The study identified seeds as the major method of propagation in *L. chinensis* and was noticed to propagate vegetatively by means of slips and rooted clumps.
- In laboratory studies, light was found to be not an absolute requirement for germination in *L. chinensis* seeds, but did stimulate germination by 23 per cent.
- The highest germination occurred at 25/15°C (87.2%) in comparison with 70.31 per cent germination at 35/25°C.
- Seeds under dark conditions also germinated and recorded maximum germination of 65 per cent at both 35/25°C and 25/15°C.
- Germination of *L. chinensis* was not significantly affected by increasing salt concentrations and 85 per cent germination was recorded at all the levels of salinity from 0 to 25 mM.
- Continuous flooding for a period of 30 days and maintaining a thin layer of water (3 cm) was found to curtail the emergence of *L. chinensis*.
- Seedling emergence of *L. chinensis* was significantly affected by seed burial depth and seedling emergence declined with increasing burial depths.
- Seedling emergence was observed to be the greatest (85%) for seeds placed on the soil surface and no emergence was observed at burial depths of 2 cm or beyond.
- Slips placed at the surface recorded 100 per cent sprouting and the time taken for 50 per cent emergence increased with increase in burial depth.
- The seeds of *L. chinensis* germinated upto nine months after harvest, with the germination declining over time.

EXPERIMENT III - MANAGEMENT OF *Leptochloa chinensis* IN WET SEEDED RICE

- Fifteen species of weeds were observed in the experimental field during both the years comprised of *L. chinensis*, *E. colona*, and *Isachne miliacea*, *Sphenoclea zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis*, *Alternanthera philoxeroides*, *Lindernia* sp., *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea* and *Marsilea quadrifolia.*
- Grass weeds were the most dominant weed species followed by broad leaf weeds and sedges during both the years.

- Among the grass weeds, *L. chinensis* was the predominant one, recorded the highest count and occupied more than 40 per cent of the grass weed population before treatment application during both the years.
- *Leptochloa chinensis* occupied 56.47, 67.0 and 81.08 and 64.83, 61.37 and 56.41 per cent of the total grass weed population in unweeded control, respectively at 15, 30 and 45 DATA during 2018 and 2019.
- At 15 DATA, *L. chinensis* count was zero in bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} (T_6), fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} (T_7), stale seedbed (SSB) *fb* chemical weeding (T_8) and hand weeding (HW) twice at 20 and 45 DAS (T_{10}) during both the years.
- Among the herbicidal treatments, T_7 recorded the lowest count of *L. chinensis* at all stages during both the years, and during 2019, T_6 and T_{10} were found to be on par with T_7 both at 30 and 45 DATA.
- At 15 DATA, T_8 resulted in zero count of grass weeds, BLWs and sedges during both the years.
- Tank mix combination of bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} (T_6) also resulted in zero count of grass weeds and sedges at 15 DATA during both the years and registered lower count of BLWs (1.33 and 2.66 m^{-2}, respectively during 2018 and 2019).
- At 15 DATA, T_8 recorded the lowest weed dry matter production (DMP) of zero kg ha^{-1} during both the years. This was followed by T_{10}, T_6, T_2 and T_5, recorded 16.40, 18.80, 23.93 and 29.66 kg ha^{-1}, respectively during 2018. However, during 2019, T_{10}, T_6, T_2 and T_5 were found to be on par with T_8 and recorded a DMP of 5.50, 4.67, 7.10 and 7.70 kg ha^{-1}, respectively.
- At 30 and 45 DATA, T_{10} recorded the lowest DMP of 28.61 and 26.60 kg ha^{-1} and 117.54 and 118.66 kg ha^{-1}, respectively during 2018 and 2019 and was statistically on par to T_6 with 29.70 and 39.43 kg ha^{-1}, respectively at 30 DATA.
- At 45 DATA, T_{10} was followed by T_6, T_5 and T_2 with DMP of 222.45, 283.96 and 287.20 kg ha^{-1}, respectively during 2018. However, during 2019, T_6 and T_5 with 127 and 224 kg ha^{-1}, respectively were on par with T_{10}.

- At 15 DATA, T_6, T_7, T_8 and T_{10} were free of *L. chinensis* and recorded zero DMP during both the years.
- At 30 and 45 DATA, T_7 registered the lowest DMP of *L. chinensis* (8.90 and 4.41 kg ha^{-1} and 23.91 and 30.15 kg ha^{-1}, respectively during 2018 and 2019) among the herbicidal treatments and was statistically comparable with T_{10}, T_6 and T_8 at both 30 and 45 DATA.
- At 15 DATA, T_8 recorded 100 per cent weed control efficiency (WCE) and was on par with T_{10} and T_6, with 96.80 and 96.55 per cent, respectively.
- The highest WCE of 98.56 and 92.84 per cent, respectively was registered by T_{10}, and was statistically comparable with T_6 and T_5 during both 30 and 45 DATA with 98.20 and 95.40 per cent and 89.70 and 84.81 per cent efficiency, respectively.
- Among the herbicidal treatments, T_1 recorded the lowest WCE at all stages with 79.05, 67.92 and 18.92 per cent control, respectively at 15, 30 and 45 DATA.
- At 15 DATA, T_6, T_7, T_8 and T_{10} recorded 100 per cent control efficiency (CE) of *L. chinensis*.
- At 30 and 45 DATA, the highest CE was obtained in T_7 with 97.55 and 96.78 per cent, respectively and all other treatments except T_4 was statistically on par to each other at 15 and 30 DATA.
- The lowest CE of 52.63, 38.68 and 42.43 per cent, respectively was recorded in T_4 at 15, 30 and 45 DATA.
- In WSR, weeds removed 27.72, 4.61 and 67.95 kg of N, P and K per hectare and *L. chinensis* removed 18.76, 1.46 and 34.81 kg N, P and K per hectare under unweeded conditions at 45 DATA.
- The highest grain and straw yield of 5.20 and 6.82 t ha^{-1}, respectively was recorded in T_{10}.
- Herbicide combination treatments T_6, T_2 and T_5 were on par to T_{10} with regard to grain yield and recorded 5.03, 4.79 and 4.76 t ha^{-1}, respectively.
- Unweeded control (T_9) recorded the lowest pooled grain yield of 2.07 t ha^{-1} and T_3 registered the lowest pooled grain yield of 3.95 t ha^{-1} among the herbicide combination treatments.

- Among the herbicidal treatments, the lowest pooled straw yield was obtained in T_1 (4.06 t ha^{-1}), which was statistically on par with T_9 and T_7 with 3.66 and 4.41 t ha^{-1}, respectively.
- Uncontrolled weed competition in T_9 resulted in 59.95 per cent reduction in grain yield.
- The least reduction in grain yield (3.09%) was registered in T_6 and was statistically comparable to T_2, T_5 and T_8, with weed index of 7.83, 8.60 and 15.77.
- Among the herbicidal treatments, T_6, T_2 and T_5 recorded higher nutrient uptake of the crop.
- Tank mix application of BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (T_6) registered maximum net returns per hectare (₹ 63,657 ha^{-1}) and B:C ratio (1.81) followed by ready mix formulation of PS + CB (6% OD) @ 0.15 kg ha^{-1} (T_2) (₹ 56,995 ha^{-1} and 1.73).

EXPERIMENT IV - SENSITIVITY OF WEED TO HERBICIDE COMBINATIONS USING WHOLE PLANT BIOASSAY TECHNIQUE

- All the tested herbicide combinations at its FRD recorded the least survival (0%) of *L. chinensis.*
- The lower dose of BS + FPE @ 0.020 + 0.04 kg ha^{-1} (T_2) recorded the least survival (0%) of *L. chinensis* whereas, BS + CB @ 0.020 + 0.06 kg ha^{-1} (T_4), CB + CE @ 0.06 + 0.01 kg ha^{-1} (T_8) and PS + CB @ 0.10 kg ha^{-1} (T_6) registered 26.66, 30.0 and 86.66 per cent survival, respectively.
- Bispyribac sodium @ 0.020 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.04 kg ha^{-1} (T_2) recorded a score of five and completely killed the plants by 4th day after spraying.

EXPERIMENT V – ASSESSMENT OF MODE OF ACTION OF TANK MIX HERBICIDE COMBINATIONS

- The highest amino acid content in *L. chinensis* (0.2904 mg mL^{-1}) was registered with application of BS @ 0.025 kg ha^{-1} alone. However, the amino acid content was lower in *L. chinensis* treated with BS @ 0.025 kg ha^{-1} + FPE @ 0.06 kg ha^{-1} (0.1775 mg mL^{-1}).

- The fatty acid content in *L. chinensis* was the lowest in plants treated with FPE @ 0.06 kg ha^{-1} (127.36 mg dL^{-1}).

EXPERIMENT VI – ASSESSMENT OF DIFFERENTIAL RESPONSE OF GRASS WEEDS TO BISPYRIBAC SODIUM

- The amino acid content of *L. chinensis* was not influenced by the increasing concentration of bispyribac sodium and a higher content of amino acid was observed in *L. chinensis* compared to *E. colona*, irrespective of the concentration of bispyribac sodium.
- In *E. colona*, the amino acid content was found to decrease with increasing concentration of bispyribac sodium.
- At 100 per cent FRD, the amino acid content was 0.1520 and 0.2904 mg mL^{-1} and at 200 per cent FRD, it was 0.0627 and 0.3234 mg mL^{-1} respectively in *E. colona* and *L. chinensis.*
- Statistically significant reduction was not observed in the protein content, number of proteins expressed and the molecular weight of proteins in *L. chinensis* with the application of bispyribac sodium from lower to higher concentration.

FUTURE LINE OF WORK

- Field validation of effective herbicide combinations at its lower dose
- Investigating the allelopathic potential of *L. chinensis*
- Assessment of response of *L. chinensis* to salinity levels under field conditions
- Bio-utilization of *L. chinensis* for its fodder value and the prospects of composting, considering its higher potassium content.

References

REFERENCES

Abeysekera, A. S. K. and Wickrama, U. B. 2004. Control of *Leptochloa chinensis* (L) Nees in wet-seeded rice fields in Sri Lanka. In: *Rice is Life: Scientific Perspectives for the 21st Century*. Proceedings of World Rice Research Conference, 4-7 November 2004, Japan. International Rice Research Institute, Philippines, pp. 215-217.

Abraham, C. T. and Jose, N. 2014. Weedy rice invasion in rice fields of India and management options. *J. Crop Weed* 10(2): 365-374.

Abraham, C. T. and Menon, M. V. 2015. Efficacy of combination of penoxsulam + cyhalofop butyl on weed management in wet seeded rice. In: Shetty, S. V. R., Prasad, T. V. R., Chinnusamy, C., Sanjay, M. T., Sondhia, S., and Kumar, S. (eds), *Proceedings of the Twenty fifth Asian-Pacific Weed Science Conference (Volume 111 poster papers)*, 13-16 October 2015, Hyderabad, India. Indian Weed Science Society, Jabalpur, pp. 41.

Abraham, C. T., Joseph, P. A., and Thomas, C. G. 1993. Ecological survey of weeds in the rice ecosystem of Kuttanad. In: Nair, R. R., Nair, K. P. V., and Joseph, C. A. (eds.) *Rice in Wetland Ecosystem*. Proceedings of the National Symposium on Rice in Wetland Ecosystem, 19-21 December 1990, Thrissur. Kerala Agricultural University, Thrissur, pp. 161-167.

Abraham, C. T., Prameela, P., and Lakshmi, P. M. 2010. Efficacy of oxyfluorfen for weed control in transplanted rice. *J. Crop Weed* 6(2): 67-71.

Ahmed, S. and Chauhan, B. S. 2014. Performance of different herbicides in dry-seeded rice in Bangladesh. *Sci. World J* [e-journal]. Available: http://dx.doi.org/10.11 55/2014/7 29418 [12 July 2020].

Ahmed, S., Chauhan, B. S., and Humphreys, E. 2013. Effect of application timings of soil applied herbicides on weed growth and crop yield in dry-seeded rice in Bangladesh. In: Bakar, B.H., Kuriniadie, D. and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of 24th Asian-Pacific Weed Science Conference, 22-25 October 2013, Bandung, Indonesia, pp. 461-464.

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

Ali, M. A., Aslam, Z., Ameen, A., Zaman, Q., and Sher, A. 2015. Bio-efficacy of fenoxaprop-p-ethyl along with bispyribac sodium to control weed flora in direct seeded rice. *Am.-Eurasian J. Agric. Environ. Sci*. 15 (12): 2406-2413.

Ali, N., Durranib, S., Abbasc, M., Ullaha, I., Ishfaqa, M., Akbara, N., Rehmana, A., and Waheedc, A. 2018. Different approaches in direct seeded rice system to avert weed infestation: review. *Int. J. Sci. Eng. Res.* 9(6): 1538-1558.

Ampong-Nyarko, K. and De Datta, S. K. 1991. *Handbook for Weed Control in Rice.* International Rice Research Institute, Manila, Philippines, 113p.

Angiras, N. N. and Attri, S. P. 2002. Efficacy of herbicide mixture to control mixed weed flora in direct seeded puddled rice. *Indian J. Weed Sci.* 34: 42-45.

Antralina, M., Istina, I. N., Yuwariah, Y., and Simarmata, T. 2015. Effect of difference weed control methods to yield of lowland rice in the SOBARI. *Proc. Food Sci*. 3: 323-329.

Anwar, M. P., Juraimi, A. S., Puteh, A., Man, A., and Rahman, M. M. 2012. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. *Acta Agriculturae Scandinavica.* 62: 604-615.

Arunbabu, T. and Jena, S. N. 2018. Weeds and progressive weed management techniques in rice (*Oryza sativa*. L.): a review. *Bull. Environ. Pharmacol. Life Sci.* 7(2):108-117.

Arunvenkatesh, S. and Velayatham, A. 2010. Evaluation of metamifop 10EC for weed control efficacy and productivity of direct seeded rice. In: *National Conference on Challenges in Weed Management in Agro-ecosystems, Present Status and Future Strategies*. Tamil Nadu Agricultural University, Coimbatore, p.125

Atheena, A. 2016. Tank mix application of cyhalofop-butyl with selected herbicides for weed control in wet seeded rice. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 101p.

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.

Aud, F. F. and Ferraz, I. D. K. 2012. Seed size influence on germination responses to light and temperature of seven pioneer tree species from the Central Amazon. *Biol. Sci.* 84: 759-766.

Aulakh, C. S. and Mehra, S. P. 2008. Nutrient uptake by red sprangletop [*Leptochloa chinensis* (L.) Nees] and transplanted rice under different cultural and weed management practices. *Indian J. Weed Sci*. 40 (1&2): 21-26.

Aurora, M. B. and De Datta, S. K. 1992. Weed management in rice. *Weed Abstr*. 41: 495-508.

Avudaithai, S. and Veerabadran, V. 2000. Effect of herbicide mixtures on the total weed spectrum in transplanted rice. *Crop Res*. 19: 6-12.

Awan, T. H., Ali, I., Manzoor, Z., Safdar, I., and Ashraf, M. 2006. Economic effect of different plant establishment techniques on rice production. *J. Agric. Res*. 9: 580-588.

Awan, T. H., Sta-Cruz, P. C., Ahmed, S., and Chauhan, B. S. 2015. Effect of nitrogen application, rice planting density, and water regime on the morphological plasticity and biomass partitioning of Chinese sprangletop (*Leptochloa chinensis*). *Weed Sci.* 63: 448-460.

Awan, 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 Crop Res*. 177: 15-25, doi:10.1016/j.fcr.2015.03.001.

Azmi, M. and Baki, B. B. 1995. The succession of noxious weeds in tropical Asian rice fields with emphasis on Malaysian rice ecosystem. In: Sugiyama (ed.) *Proceedings of the 15th Asian Pacific Weed Science Society Conference*, Tsukuba, Japan, 24-28 June 1995. Asian Pacific Weed Science Society, Tsukuba, pp. 51-67.

Azmi, M., Chin, D. V., Vongsaroj, P., and Johnson, D. E. 2005. Emerging issues in weed management of direct-seeded rice in Malaysia, Vietnam and Thailand. In: Toriyama, K., Heong, K. L., and Hardy, B. (eds*), Rice Is Life: Scientific Perspectives for the 21st Century.* International Rice Research Institute, Los Banos, Philippines and Japan International Research Center for Agricultural Sciences, Tsukuba, Japan. pp. 196-198.

Bahar, F. A. and Singh, G. 2004. Effect of herbicides on dry seeded rice and associated weeds. *Indian J. Weed Sci*. 36: 269-270.

Balasubramanian, R., Babu, R., Sakthivel, S., Balakrishnan, K., and Swaminathan, C. 2010. Evaluation of new herbicide molecules in direct seeded rice under puddled condition. In: *National Conference on Challenges in Weed Management in Agro-ecosystems*, *Present Status and Future Strategies*. Tamil Nadu Agricultural University, Coimbatore, p.128.

Barrett, S. H. 1983. Crop mimicry in weeds. *Econ. Bot.* 37: 255-282.

Barrion, A. T. and Litsinger, J. A. 1987. The bionomics, karyology and chemical control of the node-feeding black bug, *Scotinophara latiuscula* Breddin. (Hemiptera: Pentatomidae) in the Philippines. *J. Plant Prot. Trop*. 4(1): 37-54.

Baskin, C. C. and Baskin, J. M. 1998. *Seeds: Ecology, Biogeography and Evaluation of Dormancy and Germination*. Academic press, San Diego, 666p.

Batlla, D. and Benech-Arnold, R. L. 2014. Weed seed germination and the light environment: implications for weed management. *Weed Biol. Manag.* 14: 77-87.

Benvenuti, S. 2003. Soil texture involvement in germination and emergence of buried weed seeds. *Agron. J.* 95:191-198.

Benvenuti, S. and Macchia, M. 1995. Hypoxia effect on buried weed seed germination. *Weed Res*. 35: 343-351.

Benvenuti, S., Dinelli, G., and Bonetti, A. 2004. Germination ecology of *Leptochloa chinensis*: a new weed in the Italian rice agro environment. *Weed Res.* 44: 87-96.

Benvenuti, S., Macchia, M., and Miele, S. 2001. Light, temperature and burial depth effects on *Rumex obtusifolius* seed germination and emergence. *Weed Res*. 41: 177-186.

Bergeron, E. A. 2017. Nealley's Sprangletop (*Leptochloa nealleyi* Vasey) Management and Interference in Rice Production. M.Sc.(Ag.) thesis, Louisiana State University, Baton Rouge, LA, USA, 65p.

Bhatt, R. and Kukal S. S. 2011. Direct seeded rice in South Asia. In: *Sustainable Agriculture Reviews*. Springer International Publishing. pp. 217-252.

Bhowmik, P. C. 1993. Weed biology: Its importance in integrated weed management systems. In: *Proceedings of the International Symposium,* 18-20 November, 1993, Hisar. Indian Society of Weed Science, Hisar, pp.57-65.

Bhowmik, P. C. 1997. Weed biology: importance to weed management. *Weed Sci*. 45: 349-356.

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.

Bhushan, L., Ladha, J. K., Gupta, R. K., Singh, S., Tirol-Padre, A., and Saharawat, Y. S., 2007. Saving of water and labor in a riceewheat system with no-tillage and direct seeding technologies. *Agron. J*. 99: 1288-1296.

Biswas, B., Timsina, J., Garai, S., Mondal, M., Banarjee, H., Adhikary, S., and Kanthal, S. 2020. Weed control in transplanted rice with post-emergence herbicides and their effects on subsequent rapeseed in Eastern India. *Int. J. Pest. Manag*. https://doi.org/10.1080/09670874.2020.1853276.

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

Bonham, C. D. 2013. *Measurements for Terrestrial Vegetation* (2^{nd} Ed.). John Wiley and Sons, New York, 260p.

Booth, B. D., Murphy, S. D., and Swanton, C. J. 2003. *Weed Ecology in Natural and Agricultural Systems*. CABI Publishing, CAB International, Wallingford, UK, 313p.

Branson, J. W., Smith, K. L., and Namenek, R. C. 2002. *Antagonism Issues with New Rice Herbicides.* Arkansas Agricultural Experiment Station, Research series No. 495, pp. 65-69.

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(1): 215-220.

Burke, I. C., Thomas, W. E., Spears, J. F., and Wilcut. J. W. 2003. Influence of environmental factors on after-ripened crowfoot grass (*Dactyloctenium aegyptium*) seed germination. *Weed Sci*. 51: 342-347.

CABI [Commonwealth Agricultural Bureaux International]. 2019. CABI homepage [on-line]. Available: Invasive Species Compendium- *Leptochloa chinensis* (Chinese sprangletop) [12 January 2020].

Cauchy, P. 2000. Carfentrazone-ethyl: Cereal herbicide. *Phytoma* 531: 55-58.

CGIAR [Consultative Group for International Agricultural Research]. 2020. *Ricepedia* [on-line]. Available: http://ricepedia.org/rice-as-food/theglobal-staple-rice-consumers [21 December 2020].

Chaudhary, S. K., Marahatta, S., and Chaudhary, M. 2018. Performance of dry direct seeded rice and weeds on Sesbania brown manuring as compared to farmers' practice and chemical control method. *Int. J. Appl. Sci. Biotechnol*. 6(3): 265-269.

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

Chauhan, B. S. and Abugho, S. B. 2012. Effect of growth stage on the efficacy of post emergence herbicides on four weed species of direct-seeded rice. *Sci. World J*. [e-journal]. Available: http://www.hindawi.com/journals/tswj/201 2/1230 71. Article ID 123071 [15 December 2019].

Chauhan, B. S. and Abugho, S. B. 2013. Effect of water stress on the growth and development of *Amaranthus spinosus, Leptochloa chinensis,* and rice. *Am. J. Plant Sci*. 4: 989-998.

Chauhan, B. S. and Johnson, D. E. 2008. Germination ecology of Chinese sprangletop (*Leptochloa chinensis*) in the Philippines. *Weed Sci*. 56(6): 820-825.

Chauhan, B. S. and Johnson, D. E. 2009a. *Ludwigia hyssopifolia* emergence and growth as affected by light, burial depth and water management. *Crop Prot*. 28(10): 887-890. doi:10.1016/j.cropro.2009.05.005.

Chauhan, B. S. and Johnson, D. E. 2009b. Ecological studies on *Cyperus difformis, C. iria* and *Fimbristylis miliacea*: three troublesome annual sedge weeds of rice. *Ann. Appl. Biol*. 155: 103-112.

Chauhan, B. S. and Johnson, D. E. 2010. The role of seed ecology in improving weed management strategies in the tropics. *Adv. Agron*. 105: 221-262.

Chauhan, B. S. and Johnson, D. E. 2011a. Ecological studies on *Echinochloa crus-galli* and the implications for weed management in direct-seeded rice. *Crop Prot*. 30(11): 1385-1391.

Chauhan, B. S. and Johnson, D. E. 2011b. Growth response of direct seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. *Weed Sci.* 59(1): 119-122.

Chauhan, B. S. and Yadav, A. 2013. Weed management approaches for dry seeded rice in India- a review. *Indian J. Weed Sci*. 45: 1-6.

Chauhan, B. S., Kumar, V., and Mahajan, G. 2014. Research needs for improving weed management in rice. *Indian J. Weed Sci*. 46: 1-13.

Chauhan, B. S., Namuco, O. S., Ocampo, L. A. L., Son, T. N., Thu, T. A., Nam, N. N., Phuong, L. N., and Bajwa, A. A. 2015. Weedy rice (*Oryza sativa f. spontanea*) problems and management in wet direct-seeded rice (*O. sativa* L.) in the Mekong Delta of Vietnam. *Crop Prot*. 78: 40-47.

Chauhan, B. S., Singh, R. G., and Mahajan, G. 2012. Ecology and management of weeds under conservation agriculture: a review. *Crop Prot*. 38:57-65. doi: 10.1007/s11356-016-7794-7.

Chen, K., Peng, Y., Zhang, L., Wang, L., Mao, D., Zhao, Z., Bai, L., and Wang, L. 2021. Whole transcriptome analysis resulted in the identification of Chinese sprangletop (*Leptochloa chinensis*) genes involved in cyhalofop-butyl tolerance. *BMC Genomics*. https://doi.org/10.1186/s12864-021-07856-z.

Chen, W. S. and Yang, P. 2011. Weed infestation succession and its chemical control technology. *Beijing Agric.* 18.

Chin, D. V. 2001. Biology and management of barnyardgrass, red sprangletop and weedy rice. *Weed Biol. Manag*. 1: 37-41.

Chinnusamy, C., Nalini, K., and Nithya, C. 2012. Major weeds and their management in Tamil Nadu. In: *Proc. of Biennial Conference of Indian Society of Weed Science on "Weed Threat to Agriculture, Biodiversity and Environment",* 19-20 April 2012, Thrissur. Kerala Agricultural University, Thrissur, Kerala, India.

Choubey, N. K., Kolhe, S. S., and Tripathi, R. S. 2001. Relative performance of cyhalofop butyl for weed control in direct seeded rice. *Indian J. Weed Sci.* 33(3&4): 132-135.

Choudhury, P. P., Singh, R., Ghosh, D., and Sharma, A. R. 2016. *Herbicide Use in Indian Agriculture.* ICAR - Directorate of Weed Research, Jabalpur, Madhya Pradesh, 110p.

Civico, R. and Moody, K. 1979. The effect of the time and depth of submergence on growth and development of some weed species. *Philipp. J. Weed Sci.* 6: 41-49.

Concenco, G., Tomazi, M., Correia, I. V. T., Santos, S. A., and Galon, L. 2013. Phytosociological surveys: Tools for weed science?. *Planta Daninha* 31(2): 469-482.

Cousens, R. D., Baweja, R., Vaths, J., and Schofield, M. 1993. Comparative biology of cruciferous weeds: a preliminary study. In: *Proceedings of the 10th Australian and 14th Asian-Pacific Weed Conference*. Brisbane, Australia. Weed Society of Queensland, Brisbane, Australia, pp. 376-380.

Crossman, N. D., Bryan, B. A., and Cooke, D. A. 2011. An invasive plant and climate change threat index for weed risk management: Integrating habitat distribution pattern and dispersal process. *Ecol. Indicators*. 11(1): 183-198.

Cumming, G. 2002. The use of carfentrazone-ethyl to aid in the knockdown of difficult to control broad leaved weeds. In: Jacob, H. S., Dodd, J., and Moore, J. H. (eds), *Proceedings of 13th Australian Weeds Conference: Weeds "Threats Now and Forever?"*, 8-13 September 2002, Sheraton Perth Hotel, Perth, Western Australia, pp. 318-320.

Damalas, C. A. 2004. Herbicide tank mixture: common interactions. *Int. J. Agric. Biol*. 6(1): 209-212.

De Datta, S. K. 1981. *Principles and Practices of Rice Production*. John Wiley and Sons Inc, New York, 485p.

Devi, D. K. M., Abraham, C. T., and Upasana, C. N. 2015. Leaching behaviour of four herbicides in two soils of Kerala. *Indian J. Weed Sci*. 47(2): 193-196.

Devi, R. B. and Singh, Y. 2018. Nutrient uptake and yield of direct seeded rice as influenced by nitrogen and weed management practices. *Indian J. Pure Appl. Biosci*. 6(5): 34-40.

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

Dong, L. W., Wang, H. C., and Chen, G. Q., 2016. Weed management in direct seeding paddy fields. *China Agric. Press*. Beijing

Donohue, K. 2009. Completing the cycle: maternal effects as the missing link in plant life histories. *Biol. Sci*. 364: 1059-1074.

DRR [Directorate of Rice Research]. 2011. DRR home page [on line]. Available: http://14.13994.101/wisy/prsentation/yield_losses.aspx. [12 July 2020].

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

Egley, G. H. 1986. Stimulation of weed seed germination in soil. a review. *Weed Sci.* 2: 67-89.

EPA [Environmental Protection Agency]. 2002. *Cyhalofop butyl.* EPA home page [on line], United States Environmental Protection Agency. Available: http://www3.epa.gov. [20 October 2020].

EPA [Environmental Protection Agency]. 2012. *Oxyfluorfen 2E Herbicide.* EPA home page [on line], United States Environmental Protection Agency. Available: http://www3.epa.gov. [20 October 2020].

Evelyn, F. J., Shoji, F., Reynaldo, S., and Fernando, G. 2005. Management of wet direct seeded rice (II) and weed control by water and herbicides. *Philip. J. Crop Sci*. 30(1): 11-17.

Farooq, M., Siddique, K. H. M., Rehman, H. M. U., Aziz, T., Lee, D., and Wahid, A. 2011. Rice direct seeding: experiences, challenges and opportunities. *Soil Till. Res*. 111: 87-98.

Ferrero, A. 2003. Weedy rice, biological features and control. In: Labrada, R. (ed.) *Weed Management for Developing Countries: Addendum 1*, FAO, Rome FAO Plant Production and Protection Paper 120, Add. 1, pp. 89-107.

Firmansyah, E. and Pusparani, S. 2019. Weed vegetation analysis in Universitas Perjuangan of Tasikmalaya. *J. Phys. Conference Series* 1179 012132 doi:10.1088/1742-6596/1179/1/012132.

Fisher, A. J., Granados, E., and Trijullio, D. 1993. Propanil resistance in populations of jungle rice (*Echinochloa colona*) in Columbia rice fields. *Weed Sci*. 41: 201-206.

Galinato, M. I., Moody, K., and Piggin, C. M. 1999. *Upland Rice Weeds of South and South-East Asia*. International Rice Research Institute, Philippines. 156p.

Ghosh, D., Singh, U. P., Brahmachari, K., Singh, N. K., and Das, A. 2016. An integrated approach to weed management practices in direct seeded rice under zero-tilled rice–wheat cropping system. *Int. J. Pest Manag*. 63: 37-46. https://doi.org/10.1080/09670874.2016.1213460.

Gill, G. S. and Vijayakumar, K. 1969. Weed Index - a new method of reporting weed control trials. *Indian J. Agron*. 14(2): 96-98.

GOI [Government of India]. 2020. *Data bank of Crops Unit-I*, Crop division, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare. 98p.

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

Gopal, R., Jat, R. K., Malik, R. K., Kumar, V., Alam, M. M., Jat, M. L., Mazid, M. A., Saharawat, Y. S., McDonald, A., and Gupta, R. 2010. Direct dry seeded rice production technology and weed management in rice based systems. *Tech. Bull.* International Maize and Wheat Improvement Center, New Delhi, India. pp 28.

Gutterman, Y. Maternal effects on seeds during development. 2000. In: Fenner, M. (ed.). *Seeds: the Ecology of Regeneration in Plant Communities* (2nd Ed.). CABI publishing, Wallingford, pp. 59-84.

Hafliger, E. and Scholz, H. 1981. *Grass Weeds 2*. Ciba-Geigy Ltd. Basle Switzerland, 160p.

Heinrich, E. A., Nwilene, F. E., Stout, M., Hadi, B. A. R., and Freitas, T. 2017. *Rice Insect Pests and Their Management* (1st Ed.), Burleigh Dodds Science Publishing Limited: London, UK, 292p.

Hill, J. E., Mortimer, A. M., Namuco, O. S., and Janiya, J. 2001. Water and weed management in direct-seeded rice: Are we headed in the right direction?. In: Peng, S. and Hardy, B (eds), *Rice Research for Food Security and Poverty Alleviation*, International Rice Research Institute, Los Banos, Philippines, pp. 491-510.

Ho, N. K. 1998. The rice agroecosystem of the Muda irrigation scheme: An overview. In: M. Nashriyah, M. (Ed.) ‘‘*Rice Agroecosystem of the Muda Irrigation Scheme, Malaysia*’’, Malaysian Institute of Nuclear Technology Research (MINT), Bangi, Malaysia, pp. 1-24.

Ho, T. L., Nguyen, C. T., Vu, D. C., Nguyen, T. T. C., Nguyen, V. Q., and Smeda, R. J. 2021. Rice by-products reduce seed and seedlings survival of *Echinochloa crus-galli*, *Leptochloa chinensis* and *Fymbristylis miliacea*. *Agron.* 11: 776. https://doi.org/10.3390/ agronomy11040776.

Holm, L. G., Plucknett, D. L., Pancho, J. V., and Herberger, J. P. 1977. *The World's Worst Weeds: Distribution and Biology*. University Press of Hawaii, Honolulu, HI, 609p.

Hussain, S., Ramsan, M., Akhter, M., and Aslam, M. 2008. Weed management in direct seeded rice. *J. Anim. Plant Sci*. 18: 2-3.

Ihsan, M. Z., Khaliq, A., Matloob, A., El-Nakhlawy, F. S., Abohassan, R. A., Daur, I., and Aslam, Z. 2014. Influence of herbicides applied alone or supplemented with manual weeding on weed growth, rice yield and grain quality in direct-seeded rice (*Oryza sativa* L.). *Philipp. Agric. Sci*. 97(4): 377-384.

IRRI [International Rice Research Institute]. 2020a. *Rice Knowledge Bank* [on-line]. Available: http://www.knowledgebank.irri.org/training/fact-sheets/item/leptochloa-chinensis [20 December 2020].

IRRI [International Rice Research Institute]. 2020b. *Dirty Dozen Weeds* [on line]. Available: http://www.knowledgebank.irri.org/step-by-step-production/growth/weed-management/the-dirty-dozen-of-weeds [20 December 2020].

Itoh, K., Watanabe, H., and Ho, N. K. 1996. Several research topics on weed infestation and its control. In: Mooroka, Y., Jegathesan, S., and Yasunobu, K. (ed.). *Recent Advances in Malaysian Rice Production, Direct Seeding Culture in the Muda Area,* MADA/JIRCAS, Kuala Lumpur, Malaysia, 181–202.

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

Jabusch, T. W. and Tjeerdema, R. S. 2005. Partitioning of penoxsulam a new sulfonamide herbicide. *J. Agric. Food Chem*. 53: 717 9-7183.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi, 498p.

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

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

Jana, K., Mondal, R., and Mallick, G. K. 2020. Growth, productivity and nutrient uptake of aerobic rice (*Oryza sativa* L) as influenced by different nutrient management practices. *Oryza* 57(1): 49-56.

Janaki, P., Sathya Priya, R., and Chinnusamy, C. 2013. Field dissipation of oxyfluorfen in onion and its dynamics in soil under Indian tropical conditions. *J. Environ. Sci. Health,* Part B. 48: 941- 947.

Jannu, N., Raju, S. M., and Devi, S. K. B. 2017. Effect of different herbicides on weed growth and grain yield of direct seeded rice under rain fed condition. *Int. J. Pure Appl. Biosci*. 5 (4): 1122-1126.

Jayasree, P. K. 1987. Efficiency of thiobencarb in dry sown rice. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 115p.

Jiang, R. C. 1989. The field weeds chemical control series and systematic management. In: *Proceedings of Asian Pacific Weed Science Society Conference*, China, pp. 467-473.

Jiménez-Vázquez, A. M., Flores-Palacio, A., Flores-Morales, A., Perea-Arango, I., Gutiérrez, M. C., Arellano-García, J. J., and Valencia-Díaz, S. 2021. Seed longevity, viability and germination of four weed-ruderal Asteraceae Species of ethnobotanic value. *Bot. Sci.* 99(2): 279-290.

Jose, N., Abraham, C. T., Mathew, R., and Leenakumary, S. 2013. Biology and management of weedy rice in direct seeded puddled rice. In: Bakar, B. H., Kuriniadie, D. and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of 24th Asian-Pacific Weed Science Conference, 22-25 October 2013, Bandung, Indonesia, pp.472-478.

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

Juraimi, A. S., Hamdani, M. S. A., Azmi, M. R., and Anwar, M. P. 2012. Effect of water regimes on germination of weed seeds in a Malaysian rice field. *Aust. J. Crop Sci*. 6(4): 598-605.

Kachroo, D. and Bazaya, B. R. 2011. Efficacy of different herbicides on growth and yield of direct wet seeded rice sown through drum seeder. *Indian J. Weed Sci*. 43 (1&2): 67-69.

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

Kaloumenos, N. S., Chatzilazaridou, S. L., Mylona, P. V., Polidorosd, A. N., and Eleftherohorinosb, I. G. 2013. Target-site mutation associated with cross-resistance to ALS-inhibiting herbicides in late watergrass (*Echinochloa oryzicola* Vasing.). *Pest Manag. Sci*. 69: 865-873.

Kankal, V. Y. 2015. Effect of establishment techniques, weed control and integrated nutrient management on growth, yield and quality of drilled rice.(*Oryza sativa* L.). Ph.D. Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, 186p.

Karim, R. S. M., Man, A. B., and Sahid, I. B. 2004. Weed problems and their management in rice fields of Malaysia: an overview. *Weed Biol. Manag*. 4(4): 177-186.

Kartaatmadja, S., Pane, H., Wirajaswadi, L., Sembiring, H., Simatupang, S., Bachrein, S., Ismadi, D., and Fagi, A. M. 2004. Optimizing use of natural resources and increasing rice productivity. In ‘‘*Conserving Soil and Water for Society: Sharing Solutions”, 13th International Soil Conservation Organisation Conference*, Brisbane, p.748.

Karthika, R., Subramanian, E., Ragavan, T., and Kumutha, K. 2019. Studies on crop weed competition and weed management in direct seeded rice under puddled and unpuddled conditions. *Int. J. Chem. Stud*. 7(3): 2769-2773.

Kashid, N. V. 2019. Integration of post-emergence herbicide application with hand weeding for managing weeds in transplanted rice. *Indian J. Weed Sci*. 51(2): 206-208.

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

Kathiresan, R. M. 2004. Invasive alien weed in rice. *Weed Sci. Newsl.* 2, 2.

KAU [Kerala Agricultural University]. 2009. *Annual Report, 2008-09*. All India Coordinated Research Programme on Weed Control, Thrissur centre, Kerala Agricultural University, Thrissur, Kerala, pp.9.

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

Kaur, J. and Singh, A. 2017. Direct seeded rice: prospects, problems/constraints and researchable issues in India. *Curr. Agric. Res. J*. 5(1): 13-32.

Kayvan, A., Hossein, F. M., and Farshadfar, E. 2007. Correlation and path coefficient analysis for some yield-related traits in rice genotypes (*Oryza sativa* L.). *Asian J. Plant Sci*. 6(3): 513-517.

Kent, M. 2012. *Vegetation Description and Data Analysis- A Practical Approach* (2nd Ed.). Wiley-Blackwell, New York, 30p.

Kent, R. and De Johnson. 2001. Influence of flood depth and duration on growth of lowland rice weeds, Cote d'Ivoire. *Crop. Prot*. 20: 691-694.

Kettenring, K. M., Gardner, G., and Galatowitsch, S. M. 2006. Effect of light on seed germination of eight wetland carex species. *Ann. Bot*. 98: 869-874.

Kevin, C., Salamanez1, K. C., Baltazar, A. M., Rodriguez1, E. B., Lacsamana, M. S., Ismail, A. M., and Johnson, D. E. 2013. Effect of propyrisulfuron on growth and acetolactate synthase activity of five weed species and three rice (*Oryza sativa* L.) cultivars. In: Bakar, B. H., Kuriniadie, D. and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of 24th Asian-Pacific Weed Science Conference, 22-25 October 2013, Bandung, Indonesia, pp. 438-446.

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

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

Khan, Z., Abenes, M., and Fernandez, N. 1996. Suitability of gramineous weed species as host plants for rice leaf folders, *Cnaphalocrocis medinalis* and *Marasmia patnalis*. *Crop Prot*. 15(2): 121-127.

Khedr, A. A., Serag, M. S., Shaaban, H. E., and Abogadallah, G. M. 2018. Different responses of *Echinochloa crus-galli* and *Echinochloa colona* to bisbyric-sodium (Nominee^{tm}). *Egypt. J. Bot.* 58(1): 109-118.

Kim, S. C. and Moody, K. 1989. Adaptation strategy in dry matter and seed production of rice and weed species. *Korean J. Weed Sci*. 9: 183-200.

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

Kraehmer, H., Jabran, K., Mennan, H., and Chauhan, B. S. 2016. Global distribution of rice weeds - a review. *Crop Prot*. 80: 73-86.

Kuah, T. C. and Salehuddin, M. 1988. HOE (fenoxaprop-ethyl) for control of grass weeds in direct-seeded rice. In: Lam Y. M., Cheong, A. W., and Azmi M. (eds). *Proceedings National Seminar and Workshop on Rice Field Weed Management*, 7-9 June 1988. MARDI, Penang, Malaysia, 188-202.

Kumar, 2015. Performance of basmati rice under different transplanting date and weed management practices. Ph. D thesis, CCSHAU, Hisar, Haryana. 282p.

Kumar, J. and Gautam, R. C. 1986. Effect of various herbicides on yield and yield attributes of direct seeded rice on puddle soil. *Indian J. Weed Sci*. 18:154-156.

Kumar, J., Kumar, A., and Sharma, B. C. 2009. Effect of weed management and crop establishment methods on weed dynamics and productivity of rice. *Indian J. Weed Sci*. 41: 142-147.

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

Kumar, V. and Ladha, J. K. 2011. Direct seeding of rice: recent developments and future research needs. *Adv. Agron*. 111: 297-413.

Kumaran, S. T., Kathiresan, G., Arthanari, P. M., Chinnusamy, C., and Kumar, V. S. 2015. Evaluation of new herbicide (bispyribac sodium 10 SC) on weed control and yield in direct seeded lowland rice (*Oryza sativa*). *Madras Agric. J*. 102 (1&3): 52-56.

Kundu, R., Mondal, R., Garai, S., Mondal, M., Poddar, R., and Banerjee, S. 2020. Weed management efficiency of post emergence herbicides in direct seeded rice and their residuality on soil microorganisms. *J. Exp. Biol. and Agric. Sci.* 8(3): 276-286.

Ladu, M. and Singh, M. K. 2006. Crop-weed competition in upland direct seeded rice under foot hill conditions of Nagaland. *Indian J. Weed Sci*. 38: 131-132.

Lan, M. G., Yang, B. L., Cai, L. D., Yuan, L. X., Tao, T., and Ya Jun, P. 2014. Control of herbicide resistant *Echinochloa crus-galli* in direct-seeded rice crops. *Acta Prataculturae Sinica* 23(6): 259-265.

Langaro, A. C., Agostinetto, D., Oliveira, C., Silva, J. D. G., and Bruno, M. S. 2016. Biochemical and physiological changes in rice plants due to the application of herbicides. *Planta Daninha* 34(2): 277-289.

Lap, N., Somsak, S., Yuli, I. M., Duy, L., Choy, L. L., Victoria, E. B., Niranjan, B. V., and Mann, R. K. 2013. Efficacy and rice tolerance to penoxsulam+ cyhalofop herbicide mixtures in ASEAN countries. In: Bakar, B. H. J., Kurniadie, D., and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of the 24th Asian-Pacific Weed Science Society Conference October 22-25, 2013, Bandung, Indonesia, pp. 424-430.

Lim, C., Awan, T. H., Sta-Cruz, P. C., and Chauhan, B. S. 2015. Influence of Environmental Factors, Cultural Practices, and Herbicide Application on Seed Germination and Emergence Ecology of *Ischaemum rugosum* Salisb. *PLOS ONE*. 10(9): 28. e0137256. doi:10.1371/journal.pone.0137256.

MacFarlane, T. D. 1987. Poaceae subfamily Pooideae. In: Soderstrom, T. R. and Hilu, K. W. (eds) *Grass Systematics and Evolution*. CS Campbell & ME Barkworth, Smithsonian Institute, Washington, USA. pp. 265-276.

Mackill, A. O. and Bonman, J. M. 1986. New hosts of *Pyricularia oryzae*. *Plant Dis.* 70(2): 125-127.

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.

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

Maiden, J. H. 1889. *The Useful Native Plants of Australia: Including Tasmania*. Turner and Henderson, Sydney, 696p.

Maity, S. K. and Mukherjee, P. K. 2008. Integrated weed management in dry direct-seeded rice (*Oryza sativa*). *Indian J. Agron*. 53(2): 116-120.

Mallick, S., Pal. P., Tzudir, L., Kheroar, S., and Ghosh, R. K. 2009. Bio-efficacy and phytotoxicity of fenoxaprop-p-ethyl on *kharif* transplanted rice. In: *National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity*, Tamil Nadu Agricultural University, Coimbatore, p.89

Mallory-Smith, C. A. and Retzinger, E. J. 2003. Revised classification of herbicides by site of action for weed resistance management strategies. *Weed Technol*. 17: 605-619.

Manhas, S. S., Singh, G., Singh, D., and Khajuria, V. 2012. Effect of tank-mixed herbicides on weeds and transplanted rice (*Oryza sativa* L). *Ann. Agric. Res. New Series* 33(1-2): 25-31.

Manidool, C. 1992. *Leptochloa chinensis* (L.) Nees. In: Mannetje, L. and Jones, R. M. (eds). *Plant Resources of Southeast Asia*. Pudoc Scientific, Wageningen, Netherlands, pp. 149-150.

Marambe, B. 2002. Emerging weed problems in wet-seeded rice due to herbicide use in Sri Lanka. In: *Abstracts International Rice Congress*, Beijing, China, 430p.

Matsunaka, S. 1983. Evaluation of rice weed control practices and research – world perspective. In: *Proceedings of 1984 Weed Control Rice Conference*, Japan, pp. 5-18.

Matsuo, K. and Kataoka, T. 1983. Effects of light, temperature and storage conditions on the breaking of dormancy of *Leptochloa chinensis* seeds. *Weed Res*. 28(2): 122-128.

Matsuo, K., Katuyama, N., Kon, T., Komatsu, Y., and Uemura, Y. 1987. Ecology of *Leptochloa chinensis* (L.) Nees (Gramineae) and their weed control. *Bull. Shikoku Nat. Agric. Exp. Stn.*, Zensuji, 48: 1-15.

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 barnyardgrass (*Echinochloa crusgalli*) control. Planta daninha [e-journal]. Available: http://www.scielo.br/scielo.php?script=sci_artt ext&pid=S010083582015000300587. ISSN 1806-9681 [3 March 2019].

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. 2012. Efficacy of new post emergence herbicides for rice. M.Sc.(Ag.) Thesis, Kerala Agricultural University, Thrissur, 110p.

Misra, R. 1968. *Ecology Workbook*, Oxford and IBH Publishing Co., New Delhi, India, 242p.

Mohan, K. S., Muniyappa, T. V., Kalyanamurthy, K. N., Ramesh, Y. M., and Savitha, H. R. 2010. Effect of chemical weed control on growth and yield of direct seeded puddle rice (*Oryza sativa* L.). *Int. J. Agri. Sci*. 6: 471-474.

Mohapatra, S., Tripathy, S. K., Nayak, B. R., and Mohanty, A. K. 2017. Efficacy of pre-emergence herbicides for control of complex weed flora in transplanted rice. *Indian J. Weed Sci.* 49(3): 216-218.

Moody, K. 1977. Weed control in rice. In: *5th Biotroph Weed Science Training Couse, Lecture note 30*. Rubber research Institute, Kuala Lumpur, Malaysia, pp. 374-424.

Moody, K. 1983. The status of weed control in rice in Asia. *FAO Plant Protection Bulletin* 30: 110-123.

Moody, K. 1989. *Weeds reported in rice in South and South East Asia.* International Rice Research Institute, Los Baños, Philippines, 550p.

Moody, K. and Drost, D. C. 1983. The role of cropping systems on weeds in rice. In: *Proceedings of the Conference on Weed Control in Rice*. International Rice Research Institute, Los Banos, Philippines: pp. 73-86.

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, 101p.

Mubeen, K., Jhala, A. J., Hussain, M., Siddiqui, M. H., Zahoor, F., Shehzad, M., and Mehmood, K. 2014. Effects of seeding time and competition period on weeds, growth and yield of direct seeded fine rice (*Oryza Sativa* L.). *Acad. J. Interdiscip. Stud*. 3(5): 55-64.

Mukherjee, D. 2006. Weed management strategy in rice-a review. *Agric. Rev*. 27: 247-257.

Mukherjee, P. K. and Maity, S. K. 2011. Weed control in transplanted and wet seeded rainy season rice. *Indian J. Weed Sci*. 81: 134-139.

Mukherjee, P. K., Sarkar, A., and Maity, S. K. 2008. Critical period of crop-weed competition in transplanted and wet-seeded *Kharif* rice (*Oryza sativa* L.) under Terai conditions. *Indian J. Weed Sci*. 40(3&4): 147-152.

Muthukrishnan, P., Subbalakshmi, L., and Sathiya, K. 2010. Weed distribution and management in rice. In: *Proc. of National Conference on "Challenges in weed management in agroecosystems - Present status and future strategies*", 30 November and 01 December, Tamil Nadu Agricultural University, Coimbatore, India, pp. 15-20.

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

Naseeruddin, R. and Subramanyam, D. 2013. Performance of low dose high efficacy herbicides in drum seeded rice. *Indian J. Weed Sci*. 45: 285-288.

Nath, C. P., Saha, M., Pandey, P. C., Das, T. K., Meena, R. K., and Paul, T. 2014. Bio efficacy evaluation of different herbicides on weed population, grain yield and nutrient uptake in direct seeded puddled rice (*Oryza sativa* L.). *Ann. Agric. Res*. 35: 217-223.

Nguyen, T., Keizer, P., Eeuwijk, F. V., Smeekens, S., and Bentsink, L. 2012. Natural variation for seed longevity and seed dormancy are negatively correlated in Arabidopsis. *Plant Physiol*. 160: 2083-2092.

Nishan, M. A. 2012. Management of water cabbage (*Limnocharis flava* (L.) buchenau) in wetland rice ecosystem. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 104p.

Noda, K. and Eguchi, S. 1965. Studies on ecology of weeds on arable lands: Emergence patterns of annual representative weeds which are commonly found on the paddy rice fields of south-western Japan. *Bull. Kyushu Agric. Expt. Stn*, 11:153-170.

Oerke, E. C. and Dehne, H. W. 2004. Safeguarding production losses in major crops and the role of crop protection. *Crop Prot*. 23(4): 275-285.

Opena, J. L, Chauhan, B. S., and Baltazar, A. M. 2014. Seed germination ecology of *Echinochloa glabrescens* and its implication for management in rice (*Oryza sativa* L.). PLoS ONE [e-journal] 9(3). Available: https://journals.plos. org/plo son e/article?id=10.1371/journal.pone.009226 [12 December 2019].

Osborne, A., Wanielista, P., and Yousef, A. 1976. Bentic founa species diversity in six Central Florida lakes in summer. *Hydrobiologia*. 48: 125-129.

Pal, S. and Banerjee, H. 2007. Efficacy of Penoxsulam against weeds in transplanted *kharif* rice. *Indian J. Weed Sci*. 39: 172-175.

Pala, F. 2020. The effect of post emergence herbicides and their mixtures on grass and broadleaf weed control in barley *Hordeum vulgare* L. *Fresenius Environ. Bull.* 29(2): 1206-1213.

Pane, H. 1998. The ecology of *Leptochloa chinensis* (L.) Nees and its management. In: *Proceedings of an FAO CAB International workshop*, Kuala-Lumpur, Malaysia, 17-18 May, pp. 52-63.

Pane, H. and Mansor, M. 1996. Competition between red sprangletop (*Leptochloa chinensis*) and rice (*Oryza sativa*) under different nitrogen levels. *Plant Prot*. 11(3): 109-113.

Paswan, A., Kumar, R., Kumar, P., and Singh, R. K. 2012. Influence of Metsulfuron-methyl and carfentrazone-ethyl either alone or in combination on weed flora, crop growth and yield in wheat (*Triticum aestivum*). *Madras Agric. J*. 99: 560-562.

Pathak, H., Tewari, A. N., Sankhyan, S., Dubey, D. S., Mina, U., Singh, V. K., Jain, N., and Bhatia, A. 2011. Direct-seeded rice: potential, performance and problems - a review. *Curr. Adv. Agric. Sci*. 3: 77-88.

Patil, V. B. 2014. Studies on bio-efficacy and phytotoxicity of penoxsulam + cyhalofop butyl 6% OD in direct dry seeded rice. M.Sc.(Ag.) thesis, University of Agricultural Sciences, Raichur, 116p.

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

Phillips, E. A. 1959. *Methods of Vegetation Study*. Henry Holt. & Co., Inc. New York, US, 107p.

Pielou, E. C. 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol*. 13: 131-144.

Piper, C. S. 1942. *Soil and Plant Analysis* (Asian Reprint, 1996). Hans Publications, Bombay, 368p.

Poddar, R., Ghosh, R. K., Paul, T., and Bera, S. 2014. Weed management through oxyfluorfen in direct seeded rice and its impact on soil micro-organisms and succeeding crops. *Ann. Agric. Res. New Series* 35(3): 337-342.

Pons, T. L. 1982. Factors affecting weed seed germination and seedling growth in lowland rice in Indonesia. *Weed Res*. 22: 155-161.

Prakash, J., Singh, R., Yadav, R. S., Vivek, R., Yadav, 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.

Prakash, P., Nanjappa, H.V., and Ramachandrappa, B. K. 1995. Chemical weed control in direct seeded puddle rice. *J. Crop Res*. 9(2) 197-202.

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

Prasuna, J. G. and Rammohan, J. 2015. Effect of weed management practices on growth and yield attributes of aerobic rice. *J. Crop Weed* 11(1): 229-231.

Pratap, T., Singh, V. P., Singh, R., and Rekha. 2016. Herbicides for weed management in direct dry-seeded rice. *Indian J. Weed Sci*. 48(3): 275-278.

Prusty, J. C., Behera, B., and Mohanty, S. K. 1993. Study on critical threshold limit of dominant weeds in medium land rice. In: *Proceedings of the International Symposium of Indian Society of Weed Science*, 18-20 November 1993. Hisar, India, pp. 13-15.

Raghavendra, B. M., Susheela, R., Rao, V. P., and Madhavi, M. 2015. Efficacy of different weed management practices on growth and yield of direct wet seeded rice sown through drum seeder. *The Bioscan* 10(1): 97-101.

Raj, S. K. 2016. Herbicide mixtures for weed management in direct seeded puddled rice (*Oryza sativa* L.). Ph. D thesis, Kerala Agricultural University, Thrissur, 312p.

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

Raj, S. K. and Syriac, E. K. 2018. Herbicide mixtures effect on weed seed bank in direct-seeded rice. *Indian J. Weed Sci*. 50(1): 64-68.

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., Mathew, R., Jose, N., and Leenakumary, S. 2013. Evaluation of early post emergence and post emergence herbicides on weed control and productivity of direct-seeded puddled rice in Kuttanad. *Madras Agric. J.* 100: 738-742.

Rajjou, L. and Debeaujon, I. 2008. Seed longevity: survival and maintenance of high germination ability of dry seeds. *Comptes Rendus Biol*. 331(10): 796-805.

Ramamoorthy, K. 1991. Effect of integrated weed management on nutrient uptake by upland rice and associated weeds. *Indian J. Agron*. 30: 213-217.

Ramamoorthy, R., Kulandaisamy, S., and Sankaran, S. 1974. Effect of propanil on weed growth and yield of IR 20 under different seeding methods and rates. *Madras Agric. J.* 61: 307-312.

Ramzan, M. 2003. Evaluation of various planting methods in rice-wheat cropping system. *Rice Crop Res*. 4-5.

Rana, M. N., Al Mamum, M. A., Zahan, A., Ahmed, M. N., and Mridha, M. A. J. 2014. Effect of planting methods on the yield and yield attributes of short duration Aman rice. *Am. J. Plant Sci*. 5: 251-255.

Rana, N. S., Kumar, S., and Saini, S. K. 2004. Weed management in spring sugarcane based intercropping systems. *Indian J. Weed Sci*. 36: 93-95.

Rani, P. S. 2020. Biology and management of *Sacciolepis interrupta* (Wild.) stapf in rice. Ph. D thesis, Kerala Agricultural University, Thrissur, 200p.

Rao, A. N. and Ladha, J. K. 2013. Economic weed management approaches for rice in Asia. In: Bakar, B.H., Kuriniadie, D. and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of 24th Asian-Pacific Weed Science Conference, 22-25 October 2013, Bandung, Indonesia, pp. 500-509.

Rao, A. N. and Nagamani, A. 2007. Available technologies and future research challenges for managing weeds in dry-seeded rice in India. In: *Proc. 21st Asian Pacific Weed Sci. Society Conf.* 2-6 October 2007, Colombo, Sri Lanka, pp. 391-400.

Rao, A. N. and Nagamani, A. 2013. Eco-efficient weed management approaches for rice in tropical Asia. In: *Proceedings 4th Tropical Weed Science Conference,* 23-25 January, 2013, Chiang Mai, Thailand. pp. 78-87.

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.

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

Rao, V. S. 2000. *Principles of weed science* (2nd Ed.). Taylor and Francis, USA, 555p.

Rao, V. S. 2011. *Principles of weed science* (2nd Ed.). Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 277p.

Rathika, S. and Ramesh, T. 2019. Weed management in direct wet seeded rice. *J. Pharma. Phytochem*. 2: 978-981.

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

Reddy, M. S. S. K. 2020. Biology and management of goose weed (*Sphenoclea zeylanica* Gaertner) in wetland rice. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 169p.

Reddy, M. S. S. K. and Ameena, M. 2021a. Influence of weed management practices on weed flora, crop yield and nutrient uptake in direct seeded rainfed lowland rice. *J. Crop Weed.* 17(2): 1-8.

Reddy, M. S. S. K. and Ameena, M. 2021b. Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice. *Indian J. Weed Sci.* 53(1): 88-91.

Reddy, P. M. 2000. Crop stand manipulation for reducing herbicide use in transplanted rice. M.Sc. (Ag.) thesis, Punjab Agricultural University, Ludhiana, 150p.

Renjan, B. 2018. Management of blood grass (*Isachne miliacea* Roth ex Roem et Schult) in wetland rice ecosystem. Ph. D thesis, Kerala Agricultural University, Thrissur, 263p.

Renjan, B. and George, S. 2018. Management of blood grass (*Isachne miliacea* Roth ex Roem et Schult) in wetland rice. *J. Trop. Agric*. 56 (1): 17-26.

Renu, S., Thomas, C. G., Abraham, C. T., 2000. Stale seedbed technique for the management of *Sacciolepis interrupta* in semi-dry rice. *Indian J. Weed Sci*. 32: 140-145.

Riar, D. S., Norsworthy, J. K., Bond, J. A., Bararpour, M. T., Wilson, M. J., and Scott, R. C. 2012. Resistance of *Echinochloa crus-galli* populations to acetolactate synthase - inhibiting herbicides. *Int. J. Agron*. Article ID 893953:1–8.

Richter, R., Dullinger, S., Essl, F., Leitner, M., and Vogl, G. 2012. How to account for habitat suitability in weed management programmes?. *Biol. Invasions*. 15: 657-669.

Roberts, E. H. and Totterdell, S. 1981. Seed dormancy in *Rumex* species in response to environmental factors. *Plant Cell Environ*. 4: 97-106.

Roy, D. K., Singh, D., and Dharminder. 2010. Effect of crop establishment techniques and different weed management practices on growth, yield and quality of rice. In: *Proc. of National Conference on "Challenges in weed management in agro-ecosystems - Present status and future strategies"*, November 30 and December 1, Tamil Nadu Agricultural University, Coimbatore, 151p.

Sadasivam, S. and Manickam, A. 2007. *Biochemical Methods*. New Age International (P) Limited, New Delhi, 284p.

Sadohara, H., Watanabe, O., and Rich, G. 2000. Control of red rice In: Baki, B. B., Chin, D. V., and Mortimer, M. (eds), *Wild and Weedy Rice in Rice Ecosystems in Asia- A Review*, International Rice Research Institute, Manila, pp. 83-86.

Sahu, P. K. 2016. Yield variation under rice-weed competition in direct seeded lowland condition. M. Sc. (Ag.) thesis, Orissa University of Agriculture and Technology, Bhubaneswar, 72p.

Saini, J. P. 2003. Efficacy of cyhalofop butyl against weeds in direct seeded puddled rice under mid hill conditions of Himachal Pradesh. *Indian J. Weed Sci*. 35: 205-207.

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.

Saini, J. P., Angiras, N. N., and Singh, C. M. 2001. Efficacy of Cyhalofop-butyl in controlling of weeds in transplanted rice (*Oryza sativa*). *Indian J. Agron*. 46(2): 222-226.

Sangeetha, C., Velayutham, A., Thavaprakaash, N., and Chinnusamy, C. 2009. Crop establishment and weed management effects on rice productivity and weed dynamics. *Indian J. Weed Sci*. 47(1): 6-10.

Sanjay, M. T., Shetty, T. K. P., and Nanjappa, H. V. 2006. Enhancing productivity of rice under different crop establishment methods through weed management practices. *Crop Res*. 31(2): 192-197.

Sanodiya, P. and Singh, M. K. 2019. Impact of integrated weed management on weeds and yield of direct-seeded rice (*Oryza sativa*). *Indian J. Agron*. 64(1): 62-66.

Sasikala, K., Boopathi, S. N. M. R., and Ashok, P. 2015. Effect of new generation herbicides on weed parameters and seed yield of rice fallow black gram, *Vigna mungo* L. *Int. J. Farm Sci*. 5(4): 91-97.

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

Sathyapriya, R., Chinnuswamy, C., Arthanari, P. M., and Janaki, P. 2017. Pre-emergence herbicide of oxyfluorfen on weed control in transplanted rice. *Int. J. Chem. Stud*. 5(5): 271-275.

Schutte, B. J., Regnier, E. E., and Harrison, S. K. 2008. The association between seed size and seed longevity among maternal families in *Ambrosia trifida* L. populations. *Seed Sci. Res*. 18(4): 201-211. doi: https://doi.org/10.1017/S0960258508082974.

Scott, R. C. 2003. Post-flood tank-mix combinations with cyhalofop for barnyard grass control in rice. Research Series 504. Arkansas Agricultural Experiment Station, pp. 165-168.

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.

Shannon, C. E. and Wiener, W. 1963. *The Mathematical Theory of Communication.* Urbana, University of Illinois Press, Urbana, 117p.

Sharma, S. D. and Singh, M. 2007. Effect of timing and rates of application of glyphosate and carfentrazone herbicides and their mixtures on the control of some broadleaf weeds. *Hortic. Sci*. 42(5): 1221-1226.

Shekhawat, K., Rathore, S. S., and Chauhan, B. S. 2020. Weed management in dry direct-seeded rice: a review on challenges and opportunities for sustainable rice production. *Agron*. doi:10.3390/agronomy10091264.

Shen, C., Tang, W., Zeng, D., Xu, H., Su, W., and Wu, R. 2017. Isoxadifen-ethyl derivatives protect rice from fenoxaprop-p-ethyl–associated injury during the control of weedy rice. *Weed Sci.* 65(5): 579-587.

Simpson, E. H. 1949. Measurement of diversity. *Nature* 163: 688. doi: 10. 1038/163688a0.

Sindhu, P. V., Thomas, C. G., and Abraham, C. T. 2010. Seedbed manipulations for weed management in wet-seeded rice. *Indian J. Weed Sci.* 42(3&4): 173-179.

Singh, A., Nandal, D. P., and Punia, S. S. 2017. Bio-efficacy of sequential application of herbicides on weeds and yield in direct seeded rice (*Oryza sativa*). *Int. J. Curr. Microbiol. Appl. Sci*. 6(4): 900-905.

Singh, B. and Dash, B. 1988. Simple correlation and linear regression studies between weeds and growth and yield of direct seeded upland rice. *Oryza* 35: 282-286.

Singh, G. 2008. Integrated weed management in direct-seeded rice. In: Singh, Y., Singh, V. P., Chauhan, B., Orr, A., Mortimer, A.M., Johnson, D. E., and Hardy, B (eds), *Direct seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic plains*, IRRI, Los Banos, Philippines, pp. 161-175.

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, M. and Singh, R. P. 2010a. Efficacy of herbicides under different methods of direct seeded rice establishments. *Indian J. Agric. Sci*. 80: 815-819.

Singh, M. and Singh, R. P. 2010b. Influence of crop establishment methods and weed management practices on yield and economics of direct-seeded rice (*Oryza sativa*). *Indian J. Agron*. 55(3): 224-229.

Singh, M. K. 2013. Competitiveness of rice cultivars under stale seedbed in dry direct- seeded rice. *Indian J. Weed. Sci.* 45: 171-174.

Singh, P., Shrivasatava, G. K., Verma, A. K., and Singh, I. 2018. Effect of different doses of herbicides and mechanical weeding on yield attributes and grain yield of direct seeded rice (*Oryza sativa* L.) varieties under Inseptisols of Chhattisgarh plain. *Int. J. Chem. Stud.* 6(1): 1929-1933.

Singh, R. K. and Namdeo, K. N. 2004. Effect of fertility levels and herbicides on growth, yield and nutrient uptake of direct seeded rice (*Oryza sativa*). *Indian J. Agron*. 49(1): 34-36.

Singh, V. P., Singh, G., and Singh, M. 2004. Effect of fenoxaprop-p-ethyl on transplanted rice and associated weeds. *Indian J. weed Sci*. 36: 190-192.

Singh, V. P., Singh, G., Mortimer, M., and Johnson, D. E. 2008. Weed species shifts in response to direct seeding in rice. In: Singh, Y., Singh, V. P., Chauhan, B., Orr, A., Mortimer, A. M., Johnson, D. E., and Hardy, B. (eds), *Direct seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic plains*, IRRI, Los Banos, Phillippines, pp. 213-219.

Singh, V. P., Singh, S. P., Bisht, N., Kumar, A., Satyawali, K., and Paliwal, A. 2017. Assessment of post-emergence weed management in direct-seeded rice. *Indian J. Weed Sci*. 49(3): 211-215.

Singh, V. P., Singh, S. P., Pratap, T., Joshi, V., Kumar, A., Tripathi, N., Banga, A., and Bisht, N. 2016. Efficacy of ready mix of penoxsulam and cyhalofop-butyl for weed control in transplanted rice. *Ecoscan* 10(1-2): 217-221.

Singh, V. P., Singh, S. P., Tripathi, N., Kumar, A., and Singh, M. K. 2009. Bioefficacy of penoxsulam on transplanted rice weeds. *Indian J. Weed Sci*. 41: 28-32.

Smith, R. J. 1981. Control of red rice (*Oryza sativa*) in water seeded rice (*Oryza sativa*). *Weed Sci*. 29: 663-666.

Smith, R. J. J. and Fox, W. T. 1973. Soil water and growth of rice and weeds. *Weed Sci*. 21: 61-63.

Soerjani, M., Kostermans, A. J. G. H., and Tjitrosoepomo, G. 1987. *Weeds of Rice in Indonesia*. Balai Pustaka, Jakarta. 716p.

SongHan, Z., Guan, L., Chen, J., Hou, Q., and Lu, S. 1996. Study in infestation, damage and economic threshold of *Leptochloa chinensis* in direct sown rice fields. *Acta Agriculturae* 12(3): 57-59.

Sreedevi, B., Murthy, P. K., and Singh, S. P. 2009. Nitrogen uptake and energy consumption of weeds in wet seeded rice. In: *National Symposium on Weed Threat to Environment, Biodiversity and Agriculture Productivity,* Tamil Nadu Agricultural University, Coimbatore, p. 49.

Srinithan, T., Arivukkarasu, K., and Sivasakthivelan, P. 2020. Studies on performance of early post-emergence application of herbicides on weed management in transplanted rice. *Plant Arch.* 20(2): 9662-9664.

Srinivasan, J. T. 2012. An economic analysis of paddy cultivation in the *Kole* land of Kerala. *Indian J. Agric. Econ*. 67(2): 213-224.

Storkey, J., Moss, S. R., and Cussans, J. W. 2010. Using assembly theory to explain changes in a weed flora in response to agricultural intensification. *Weed Sci.* 58, 39-46. doi: 10.1614/WS-09-096.1.

Suada, A. P. 2015. Growth and physiology of *Isachne miliacea* Roth. in different soil types and its sensitivity to common herbicides. M. Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 152p.

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

Sumit, Nandeha, K. L., and Kumar, S. 2020. Effect of different weed management practices on growth, yield attributes and yield of direct seeded rice (*Oryza sativa* L.). *Int. J. Chem. Stud*. 8(2): 2879-2883.

Sumiyoshi, T. 2008. Control of Red sprangletop (*Leptochloa chinensis* Nees) with several herbicides. The Kyushu Branch of the Crop Science Society of Japan, No.74, pp. 56-58.

Sumiyoshi, T. and Suzuki, K. 2006. Growth characteristics of Red sprangletop (*Leptochloa chinensis* Nees) as an indicator of herbicide treatment. In: *The report of the Kyushu Branch of the Crop Science Society of Japan*, 72: 51-53.

Sunil, C. M., Shekara, B. G., Ashoka, P., Murthy, K. K., and Madhukumar, V. 2011. Effect of integrated weed management practices on nutrient uptake in aerobic rice. *Res. Crops* 12(3): 629-632.

Swapna, M. M., Prakashkumar, R., Anoop, K. P., Manju, C. N., and Rajith, N. P. 2011. A review on the medicinal and edible aspects of aquatic and wetland plants of India. *J. Med. Plants Res.* 5(33): 7163-7176.

Teja, C. K., Duray, B., and Bhowmik, M. K. 2015. Efficacy of herbicides on weed management in wet season transplanted rice. *J. Crop and Weed* 11: 224-227.

Thomas, C. G. and Abraham, C. T. 1998. *Common Weeds in Rice Ecosystems of Kerala and Their Management*. Kerala Agricultural University, Thrissur, 80p.

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

Tiwari, R. B., Pandey, T. D., and Nandeha, K. L. 2010. Weed management studies in direct seeded rice. In: *Biennial Conference of Indian Society of Weed Science on Recent Advances in Weed Science Research*. 25-26 February 2010. Indira Gandhi Krishi Vishwavidyalaya, Raipur, p.30

Tranel, P. J. and Wright, T. R. 2002. Resistance of weeds to ALS inhibiting herbicides: What have we learned? *Weed Sci*. 50: 700-712.

Tranel, P. J., Wright, T. R., and Heap, I. M. 2012. ALS mutations from herbicide-resistant weeds [on-line]. Available: http:// www.weedscience.com.

Travlos, I. S., Cheimona, N., Roussis, I., and Bilalis, D. J. 2018. Weed-species abundance and diversity indices in relation to tillage systems and fertilization. *Front. Env. Sci.* 6. doi: 10.3389/fenvs.2018.00011.

Umkhulzum, S. F. 2018. Management of rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla in wet-seeded rice. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 117p.

Umkhulzum, S. F. and Ameena, M. 2019. Integrated management of rock bulrush (*Schoenoplectus juncoides*) in wet seeded rice. *J. Crop Weed* 15(3): 139-144.

Umkhulzum, S. F., Ameena, M., and Pillai, S. P. 2018. Comparative efficacy of herbicides against rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla in wet-seeded rice. *Indian J. Weed Sci*. 50(4): 395-398.

Umkhulzum, S. F., Ameena, M., and Pillai, S. P. 2019. Biology of rock bulrush (*Schoenoplectus juncoides*) in the wet land rice fields of south Kerala. *J. Trop. Agric*. 57(2): 167-171.

Upadhyay, U. C. and Sivanand, K. 1985. *A Practical Manual on Weed Control*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 280p.

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

Vencill, W. K. 2002. *Herbicide Handbook* (8th Ed.). Weed science society of America, Lawrence, pp. 230-233.

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. Pharma. Phytochem*. 522-525.

Vidya, A. S. 2003. Weed dynamics in rice fields: influence of soil reaction and fertility. M. Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 96p.

Vidya, A. S., Abraham, C. T., and Krishnan, S. 2004. Weed biodiversity in the rice ecosystems of Kerala and its implications for weed management. In: *Sixteenth Kerala Science Congress,* 29-31 January 2004, Kozhikode, pp. 401-411.

Walia, U. S. and Singh, B. 2006. Performance of triasulfuron and carfentrazone-ethyl against broad leaf weeds in wheat. *Indian J. weed Sci*. 38(3&4): 237-239.

Walia, U. S., Bhullar, M. S., Nayyar, S., and Walia, S. S. 2008. Control of complex weed flora of dry seeded rice with pre and post emergence herbicides. *Indian J. Weed Sci*. 40: 161-164.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci*. 37: 29-38.

Wang, Q., Zhao, X. P., Wu, C. X., Dai, F., Wu, L. Q., Xu, H., Zhang, R. J., Cai, G. L., and Weng, X. Z. 2000. Application techniques of bispyribac- sodium for controlling weeds in direct seeded rice fields. *Acta Agric. Zhejiangensis* 12, 338-344.

Wang, W. P., Gan, H. H., Zhang, J. G., and Liu, F. 2013. The incidence, causes and control strategy of weeds in direct seeded rice fields in Jiading district. *Anhui Agric. Sci*. 19: 92-93.

WDNR [Wisconsin Department of Natural Resources]. 2012a. *Penoxsulam Chemical Fact Sheet.* WDNR homepage [on line]. Wisconsin Department of Natural Resources. Available: http://dnr.wisconsin.gov. [18 October 2020].

WDNR [Wisconsin Department of Natural Resources]. 2012b. *Carfentrazone ethyl Chemical Fact Sheet.* WDNR homepage [on line]. Wisconsin Department of Natural Resources. Available: http://dnr.wisconsin.gov. [18 October 2020].

Westbrooks, R. 1989. Regulatory exclusion of federal noxious weeds from the United States. Ph.D. Dissertation, Department of Botany, North Carolina State University, Raleigh.

Woolley, J. T. and Stoller, E. 1978. Light penetration and light-induced seed germination in soil. *Plant Physiol*. 61: 597-600.

WSSA [Weed Science Society of America]. 2007. *Herbicide Handbook* (9^{th} Ed.). In: Vencill, W. K. (Ed.), Weed Science Society of America, Lawrence, KS, 493p.

Yadav, D. B., Singh, N., Duhan, A., Yadav, A., and Puniya, 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., 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.

Yang, Y., Zhang, Y. C., Ge, Y. L., Hyang, F. G., and Ding, Z. J. 2004. Control effect of Chugianjn and other herbicides on *Leptochloa chinensis* in direct sowing rice field. *Weed Sci*. (China) 1: 19-20.

Yao, Z. W., Wu, J., Mann, R. K., and Huang, Y. H. 2013. RICER^{TM}60OD: a novel penoxsulam + cyhalofop-butyl formulation for use in direct-seeded rice in China. In: Bakar, B. H., Kuriniadie, D., and Tjitrosoedirdjo, S. (eds), *The Role of Weed Science in Suppressing Food Security by 2020*. Proceedings of 24th Asian-Pacific Weed Science Conference, 22-25 October 2013, Bandung, Indonesia, pp. 606-610.

Ying, G. 1999. The environmental behavior of herbicides in Australian Viticulture. Ph. D thesis, The University of Adelaide, Australia, 216p.

Yokohama, K., Kondo, K., Poolkumlung, P., and Zaprong, P. 2001. Herbicidal efficacy against *Leptochloa chinensis* of bispyribac-sodium in tank mixture with some rice herbicides. In: *Proceedings of the 18th Asian Pacific Weed Science Society Conference,* Beijing, China, pp. 763-769.

Zhang, J. H., Hamill, A. S., and Weaver, S. E. 1995. Antagonism and synergism between herbicides - trends from previous studies. *Weed Technol*. 9(1): 86-90.

Zhang, W., Webster, E. P., Blenin, D. C., and Leon, C. T. 2001. Herbicide interaction for nut grass (*Cyperus rotundus* L.) control in rice. *Weed Technol*. 19: 293-297.

Zhang, Z. P. 2003. Development of chemical weed control and integrated weed management in China. *Weed Biol. Manag.* 3(4): 197-203.

Ziska, L. H., David, R. G., Burgos, N., Caicedoj, L., Gressel, N., Lawton-Rauh, L., Avilaxx, L., Giovani, T., Norsworthy, J., and Ferrero, A. 2015. Weedy (Red) rice: an emerging constraint to global rice production. *Adv. Agron.* 129: 2-38.

Appendices

APPENDIX I

Weakly weather data during the experimental period
(January to April, 2019)

Standard weeks	Temperature (^{O}C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	Max	Min	
2	31.57	22.14	92.0	68.6	0.0
3	32.20	20.85	91.6	68.1	0.0
4	32.04	21.22	92.1	67.3	0.0
5	32.45	22.14	92.6	64.6	0.3
6	32.88	24.31	88.9	67.7	0.1
7	33.28	24.10	86.7	64.3	0.0
8	35.30	23.44	87.4	61.3	0.0
9	34.41	24.18	85.0	62.3	0.0
10	34.62	24.80	85.4	60.0	0.0
11	34.38	24.40	85.3	61.3	0.0
12	34.22	24.82	84.9	61.3	0.0
13	34.84	25.40	85.7	61.9	0.0
14	35.18	26.00	83.7	61.6	0.0
15	34.97	25.92	78.6	61.9	0.0
16	34.92	25.62	82.8	67.3	1.6

APPENDIX II

Weakly weather data during the experimental period
(May to November, 2018)

Standard weeks	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	Max	Min	
20	32.17	24.82	89.3	75.0	15.6
21	32.20	24.82	91.0	81.6	9.15
22	31.54	25.11	93.0	80.9	14.0
23	30.60	24.68	96.4	85.6	18.08
24	31.17	25.05	92.0	80.6	9.07
25	31.00	24.57	92.4	83.7	8.14
26	31.45	24.40	89.7	80.7	3.60
27	31.55	24.68	86.6	75.4	1.45
28	29.62	23.00	93.9	85.4	9.90
29	30.41	23.54	91.1	79.1	8.04
30	31.35	23.57	89.3	73.3	2.18
31	29.48	23.91	90.4	80.9	19.45
32	30.28	23.32	91.0	85.1	15.32
33	29.08	22.57	94.9	89.9	29.31
34	30.95	24.00	89.4	76.6	0.46
35	31.97	24.45	89.1	71.9	0.00
36	32.17	24.05	87.1	72.0	0.00
37	33.00	24.07	85.1	70.9	0.00
38	32.00	24.22	88.4	72.0	1.32
39	32.54	24.60	90.1	81.4	8.24
40	31.45	24.72	92.0	85.4	6.90
41	30.67	24.28	93.1	80.1	19.22
42	32.02	24.45	91.4	77.3	12.94
43	31.40	24.24	93.7	76.4	1.61
44	31.80	24.30	93.4	77.1	10.20
45	31.10	24.30	93.6	78.7	8.50

APPENDIX III

Weakly weather data during the experimental period
(June 11th to October 30th, 2018)

Standard weeks	Temperature (^{o}C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	Max	Min	
24	30.35	24.5	85.92	0.00	47.0
25	30.21	24.28	85.14	0.00	69.0
26	30.78	24.00	82.64	73.57	31.2
27	30.78	24.28	92.00	71.28	7.2
28	29.57	20.07	90.14	73.00	83.5
29	30.42	23.78	88.85	74.28	44.7
30	30.71	24.50	85.42	67.42	7.8
31	30.00	24.21	87.57	82.00	124.2
32	29.64	20.64	90.14	79.00	117.4
33	28.28	22.85	93.85	84.42	188.8
34	31.00	24.42	85.57	72.57	0.0
35	30.85	24.28	84.00	72.71	0.0
36	31.28	23.92	81.28	69.14	0.0
37	31.92	24.35	80.42	66.00	0.0
38	31.57	24.50	85.28	73.71	8.3
39	32.21	24.57	82.28	73.71	91.6
40	30.21	25.00	91.71	85.57	75.4
41	30.57	24.64	90.00	75.28	25.2
42	31.28	23.85	88.57	71.57	82.0
43	31.07	24.28	91.28	75.57	20.6
44	31.28	24.28	86.85	75.28	78.4

APPENDIX IV

Weakly weather data during the experimental period
(June 4th to October 15th, 2019)

Standard weeks	Temperature (^{O}C)		Relative humidity (%)		Rainfall (mm)
	Max	Min	Max	Min	
23	31.29	24.57	87.43	82.86	136.0
24	30.87	24.55	97.28	90.88	72.0
25	30.65	25.07	99.05	90.45	29.0
26	30.74	26.23	95.92	88.97	0.0
27	30.78	25.72	99.99	89.49	21.0
28	30.45	24.42	97.96	93.05	19.0
29	29.33	23.35	99.89	85.73	82.0
30	29.99	23.99	98.86	91.15	9.0
31	30.46	25.37	99.99	91.84	6.0
32	29.56	23.42	98.92	91.01	180.0
33	30.08	24.12	99.90	92.42	18.0
34	30.06	23.83	97.99	85.90	35.0
35	30.25	23.88	99.99	88.34	78.0
36	30.62	24.56	99.66	89.87	70.0
37	30.73	24.68	99.99	88.49	16.0
38	30.72	24.59	99.91	88.13	52.0
39	30.85	24.27	97.43	90.28	129.0
40	31.07	23.71	87.14	78.85	15.0
41	31.21	23.57	91.00	75.14	56.0
42	30.21	23.71	92.00	84.00	64.0

GERMINATION ECOLOGY AND MANAGEMENT OF CHINESE SPRANGLETOP [*Leptochloa chinensis* (L.) Nees.] IN WET SEEDED RICE

by

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ABSTRACT OF THE THESIS

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ABSTRACT

An investigation entitled 'Germination ecology and management of Chinese sprangletop [*Leptochloa chinensis* (L.) Nees.] in wet seeded rice' was undertaken at the College of Agriculture, Vellayani during 2017-2020. The objectives were to study the habitat, germination ecology and distribution of *Leptochloa chinensis* in major rice growing tracts of Kerala; to test the efficacy of tank mix combinations of herbicides for the management of the weed; to test the sensitivity of the weed to herbicide combinations and to assess the mode of action of the herbicide combinations.

The phytosociological survey was conducted to document the habitat, composition and distribution of *L. chinensis* in different rice tracts of Kerala *viz*., Palakkad, *Kole* and Kuttanad after selecting three severely infested *padasekharams* in each tract during 2018 and 2019. *L. chinensis* was found to occur in all the major rice growing tracts of Kerala and registered summed dominance ratio of 13.05, 12.40 and 17.49, respectively in Kuttanad, *Kole* and Palakkad (*Kharif*). Appraisal of weed vegetation analysis indices displayed the highest weed species richness (17) and Simpson's diversity index in *Kole* and the lowest Shannon Wiener diversity index (2.09) in Palakkad. *L. chinensis* was the dominant weed in all these tracts with an abundance of 17.33, 17.0 and 16.36, respectively and the weed inhabited both upland and lowland situations, either in crop lands, field bunds, stream banks or waterways. Profuse growth of the weed was observed along the inner bunds separating individual fields. The weed was a prolific seed producer with seed production potential ranging from 7400-33,941 seeds per plant across the surveyed locations.

Germination ecology experiments encompassed studies on weed phenology and germination of Chinese sprangletop. *L. chinensis* is an erect or creeping, annual or perennial grass that can grow upto a height of 120-150 cm, propagates both by seed and slips with very minute seeds (thousand seed weight of 0.10-0.18 g). The weed was noticed to develop through five phenological stages, *viz*., emergence, tillering, heading, flowering and maturity with an average duration of 10.6, 41.5, 73.5, 78.5 and 95 days, respectively.

Investigations on germination ecology revealed that light was not an absolute requirement for germination of seeds of *L. chinensis*, but stimulated germination by 23 per cent. When exposed to alternating temperatures in light/dark, seeds germinated at 15°C to 35°C. The highest germination occurred at 25/15°C (87.2%), while at 35/25°C it was only 70.31 per cent. Germination of *L. chinensis* was significantly influenced by moisture regime; with zero germination under continuous flooding or with thin layer of water (3 cm) and 70 per cent germination on irrigating at alternate days. Seedling emergence was also significantly affected by seed burial depth. Seedling emergence was high (85%) for seeds placed on the soil surface, while no emergence was observed at burial depths of 2 cm or beyond. Slips placed at the surface recorded 100 per cent sprouting and the time taken for 50 per cent emergence increased with increase in burial depth. The seeds germinated upto nine months after harvest with the germination declining over time.

The field experiments on management of *L. chinensis* were conducted during 2018 and 2019 *Kharif* at Integrated Farming System Research Station, Karamana. The experiment was laid out in randomized block design with 10 treatments and three replications. The treatments included T_1: cyhalofop butyl @ 0.08 kg ha^{-1}, T_2: penoxsulam + cyhalofop butyl (6% OD) @ 0.15 kg ha^{-1}, T_3: cyhalofop butyl + carfentrazone ethyl @ 0.08 + 0.02 kg ha^{-1}, T_4: bispyribac sodium @ 0.025 kg ha^{-1}, T_5: bispyribac sodium + cyhalofop butyl @ 0.025 + 0.08 kg ha^{-1}, T_6: bispyribac sodium + fenoxaprop-p-ethyl @ 0.025 + 0.06 kg ha^{-1}, T_7: fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}, T_8: stale seedbed followed by (*fb*) glyphosate + oxyfluorfen @ 0.8 + 0.15 kg ha^{-1} at 15-20 days after land preparation *fb* cyhalofop butyl + carfentrazone ethyl @ 0.08 + 0.02 kg ha^{-1}, T_9: unweeded control and T_{10}: hand weeding twice at 20 and 45 days after sowing (DAS).

The weed management practices had significant influence on *L. chinensis* count, dry matter production, control efficiency and nutrient removal at different stages of observation. Count of *L. chinensis* was zero in T_6, T_7, T_8 and T_{10} at 15 days after treatment application (DATA) during both the years. The lowest count and dry matter production and the highest pooled control efficiency of *L. chinensis* (97.55 and 96.78 per cent, respectively at 30 and 45 DATA) was registered in T_7.

It was statistically on par with all other treatments except T_4 and T_9. Bispyribac sodium was not effective in controlling *L. chinensis* and resulted in lower control efficiency of 52.63, 38.68 and 42.43 per cent, respectively at 15, 30 and 45 DATA. However, its combination with fenoxaprop-p-ethyl (T_6) or cyhalofop butyl (T_5) resulted in higher control efficiency of *L. chinensis* at all stages of observation and recorded 100, 96.06 and 95.96 and 97.23, 92.37 and 94.55 per cent, respectively at 15, 30 and 45 DATA.

Among the herbicide treatments, T_6 registered the least total weed dry matter production at all stages and resulted in the highest pooled weed control efficiency of 98.20 and 89.70 per cent which was on par with T_2 (96.61 and 83.86%) and T_5 (95.40 and 84.81%) respectively at 30 and 45 DATA. The highest pooled grain yield (5.03 t ha^{-1}) also was registered in T_6 which was on par with T_2 and T_5 with 4.79 and 4.76 t ha^{-1}. Pooled data revealed that season long weed competition in wet seeded rice (WSR) with *L. chinensis* as a major weed caused a yield reduction of 59.95 per cent. Compared to the unweeded control, herbicidal treatments enhanced grain yield by 23.89-58.84 per cent, whereas herbicide combinations increased grain yield by 56-59 per cent in WSR. Pooled mean of the economics of cultivation registered maximum net returns per hectare (₹ 63,657 ha^{-1}) and B:C ratio (1.81) in T_6 followed by T_2 (₹ 56,995 ha^{-1} and 1.73) and T_5 (₹ 56,044 ha^{-1} and 1.72).

The sensitivity of *L. chinensis* to herbicide combinations was tested at the field recommended dose and its lower doses using whole plant bioassay technique after identifying best combinations *viz*., bispyribac sodium + fenoxaprop-p-ethyl @ 0.025 + 0.06 kg ha^{-1}, bispyribac sodium + cyhalofop butyl @ 0.025 + 0.08 kg ha^{-1}, penoxsulam + cyhalofop butyl @ 0.15 kg ha^{-1} and cyhalofop butyl + carfentrazone ethyl @ 0.08 + 0.02 kg ha^{-1}. The experiment was laid out in completely randomized design (CRD) with eight treatments and three replications. Lower dose of bispyribac sodium + fenoxaprop-p-ethyl @ 0.020 + 0.04 kg ha^{-1} recorded the least survival (0%) of *L. chinensis* whereas, bispyribac sodium + cyhalofop butyl @ 0.020 + 0.06 kg ha^{-1}, cyhalofop butyl + carfentrazone ethyl @ 0.06 + 0.01 kg ha^{-1} and penoxsulam + cyhalofop butyl @ 0.10 kg ha^{-1} registered 26.66, 30.0 and 86.66 per cent survival, respectively.

The experiment on mode of action of tank mix herbicide combination was laid out in CRD with four treatments and five replications. The treatments included T_1: ALS inhibitor alone (bispyribac sodium @ 0.025 kg ha^{-1}), T_2: ACCase inhibitor alone (fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}), T_3: ALS + ACCase inhibitor (bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1}) and T_4: Control. Treatment T_3 recorded lower amino acid content (0.1775 mg mL^{-1}) than T_1 (0.2904 mg mL^{-1}) confirming that the combined application of an ALS + ACCase inhibitor could provide better control of *L. chinensis* compared to sole application of ALS inhibitor.

The experiment on assessing the differential response of *L. chinensis* and *Echinochloa colona* to the broad-spectrum herbicide bispyribac sodium, revealed that amino acid content of *L. chinensis* was not influenced by the increasing concentration of bispyribac sodium. High content of amino acid was registered in *L. chinensis* (0.2904 and 0.3234 mg mL^{-1}) compared to *E. colona* irrespective of the concentration of bispyribac sodium. However, in *E. colona*, the amino acid content (0.1520 and 0.0627 mg mL^{-1}) was found to decrease with increasing concentration of bispyribac sodium.

The present study identified *L. chinensis* as a major weed in all the major rice growing tracts of Kerala indicating its invasive potential under diverse environmental conditions owing to its prolific seed production, sprouting from weed slips on soil surface, extended period of seed viability and different mode of propagation. The results revealed that early and continuous flooding, deep tillage for burial of seeds and slips into the soil beyond 5 cm could suppress its emergence. The study identified fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} as the most effective herbicide against *L. chinensis* to be sprayed at 15-18 DAS in WSR. In areas where *L. chinensis* is a dominant weed in the WSR, tank mix application of bispyribac sodium @ 0.025 kg ha^{-1} + fenoxaprop-p-ethyl @ 0.06 kg ha^{-1} at 15-18 DAS could be recommended for broad spectrum weed management. Whole plant bioassay of the above combination proved effective at its still lower dose and the differential response of *L. chinensis* to bispyribac sodium indicated herbicide combinations for managing the complex spectrum of weeds in wet seeded rice.

സംഗ്രഹം

നെല്ലിൽ ചേറ്റുവിത രീതി അവലംബിക്കുമ്പോൾ വരുന്ന കുതിരവാലി പുല്ല്/ പീലിക്കവട അഥവാ ലെപ്റ്റോക്ലോവ ചൈനെൻസിസ് എന്ന പുല്ല് വർഗ്ഗ കളയുടെ വളർച്ചാ രീതിയും നിയന്ത്രണമാർഗ്ഗവും കണ്ടെത്താൻ 2017-2020 കാലഘട്ടത്തിൽ വെള്ളായണി കാർഷിക കോളേജിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി. കേരളത്തിൽ, പ്രധാനമായും നെൽകൃഷി ചെയ്തുവരുന്ന മേഖലകളിൽ കുതിരവാലിപ്പുല്ലിന്റെ ആവാസ വ്യവസ്ഥ, മുളയ്ക്കാനനുകൂലമായ പരിസ്ഥിതി സാഹചര്യങ്ങൾ, വ്യാപനം, കള നിയന്ത്രണത്തിനായി കളനാശിനി സംയോജനങ്ങളുടെ ഫലപ്രാപ്തി പരിശോധിക്കുക, കളനാശിനി സംയോജനങ്ങളോടുള്ള കളയുടെ സംവേദനക്ഷമത പരിശോധിക്കുക, കളനാശിനി സംയോജനങ്ങളുടെ പ്രവർത്തനരീതി വിലയിരുത്തുക എന്നിവയായിരുന്നു പ്രധാന ലക്ഷ്യങ്ങൾ.

കുതിരവാലിപ്പുല്ലിന്റെ ആവാസവ്യവസ്ഥ, ഘടന, വ്യാപനം എന്നിവ രേഖപ്പെടുത്തുന്നതിനായി കേരളത്തിലെ പ്രധാന നെൽകൃഷി മേഖലകളായ കുട്ടനാട്, കോൾ, പാലക്കാട് എന്നിവിടങ്ങളിൽ 2018-ലും 2019-ലും ഫൈറ്റോസോഷ്യോളജിക്കൽ സർവ്വേ നടത്തുകയുണ്ടായി. പ്രസ്തുത സർവ്വേയിൽ ഈ കളയുടെ പ്രബലമായ സാന്നിധ്യം എല്ലാ നെൽകൃഷി മേഖലകളിലും രേഖപ്പെടുത്തുകയുണ്ടായി. കുട്ടനാട്, കോൾ, പാലക്കാട് (വിരിപ്പ്) എന്നിവിടങ്ങളിൽ യഥാക്രമം 13.05, 12.40, 17.49 എന്നീ സംഗ്രഹ ആധിപത്യ അനുപാതം (SDR) രേഖപ്പെടുത്തി.

നെൽപാടങ്ങൾ, വയൽവരമ്പുകൾ, വെള്ളച്ചാലുകൾ, കരപ്രദേശങ്ങൾ, ജലാശയങ്ങളുടെ തീരങ്ങളിലും കുതിരവാലി പുല്ലിന്റെ സാന്നിദ്ധ്യം രേഖപ്പെടുത്തി. പാടങ്ങൾക്കിടയിലുള്ള വരമ്പുകളിൽ കളയുടെ സമൃദ്ധമായ വളർച്ച നിരീക്ഷിക്കപ്പെട്ടു. സർവേ നടത്തിയ സ്ഥലങ്ങളിൽ ഒരു ചെടിയിൽ നിന്ന് ഏകദേശം 7400-33,941 വിത്തുകൾ വരെ ഉത്പ്പാദിപ്പിക്കപ്പെടുന്നതായി കാണപ്പെട്ടു.

വളർച്ച രീതി നിരീക്ഷിച്ചതിൽ ഈ കളയ്ക്ക് വാർഷികകളയായോ ബഹുവർഷിയായോ നിലനിൽക്കാൻ കഴിയുമെന്ന് കണ്ടെത്തി. ധാരാളമായി ഉത്പാദിപ്പിക്കപ്പെടുന്ന ചെറിയ വിത്തുകളിലൂടെയും (ആയിരം വിത്ത് തൂക്കം 0.10-0.18 ഗ്രാം) പുൽകടകളിലൂടെയും (സ്ലിപ്പ്) ഈ കള വംശവർദ്ധനവ് നടത്തുന്നു എന്ന് നിരീക്ഷിച്ചു. കള വിത്തുകൾ മുളയ്ക്കുന്നതിന് ശരാശരി 10.6 ദിവസവും, ചിനപ്പ് വരുന്നതിന് 41.5 ദിവസവും, പൂങ്കുലകൾ പുറത്തേക്ക് കാണുന്നതിന് 73.5 ദിവസവും, പൂവിടുവാൻ 78.5 ദിവസവും, ചേറ്റുവിത പാടങ്ങളിൽ ശരാശരി ജീവിതചക്രം പൂർത്തിയാക്കുന്നതിന് 95 ദിവസവും വേണ്ടിവരുന്നതായി കണ്ടെത്തി.

കുതിരവാലിപ്പുല്ലിന്റെ മുളയ്ക്കുന്നതിനനുകൂലമായ സാഹചര്യങ്ങളെക്കുറിച്ച് പഠനം നടത്തിയപ്പോൾ വിത്തുകൾ മുളയ്ക്കുന്നതിന് വെളിച്ചം ആവശ്യഘടകമല്ലെന്നും എന്നാൽ വെളിച്ചം മുളയ്ക്കുന്നതിനെ 23 ശതമാനം ഉത്തേജിപ്പിക്കുമെന്നും വെളിപ്പെടുത്തി. വെള്ളം തുടർച്ചയായി കെട്ടിനിർത്തുന്നതും നേർത്ത പാളിയായി നിലനിർത്തുന്നതും വിത്തിന്റെ മുളയ്ക്കലിനെ പൂർണ്ണമായും തടസ്സപ്പെടുത്തുന്നു.

ഒന്നിടവിട്ട ദിവസങ്ങളിലെ നന 70 ശതമാനത്തോളം വിത്തുകൾ മുളയ്ക്കുവാൻ കാരണമായി. മണ്ണിൽ കളവിത്ത് കാണപ്പെടുന്ന ആഴവും തൈകളുടെ ഉയർന്നു വരവിനെ സാരമായി ബാധിക്കുന്നു. കളവിത്ത് മുളയ്ക്കാൻ അനുകൂലമായ മണ്ണിലെ ആഴം പരിശോധിച്ചതിൽ മണ്ണിന്റെ ഉപരിതലത്തിൽ വിന്യസിച്ച വിത്തുകളിൽ 85 ശതമാനത്തോളം മുളയ്ക്കുകയും അതേസമയം 2 സെന്റിമീറ്ററോ അതിൽ കൂടുതലോ ആഴത്തിൽ വിന്യസിച്ചിരുന്ന വിത്തുകൾ മുളയ്ക്കാതിരിക്കുകയും ചെയ്തു. ഉപരിതലത്തിൽ സ്ഥിതിചെയ്തിരുന്ന സ്ലിപ്പുകൾ 100 ശതമാനം മുളച്ചതായി രേഖപ്പെടുത്തി. വിളവെടുപ്പ് കഴിഞ്ഞ് ഒമ്പത് മാസം വരെ വിത്തുകൾ മുളയ്ക്കുകയും, കാലക്രമേണ അങ്കുരണശേഷി കുറയുന്നതായും നിരീക്ഷിച്ചു.

കളയുടെ നിയന്ത്രണ മാർഗ്ഗം കണ്ടെത്താൻ 2018, 2019 വിരിപ്പ് കാലത്തിൽ സംയോജിത കൃഷി സമ്പ്രദായ ഗവേഷണ കേന്ദ്രത്തിൽ പഠനം നടത്തുകയുണ്ടായി. റാൻഡണ്ടമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ അവലംബിച്ചു നടത്തിയ പരീക്ഷണത്തിൽ 10 വ്യത്യസ്ത കളനിയന്ത്രണ മാർഗ്ഗങ്ങളുടെ മികവാണ് പരീക്ഷിച്ചത്. സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ 0.08 കി.ഗ്രാം (T1), പെനോക്സുലം + സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ 6% OD 0.15 കി.ഗ്രാം (T2), സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ + കാർഫെൻട്രാസോൺ എഥൈൽ 0.08 + 0.02 കി.ഗ്രാം (T3), ബിസ്പൈറിബാക് സോഡിയം 0.025 കി.ഗ്രാം (T4), ബിസ്പൈറിബാക് സോഡിയം + സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ 0.025 + 0.08 കി.ഗ്രാം (T5), ബിസ്പൈറിബാക് സോഡിയം + ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ 0.025 + 0.06 കി.ഗ്രാം (T6), ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ 0.06 കി.ഗ്രാം (T7) (കി.ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ, വിതച്ചു 18-20 ദിവസങ്ങൾക്കു ശേഷവും T1 മുതൽ T7 വരെ), സ്റ്റൈൽ സീഡ് ബെഡ്, തുടർന്ന് ഗ്ലൈഫോസേറ്റ് + ഓക്സിഫ്ലൂർഫെൻ 0.8 + 0.15 കി.ഗ്രാം എന്ന തോതിൽ നിലമൊരുക്കി 15-20 ദിവസങ്ങൾക്ക് ശേഷവും തുടർന്ന് സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ + കാർഫെൻട്രാസോൺ എഥൈൽ 0.08 + 0.02 കി.ഗ്രാം എന്ന തോതിൽ വിതച്ചു 18-20 ദിവസങ്ങൾക്കു ശേഷവും (T8), കളകൾ നീക്കം ചെയ്യാത്ത അൺവീഡഡ് കൺട്രോൾ (T9) രണ്ടു തവണ കളപറിച്ചു നീക്കൽ - വിതച്ചു 20 ദിവസത്തിനു ശേഷവും 45 ദിവസത്തിനു ശേഷവും (T10) എന്നീ രീതികൾ ആണ് പഠന വിധേയമാക്കിയത്.

പരീക്ഷിച്ച കള പരിപാലന രീതികളിൽ, കുതിരവാലിപ്പുല്ലിന്റെ ഏറ്റവും കുറഞ്ഞ എണ്ണവും, ഏറ്റവും ഉയർന്ന നിയന്ത്രണ കാര്യക്ഷമതയും രേഖപ്പെടുത്തിയത് T7-ൽ ആണ്. ബിസ്പൈറിബാക് സോഡിയം കുതിരവാലിപ്പുല്ലിനെ നിയന്ത്രിക്കുന്നതിൽ ഫലപ്രദമല്ലാത്തതായി കണ്ടെത്തി. എന്നിരുന്നാലും, ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ (T6) അല്ലെങ്കിൽ സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ (T5) എന്നിവയുമായുള്ള അതിന്റെ സംയോജനം നിരീക്ഷണത്തിന്റെ എല്ലാ ഘട്ടങ്ങളിലും കുതിരവാലിപ്പുല്ലിന്റെ ഉയർന്ന നിയന്ത്രണ കാര്യക്ഷമത രേഖപ്പെടുത്തി. കള നിയന്ത്രണ മാർഗ്ഗങ്ങളിൽ, T6 എല്ലാ ഘട്ടങ്ങളിലും ഏറ്റവും കുറഞ്ഞ കളവളർച്ച രേഖപ്പെടുത്തുകയും ഏറ്റവും ഉയർന്ന കളനിയന്ത്രണ കാര്യക്ഷമത കൈവരിക്കുകയും ചെയ്തു.

പരീക്ഷിച്ച കള പരിപാലന രീതികളിൽ, വിളവ് ഹെക്ടറിന് 5.03, 4.79, 4.76 ടൺ എന്നിങ്ങനെ T6-ലും T2-ലും T5-ലും യഥാക്രമം രേഖപ്പെടുത്തി.

കളകൾ മൂലം ചേറ്റുവിതയിൽ വിളവ് കുറയുന്നതിന്റെ വ്യാപ്തി 59.95 ശതമാനമായി കണക്കാക്കപ്പെട്ടു. കളനിയന്ത്രണ മാർഗ്ഗങ്ങൾ അവലംബിക്കാതെയുള്ള കൃഷിയുമായി താരതമ്യം ചെയ്യുമ്പോൾ, കളനാശിനികളുടെ ഉപയോഗം 23 മുതൽ 58 ശതമാനം വരെ വിളവ് വർദ്ധിപ്പിച്ചു, അതേസമയം കളനാശിനികളുടെ സംയോജനം ധാന്യവിളവ് 56-59 ശതമാനം വർദ്ധിപ്പിച്ചു. ബിസ്പൈറിബാക് സോഡിയം + ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ 0.025 + 0.06 കി.ഗ്രാം എന്ന തോതിൽ, വിതച്ചു 18-20 ദിവസങ്ങൾക്കു ശേഷം അവലംബിക്കുന്നത് ഏറ്റവും ഫലപ്രദവും ലാഭകരവുമായ കളനിയന്ത്രണ മാർഗ്ഗമായി കണ്ടെത്തി.

കേരളത്തിലെ എല്ലാ പ്രധാന നെല്ലുൽപാദന മേഖലകളിലും കുതിരവാലിപ്പുല്ലിനെ ഒരു പ്രധാന കളയായി ഈ പഠനം തിരിച്ചറിഞ്ഞു, സമൃദ്ധമായ വിത്തുൽപാദനം, മണ്ണിന്റെ ഉപരിതലത്തിൽ വിത്തുകളിൽ നിന്നും സ്ലിപ്പുകളിൽ നിന്നുമുള്ള മുളയ്ക്കൽ, ഉയർന്ന ജീവനസാമർഥ്യം (ദീർഘകാലം നിലനിൽക്കുന്നതിനുള്ള വിത്തിന്റെ കഴിവ്), എന്നിവയെല്ലാം വൈവിധ്യമാർന്ന പാരിസ്ഥിതിക സാഹചര്യങ്ങളിലും ഈ കളയുടെ അധിനിവേശ സാധ്യതയെ സൂചിപ്പിക്കുന്നു. വെള്ളം തുടർച്ചയായി കെട്ടിനിർത്തുന്നതും അഞ്ച് സെന്റിമീറ്ററോ അതിൽ കൂടുതലോ ആഴത്തിൽ വിത്തുകളെയും സ്ലിപ്പുകളെയും മണ്ണിലേക്ക് ആഴ്ത്തിവിടുന്നതും കുതിരവാലിപ്പുല്ലിന്റെ ആവിർഭാവത്തെ അടിച്ചമർത്താൻ കഴിയുമെന്ന് ഫലങ്ങൾ വെളിപ്പെടുത്തി. ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ 0.06 കി.ഗ്രാം വിതച്ചു 18-20 ദിവസങ്ങൾക്കു ശേഷം അവലംബിക്കുന്നത് കുതിരവാലിപ്പുല്ല് നിയന്ത്രിക്കുന്നതിൽ ഏറ്റവും ഫലപ്രദവും ലാഭകരവുമായ കളനിയന്ത്രണ മാർഗ്ഗമായി കണ്ടെത്തി. എന്നാൽ, ചേറ്റുവിതപ്പാടങ്ങളിലെ വിവിധതരം കളകളുടെ നിയന്ത്രണത്തിനായി ബിസ്പൈറിബാക് സോഡിയം + ഫെനോക്സാപ്രോപ്പ്-പി-എഥൈൽ 0.025 + 0.06 കി.ഗ്രാം എന്ന തോതിൽ, വിതച്ചു 18-20 ദിവസങ്ങൾക്കു ശേഷം തളിക്കുന്നത് ശുപാർശ ചെയ്യാവുന്നതാണ്.