MANAGEMENT OF ROCK BULRUSH (*Schoenoplectus juncoides* (Roxb.) Palla) IN WET SEEDED RICE

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"MANAGEMENT OF ROCK BULRUSH (*Schoenoplectus juncoides* (Roxb.) Palla) IN WET SEEDED RICE"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATION

µg	-	Microgram
2, 4-D	-	2, 4-dichloro phenoxy acetic acid
a.i.	-	Active ingredient
ALS	-	Acetolactate synthase
B: C	-	Benefit: Cost ratio
BLW	-	Broad leaved weeds
Ca	-	Calcium
CD(0.05)	-	Critical difference at 5 per cent level
cm	-	Centimeter
culm^{-1}	-	Per culm
CV	-	Coefficient of variation
DAF	-	Days after flowering
DAS	-	Days after sowing
DAT	-	Days after transplanting
DF	-	Dry flowable
dSm^{-1}	-	Deci seimens per meter
EC	-	Electrical conductivity
et al.	-	Co-workers/ Co-authors
etc.	-	Excetra
f	-	Forma
fb	-	Followed by
Fig	-	Figure
g m^{-2}	-	Gram per square meter

g mol^{-1}	-	Gram per mole
g $plant^{-1}$	-	Gram per plant
g	-	Gram
g^{-1}	-	Per gram
GR	-	Granule
h^{-1}	-	Per hour
ha^{-1}	-	Per hectare
HI	-	Harvest Index
HW	-	Hand weeding
i.e.	-	That is
IAA	-	Indole-3-acetic acid
K	-	Potassium
K_2O	-	Potash
kg ha^{-1}	-	Kilogram per hectare
kg	-	Kilogram
km	-	Kilometer
L ha-1	-	Litre per hectare
L	-	Litre
Lakh t	-	Lakh hectare
m	-	Meter
m^{-2}	-	Per square meter
m^2	-	Square meter
Max.	-	Maximum
mg kg^{-1}	-	Milligram per kilogram
Mg	-	Magnesium

Mha	-	Million hectare
Min.	-	Minimum
ml ha-1	-	Milli litre per hectare
ml	-	Milli litre
mm	-	Millimeter
MO	-	Moncompu
Mt	-	Million tons
N	-	Nitrogen
No.	-	Number
NS	-	Non significant
P	-	Phosphorus
P_2O_5	-	Phosphoric acid
$panicle^{-1}$	-	Per panicle
pH	-	Potential hydrogen
$plant^{-1}$	-	Per plant
PPO	-	Protoporphyrinogen oxidase
Roxb.	-	Roxburgh
Rs ha-1	-	Rupees per hectare
SC	-	Soluble Concentrate
SEm	-	Standard error mean
sp.	-	Species
$spike^{-1}$	-	Per spike
subsp.	-	Sub species
$t\ ha^{-1}$	-	Tonnes per hectare
$tiller^{-1}$	-	Per tiller

TPF	-	Triphenyl formazan
viz.	-	Namely
vs.	-	Versus
WDG	-	Wet dispersible granules
WG	-	Wettable Granules
WI	-	Weed Index
WP	-	Wettable Powder

LIST OF SYMBOLS

@	-	At the rate of
%	-	Per cent
^{0}C	-	Degree Celsius
^{0}E	-	Degree East
^{0}N	-	Degree North
^{0}S	-	Degree South
^{0}W	-	Degree West
>	-	Greater than
/	-	Or

Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the global staple crop that alleviates the hunger needs of over 70 per cent of the human population (Kumar *et al.*, 2018). Besides being the major food crop of South and Southeast Asia, carbohydrate rich rice grains are an excellent calorie provider to the poor, especially in Asia. Suitability to diverse ecosystems and cultivation practices makes rice an attractive choice for the farmers. Significance of rice was duly appreciated by the United Nations by declaring 2004 as the "International year of Rice". Population explosion in the world has increased the demand for rice. But higher production from limited area should be targeted for satiating the ever increasing demand for the staple crop.

The method adopted for rice cultivation has profound influence in determining the crop's productivity. Among the several methods practiced, manual transplanting is the traditional and highly accepted system for paddy establishment. However, timely labour availability decides the success of crop establishment and yield. In Asia, the labour available for agricultural purpose is declining at a steady rate thereby increasing the wage rates. Significant reduction in labour force coupled with inflating wage rates speak out the need for a shift to less labour intensive methods of rice cultivation. In such a scenario, direct seeding of rice has emerged as a cost-effective, less laborious alternative for transplanting. Direct seeding can be either dry seeding or wet seeding. Wet seeding refers to the broadcasting or drilling of pre-germinated seeds on puddled soil followed by gradual flooding.

Though the requirement for skilled manpower is less, severe weed infestation is observed in direct sown crop and effective management of this bio-factor decides the ultimate yield of the system. Direct sown rainfed crop experiences higher weed competition than transplanted crop due to the co-emergence of weed and rice seedlings in the former that spurs the yield loss. Absence of initial flooding further aggravates the early crop-weed competition in the direct seeded system. Uncontrolled weeds reduce the grain yield in dry direct seeded rice by 96 per cent and by 61 per cent in wet direct seeded rice (Maity and Mukerjee, 2008).

Wet seeded rice is infested with composite weed flora comprising of grasses, sedges and broad leaved weeds as in all other systems. Among the three weed groups, sedges pose greater threat to rice (Satapathy *et al.*, 2017) as they are usually perennial with underlying propagules that help in tiding over unfavourable climatic conditions.

Rock bulrush (*Schoenoplectus juncoides*) is a sedge species which is found to inhabit the lowland rice fields of South Kerala. This weed emerges directly from seeds in puddled rice fields and seedlings emerge from vegetative buds also. Small rhizomes produced by the weed ensure its presence in dry, unpuddled lowlands. Moist, warm, aerobic condition in this system promotes rapid germination and emergence of the weed which is rarely affected by subsequent flooding. Strong tillering habit combined with lodging of plants with mature seeds increase the level of damage, which is even worse in broadcasted crop. The occurrence of *Schoenoplectus juncoides* is extended over the entire crop growing period. Tremendous capacity for seed production increases the weed seed bank ensuring the weed infestation in all seasons. Raj (2016) reported the dominance of *Schoenoplectus juncoides* in the rice fields of Nemom block of Thiruvananthapuram district.

Hand weeding at critical stages of crop-weed competition (20 and 40 DAS) is the most effective method of weed management in rice. But, manual weeding in wet seeded broadcasted crop is nearly impractical, due to sub aerial propagules and absence of definite row arrangement for the crop. Apart from the ineffectiveness, escalating wage rates of labour and lower labour availability makes manual weeding, a least reliable to method of weed management. This highlights the importance of herbicides - an attractive, cheap, quick acting, feasible, cost effective and promising remedy for weed management in reducing the production cost of wet seeded rice.

Weed management using herbicides has become an integral part of modern agriculture. New generation herbicides are a viable option compared to conventional herbicides due to very low application rates with increased efficacy in managing grasses, sedges and broad leaved weeds. Pre-emergence and early post-emergence herbicides are available, which alone or supplemented with hand weeding have been reported to provide a fair degree of weed control. The effectiveness of these herbicides against *Schoenoplectus juncoides* is to be documented for proper management of the weed in wet seeded system.

In this backdrop, the study is proposed with the following objectives:

1. To study the biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)
2. To develop an effective and economic method for its management in wet seeded rice.

Review of Literature

2. REVIEW OF LITERATURE

Rice (*Oryza sativa*), the most important cereal crop in the world has an increasing demand with population explosion. By 2035, 114 Mt of milled rice needs to be produced in surplus i.e. 26 per cent increase in production within 25 years. The challenge in achieving this target with the declining area, water and labour can be over ridden by switching over to direct seeding of rice instead of the traditional method of transplanting (Kumar and Ladha, 2011). Rao *et al.* (2017) reported that $1/4^{th}$ of the world rice production come from the 43 M ha under rice in India. Area under rice in Kerala has decreased to 1.71 lakh ha with production and productivity of 4.36 lakh t and 2.55 t ha^{-1}, respectively (GoK, 2017).

Recently, a succession of sedge species especially of the genera *Scirpus* is observed to dominate the rice fields of South Kerala. Among these, rock bulrush or hard stem bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) locally known as 'Mattipullu' or 'Manapullu' is an emerging sedge weed in the wetland rice fields of Kerala. It is also known as *Scirpus juncoides* Roxburgh or *Scirpus rockii* Kukenth. Information obtained from the available literature on "Management of *Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice" including biology of the weed is dealt in this chapter.

2.1. BIOLOGY OF ROCK BULRUSH

Understanding the biology of the weed is very essential for formulating effective management strategies. The information available on the biology of *Schoenoplectus juncoides* is explained under different heads in the following section.

2.1.1. Classification

Sedges belonging to the genera *Schoenoplectus*, *Blysmus*, *Bolboschoenus*, *Scirpus*, *Scirpoides*, *Isolepis* and *Trichophorum* were included into a common tribe, Scirpeae by Bruhl (1995). The seven genera were split and included in four separate tribes by Goetghebeur (1998). The four tribes according to his classification were Scirpeae (*Scirpus* and *Trichophorum*), Fuireneae (*Bolboschoenus* and *Schoenoplectus*), Cypereae (*Isolepis* and *Scirpoides*) and Dulichieae (*Blysmus*).

Rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) belonging to the Cyperaceae family, is a graminoid weed coming under the class Equisetopsida and order Poales. *Schoenoplectus* is a *Scirpus* segregate and possess the highest number of species *viz.* 77 species (Hayasaka, 2002). It is a polyploid species with 2n=74 (Yano and Hoshino, 2005). *Schoenoplectus juncoides* is one of the polyphyletic members in the sedge family (Jung and Choi, 2011).

The generic name *Schoenoplectus* had its genesis from two Greek words '*schoinos*': rush and '*plektos*': plaited or twisted. The species name '*juncoides*' means: similar to juncus - a non native rush in the juncaceae family (Eickhoff, 2009).

2.1.2. Origin and Distribution

Schoenoplectus juncoides is a native of Hawaii, U.S.A, where it is known as 'Kaluha' (Eickhoff, 2009). A report by Bayer (2017) revealed that the incidence of *S. juncoides* was first reported from Japan in 1996.

EPPO Global Database (2004) revealed the different names of *Schoenoplectus juncoides* in different languages. In English, rock bulrush, hard stem bulrush, Japanese bulrush or three-square bulrush; binsenartige simse (German); hotarui (Japanese) and junquilho (Portuguese).

IRRI (2017) recognized *Schoenoplectus juncoides* as one among the twelve most troublesome weeds in the South and South East Asian rice fields. IRRI also reported the cosmopolitan distribution of *S. juncoides* with serious infestations in Japan, Korea (Asia), Bangladesh, Cambodia, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Srilanka, Thailand, Vietnam (South and South East Asia) and along Australia, Ecuador, Fiji, Madagascar and United States- Hawaii.

Sasidharan (2017) reported the occurance of *S. juncoides* across Kottayam, Alappuzha, Kollam, Idukki, Pathanamthitta, Thiruvananthapuram, Malappuram and Kozhikode districts of Kerala.

2.1.3. Habit and Habitat

Schoenoplectus juncoides is an annual sedge species that has the potential to grow perennially under favourable soil and climatic conditions (Khalid and Sadar-U-Siddiqui, 2014). NPPC (2017) described rock bulrush as an annual rush in the lowland paddy fields. *Schoenoplectus juncoides* is monocotyledonous and has both annual and perennial nature (USDA, 2018).

Bhatt *et al.* (2009) reported the occurrence of *Schoenoplectus juncoides* both in uplands and lowlands thus revealing its amphibious nature. *S. juncoides* grow luxuriously in marshes, ditches, pond banks, river banks and a common weed in lowland paddy (Pal and Choudhury, 2014). Donayre *et al.* (2016) reported the copious growth of *S. juncoides* in irrigated and rainfed lowland paddy fields.

Barooah and Ahmed (2014) found rock bulrush growing in tanks and marshes. Occurrence of *Schoenoplectus juncoides* in plains and swampy areas in grasslands were also reported (Sasidharan, 2017).

2.1.4. Vegetative characteristics of rock bulrush

Although belonging to the same family Cyperaceae, sedges and rushes are strikingly different in their morphology. Sedges are identified by stems with triangular cross section, while rushes have round or cylindrical stems (Eickhoff, 2009). Caton *et al*. (2010) described rock bulrush's culms as tufted and cylindrical with light green coloured leaf sheaths at the base. It is a tufted annual with upright culms (Prasad and Raveendran, 2011) growing to a height of about 75cm. Rock bulrush is erect, profusely tillering sedge with small rhizomes (NPPC, 2017).

Chiang (1983) observed that the height of rock bulrush ranged between 40 and 100 cm with a maximum of 187 leaves per plant. Smith and Hayasaka (2002) described rock bulrush as a non-amphicarpous perennial in Asia. The weed has a highly reduced lamina with leaf sheaths clothing the leaf base (Le Bourgeois *et al*., 2008). Khalid and Sadar-U-Siddiqui (2014) observed 2 to 3 short lived, smooth leaf sheaths without lamina at the plant base.

2.1.5. Reproductive characteristics of rock bulrush

Chiang (1983) reported that flower initiation in rock bulrush commenced in less than 45 DAS during *rabi* season. Rock bulrush attained reproductive maturity during August to September with the initiation of spike head, laterally from culm (Pignotti, 2003). Sessile spikes of rock bulrush are ovoid or oblong in shape with 2 to 5 spikelets (Ghimiray *et al*., 2009). Khalid and Sadar-U-Siddiqui (2014) reported the production of 1 to 3 sessile spikes in a single culm of rock bulrush.

Ishikura and Soga (1978) reported the change in pericarp colour with the stages of maturity i.e. green at 15 days after flowering (DAF) turned brown at 30 DAF and black upon maturity. Pignotti and Mariotti (2004) observed narrow, oblong pericarp for S. *juncoides* with rough surface having bands of ridges and depressions. Lodging of heavy, seed bearing stalks was found to facilitate seed dispersal in rock bulrush (Eickhoff, 2009).

2.1.6. Propagation

Schoenoplectus juncoides propagates largely through seeds. Number of seeds produced per plant was observed to be high in the warm temperates, favouring immense weed growth after the harvest of rice (Sakamoto *et al*., 1982). Leck and Schutz (2005) reported the prolific seed production capacity of rock bulrush (82,098 seeds m^{-2}). IRRI (2017) reported the seed production capacity of rock bulrush as 1500 seeds $plant^{-1}$. Abundant fruit production capacity helps rock bulrush in propagation after harvest of rice (Kamoshita *et al*., 2014).

Le Bourgeois (2008) observed the presence of short rhizomes in rock bulrush. IRRI (2017) reported the regrowth of rock bulrush from vegetative buds and rhizomes in marshy unpuddled areas. Presence of rhizomes confers perennial nature to rock bulrush (Khalid and Sadar-U-Siddiqui, 2014).

2.1.6.1. Seed dormancy

Weed species that propagate through seeds exhibit an extended longevity compared to the vegetatively propagated weeds (FAO, 2016). Weed seed persistence in the field can be estimated by its half life which varied with the depth of soil and cultivation practices. In the transplanted paddy fields of Japan, Watanabe *et al*. (1991) observed 30 per cent reduction in the seed bank of *Scirpus juncoides* in 709 days that coincided with its half life. He also reported that the seeds of rock bulrush remained dormant in the field for a longer period compared to *Echinochloa oryzicola* with a longevity extending to maximum one year.

Development of seed dormancy from 20 to 25 days after flowering was observed by Ishikura and Soga (1978). On the contrary, Chiang (1983) observed 53 and 59 per cent germination of rock bulrush seeds in 21^{st} and 28^{th} day after flowering respectively.

Harper (1977) opined that innate and induced dormancy can cause extended longevity in weed seeds. However, dormancy is induced in weed seeds as a response to adverse climate conditions (Begon *et al*., 1996). Seed dormancy in rock bulrush was observed to be the best example of induced dormancy, where the seeds remain dormant from summer to autumn for considerable seed saving for winter and spring.

2.1.6.2. Germination and emergence

Miyahara (1968) observed that the germination of rock bulrush seeds are stimulated under low oxygen atmosphere and also reported robust growth of the weed in deep water paddy fields. In the lowlands, *S. juncoides* seeds germinate best from the deeper layers of soil, since anaerobic condition coupled with variations in temperature favour germination (Pons and Schroder, 1986). Sahid *et al*. (1995) observed that as the depth of soil increased from 5 to 15 cm, number of rock bulrush seeds increased from 4158 to 7785 in wet seeded rice. Perianth lobe is the major pathway for imbibing water required to effect germination (Hamamura, 2002).

Chiang (1983) observed significant influence of season in deciding the emergence time of *S. juncoides*. He reported that the weed seeds emerge faster during *rabi* season (2 days) compared to *kharif*, where it takes 5 days for emergence. Watanabe *et al*. (1991) opined that the seed viability of *S. juncoides* may extend beyond a decade, thus making it unpractical to eliminate the soil weed seed bank.

S. juncoides developed the highest soil weed seed bank both *in situ* (green house) and *ex situ* (rice field) in terms of importance value (47.4 per cent) in comparison with other sedges *Cyperus iria, C.compressus*, *Fimbristylis miliacea*, *Fimbristylis dichotoma*, *Kyllinga brevifolia* (Mesquita *et al*., 2013).

Ishikura and Soga (1978) observed vigorous germination of *Scirpus* seeds stored in submerged soil at a moisture content of 18 per cent at 5 to 20°C and absence of germination in dry soil at 5 to 30°C. Seed propagated sedges like *Schoenoplectus juncoides* subsp. *juncoides*, *S. juncoides* subsp. *hotarui*, *S. wallichii* and *S. triqueter* broke dormancy in 2 to 3 months after dark storage at 5 to 15°C giving a germination maximum of 83, 95, 84 and 91 per cent respectively. More than 80 per cent germination of *S. juncoides, S. wallichii* and *S. mucronatus* observed with a change in season from winter to spring and maximum at March (Watanabe and Miyahara, 1989).

2.2. DIRECT SEEDED RICE

Among the several methods practised, manual transplanting is the traditional and the highly accepted system for paddy establishment (Rao and Chauhan, 2015). Maintenance of seedling nursery and transplanting-related operations *viz*. uprooting, bundling and transplanting have high labour requirement. Wet tillage and flooding in the system create field conditions unfavourable for weed growth (Kabdal *et al*., 2018).

According to Balasubramanian and Hill (2000), direct seeding has considerable labour saving, early crop maturity, lower water requirement, high level of water stress tolerance and low methane emission compared to transplanting. Decline in labour available pool at the rate of 0.1 to 0.4 per cent for agricultural purpose has been reported in Asia (Dawe, 2005). Bouman (2009) reported the requirement of about 1500 to 2000L of water for producing less than 1 kg grains. Dhakal *et al*. (2015) reported direct seeding of rice as a cost-effective, less laborious alternative for transplanting, attributing to its lower water (35 to 57 per cent less) and labour requirement (67 per cent less).

Direct seeded rice (DSR) - an immensely accepted sowing method is found to be early maturing by 7 to 10 days than transplanted crop due to the lack of transplanting shock in the former (Rana *et al.*, 2014). This has led to a wider acceptance of DSR including both dry DSR (40 per cent) and wet DSR (30 per cent) out of the total 30.2 M ha area under rice in the largest rice producing country, China (Luo *et al.*, 2016).

Though highly accepted, the crop suffers from severe weed competition due to lack of flooding in the early establishment period. Weeds deprive the crop from getting adequate moisture, nutrients, light and space, thereby reducing grain yield by 50 to 91 per cent (Rao *et al.*, 2007). Moreover, weeds are harmful than insects, pathogens and other pests (Gharde *et al.*, 2018).

Tanaka (1976) observed more than 90 per cent of total weed dry weight in rice as occupied by two groups of weeds *viz.*, grasses and sedges. Weed, the toughest competitor among biotic factors has been reported to cause grain yield reduction in transplanted rice (20 to 60 per cent) and DSR (30 to 80 per cent) as observed by Janiya (2002). Rao *et al.* (2007) recommended the practices like stale seed bed (SSB), puddling, using competent rice varieties, herbicides and water management for proper weed control in DSR. The ill effect of direct seeding (dry and wet DSR) is experienced as severe weed infestation by co-emergence of crop and weeds along with uncontrolled initial weed flushes due to the absence of flooding (Kumar *et al.*, 2008).

2.2.1. Wet seeded rice

Wet seeded rice includes sowing of pre-sprouted seeds in puddled soil which reduces the requirement of labour, maintenance of seedling nursery and transplanting-related operations (Serrano, 1975). Tao *et al.* (2016) obtained 10.8 per cent higher grain yield and 13.4 per cent higher water productivity in wet seeded crop compared to transplanted and dry DSR. DSR farmers obtained 3.74 per cent yield increase coupled with 7.51 per cent reduction in cultivation cost (Mishra *et al.*, 2017). Direct sowing under puddled conditions has increased the yield by 1.3 to 4.7 per cent, net return by 13 per cent with 15 per cent less water and 2.4 to 8.8 per cent less production costs (Chakraborty *et al.*, 2017).

Wet seeded rice is infested with composite weed flora comprising of 51.5 per cent grasses, 30.9 per cent sedges and 17.5 per cent broad leaved weeds (BLW) (Ravisankar *et al*., 2008). Raj *et al*. (2013) observed the dominance of sedges in the rice fields during *rabi* season (96.8 per cent) compared to broad leaved weeds (2.7 per cent) and grasses (0.5 per cent). Satapathy *et al*. (2017) reported the dominance of sedges (71.5 per cent) in wet seeded rice, compared to grasses (15.1 per cent) and BLW (13.4 per cent).

Khan *et al*. (1992) reported comparatively lower weed infestation in wet seeded crop than dry seeded crop. Singh *et al*. (2005) recorded a loss of 75.8 per cent, 70.6 per cent and 62.6 per cent in dry seeded, wet seeded and transplanted paddy due to weeds in the system. Uncontrolled weeds reduces the grain yield in dry DSR and wet DSR by 96 per cent and 61per cent, respectively (Maity and Mukerjee, 2008).

There are several ways including cultural, physical, chemical and biological methods to manage weeds in the rice ecosystem (Buhler *et al*., 2000). Among all the methods employed, hand weeding is the most effective if practiced at the right time of crop-weed competition (Hooda, 2002).

But Moody (1990) considers hand weeding as an impractical method of weed control in wet seeded, broadcasted rice. This highlights the need for resorting to chemicals for uniform and effective weed control. However, weeds in rice ecosystem cannot be effectively managed by a single herbicide spray. Hence, integration of more than one method of weed management can offer long lasting control of weeds belonging to all the groups (Ali *et al.*, 2018).

2.2.2. Critical period of crop-weed competition

Nearly all the annuals are sensitive to weeds during early growth and development. Generally, the initial one-third to half of the entire crop lifecycle is critical to weed competition (Mercado, 1979). Critical period of crop weed competition has two parts: (a) weed-free period required for the crop to grow robust and control the upcoming weed problem (b) time period to which the co-emerged weeds retain in the field before threatening the crop to yield reduction (Ghosheh *et al.*, 1996). Chauhan *et al.* (2014) observed similarities in necessary resources required for rice and its associated weed flora for optimum growth. Among the different groups of weeds, strong competition for nutrients is offered by sedges due to the presence of well developed fibrous root system.

Selvam and Krishnan (1992) opined that upto 40 to 60 DAS the field should be maintained free from weeds to enable the direct sown low land rice to effectively make use of the inputs for realizing higher growth rate and grain yield. The competition period upto 45 DAS has a greater impact on the yield of wet seeded rice (Sathyamoorthy and Kandasamy, 1998). The critical period of crop weed competition in transplanted and wet seeded rice was from 20 to 40 days after transplanting (DAT) and 15 to 60 DAS respectively as observed by Mukherjee *et al.* (2008).

Entire crop growing period should be maintained weed free with special emphasis upto 29 to 32 days and 4 to 83 days in wet seeded and dry seeded rice respectively (Johnson *et al.*, 2004). Weed competition during the entire crop season is reported to cause grain yield reduction by 69.71 per cent and 67.40 per cent in *kharif* and *rabi* rice, respectively (Raj *et al.*, 2013).

2.2.3. Weed flora in wet seeded rice

The cultivation practices selected for rice establishment has a decisive role on the weed species infesting the field and its dýnamics (Kuyeonchung *et al.*, 2002). Matloob *et al.* (2015) considers the shift in rice establishment system from transplanting to direct seeding as the main reason for aggravating the crop-weed competition in lowland rice.

Bhagat *et al.* (1996) observed a strong relationship between weed flora and water management practices, where saturated field conditions triggered the germination of sedges and grasses.

Weeds belonging to Cyperaceae family are found to be the worst weeds in rice with respect to its extremely hydrophilic nature and alkaline tolerance (Kumar *et al.*, 2008). Sedges such as *Schoenoplectus juncoides*, *Fimbristylis miliacea*, *Cyperus flavidus* and *Cyperus difformis* grow aggressively throughout the growing period of rice (Mukherjee *et al.*, 2008). In wet land ecosystems of Bhutan, *Schoenoplectus juncoides*, *Blyxa aubertii*, *Echinochloa crus-galli*, *Cyperus difformis*, *Monochoria vaginalis*, *Paspalum distichum* and *Commelina benghalensis* pose serious threat to rice (Dorji *et al.*, 2013). IRRI (2017) identified four sedges *viz.* *Schoenoplectus juncoides*, *Cyperus difformis*, *Cyperus iria*, *Fimbristylis miliacea*; five grasses *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Oryza sativa, Ischaemum rugosum*; three BLW *Ludwigia hyssopifolia*, *Sphenoclea zeylanica* and *Eclipta prostrata* as troublesome in Asian rice fields.

Kurmi and Das (1993) reported the dominance of *Schoenoplectus juncoides*, *Fimbristylis miliacea, Cyperus iria, Cyperus rotundus, Cyperus difformis, Echinochloa crus-galli, Eleusine indica, Digitaria sanguinalis, Monochoria vaginalis* and *Sphenoclea zeylanica* in transplanted rice.

Abtali *et al*. (1995) observed higher densities of *Scirpus mucronatus*, *Scirpus maritimus*, *Cyperus difformis* and *Scirpus juncoides* in the paddy fields of Iran due to continuous application of grass killers. Dominance of sedges belonging to *Scirpus* sp. *viz*. *Scirpus juncoides*, *Scirpus maritimus* and *Scirpus mucronatus* were reported in the paddy fields of Iran by Aminpanah (2015). Deivasigamani (2016) observed the predominance of *Scirpus* sp., *Cyperus* sp., *Leptochloa chinensis*, *Echinochloa colonum* and *Eclipta alba* in the direct seeded lowlands of Tamil Nadu.

Raj and Syriac (2017) reported *Schoenoplectus juncoides* (Roxb.) Palla, as one of the major sedge weeds in direct seeded, puddled rice along with other weeds such as *Cyperus iria*, *Cyperus difformis*, *Eclipta prostrata*, *Spheoclea zeylanica*, *Ludwigia hyssopifolia*, *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis*, *Oryza sativa f* sp. *spontanea* and *Ischaemum rugosum*.

Recently *S. juncoides* has emerged as one of the important sedge weeds under rushes in the rice fields of Kerala. Yield loss due to *S. juncoides* largely depended on its emerging intensity and cropping season. Higher competence of rock bulrush was observed in direct seeded rice. *S. juncoides* infestation occurs both in transplanted rice and direct sown rice, unproblematic in modan rice except for India (Moody, 1990). Moreover, *Scirpus juncoides* is reported to occur in wet seeded, dry seeded and volunteer seedling rice fields with a summed dominance ratio of 2.40 per cent, 1.24 per cent and 0.36 per cent respectively (Sahid *et al*., 1995). Raj (2016) observed the dominance of *Schoenoplectus juncoides* in the rice fields of Nemom block of Thiruvananthapuram district.

2.2.4. Yield loss due to weeds

Yield reduction in rice ranges from 16 to 86 per cent depending on the climate, variety, method of rice establishment, spacing, fertilizer rates and weed interference (Kolay, 2007). Weeds alter the soil pH, reduces soil nitrogen (N) and soil phosphorus (P) resulting in reduction of grain and straw yields by 25 to 47 per cent and 13 to 38 per cent respectively (Manandhar *et al.*, 2007). Decline in crop yield is directly related to the duration of crop-weed interference (Azmi *et al.*, 2007). Wet seeded rice is infested with composite weed flora comprising of 51.5 per cent grasses, 30.9 per cent sedges and 17.5 per cent broad leaved weeds (Ravisankar *et al.*, 2008). Mukherjee *et al.* (2008) reported yield loss of 64 to 66 per cent in wet seeded paddy due to unchecked weed growth in comparison with the weed-free condition.

Ali and Sankaran (1984) reported 50 to 60 per cent reduction in grain yield due to uncontrolled weeds in puddled lowlands. Uncontrolled weeds reduce the grain yield in dry direct seeded rice by 96 per cent and by 61 per cent in wet direct seeded rice (Maity and Mukerjee, 2008). In India, per cent yield loss recorded in transplanted and direct seeded paddy is to the tune of 12 to 69 per cent and 17 to 98 per cent respectively (Kathirvelan and Vaiyapuri, 2003; Singh *et al.*, 2011).

Sakamoto *et al.* (1982) reported 12 to 27 per cent yield loss in transplanted paddy in Japan at higher density of rock bulrush. Balasubramaniyan and Palaniappan (2001) observed a reduction in nutrient uptake by lowland rice to the tune of 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg due to weeds in the system.

In irrigated paddy, grasses are the dominant weeds whereas sedges offer the strongest competition in rainfed system (Johnson, 1996). Yield reduction upto 91 per cent occurs in DSR due to weeds (Rao *et al.*, 2007). Khaliq and Matloob (2011) reported nearly 70 per cent yield loss in DSR if weeds are left unchecked.

Ramzan (2003) observed that weeds in transplanted, wet seeded and dry seeded DSR are capable of causing a yield loss of 48 per cent, 53 per cent, and 74 per cent respectively. Reduction in grain yield due to all the biotic factors is estimated to be 40 per cent of which 32 per cent loss is solely due to weeds (Rao *et al.*, 2007). Jabran *et al.* (2012) reported a grain yield reduction ranging from 80 to 90 per cent in wet seeded rice.

2.3. MANAGEMENT OF ROCK BULRUSH

Direct seeded rice is exposed to heavy competition from weeds during the entire growing season (Ehsanullah *et al.*, 2014). Co-emergence of weed seeds and direct seeded paddy induces crop-weed competition in the early stages of crop growth and development. Hence, the success of this system depends primarily on the effectiveness of the weed management practices adopted. Broadcasting or direct sowing further aggravates the competition due to difficulty in managing the weeds physically due to lack of proper row arrangement for the crop. Several methods for managing weeds *viz*. cultural, physical, chemical and biological methods are practised in the farmer's field. Application of a single weed control method may not give considerable control of all groups of weeds. Hence, different weed control methods should be integrated based on the climate, soil and weed flora for maintaining weeds below the economic threshold (Singh *et al.*, 2018).

2.3.1. Cultural control methods

Minimal tillage or zero tillage in lowland favour *S. juncoides* whereas, dry soil conditions hinder the sprouting of vegetative propagules. Thorough land preparation followed by dry rotovation and wet tillage destroy underlying vegetative buds of *S.*

juncoides (Iwasaki *et al*., 1981). Submergence of field at early crop growth stages, especially within 4 to 6 weeks after sowing (WAS) is effective in managing rock bulrush below the economic threshold limits (NPPC, 2017).

Kim *et al*. (2001) suggested the use of rice bran in lowlands under shallow submergence for the suppressing the growth of *Scirpus juncoides*, *Cyperus serotirus* and *Monochoria vaginalis*. Recycled paper mulch gave 50 per cent control of *S. juncoides* in the rice field as reported by Lee *et al*. (2005).

Chung *et al*. (2006) suggested the cultivation of Noindari, Baekna and Baekgwangok varieties of rice in Korea to manage *Scirpus juncoides*, *Echinochloa crus-galli*, *Monocharis vaginalis* and *Eleocharis kuroguwai* considering their ability to release allelochemicals (Momilactone A and B) against the weeds. Soil solarization results in the survival of *Scirpus juncoides* seeds at greater soil depths *viz*. survival of 5 per cent seeds at 3, 6 and 9 cm deep and 60 per cent at 12 cm depth making this otherwise effective strategy ineffective (Ushiki *et al*., 2008).

2.3.2. Hand weeding

Hand weeding is the traditional and the most effective method of weed management especially in India (Yaduraju *et al*., 2015). However, availability of timely labour decides the success of this method for controlling weeds (Ali *et al*., 2018).

Hand weeding at critical stages of crop-weed competition (20 and 40 DAS) is better compared to herbicide use in terms of growth and yield attributes of rice (Prasad *et al*., 2001). Dutta *et al.* (2005) reported the higher efficiency of HW twice at 21 and 42 DAS recording a significant increase in grain and straw yield of rice. Normally two to three HW is given based on the weed density to realize potential yield from paddy. But in the absence of other management practices, manual weeding needs to be performed thrice or five times during the cropping season (Chauhan and Opena, 2013).

Lower weed interference ensured during critical crop growth stages helps in attaining higher grain and straw yields in hand weeded plots (Chander and Pandey, 2001). Pal *et al.* (2009) reported higher grain yield (5.08 t ha^{-1}) with HW at 20 and 40 DAT in the Gangetic alluvial attributing to the better weed control efficiency. Manual weeding recorded superior yield attributes *viz.* number of productive tillers m^{-2}, grains $panicle^{-1}$, grain weight $plant^{-1}$ and thousand grain weight resulting in higher grain yields (Suresh and Singh, 2003; Dave and Sahu, 2006). Hand weeding was more effective compared to the use of herbicides in wet seeded system (Sahu, 2016).

Chander and Pandey (1996) observed lower weed density and dry weights in hand weeded plots with an increase in grain yield of transplanted and wet seeded paddy. Weed control efficiencies of 69.9 and 70.1 per cent were obtained in manually weeded plots in kharif and rabi seasons respectively (Gnanavel and Kathiresan, 2002). Hand weeding at 20 and 40 DAS reduced the density and dry weight of weeds more effectively than herbicides (Rekha *et al.*, 2002).

Though the most effective, hand weeding can cause the escape of sedge weeds that later pose threat due to its perennial nature (Yaduraju and Mishra, 2008). Hand weeding is the best weed management practice at later stages of crop growth since at earlier stages difference between crop and weed seedlings are not evident (Prasad and Raveendran, 2011). Among the several available weed management methods, manual and mechanical methods of weed management had been proven ineffective against sedges and broad-leaved weeds in DSR (Devi and Singh, 2018).

Though hand weeding is highly effective, it is cumbersome, time consuming and uneconomical on a large scale. But the method is efficient if performed at the right time of crop-weed competition (Hooda, 2002). Adverse climatic conditions like heavy rainfall, reduces labour availability and therby affecting the effectiveness of the system (Puniya *et al*., 2007).

For long term control of rock bulrush, Barrett (1983) suggested the integrated use of hand weeding and herbicides. Shultana *et al*. (2016) observed that integrated use of pre and post-emergence herbicides in conjuction with hand weeding gave better weed management in wet seeded rice.

2.3.3. Biological control

In Japan, *Scirpus juncoides* is effectively managed by Aigamo ducks that feeds on the insects and weeds associated with paddy (Hiroomi *et al*., 1999). Complete inhibition of *Scirpus juncoides* and *Monochoria vaginalis* have been observed in rice, dual cultured with *Azolla pinnata* in the lowlands of Japan (Biswas *et al*., 2005). Chung *et al*. (2006) suggested momilactone A - the allelochemical secreted by rice as an effective natural control against S. *juncoides* due to 90 per cent inhibition obtained at an application rate of 4000 g a.i. ha^{-1}. Low dry weight (1.20 g) and higher inhibition (84.47 per cent) of *S. juncoides* was observed when mustard crop residue was applied at the rate of 2 t ha^{-1} (Hossain *et al*., 2017).

2.3.4. Chemical methods

Though, conventional method of manual weeding is practised, use of herbicides is the most common practice as it is easier, time and labour saving and economical compared to hand weeding (Rekha *et al*., 2003). This signifies the use of herbicides-an attractive, cheap, quick acting, feasible, cost effective and promising remedy for weed management which play a key role in reducing the production cost in DSR (Jacob *et al*., 2014; Kabdal *et al*., 2018).

Globally noxious weeds of the genera, *Echinochloa* sp., *Cyperus* sp., *Scirpus* sp. and *Fimbristylis* sp. are reported to dominate even after repeated application of herbicides for a decade (Kraehmar *et al*., 2016).

Aurora and De Datta (1992) have reported the need for the combining different herbicides for increasing the efficacy at lower doses. Chauhan and Yadav (2013) suggested the mixing of two or more herbicides for effecting considerable management of weeds in DSR.

2.3.4.1. Bensulfuron methyl + pretilachlor

Bensulfuron methyl is an ALS inhibiting herbicide giving better suppression of sedges and BLW compared to grasses at lower rates of application (30-70 g a.i. ha^{-1}), especially in direct seeded rice. In order to increase its spectrum of control, mixtures of bensulfuron methyl with graminicides such as pretilachlor, butachlor and mefenacet is gaining popularity for controlling weeds in rice (Kabdal *et al*., 2018).

Effect of hand weeding twice at 20 and 40 DAS significantly reduced sedge density upto 72 DAS, whereas londax power had an extended period of control upto 85 days after application thus increasing the rice yield by 80 per cent and 100 per cent respectively (Abtali *et al*., 1995). Application of bensulfuron methyl alone at 60 g a.i. ha^{-1} and tank mixture of bensulfuron methyl + pretilachlor @ 50 + 450 g a.i. ha^{-1} gave broad spectrum weed control in wet seeded rice (Saha and Rao, 2009). Integration of bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i ha^{-1} and HW at 40 DAT reduced the weed density and dry weight in turn increasing the grain yields (Sunil *et al*., 2010). Arya (2015) suggested bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i ha^{-1} as a promising broad spectrum herbicide for weed control in semi dry rice at the early stages.

Pre-emergence spray with bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i ha^{-1} recorded higher WCE (91.37 per cent) and superior yield attributes in aerobic rice (Madhukumar *et al*., 2013). Lower weed density and dry weight were recorded in rice fields treated with bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i. ha^{-1} (Teja *et al*., 2015).

2.3.4.2. Penoxsulam

Penoxsulam is a new, acetolactase synthase (ALS) inhibitor herbicide for post-emergence control of annual grasses, sedges and broad leaved weeds in rice culture (Jabusch and Tjeerdema, 2005). It is a triazolopyrimidine sulfonamide herbicide, highly effective against grasses, sedges and BLW in rice (Kabdal *et al*., 2018).

Penoxsulam @ 22.5 g ha^{-1} at 8 to 12 DAT gave broad spectrum control of weeds in paddy and recorded highest grain (3.53 t ha^{-1}) and straw yield (4.73 t ha^{-1}) as per the reports of Pal *et al*. (2009). Both pre-emergence (3 DAT) and post-emergence (10-12 DAT) application of penoxsulam @ 25 g ha^{-1} and 22.5 g ha^{-1} respectively was effective against all the weeds in lowland rice of Karnal (Yadav *et al*., 2010). Pre-emergence application of penoxsulam (Chauhan and Seth, 2013) is considered to be an alternative or supplement to hand weeding. Early post- emergence application of penoxsulam 24 per cent SC @ 25 g a.i. ha^{-1} 15-20 DAS or at 2-4 leaf stage of weeds was very effective in reducing the biomass of all categories of weeds in direct seeded rice under puddled conditions and resulted in higher grain yield and net returns (Reddy *et al*.,2016).

Penoxsulam @ 25 g ha^{-1} gave satisfactory control of BLW and sedges compared to butachlor and pretilachlor (Nath and Pandey, 2013). Sansa (2016) reported higher grain yield (5.4 t ha^{-1}) and net returns from transplanted rice field treated with penoxsulam @ 22.5 g ha^{-1}. On the other hand, Ramesha *et al.* (2017)

reported the higher dose of penoxsulam (83.3 ml ha^{-1}) as effective against all groups of weeds in rice thereby increasing the grain yield. Penoxsulam @ 22.5 g ha^{-1}at 15 DAS fb hand weeding at 35-40 DAS recorded higher WCE at 60 DAS in Karnataka as per the report of Athaulla *et al*. (2017).

Combined application of penoxsulam and cyhalofop butyl gave broad spectrum management of weeds in direct seeded paddy (Lap *et al*., 2013). Early post-emergence (10 DAS) application of penoxsulam @ 35 g ha^{-1} integrated with HW at 35 DAS helped in realizing higher grain yield (5.04 t ha^{-1}) from DSR (Sanodiya *et al*., 2017).

2.3.4.3. Ethoxysulfuron

Ethoxysulfuron, chemically 3-(4,6-dimethoxyoyrimidin-2-yl)-1-(2-ethoxy phenoxysulfonyl) urea, an acetolactase synthase (ALS) inhibitor belonging to the sulfonylurea group is an effective post-emergence herbicide used for weed control in cereals especially rice (Brown and Cotterman, 1994). It is a selective herbicide highly effective at low doses ranging from 10 to 40 g ha^{-1} against weeds in lowland paddy (Kabdal *et al*., 2018).

Ethoxysulfuron (30 g ha^{-1}) applied 10 days after transplanting (DAT) provided better control of *Schoenoplectus supinus, Cyperus difformis* and *Cyperus iria* (Reddy *et al*., 2000). High herbicide efficacy at small rates of application was observed by Son and Rutto (2002) in controlling grasses, BLW and sedges. Ethoxysulfuron has been proved especially good for controlling the sedges of *Scirpus* sp. (Sondhia and Dixit, 2012).

Reduction in weed density and dry weight to the tune of 73.95 and 85.71 per cent respectively were obtained with the application of ethoxysulfuron @ 25 and 30 g

ha^{-1} (Cheema *et al.*, 2005). Ali *et al.* (2018) reported ethoxysulfuron as an effective sulfonyl urea herbicide against *Scirpus maritimus*, *Cyperus rotundus*, *Cyperus difformis* and *Fimbristylis dichotoma*.

2.3.4.4. Carfentrazone-ethyl

Carfentrazone-ethyl is an aryl triazolinone herbicide applied as post-emergence against sedges and BLW in rice (Singh, 2012). Wersal and Madsen (2012) reported the effectiveness of carfentrazone-ethyl in reducing the dry matter accumulation in weeds. Raj *et al.* (2013) reported that application of carfentrazone-ethyl at 20 g ha^{-1} on 15-20 DAS can be recommended for the control of broad leaved weeds and sedges (non- grassy weeds) in direct seeded rice with higher grain yield, gross returns, net returns and B: C ratio. It was also reported to be used as an alternative to 2, 4-D sodium salt, a popular herbicide for controlling non- grassy weeds in rice.

2.3.4.5. Metsulfuron methyl + chlorimuron ethyl

Metsulfuron methyl + chlorimuron ethyl is a combination sulfonyl urea herbicide, effective against grasses and BLW at lower rates of application (Banerjee, 2000). This ALS inhibitor is highly effective in managing BLW and sedges when applied @ 4 g a.i. ha^{-1} at 15 to 25 DAS (Kumar and Ladha, 2011). It is found to be a broad spectrum sulfonyl urea herbicide with post-emergence action (Ali *et al.*, 2018).

Application of metsulfuron methyl (10 per cent) + chlorimuron ethyl (10 per cent) as post- emergence showed better weed control efficiency against broad leaved weeds and sedges as compared to grasses (Saha and Rao, 2009). Among the post emergence herbicides, ethoxysulfuron, cyhalofop-butyl, pretilachlor, chlorimuron ethyl, metsulfuron methyl, bispyribac sodium and penoxsulam effectively controlled weeds in direct seeded rice (Mann *et al.*, 2007; Singh *et al.*, 2008; Mahajan *et al.*, 2009; Juraimi *et al.*, 2009).

2.3.4.6. 2, 4-D sodium salt

2, 4-D is a chlorinated phenoxy group of herbicide, first synthesized by Pokorny in 1941. 2, 4-D sodium salt was observed to be an effective BLW and sedge-killer (Vangsaroj and Chinawong, 1982). 2, 4-D @ 1 kg ha^{-1} when applied post-emergence, gave satisfactory suppression of sedges and BLW (Angiras and Attri, 2002).

Pre-emergence application of 2, 4-D @ 0.5 and 1 kg ha^{-1}, substantially reduced the weed population and dry weights in the upland rice fields of Jorhat (Borghohain and Upadhyaya, 1980). However, for effective weed management in wet seeded rice, post-emergence application of 2, 4-D @ 0.4 kg ha^{-1} can be suggested (Vaishya and Tomar, 2000).

Repeated use of 2, 4-D against sedges and BLW in rice ecosystem of Philippines and Malaysia has resulted in a weed shift towards grasses (Ho, 1994). Singh *et al.* (2008) reported the successive application of pre-emergence herbicides like pendimethalin and post-emergence herbicides like 2, 4-D as effective against sedges and non-verdant weeds in wet and dry seeded rice.

2.3.4.7. Soil dehydrogenase activity

Soil enzyme activity is a direct measure of soil microbial activity that gives a clear picture of the effect of herbicides (or any chemicals) on the soil micro flora (Andreoni *et al.*, 2004). Kumar *et al.* (2013) described dehydrogenase activity as an index of the level of damage on soil microorganisms due to pesticide application.

Bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} did not harm the soil microbes as evidenced from the higher microbial population in the soil analyzed 5 days after herbicide spray (Rajagopal, 2013).

Sanyal *et al.* (2006) reported shorter half-life for metsulfuron methyl + chlorimuron ethyl at all rates of application making it a safe-to-environment herbicide.

Rapid disintegration to safe limits could render higher level of microbial activity in the plots treated with metsulfuron methyl + chlorimuron ethyl.

Carfentrazone-ethyl with short disintegration time in soil and water makes it an environmentally-safe herbicide (Singh, 2012). Sondhia and Dixit (2012) reported faster dissipation and environment friendly nature of ethoxysulfuron that maintain only negligible amounts of the herbicide in the harvested produce.

2.4. Other damages

Kashin (2014) described *Schoenoplectus juncoides* as a noxious weed in rice that cause extensive damage to the grain by acting as the oviposition site for sorghum plant bug (*Stenotus rubrovittatus*) apart from competence as weed.

2.5. Uses

Schoenoplectus juncoides is reported to possess high potential of accumulating osmotic substances *viz.* proline, sugars, proteins and free amino acids (Mezni *et al.*, 2010). In conjunction with this, high K^+ uptake and succulent stem render saline tolerance to *S. juncoides* (Zahoor *et al.*, 2012), thus making it a promising candidate for rehabilitating saline lowlands. NPPC (2017) suggested the potential of rock bulrush as a fodder for cattle.

Materials and Methods

3. MATERIALS AND METHODS

The study entitled "Management of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) in wet seeded rice" was effectuated through a field experiment conducted during the *rabi* season of 2017. The investigation was aimed at studying the biology of the weed *Schoenoplectus juncoides* and formulating an effective management strategy using new generation herbicides. The materials used and the methods employed for conducting the investigation is dealt in this chapter.

3.1. EXPERIMENTAL SITE

3.1.1. Location

Field experiment was carried out in a lowland paddy field (farmer's field) at Ookkode, Nemom block, Thiruvananthapuram. It is located 5.5 km away from College of Agriculture, Vellayani at 8.4°N latitude, 77.08°E longitude and 28m above mean sea level. An adjoining water channel provided adequate water to the field. Satellite map of Ookkode is shown in Plate 1.

3.1.2. Climate and season

The experimental site has warm, humid tropical climate. Crop was raised during *rabi* season extending from November 2017 to March 2018. Northeast monsoon normally sets in October and ends by December in this region. Amidst the study, heavy rainfall accompanied with strong winds (Ockhi cyclone) outraged in the state and resulted in 28 per cent excess rainfall (667.4 mm) than the normal (522.7 mm) in Thiruvananthapuram. Data on minimum temperature, maximum temperature, minimum relative humidity (RH), maximum RH, rainfall, bright sunshine hours and evaporation were recorded from the Class B Agromet observatory of the Department of Agricultural Meteorology, College of Agriculture, Vellayani are given in Appendix.1 and graphically depicted in Fig.1.

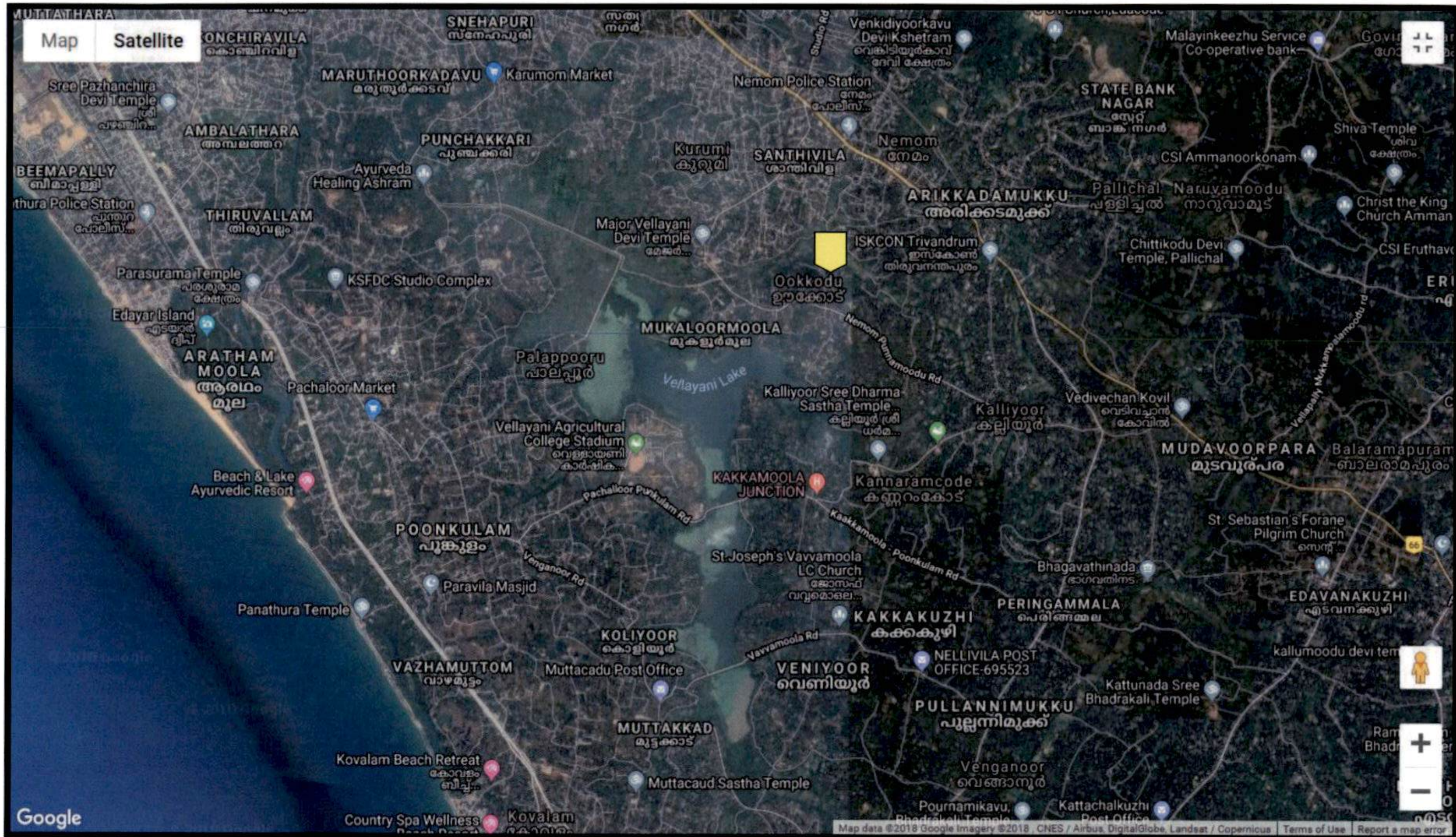


Plate 1: Satellite map of the experimental site at Ookkode, Nemom block, Thiruvananthapuram

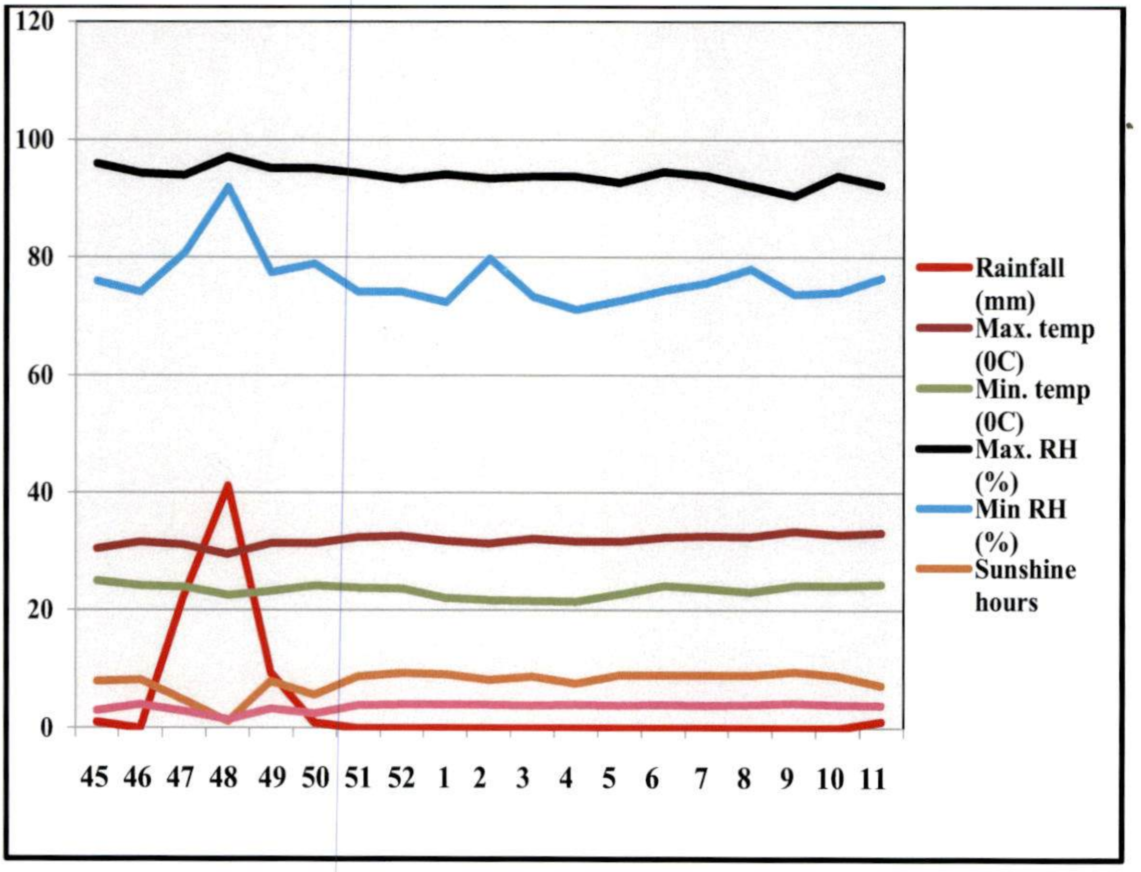


Fig 1. Weather parameters during the experiment (November 2017 to March 2018)

3.1.3. Soil

To determine the inherent soil fertility status, soil samples from different points in the field were collected from 15cm depth and made into composite sample for analysis. Representative sample was used for estimating the physico-chemical properties of soil using standard procedures. pH, organic carbon, available nitrogen, phosphorus and potassium in the soil before the experiment were determined. Soil in the experimental field was strongly acidic with normal electrical conductivity (EC). The soil was low in available nitrogen, high in available phosphorus, medium in available potassium and high in organic carbon. Physico-chemical properties of the soil are presented in Table 1.

3.1.4. Cropping history of field

The field has been under rice crop for the past many years. Direct sowing of pre-germinated seeds (wet seeding) was practiced in previous *kharif* due to high labour charges incurred for transplanting. Grasses, sedges and broad leaved weeds associated the rice crop. But recently, the wetland sedge species-*Schoenoplectus juncoides*, has been observed as the dominant weed flora in the locality.

3.2. MATERIALS

3.2.1. Crop and variety

In this experiment, the rice variety *Sreyas* was used. '*Sreyas*' (MO-22) is a promising rice variety developed under the All India Co-ordinated Research Project of ICAR. The variety was released from Rice Research Station, Moncompu, Alappuzha in 2015. It is a cross between Pavithra (MO-13) and Triguna (IET-12875). *Sreyas* is dwarf statured with around 100 cm height. It is a medium duration (115-120 days) high yielding (7-7.5 t ha^{-1}) variety with medium bold red grains and moderate

Table 1. Physico-chemical properties of the soil

Particulars	Content	Status	Method adopted	Reference
a) Physical composition				
Soil separates (%)			Bouyoucos Hydrometer method	Bouyoucos, 1962
(i) Coarse sand	47.52			
(ii) Fine sand	12.10			
(iii) Silt	7.93			
(iv) Clay	32.40			
(v) Textural class		Sandy clay loam		
b) Chemical composition				
(i) Soil reaction (pH)	5.40	Strongly acidic	1:2.5 soil: water ratio using pH meter	Jackson, 1973
(ii) EC (dSm^{-1} at 25^0C)	0.47	Normal	1:2.5 soil: water ratio using EC meter	Jackson, 1973
(ii) Organic carbon (%)	1.10	High	Walkley and Black's rapid titration	Jackson, 1973
(iii) Available N ($kg\ ha^{-1}$)	275.97	Low	Alkaline permanganate method	Subbiah and Asija, 1956
(iv) Available P ($kg\ ha^{-1}$)	39.20	High	Bray colorimetric method	Jackson, 1973
(v) Available K ($kg\ ha^{-1}$)	240.00	Medium	Ammonium acetate method	Jackson, 1973

resistance to sheath blight, sheath rot and bacterial leaf blight. Higher level of resistance offered by *Sreyas* to false smut (Lakshmi disease) makes it a promising substitute for *Uma*- the most popular rice variety in Kerala. Varietal characters of Sreyas is given in Appendix 1.

3.2.2. Manures and fertilizers

The basal recommendation of organic manure was applied as dried, well-rotten cowdung @ 5 t ha^{-1}. Fertilizer schedule for medium duration rice was adopted. 90:45:45 kg N: P_2O_5: K_2O ha^{-1} was provided by broadcasting urea (46 per cent N), factamphos (20 per cent P_2O_5, 20 per cent N) and muriate of potash (60 per cent K_2O).

3.2.3. Herbicides

Six herbicides *viz.* bensulfuron methyl + pretilachlor, penoxsulam, ethoxysulfuron, carfentrazone-ethyl, metsulfuron methyl + chlorimuron ethyl and 2, 4- D sodium salt were used for the study. Data on the technical and toxicity aspects of the herbicides are detailed in Table 2.

3.3. METHODS

Experiment I: Biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

The weed biology was studied by observing sample plants earmarked in the experimental field. The sample plants were randomly selected from 20 m^2 area (weedy check) and observed from their emergence onwards. A separate set of sample plants were used for destructive sampling. Range and average for each character was worked out.

Table 2. General information of the herbicide

Common name	Bensulfuron methyl + Pretilachlor	Penoxsulam
Trade name	Londax Power	Granite, Duton
Chemical name	Methyl α- (4,6 dimethoxy pyrimidin-2yl carbamoyyl sulfamoyl)-otoluate+2- chloro -N-(2,6-diethylphenyl)-N-(2-propoxyethyl) acetamide	3-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]triazolo[1,5-c]pyrimidin-2-yl)-α,α,α-trifluorotoluene-2-sulfonamide
Molecular formula	$C_6H_{18}N_4O_7S + C_{17}H_{26}ClNO_2$	$C_{16}H_{14}F_5N_5O_5S$
Molecular weight	410.4+311.9 $gmol^{-1}$	483.37 g mol^{-1}
Group	Sulfonyl urea	Sulfonyl urea
Mode of action	ALS inhibitor	ALS inhibitor
Formulation	0.6%+6% GR	24% SC
Colour, state, odour	Light brown, dry free flowing granule without appreciable odour	Off white to pale pink solid with musty odour
Toxicity class	Green	Green
Acute oral toxicity LD_{50} (Rats)	>5000 mg kg^{-1}	>5000 mg kg^{-1}
Acute dermal toxicity LD_{50} (Rats)	>2000 mg kg^{-1}	>5000 mg kg^{-1}
Manufacturer	DuPont	Dow Agro Sciences
Cost (Rs)	982 per 4kg	2000 per 100ml

Table 2. General information of the herbicide (continued)

Common name	Ethoxysulfuron	Carfentrazone-ethyl
Trade name	Sunrice	Affinity
Chemical name	(2-ethoxyphenyl)N-[(4,6-dimethoxypyrimidin-2-yl) carbamoyl]sulfamate	ethyl 2-chloro-3-[2-chloro-5-[4-(difluoromethyl)-3-methyl-5-oxo-1,2,4-triazol-1-yl]-4-fluorophenyl]propionate
Molecular formula	$C_{15}H_{18}N_4O_7S$	$C_{15}H_{14}Cl_2F_3N_3O_3$
Molecular weight	398.39 g mol^{-1}	412.19 g mol^{-1}
Group	Pyrimidinyl sulfonyl urea	Aryl triazolinone
Mode of action	ALS inhibitor	PPO inhibitor
Formulation	15% WDG	40% DF
Colour, state, odour	White, crystalline solid with no odour	Yellow-orange viscous liquid with faint petroleum odour
Toxicity class	Blue	Green
Acute oral toxicity LD_{50} (Rats)	>5000 mg kg^{-1}	>5000 mg kg^{-1}
Acute dermal toxicity LD_{50} (Rats)	>2000 mg kg^{-1}	>4000 mg kg^{-1}
Manufacturer	Bayer Crop Science	FMC
Cost (Rs)	302 per 50g	315 per 25g

Table 2. General information of the herbicide (continued)

Common name	Metsulfuron methyl + chlorimuron ethyl	2,4-D Sodium salt
Trade name	Almix	2,4 Agan
Chemical name	Methyl 2- (methoxy-6-methyl-1,3,5-triazin-2-yl carbamoyl sulfamoyal) benzoate + Ethyl-2-(4-chloro-6-methoxy pyrimidin-2-ylcarbamoyl sulfamoyl) benzoate	2,4-dichloro-phenoxy acetic acid
Molecular formula	$C_{14}H_{15}N_5O_6S$ + $C_{15}H_{15}ClN_4O_6S$	$C_8H_6Cl_2O_3$
Molecular weight	398.39 g mol^{-1}	221.003 g mol^{-1}
Group	Sulfonyl urea	Chlorinated phenoxy
Mode of action	ALS inhibitor	IAA inhibitor
Formulation	20% WP	80% WP
Colour, state, odour	Grey or beige colour powder with a slight odour	White to yellow powder solid
Toxicity class	Blue	Yellow
Acute oral toxicity LD_{50} (Rats)	>5000 mg kg^{-1}	>200-2000 mg kg^{-1}
Acute dermal toxicity LD_{50} (Rats)	>2000 mg kg^{-1}	>2000 mg kg^{-1}
Manufacturer	DuPont	Dow Agro Sciences
Cost (Rs)	207 per 8g + 250 per 100ml surfactant	160 per 500g

Experiment II: Management of *Schoenoplectus juncoides* (Roxb.) Palla using new generation herbicides

Location	: Farmer's field, Nemom
Design	: RBD
Treatments	: 8
Replications	: 3
Plot size	: 5 m x 4 m
Variety	: *Sreyas*
Season	: *Rabi*, 2017
System	: Wet seeding

3.3.1. Treatments

T_1: Bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} at 4-7 DAS followed by hand weeding at 35- 40 DAS

T_2: Penoxsulam @ 22.5 g ha^{-1} at 15 DAS followed by hand weeding at 35- 40 DAS

T_3: Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS followed by hand weeding at 35- 40 DAS

T_4: Carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS followed by hand weeding at 35- 40 DAS

T_5: Metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS followed by hand weeding at 35- 40 DAS

T_6: 2, 4-D sodium salt @ 1 kg ha^{-1} at 20 DAS followed by hand weeding at 35- 40 DAS

T_7: Hand weeding at 20 and 40 DAS

T_8: Weedy check (un-weeded control)

3.3.2. Cultivation practices

The crop was raised and maintained according to the crop management practices given in the Package of Practices Recommendation, 'Crops' (KAU, 2011). Weed management was done as per the treatments.

3.3.2.1. Field preparation

Wet seeding was the system adopted for establishing rice crop. Land was thoroughly prepared by puddling followed by leveling. Weeds and stubbles of the previous crop were incorporated by wet tillage. Standing water in the field was drained for laying out the plots. Land was divided into three blocks with eight plots each of size 5m x 4m. The blocks were separated with water channels of width 40cm and plots within the block were partitioned by bunds of 20cm width. Altogether, 24 plots were laid out for the experiment (Fig 2). General view of the experimental site is shown in Plate 2.

3.3.2.2. Lime application

Manures, fertilizers and lime were applied in accordance with the Package of Practices Recommendations 'Crops' (KAU, 2011). Lime was applied at the rate of 600 kg ha^{-1} in two splits with 350 kg ha^{-1} as basal at the time of first ploughing and remaining 250 kg ha^{-1} as top dressing one month after sowing. Lime was applied one week prior to organic manure incorporation.

3.3.2.3. Manure and fertilizer application

Well decomposed dry cowdung powder was incorporated at the rate of 5 t ha^{-1} at the time of last ploughing. The recommendation of medium duration rice (90:45:45 kg N: P_2O_5: K_2O ha^{-1}) was given through urea, factamphos and Muriate of Potash.

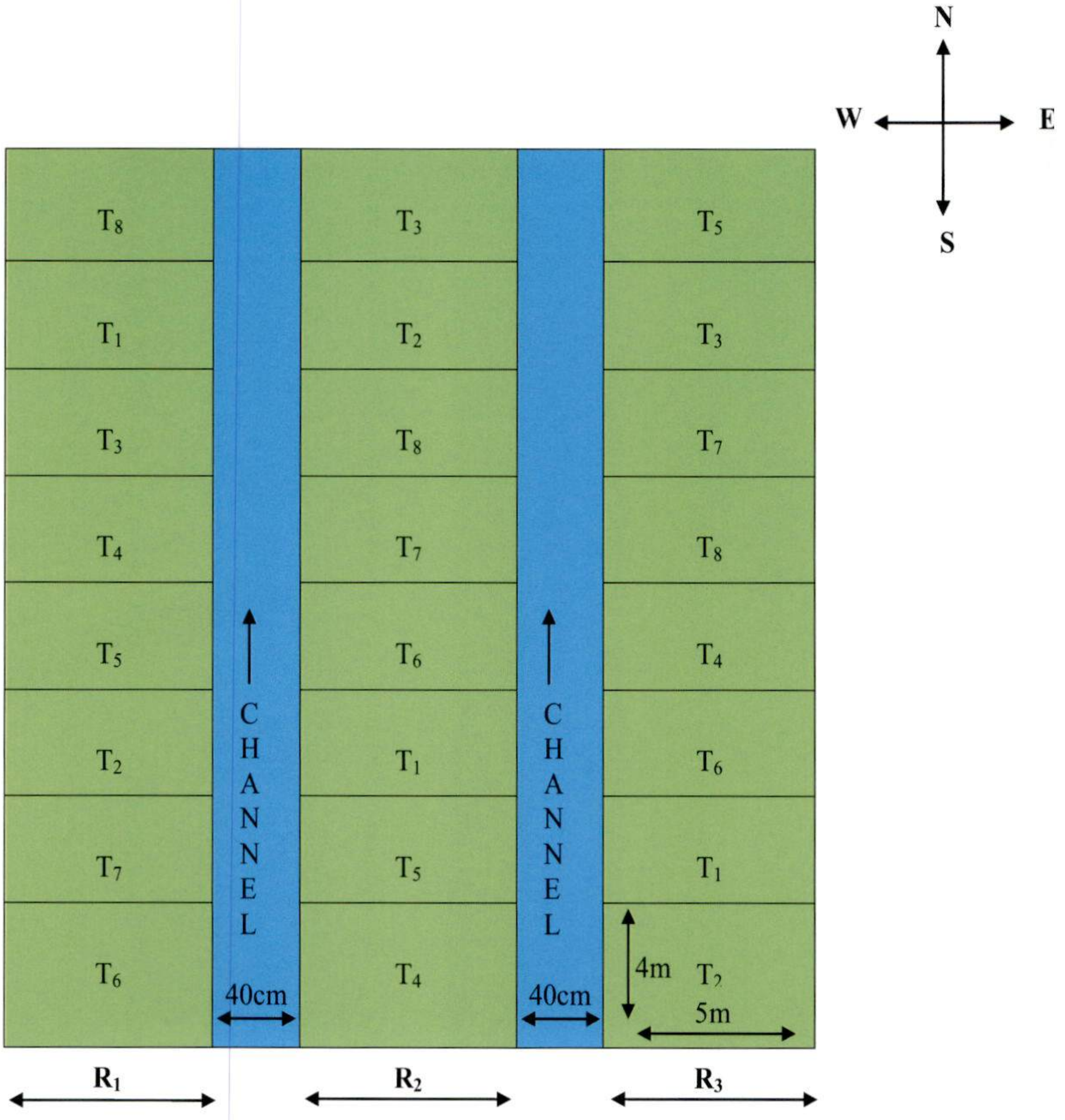


Fig 2. Layout of the experimental field

Design	: RBD
Treatments	: 8
Replications	: 3
Gross plot	: 5 m x 4 m
Net plot	: 4 m x 3 m

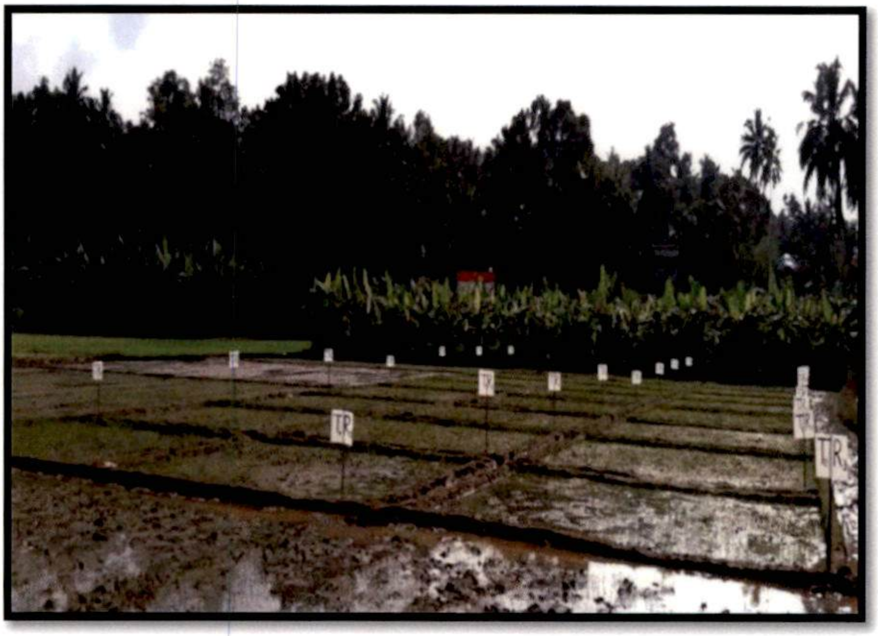


Plate 2. General view of the experimental field

Fertilizer application was scheduled in three splits. One-third N + full P + half K were applied as basal at 15 DAS. One-third dose of N was top dressed at active tillering and the final one-third dose of N + half K were top dressed at panicle initiation.

3.3.2.4. Seeds and Sowing

Healthy paddy seeds were soaked overnight in water followed by draining and incubation in gunny bags to initiate sprouting. The pre-germinated seeds were broadcasted on to the prepared plots at a seed rate of 100 kg ha^{-1}.

3.3.2.5. Weed management

Weed management was practiced according to the treatments fixed for the experiment. Pre-emergent herbicide was sprayed within one week of sowing. Early post-emergence herbicides were applied at 15 DAS and post-emergence herbicides at 20 DAS as scheduled. The spray volume used was 500 L ha^{-1}. Herbicides were sprayed using hand operated knapsack sprayer with flat fan nozzle. All the herbicide treatments were given a follow up with hand weeding at 40 DAS. Hand weeding twice at 20 DAS and 40 DAS (critical period of weed management in rice) was followed in weeded check. Weedy check or un-weeded control was free of any weed control measures and was used for studying the biology of *Schoenoplectus juncoides*.

3.3.2.6. Plant protection

Rice bug (*Leptocorisa acuta*) observed during milky stage of the crop was managed using two sprays of quinalphos at the rate of 750 ml ha^{-1} (Ekalux 25 EC) at milky stage of the crop. No serious disease incidence occurred during the crop growth stages.

3.3.2.7. Harvest

The crop was manually harvested when the grains became dry and attained straw-brown colour (hard dough stage). Net plot was harvested separately, threshed and winnowed. Individual plot yields of both grain and straw were noted down and expressed in kg ha^{-1} on dry weight basis.

3.3. Observations

3.3.1. Experiment I: Biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

The weed biology was studied by observing sample plants earmarked in the experimental field. Ten sample plants drawn at random from 20 m^2 area (weedy check) were observed from emergence onwards.

3.3.1.1. Phenology of rock bulrush

3.3.1.1.1. Days to germination

The number of days taken for appearance of weed sprouts under field condition in weedy check plot was observed and recorded.

3.3.1.1.2. Days to flowering

The sample plants were periodically observed till flower initiation. Emergence of small spike head on the tiller was considered as flowering. The number of days from emergence to flowering were counted and expressed in days.

3.3.1.1.3. Days to spike maturity

The change in spike colour from green to brown was considered as maturity. Number of days from flowering to maturity were counted and expressed in days.

3.3.1.1.4. Days to lodging

After spike maturity, the sample plants exhibited a lodging behavior. Number of days taken for lodging was counted and expressed in days.

3.3.1.1.5. Days to seed maturity

Colour change of seeds from cream to dark brown or black was considered as seed maturity. Number of days taken for attaining seed maturity was counted and expressed in days.

3.3.1.1.6. Duration

Duration of the weed was determined by counting the number of days starting from germination to drying of aerial parts in the field and expressed in days.

3.3.1.2. Shoot characteristics of rock bulrush

3.3.1.2.1. Plant height at seedling stage

Heights of ten sample plants were measured using a scale after completion of germination and expressed in cm.

3.3.1.2.2. Plant height at flowering

Plant height was measured from the tagged plants using a scale, starting from the stem portion just above the soil to the shoot tip at the flowering stage and expressed in cm.

3.3.1.2.3. Plant height at maturity

Sample plant heights were measured using a scale at maturity and expressed in cm.

3.3.1.2.4. Number of leaves plant^{-1}

The number of leaves was same as the number of tillers in case of the weed under study. Hence, the number of tillers produced by the sample plants were counted and expressed in plant^{-1} basis.

3.3.1.2.5. Shoot dry weight

Ten sample plants uprooted after maturity, washed and made free of dirt and soil was oven-dried over night at 70 ± 5°C. Roots were carefully removed and dry weight of shoot was taken and expressed as g plant^{-1}.

3.3.1.2.6. Dry matter plant^{-1}

Ten sample plants uprooted after maturity, washed and made free of dirt and soil was oven-dried over night at 70 ± 5°C. The dry weight per plant was taken and expressed in g plant^{-1}.

3.3.1.2.7. Biomass production

Iron quadrat of size 50cm x 50cm was randomly placed at three points in the weedy check to determine the number of rock bulrush m^{-2}. The weeds within the frame was uprooted, washed, made free of dirt and soil and oven-dried at 70 ± 5°C for 24 h. Dry weight of S. *juncoides* was taken in g m^{-2} and converted to t ha^{-1}.

3.3.1.3. Root characteristics of rock bulrush

3.3.1.3.1. Depth of rooting

Weed samples carefully uprooted at maturity were washed and made free of soil and dirt. Root length was measured using a scale and expressed in cm.

3.3.1.3.2. Root dry weight

Ten sample plants uprooted after maturity, washed and made free of dirt and soil was oven-dried at 70 ± 5°C for 24 h. Roots were carefully removed and dry weight of roots were taken and expressed in g $plant^{-1}$.

3.3.1.3.3. Rhizome dry weight

Rhizomes were not observed till the end of the experiment. Presence of small rhizomes was observed after crop harvest. The rhizomes were washed and freed from dirt, soil and small roots, dried at 70 ± 5°C for 24 h. Rhizome dry weight was recorded and expressed in g $plant^{-1}$.

3.3.1.3.4. Root: shoot ratio (length)

Sample plants were uprooted, washed and separated into shoot and root. The length of the root and shoot was measured using a scale to determine root: shoot ratio on length basis.

3.3.1.3.5. Root: shoot ratio (dry weight)

Root and shoot of sample plants were cleaned and oven dried for 24 h at 70 ± 5°C to obtain the root: shoot ratio on the basis of dry weight.

3.3.1.4. Floral characteristics of rock bulrush

3.3.1.4.1. Number of spike bearing tillers $plant^{-1}$

Number of spike bearing tillers $plant^{-1}$ was determined by counting the number of tillers with spike out of the total number of tillers produced by a plant and expressed in number $plant^{-1}$.

3.3.1.4.2. Number of spikes tiller^{-1}

Number of spikes in a tiller was estimated by counting the number of spike heads produced in a tiller and it is expressed in number tiller^{-1}.

3.3.1.4.3. Number of spikes plant^{-1}

Total number of spikes produced by the plant were counted and expressed in number plant^{-1} basis.

3.3.1.4.4. Length of spike

Length of spikes produced by the sample plants from base to top were measured using a scale and expressed in cm.

3.3.1.4.5. Spike diameter

Diameter of the spike was taken by encircling the spike with a thread and measuring the corresponding thread length using a scale. Spike diameter is expressed in cm.

3.3.1.5. Seed characteristics of rock bulrush

3.3.1.5.1. Number of seeds spike^{-1}

Seeds in dried spikes were detached, counted and expressed as number of seeds spike^{-1}.

3.3.1.5.2. Number of seeds plant^{-1}

The dried spikes from each sample plant were detached and seeds counted.

3.3.1.5.3. Seed length

Length of seed was measured using stereo microscope under 10x magnification and expressed in mm.

3.3.1.5.4. Seed width

Width of seed was measured using stereo microscope under 10x magnification and expressed in mm.

3.3.1.5.5. Test weight

Thousand mature, bold seeds of *Schoenoplectus juncoides* were counted and weighed to obtain the test weight and expressed in g.

3.3.1.5.6. *Seed viability percentage*

Mature seeds of the weed *S. juncoides* were collected and kept in petriplates laid with moistened filter paper, filter paper with standing water column, lowland soil and lowland soil with standing water column. Petri dishes were kept in light and dark under ambient conditions of temperature and humidity. The observations on seed viability were recorded and expressed in percentage.

3.3.1.6. Nutrient composition and uptake of rock bulrush

Weed samples collected after maturity were washed, cleaned and dried at 70 ± 5°C for 24 h. The dried samples were ground and sieved through 0.5 mm sieve. The samples were accurately weighed using an electronic balance, subjected to acid extraction and used for NPK analysis following standard procedures. The standard analytical methods followed for plant analysis are tabulated and presented (Table 3).

Table 3. Standard analytical methods followed in plant analysis

Sl No.	Component	Method	Reference
1.	Nitrogen	Micro kjeldahl method	Jackson (1973)
2.	Phosphorus	Vanadomolybdo phosphoric yellow colour method	Jackson (1973)
3.	Potassium	Flame photomery	Jackson (1973)

3.3.1.6.1. Protein content

Protein content of the weed was calculated by multiplying the N content with 6.25 and the content was expressed in percentage.

3.3.1.6.2. N uptake

N uptake was computed by multiplying the N content and biomass production of the weed ha^{-1} and expressed in kg ha^{-1}.

3.3.1.6.3. P uptake

P uptake was computed by multiplying the P content and biomass production of the weed ha^{-1} and expressed in kg ha^{-1}.

3.3.1.6.4. K uptake

K uptake was computed by multiplying the K content and biomass production of the weed ha^{-1} and expressed in kg ha^{-1}.

3.4.2. Experiment II: Management of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) using new generation herbicides

3.4.2.1. Observations on weeds

Iron quadrat of size 50cm x50cm was placed randomly at three different sites within the net plot area of each plot. Weeds within the frame were used for taking the following observations.

3.4.2.1.1. Weed flora

Weed flora associated with *Schoenoplectus juncoides* included grasses, sedges and broad leaved weeds (BLW). Observations on weed flora were periodically taken at 15, 30, 45 and 60 DAS. Weed shift (if any) were also observed.

3.4.2.1.2. Weed density

Weeds within the quadrat were counted and classified into S. *juncoides* and other weeds. Observations were recorded at 15, 30, 45 and 60 DAS and expressed in number m^{-2}.

3.4.2.1.3. Weed dry weight

Uprooted, washed and cleaned weed samples were oven dried at 70 ± 5°C for 24 h to a constant weight and the weights were noted in g m^{-2}.

3.4.2.1.4. Weed control efficiency

Weed control efficiency was computed using the formula derived by Upadhyay and Sivanand (1985).

$$WCE = \frac{(X-Y)}{X} \times 100$$

WCE = Weed control efficiency

X = Weed dry weight from the treatment with maximum number of weeds (weedy check)

Y = Weed dry weight from the treatment whose weed control efficiency has to be calculated

3.4.2.1.5. Herbicide phytotoxicity

Symptoms of herbicide phytotoxicity on weeds were closely observed seven days after spraying. The stages of phytotoxicity were recorded and noted down in a scale of 0 to 10 as given by Rao (2000).

3.4.2.2. Growth and yield attributes of crop

Ten sample plants selected at random from the net plot area of individual plots were tagged and the following observations were recorded.

3.4.2.2.1. Plant height

Height of the sample paddy plants was measured from portion just above the soil to the tip of the longest leaf. Height was taken thrice during the crop growing season *viz.* 30, 60 DAS and at harvest. The observations were expressed in cm.

3.4.2.2.2. Number of productive tillers m^{-2}

Number of panicles produced in the sample hills were counted at harvest from the net plot area and recorded as number of productive tillers m^{-2}.

3.4.2.2.3. Number of grains $panicle^{-1}$

The number of filled and unfilled grains $panicle^{-1}$ from ten randomly selected panicles were counted and recorded as number of grains $panicle^{-1}$.

3.4.2.2.4. Sterility percentage

The number of filled and unfilled grains from ten randomly selected panicles were counted separately and used to determine the sterility percentage as per the given formula:

$$\text{Sterility percentage (\%)} = \frac{\text{Number of unfilled grains panicle}^{-1}}{\text{Total number of grains panicle}^{-1}} \times 100$$

3.4.2.2.5. Thousand grain weight

One thousand bold, completely filled grains from the selected panicles in the net plot were counted and weighed. The observation was recorded in g.

3.4.2.2.6. Grain yield

Plants from the net plot was harvested, threshed and winnowed separately. Grains with 13 per cent moisture content were weighed using a balance. Grain yield was recorded in kg ha^{-1}.

3.4.2.2.7. Straw yield

Straw obtained after threshing the net plot was sundried to a constant weight and weighed using a balance and the weight was expressed in kg ha^{-1}.

3.4.2.2.8. Harvest Index **(HI)**

Harvest index was computed by using the formula given by Donald and Hanohlin (1976).

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

3.4.2.2.9. Herbicide phytotoxicity

Phytotoxicity symptoms shown by the crop was keenly observed for seven days after the date of herbicide spray. The visible symptoms (if any) were noted down in a scale of 0 to 10 as given by Rao (2000).

3.4.2.2.10. Weed index

Weed index was calculated using the formula suggested by Gill and Vijayakumar (1969).

$$WI = \frac{(X-Y)}{X} \times 100$$

WI = Weed Index

X = Yield from the treatment with minimum number of weeds

Y = Yield from the treated plot whose weed index has to be calculated

3.4.2.2.11. Pest and disease incidence

Scoring of the important pest noticed *viz.* rice bug was done using standard evaluation system developed by the International Rice Research Institute (IRRI, 2002).

3.5. Chemical analysis

3.5.1. Nutrient content of crops and weeds

Crop and weed samples collected were analyzed for NPK. Weed samples were collected at 20 DAS and 40 DAS. Crop sample was taken during harvest. Collected plant samples were prepared by cleaning and drying in hot air oven to constant weight. Dried samples were ground and sieved using 0.5mm mesh size sieve. Appropriate quantity of the sieved sample was weighed in electronic balance and kept for acid digestion. N, P_2O_5 and K_2O content in crop and weed samples were calculated and expressed in percentage. Standard analytical procedures followed for plant nutrient analysis are presented in Table 3.

3.5.2. Nutrient uptake by crop

Nutrient uptake by the crop was determined by multiplying the nutrient content and dry weight of the crop. The uptake was expressed in kg ha^{-1}.

3.5.3. Nutrient removal by weed

Nutrients removed by the weed S. *juncoides* was computed by multiplying the NPK content with the respective weed dry weight. Nutrient removal by weed was calculated and expressed in kg ha^{-1}.

3.5.4. Available NPK and organic carbon status of soil after the experiment

Soil samples collected from the field before and after the experiment were air dried and analyzed for assessing the N, P, K and organic carbon status of the soil. The nutrient content of the soil was expressed in kg ha^{-1}.

3.6. Economic analysis

3.6.1. Net income

Net income was computed after estimating the cost of cultivation and gross income obtained, using the given formula:

$$\text{Net income (Rs ha}^{-1}\text{)} = \text{Gross income} - \text{Cost of cultivation}$$

3.6.2. B: C ratio

Benefit cost ratio (BCR) of all the treatments were calculated using the given formula:

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

3.7. Enzyme analysis

3.7.1. Dehydrogenase activity

Effect of applied herbicides on the soil microbes was determined by analyzing soil dehydrogenase activity before and 15 days after herbicide spray as per the procedure given by Casida *et al*. (1964) and expressed in µg TPF g^{-1} of soil 24 h^{-1}.

3.8. Statistical analysis

Recorded data were tabulated and subjected to Analysis of Variance (ANOVA) applicable to Randomized Block Design which was formulated by Cochran and Cox (1965). Data requiring transformation were appropriately transformed and analyzed. The treatment *vs* control comparison has been denoted as 'S' when significant and 'NS' when not significant.

Results

4. RESULTS

A field experiment was carried out in the lowland paddy field of Nemom block, Thiruvananthapuram for studying the biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) and formulating an effective and economic method of weed management in wet seeded rice. The observations recorded were statistically analyzed and the results are presented in this chapter.

4.1. EXPERIMENT I: WEED BIOLOGY

Rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) belonging to the family Cyperaceae is an emerging weed in the rice fields of Kerala. Information on the weed biology is essential for formulating effective weed management practices. Hence, weed biology was studied by observing ten sample plants earmarked in the weedy check plots of the experimental field. Observations regarding the weed biology were recorded during the crop growth period in *rabi* season.

4.1.1. Phenology of rock bulrush

Schoenoplectus juncoides (Roxb.) Palla was observed to be an erect tillering plant with upright culms. Relevant observations required for understanding the phenology of rock bulrush, were made during November 2017 to March 2018 and are presented in Table 4.

Seed germination of rock bulrush commenced simultaneously with the crop in wet seeded paddy fields. However, the seeds of *Schoenoplectus juncoides* did not germinate in petri dishes kept under the laboratory conditions of light, temperature and water. Under field condition, the weed started its seed germination from 3 days and extended up to 7 days after wet seeding of paddy. The average number (number) of days required for seed germination of rock bulrush was found to be 5.30 days.

Emergence of inflorescence (spike) laterally from the culm marked the beginning of flowering stage which started from 20th day continuing up to 24th day. The mean number of days to flower initiation was observed to be 22.30 days. Colour change of spike from green to light brown was regarded as spike maturity. Spike maturation started from the 30th day extending to 35th day with a mean of 33 days.

Lodging of culms bearing mature spikes was a peculiar character observed in rock bulrush. Lodging was observed from 39th day onwards and continued till 42nd day. The mean number of days to lodging was recorded as 40.30 days. As the seeds matured, they started shedding from the spike into the soil along with the glumes attached to it. Shedding of mature, bold seeds from the lodged culms was observed from 66th day up to 70th day with a mean period of 67.80 days for seeds to get matured and dispersed.

Sprouting of vegetative buds occurred simultaneously with drying of spikes and seed dispersal. Under field conditions, infestation of rock bulrush was observed throughout the crop growing season. Complete drying of the weed occurred from 90th to 120th day with a mean duration of 106.10 days for completing the life cycle.

4.1.2. Shoot characteristics of rock bulrush

Observations recorded to study the shoot characteristics of rock bulrush, *Schoenoplectus juncoides* (Roxb.) Palla are presented in Table 5.

Shoot or culm of *Schoenoplectus juncoides* (Roxb.) Palla was hollow and circular in cross section like other rushes. At seedling stage, height of culms varied from 1.50 cm to 2.30 cm with a mean height of 1.94 cm. At flowering stage, the plant height ranged from 42 cm to 48.20 cm with a mean height of 45.21 cm. Maximum shoot height was observed at maturity and it varied from 64.7 cm to 70.2 cm with average of 66.76 cm. Tillers, leaves and culms were the same and its number ranged from 14 to 28 plant^{-1} with a mean tiller production of 19.60 tillers plant^{-1}. Shoot dry

Table 4. Phenology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Min.	Max.	Mean	CV (%)	SEm(±)
Days to germination	3.00	7.00	5.30	23.62	0.40
Days to flowering	20.00	24.00	22.30	7.34	0.52
Days to spike maturity	30.00	35.00	33.00	4.95	0.52
Days to lodging	39.00	42.00	40.30	2.88	0.37
Days to seed maturity	66.00	70.00	67.80	2.39	0.51
Duration	90.00	120.00	106.10	9.59	3.22

Table 5. Shoot characteristics of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Min.	Max.	Mean	CV (%)	SEm(±)
Plant height at seedling (cm)	1.50	2.30	1.94	14.00	0.09
Plant height at flowering (cm)	42.00	48.20	45.21	5.11	0.73
Plant height at maturity (cm)	64.70	70.20	66.76	2.91	0.62
Number of leaves plant^{-1}	14.00	28.00	19.60	20.72	1.29
Shoot dry weight (g plant^{-1})	1.11	3.31	1.82	40.61	0.23
Dry matter plant^{-1} (g)	1.56	5.98	2.81	46.92	0.42
Biomass production (t ha^{-1})	0.83	1.08	0.96	13.16	0.07

weight ranged from 1.11 to 3.31g plant^{-1} based on the number of tillers. Mean shoot dry weight was observed to be 1.82 g plant^{-1}. Average dry matter production of individual plant was 2.81g. Rock bulrush produced 0.83 to 1.08 t of biomass ha^{-1} with an average of 0.96 t ha^{-1} in weedy check.

4.1.3. Root characteristics of rock bulrush

Observations recorded for determining the root characteristics of rock bulrush are presented in Table 6.

Schoenoplectus juncoides (Roxb.) Palla had a fibrous root system with small rhizomes produced after the crop growing season. Rooting depth of rock bulrush ranged from 15 cm to 19.90 cm with a mean depth of 17.76 cm at maturity. Root dry weight was observed to range from 0.40 to 2.90 g plant^{-1} with an average of 0.99 g plant^{-1}. Rhizomes developed in the undisturbed field one month after the cropping season, registering an average rhizome dry weight of 0.03 g plant^{-1}. Root: shoot ratios on length and dry weight basis were 0.27 and 0.52 respectively.

4.1.4. Floral characteristics of rock bulrush

Floral characteristics of rock bulrush were documented and presented in Table 7.

Inflorescence in rock bulrush was a sessile spike. Only few tillers in a plant had spike. Seeds along with the glumes detached from the base to the tip of the mature, dried spike. The number of tillers bearing spikes in a plant ranged from 6 to 16 with a mean of 12.40 tillers plant^{-1}. Number of spikes tiller^{-1} varied from 2 to 4 with an average 2.80 spikes tiller^{-1} and the total number of spikes plant^{-1} ranged from 24 to 48 with mean of 33.20 spikes plant^{-1}. Individual spike length and diameter ranged from 1 to 1.60 cm and 1.40 to 1.70 cm respectively.

Table 6. Root characteristics of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Min.	Max.	Mean	CV (%)	SEm(±)
Depth of rooting (cm)	15.00	19.90	17.76	10.60	0.60
Root dry weight (g plant^{-1})	0.40	2.90	0.99	70.97	0.22
Rhizome dry weight (g plant^{-1})	0.02	0.04	0.03	15.24	0.002
Root: shoot ratio (length)	0.21	0.30	0.27	10.48	0.01
Root: shoot (dry weight)	0.36	0.88	0.52	30.24	0.05

Table 7. Floral characteristics of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Min.	Max.	Mean	CV (%)	SEm (±)
No of tillers with spike $plant^{-1}$	6.00	16.00	12.40	26.12	1.02
No of spikes $tiller^{-1}$	2.00	4.00	2.80	28.17	0.25
No of spikes $plant^{-1}$	24.00	48.00	33.20	25.55	2.68
Length of spike (cm)	1.00	1.60	1.24	14.82	0.06
Spike diameter (cm)	1.40	1.70	1.56	7.52	0.04

4.1.5. Seed characteristics of rock bulrush

Observations recorded on the seed characteristics of rock bulrush are presented in Table 8.

Seeds of rock bulrush were obcordate in shape with 4 to 6 bristles and spiny apex. Mature seeds of rock bulrush were dark brown to black in colour. Number of seeds spike^{-1} varied from 17 to 23 with a mean seed number of 19.90. Seeds under 10x magnification of stereo microscope measured a length of 0.582 mm and width of 0.452 mm with a thousand seed weight of 1.5 g. A single plant was capable of producing a minimum of 528 and maximum of 1120 seeds with an average seed production capacity of 861.60 seeds plant^{-1}. Seed dispersal of rock bulrush was aided by the spiny seed tip, bristles and lodging of culms.

4.1.6. Nutrient composition of rock bulrush

Nutrient composition and uptake of rock bulrush were analyzed and presented in Table 9.

Total N, P and K content of rock bulrush were analyzed to be 0.90, 0.33 and 1.14 per cent respectively. Average biomass production of 0.96 t ha^{-1} by rock bulrush in the un-weeded control corresponded to a nutrient removal of 8.61, 3.13 and 10.95 kg NPK ha^{-1} respectively. Protein content of rock bulrush was estimated to be 5.6 per cent.

Table 8. Seed characteristics of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Min.	Max.	Mean	CV (%)	SEm(±)
No of seeds spike^{-1}	17.00	23.00	19.90	9.61	0.61
No of seeds plant^{-1}	528.00	1120.00	861.60	20.66	56.30
Seed length (mm)	0.582				
Seed width (mm)	0.452				
Test weight (g)	1.50				

Table 9. Nutrient composition and uptake of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Nutrient	Content (%)	Nutrient uptake (kg ha^{-1})
Nitrogen	0.90	8.61
Phosphorus	0.33	3.13
Potassium	1.14	10.95
Protein	5.6	

4.2. EXPERIMENT II: WEED MANAGEMENT

4.2.1. Observation on weeds

4.2.1.1. Weed flora

Weed species associated with wet seeded broadcasted paddy at various stages of growth *viz*. 15, 30, 45 and 60 DAS are presented in Table 10. Details of the weed flora associated with rice at the experimental field are presented in Table 11.

The crop was seen associated with a multitude of weeds including grasses, sedges and broad leaved weeds throughout the growing season. *Schoenoplectus juncoides* was the dominant weed in the experimental field throughout the crop growth. *Fimbristylis miliacea*, *Isachne miliacea*, *Lindernia rotundifolia* and *Ludwigia perennis* were also observed to infest the field throughout the crop life cycle.

4.2.1.1.1. Weed flora at 15 DAS

At 15 DAS, sedges were the dominant group based on the intensity of occurrence. Sedges present were *Schoenoplectus juncoides* and *Fimbristylis miliacea*. *Isachne miliacea* was also present along with BLW *viz. Lindernia rotundifolia*, *Ludwigia perennis*, *Alternanthera sessilis* and *Oxalis corniculata.* A fern species, *Marselia quadrifolia* was also seen at 15 DAS.

4.2.1.1.2. Weed flora at 30 DAS

At 30 DAS also, sedges dominated the field based on the diversity of species present in the field. *Fimbristylis miliacea*, *Cyperus exaltatus*, *Cyperus haspan*, *Cyperus difformis*, *Cyperus iria* and *Cyperus cyperoides* were the sedge species present. Among grasses, *Isachne miliacea* was seen associated with rice. *Eclipta alba*, *Alternanthera sessilis*, *Lindernia rotundifolia*, *Ludwigia perennis* and *Portulaca oleracea* were the BLW present in the field at one month of sowing.

Table 10. Weed flora associated with rice at 15, 30, 45 and 60 DAS

15 DAS	30 DAS	45 DAS	60 DAS
Schoenoplectus juncoides	*S. juncoides*	*S. juncoides*	*S. juncoides*
Fimbristylis miliacea	*Isachne miliacea*	*Isachne miliacea*	*Echinochloa glabrescens*
Isachne miliacea	*Fimbristylis miliacea*	*Limnocharis flava*	*Oryza sativa f. spontanea*
Lindernia rotundifolia	*Cyperus exaltatus*	*L. rotundifolia*	*Isachne miliacea*
Ludwigia perennis	*Cyperus haspan*	*Ludwigia perennis*	*Digitaria sanguinalis*
Alternathera sessilis	*Cyperus difformis*	*Fimbristylis miliacea*	*Eragrostis tenella*
Oxalis corniculata	*Cyperus iria*	*Cyperus exaltatus*	*Fimbristylis miliacea*
Marselia quadrifolia	*Cyperus cyperoides*	*Cyperus haspan*	*Limnocharis flava*
	Eclipta alba	*Cyperus difformis*	*Ludwigia perennis*
	Alternanthera sessilis	*Cyperus iria*	*Ceratopteris thallictroides*
	Lindernia rotundifolia	*Cyperus cyperoides*	*L. rotundifolia*
	Ludwigia perennis	*Digitaria sanguinalis*	
	Portulaca oleracea	*Eclipta alba*	

Table 11. Details of the weed flora associated with rice in the experimental field

Sl. No.	Common name	Scientific name	Malayalam name	Family
Grasses				
1.	Blood grass	*Isachne miliacea*	Naringa/changalipullu	Poaceae
2.	Large crab grass	*Digitaria sanguinalis*	-	
3.	Love grass	*Erasgrostis tenella*	Darbha pullu	Poaceae
4.	Barnyard grass	*Echinochloa glabrescens*	Kavada	Poaceae
5.	Weedy rice	*Oryza sativa f* sp. *spontanea*	Varinellu	Poaceae
Sedges				
6.	Rock bulrush	*Schoenoplectus juncoides*	Matipullu/manapullu	Cyperaceae
7.	Globe finger rush	*Fimbristylis miliacea*	Mungai	Cyperaceae
8.	Tall flat sedge	*Cyperus exaltatus*	Wara pullu	Cyperaceae
9.	Rice flat sedge	*Cyperus iria*	Manjakora/chengoal	Cyperaceae
10.	Umbrella sedge	*Cyperus difformis*	Thalekkettan	Cyperaceae
11.	Pacific island flat sedge	*Cyperus cyperoides*	Kolpullu	Cyperaceae
12.	Sheathed flat sedge	*Cyperus haspan*	-	Cyperaceae
Broad leaved weeds				
13.	Baby tears	*Lindernia rotundifolia*	-	Linderniaceae
14.	Water primrose	*Ludwigia perennis*	Neergrampu	Onagraceae
15.	Water cabbage	*Limnocharis flava*	Nagappola	Limnocharitaceae
16.	Creeping wood sorrel	*Oxalis corniculata*	Puliyaarila	Oxalidaceae
17.	Dwarf copper leaf	*Alternanthera sessilis*	Vayalcheera/kozhuva	Amaranthaceae
18.	Common purslane	*Portulaca oleracea*	Kozhuppa	Portulacaceae
19.	False daisy	*Eclipta alba*	Kayyonni	Asteraceae
Ferns				
20.	Airy pepper wort	*Marselia quadrifolia*	Naalilakodian	Marsiliaceae
21.	Water sprite	*Ceratopteris thallictroides*	Yakshippayal	Parkeriaceae

4.2.1.1.3. Weed flora at 45 DAS

At 45 DAS, occurrence of *Limnocharis flava* was observed along with other BLW *Ludwigia perennis*, *Lindernia rotundifolia* and *Eclipta alba*. *Schoenoplectus juncoides*, *Fimbristylis miliacea*, *Cyperus exaltatus*, *Cyperus haspan*, *Cyperus difformis*, *Cyperus iria* and *Cyperus cyperoides* were the associated sedges. The grasses present were *Isachne miliacea* and *Digitaria sanguinalis*.

4.2.1.1.4. Weed flora at 60 DAS

By 60 DAS, emergence of grass weeds like *Echinochloa glabrescens* and *Oryza sativa* f sp. *spontanea* were noticed. *Isachne miliacea*, *Eragrostis tenella* *Schoenoplectus juncoides*, *Fimbristylis miliacea*, *Limnocharis flava*, *Ludwigia perennis*, *Lindernia rotundifolia* and a fern *Ceratopteris thalictroides* were also present.

4.2.1.2. Weed density

Data on weed density at 15, 30, 45 and 60 DAS was statistically analyzed, appropriately transformed and presented in Table 12.

Number of *Schoenoplectus juncoides* per unit area varied with the crop growth stages and management practices experimented.

4.2.1.2.1. Weed density at 15 DAS

At 15 DAS, pre-emergence application of bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS (T_1) recorded the lowest count of *S. juncoides* (0.67 m^{-2}). Since no other treatments were applied at that stage of observation, all the other plots recorded higher density of the weed. Weed count per unit area (m^2) recorded in T_3, T_5, T_2, T_6, T_7 and T_4 were 34.22, 32.33, 31.40, 28.89, 28.56 and 22.55 m^{-2} respectively.

4.2.1.2.2. Weed density at 30 DAS

At 30 DAS also, the pre-emergence application of bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS (T_1) recorded lesser number of the weed per unit area (m^2) recording a density of 3.58 m^{-2}. Densities of the weed S. *juncoides* recorded from the plots treated with penoxsulam @ 22.5 g ha^{-1} at 15 DAS (3.59 m^{-2}), carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS (4.04 m^{-2}), HW twice at 20 and 40 DAS (5.19 m^{-2}) and ethoxysulfuron @ 15 g ha^{-1} at 15 DAS (5.96 m^{-2}) were at par with T_1. Weedy check registered higher number of the weed m^{-2} (53.57 m^{-2}) by 30 DAS.

4.2.1.2.3. Weed density at 45 DAS

At 45 DAS, early post-emergence spray of ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) gave better control of S. *juncoides* with a weed density of 2.09 m^{-2}. Penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (2.92 m^{-2}) and HW twice at 20 and 40 DAS (3.14 m^{-2}) also recorded lower weed densities which were at par with T_3. Higher density of *S. juncoides* (62.34 m^{-2}) was observed in un-weeded plot.

4.2.1.2.4. Weed density at 60 DAS

At 60 DAS, lesser number of *S. juncoides* was noticed and recorded in plots that received an early post-emergence spray with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (3.15 m^{-2}). Early post-emergence spray of penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS was also as effective as T_3 with 4.22 *S. juncoides* m^{-2}. Hand weeding twice at 20 and 40 DAS recorded higher number (9.88 m^{-2}) of S. *juncoides*. Weedy check registered maximum density of S. *juncoides* (64.11 m^{-2}).

Table 12. Effect of weed management practices on weed density at 15, 30, 45 and 60 DAS, number m^{-2}

Treatments	15 DAS	30 DAS	45 DAS	60 DAS
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	0.67 (1.24)	3.58 (2.01)	6.81 (2.79)	10.49 (3.39)
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	31.40 (5.69)	3.59 (2.14)	2.92 (1.97)	4.22 (2.28)
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	34.22 (5.92)	5.96 (2.64)	2.09 (1.69)	3.15 (2.04)
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	22.55 (4.84)	4.04 (2.24)	5.04 (2.44)	7.43 (2.90)
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	32.33 (5.75)	6.78 (2.78)	7.21 (2.86)	9.34 (3.22)
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	28.89 (5.43)	8.22 (3.04)	9.79 (3.28)	7.53 (2.92)
T_7: HW at 20 and 40 DAS	28.56 (5.24)	5.19 (2.47)	3.14 (2.03)	9.88 (3.29)
T_8: weedy check	40.55 (6.46)	53.57 (7.39)	62.34 (7.96)	64.11 (8.07)
SEm (±)	0.47	0.21	0.18	0.09
CD (0.05)	1.450	0.640	0.550	0.270

The data were subjected to square root transformation $\sqrt{(x + 0.5)}$ and transformed values are given in paranthesis

4.2.1.3. Weed dry weight

Dry weight of the weeds at 15, 30, 45 and 60 DAS were tabulated and presented in Table 13.

The weed management practices tested had significant influence on weed dry weight at 15, 30, 45 and 60 DAS.

4.2.1.3.1. Weed dry weight at 15 DAS

At 15 DAS, bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS registered lower weed dry weight of 0.08 g m^{-2}. The treatments T_2, T_4, T_7, T_5, T_6, T_3 and T_8 recorded weed dry weights of 10.62, 11.79, 11.98, 11.99, 12.94, 13.17 and 14.11 g m^{-2} respectively.

4.2.1.3.2. Weed dry weight at 30 DAS

At 30 DAS, all the treatments except weedy check gave considerable management of S. *juncoides* as indicated by the lower values for weed dry weight. However, early post-emergence application of carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_4) recorded the lowest dry weight of 1.25 g m^{-2}. T_1, T_3, T_2, T_7, T_6 and T_5 were observed to be equally effective as T_4 registering weed dry weights of 1.42, 1.56, 1.58, 1.76, 2.26 and 2.38 g m^{-2} respectively. Dry weight of S. *juncoides* obtained from weedy check was recorded to be 35.47 g m^{-2}.

4.2.1.3.3. Weed dry weight at 45 DAS

Early post-emergence spray with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) recorded lower dry weight of the weed (0.13 g m^{-2}) at 45 DAS. Spray with penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS and HW twice (20 and 40 DAS) and were at par with T_3 registering weed dry weights of 0.66 and 0.80 g m^{-2} respectively. Dry weight of S. *juncoides* obtained from weedy check was 70.11 g m^{-2}.

Table 13. Effect of weed management practices on weed dry weight at 15, 30, 45 and 60 DAS, g m^{-2}

Treatments	15 DAS	30 DAS	45 DAS	60 DAS
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	0.08 (1.04)	1.42 (1.51)	2.87 (1.97)	4.04 (2.25)
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	10.62 (3.41)	1.58 (1.60)	0.66 (1.28)	1.99 (1.73)
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	13.17 (3.76)	1.56 (1.59)	0.13 (1.06)	1.83 (1.68)
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	11.79 (3.58)	1.25 (1.49)	1.59 (1.61)	4.03 (2.24)
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	11.99 (3.60)	2.38 (1.84)	2.80 (1.95)	6.33 (2.71)
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	12.94 (3.73)	2.26 (1.78)	1.85 (1.69)	3.55 (2.13)
T_7: HW at 20 and 40 DAS	11.98 (3.60)	1.76 (1.65)	0.80 (1.32)	2.78 (1.94)
T_8: weedy check	14.11 (3.89)	35.47 (6.01)	70.11 (8.41)	96.05 (9.84)
SEm (±)	0.07	0.20	0.15	0.13
CD (0.05)	0.201	0.624	0.460	0.405

The data were subjected to square root transformation $\sqrt{(x + 0.5)}$ and transformed values are given in paranthesis

4.2.1.3.4. Weed dry weight at 60 DAS

Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) recorded the lowest weed dry weight of 1.83 g m^{-2} at 60 DAS. T_2 and T_7 were on a par with T_3, recording weed dry weights of 1.99 and 2.78 g m^{-2} respectively. Weed dry weight recorded in weedy check was 96.05 g m^{-2}.

4.2.1.4. Weed control efficiency

Weed control efficiencies of the applied weed management treatments were statistically analyzed and presented in Table 14.

At all stages of observation *viz.* 15, 30, 45 and 60 DAS weed control efficiency varied among the treatments applied.

4.2.1.4.1. Weed control efficiency at 15 DAS

At 15 DAS, weed control efficiency (WCE) computed was higher for bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS (T_1) registering a value of 99.40 per cent. Weed control efficiency was lower in rest of the treatments.

4.2.1.4.2. Weed control efficiency at 30 DAS

At 30 DAS, early post-emergence spray with carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_4) was observed to have higher efficiency for controlling *S. juncoides* as evidenced by a higher value of WCE (96.08 per cent). All the weed management practices except weedy check were equally effective in managing weeds at 30 DAS. Weed control efficiencies of 95.60, 95.55, 95.31, 94.66, 94.45 and 92.92 per cent were recorded in T_3, T_1, T_2, T_7, T_6 and T_5 respectively.

4.2.1.4.3. Weed control efficiency at 45 DAS

At 45 DAS, ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS was observed to be effective in controlling *S. juncoides* based on the higher WCE recorded (99.82 per cent). Penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS with a WCE of 99.07 per cent and HW twice at 20 and 40 DAS with an efficiency of 98.91 per cent were as effective as ethoxysulfuron @ 15 g ha^{-1} at 45 DAS. Lower WCE of 95.85 per cent was recorded in T_1.

4.2.1.4.4. Weed control efficiency at 60 DAS

At 60 DAS, ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) effectively reduced *S. juncoides* with a WCE of 98.07 per cent. Penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS was at par with T_3, registering a WCE of 97.90 per cent. Though not at par with the most effective treatment (T_3), HW twice at 20 and 40 DAS recorded a better WCE of 97.08 per cent.

4.2.1.5. Herbicide phytotoxicity

Symptoms of herbicide phytotoxicity differed with the herbicide molecules. After seven days of herbicide spray, visual symptoms of herbicide phytotoxicity were observed in weeds. Yellowing and subsequent necrosis was the common symptom of phytotoxicity exhibited by weeds present in the plots sprayed with penoxsulam @ 22.5 g ha^{-1}, metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} and 2,4-D sodium salt @ 1 kg ha^{-1}. Chlorosis was observed up to 10 days after spraying followed by general necrosis up to 15 days after herbicide spray. Withering and browning from tip downwards was observed from 8-10 days after herbicide spray, in weeds that were present in plots treated with carfentrazone-ethyl @ 20 g ha^{-1} and ethoxysulfuron @ 15 g ha^{-1}.

Table 14. Weed control efficiency of treatments at 15, 30, 45 and 60 DAS, %

Treatments	15 DAS	30 DAS	45 DAS	60 DAS
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	99.40 (10.02)	95.55 (9.82)	95.85 (9.84)	95.75 (9.84)
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	24.68 (5.04)	95.31 (9.81)	99.07 (10.00)	97.90 (9.94)
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	6.60 (2.68)	95.60 (9.83)	99.82 (10.04)	98.07 (9.95)
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	16.37 (4.16)	96.08 (9.85)	97.69 (9.93)	95.74 (9.84)
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	15.09 (3.89)	92.92 (9.69)	95.92 (9.85)	93.31 (9.71)
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	8.38 (2.95)	94.45 (9.77)	97.34 (9.92)	96.27 (9.86)
T_7: HW at 20 and 40 DAS	15.11 (3.97)	94.66 (9.78)	98.91 (9.99)	97.08 (9.90)
T_8: weedy check	0.00	0.00	0.00	0.00
SEm (±)	0.44	0.07	0.02	0.01
CD (0.05)	1.352	0.198	0.050	0.031

The data were subjected to square root transformation $\sqrt{(x + 0.5)}$ and transformed values are given in paranthesis

4.2.2. Growth and yield attributes of crop

4.2.2.1. Plant height

Data on the response of plant height (cm) at 30 DAS, 60 DAS and harvest to the weed management practices were statistically analyzed and presented in Table 15.

4.2.2.1.1. Plant height at 30 DAS

At 30 DAS, height of wet seeded broadcasted paddy was not found to be influenced by the treatments tested. Plant height was observed to range from 40.36 cm to 46.61 cm. Average height of crop at 30 DAS was measured to be 42.77 cm.

4.2.2.1.2. Plant height at 60 DAS

The treatments tested for weed management showed significant influence on the height of Sreyas variety (var.) of rice at 60 DAS. Hand weeding (HW) twice at 20 and 40 DAS (T_7) recorded higher plant height of 70.51 cm. Plant heights recorded in plots treated with carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS (69.86 cm), ethoxysulfuron @ 15 g ha^{-1} at 15 DAS (69.56 cm) and 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS (67.94 cm) all fb HW at 35-40 DAS were at par with T_7. Plants in weedy check recorded a lower height of 62.47 cm.

4.2.2.1.3. Plant height at harvest

Plant height at harvest varied significantly with the weed management practices adopted. Plants were taller (104.67 cm) in plots that received an early post-emergence spray with penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_2). Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (104.59 cm), HW twice at 20 and 40 DAS (104.46 cm), bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS (102.82 cm), carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (102.57 cm) and 2,4-D sodium salt @ 1 kg ha^{-1} at 20

Table 15. Effect of weed management practices on crop height at 30 DAS, 60 DAS and harvest,

Treatments	30 DAS	60 DAS	Harvest
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	42.92	66.86	102.82
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	41.00	65.11	104.67
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	42.19	69.56	104.59
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	42.64	69.86	102.57
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	46.61	65.97	100.86
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	42.72	67.94	101.92
T_7: HW at 20 and 40 DAS	40.36	70.51	104.46
T_8: weedy check	43.69	62.47	98.83
SEm (±)	1.29	0.86	1.09
CD (0.05)	NS	2.621	3.334

DAS fb HW at 35-40 DAS (101.92 cm) were on a par with T_2. Shorter plants (98.83 cm) were observed in weedy check (T_8) at harvest.

4.2.2.2. Number of productive tillers m^{-2}

Data regarding the influence of weed management practices on number of productive tillers m^{-2} were statistically analyzed and presented in Table 16.

The treatments tested for weed management had significant influence on the number of productive tillers m^{-2} in wet seeded rice. Early post-emergence application of ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) was superior to all other treatments with 382 productive tillers m^{-2}. HW twice at 20 and 40 DAS was recorded to produce 354.33 panicles m^{-2} which was found to be higher than the remaining treatments but not on a par with T_3. Lowest number of panicles m^{-2} (308.67) observed in weedy check was at par with bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} fb HW at 35-40 DAS (317), penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (318.33) and metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} (331.67) fb HW at 35-40 DAS.

4.2.2.3. Number of grains $panicle^{-1}$

Data on the effect of treatments on number of grains $panicle^{-1}$ were statistically analyzed and presented in Table 16.

The applied treatments exhibited significant effect on the number of grains $panicle^{-1}$. Ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS (T_3) was significantly superior to all other treatments with 134.27 grains $panicle^{-1}$. 2,4-D sodium salt @ 1 kg ha^{-1} fb HW at 35-40 DAS and HW twice at 20 and 40 DAS was observed to produce 116.72 and 115.71 grains $panicle^{-1}$ respectively. However, the number of grains $panicle^{-1}$ in bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} (100.36), penoxsulam @ 22.5 g ha^{-1} (100.79) and carfentrazone-ethyl @ 20 g ha^{-1} (105.67) each one fb HW at 35-40 DAS were on a par with the lower value (97.37) obtained from weedy check (T_8).

4.2.2.4. Filled grains panicle^{-1}

Data on the effect of treatments on number of filled grains panicle^{-1} were statistically analyzed and presented in Table 16.

Weed management practices were recorded to have a positive influence on the number of filled grains panicle^{-1}. Panicles from the plots treated with ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS (T_3) had 115.85 filled grains panicle^{-1} and was significantly higher to all other treatments. HW twice at 20 and 40 DAS could produce panicles with 99.19 filled grains. It was not found to be on a par with T_3. Panicles produced in the weedy check plot had 78.82 filled grains per panicle.

4.2.2.5. Sterility percentage

Data on the effect of treatments on sterility percentage was statistically analyzed and presented in Table 16.

The weed control measures had no significant influence on sterility percentage of wet seeded paddy. Sterility percentage of the paddy var. Sreyas was found to range between 13.65 to 18.94 per cent with ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS recording the lowest value of 13.65 per cent. Hand weeding twice at 20 and 40 DAS resulted in a sterility percentage of 14.18 per cent, while weedy check (T_8) recorded a higher sterility percentage of 18.94 per cent.

4.2.2.6. Thousand grain weight

Data on the effect of treatments on thousand grain weight was statistically analyzed and presented in Table 16.

Table 16. Effect of weed management practices on yield attributes of rice

Treatments	Productive tillers m^{-2}	Number of grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Sterility percentage	Thousand grain weight (g)
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fbHW at 35-40 DAS	317.00	100.36	85.45	14.87	27.60
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fbHW at 35-40 DAS	318.33	100.79	86.09	14.59	28.87
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fbHW at 35-40 DAS	382.00	134.27	115.85	13.65	28.97
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fbHW at 35-40 DAS	337.00	105.67	90.87	13.92	28.27
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fbHW at 35-40 DAS	331.67	107.65	92.40	14.16	27.03
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fbHW at 35-40 DAS	352.33	116.72	98.19	15.79	29.17
T_7: HW at 20 and 40 DAS	354.33	115.71	99.19	14.18	29.17
T_8: weedy check	308.67	97.37	78.82	18.94	28.13
SEm(±)	8.57	2.83	1.75	1.51	1.02
CD(0.05)	26.251	8.654	5.348	NS	NS

Treatments for weed management did not have significant effect on thousand grain weight. Thousand grain weight was found to range between 27.03 g and 29.17 g for Sreyas under wet seeded broad casted system.

4.2.2.7. Grain yield

Grain yield obtained from the individual plots were statistically analyzed and presented in Table 17.

Weed management practices exhibited a significant influence in deciding the grain yield of wet seeded broadcasted rice. Ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS (T_3) yielded higher grain yield of 5750 kg ha^{-1}. It was on a par with T_2, penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (5500.67 kg ha^{-1}). From the plots that received HW twice at 20 and 40 DAS, 5432.67 kg ha^{-1} of grain was obtained but was not at par with T_3 and T_2. Grain yield recorded in 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS (T_6), carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_4), bensulfuron methyl+ pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS (T_1) and metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS (T_5) were 5148.67, 5061.33, 5050 and 4310.67 kg ha^{-1} respectively. Grain yield recorded in weedy check was the lowest (2750 kg ha^{-1}).

4.2.2.8. Straw yield

Data on the straw yield obtained from individual plots were statistically analyzed and presented in Table 17.

Straw yield of wet seeded rice was significantly influenced by the weed management practices tested. Straw yield recorded from ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS was higher (9955 kg ha^{-1}) and at par with 2,4-D sodium salt @ 1 kg ha^{-1} fb HW at 35-40 DAS (9847 kg ha^{-1}), HW twice at 20 and 40 DAS (9735 kg ha^{-1}), carfentrazone-ethyl @ 20 g ha^{-1} fb HW at 35-40 DAS (9208.67 kg ha^{-1}) and penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (9201.67 kg ha^{-1}). Straw yield in un-weeded control was 5692 kg ha^{-1}.

4.2.2.9. Weed index

The extent of yield reduction due to weeds was estimated in wet seeded broadcasted rice and the data was statistically analyzed and presented in Table 17.

Yield loss due to weed infestation varied with the effectiveness of the applied treatments. Penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (T_2) and HW twice at 20 and 40 DAS (T_7) also recorded lower grain yield reduction (4.32 and 5.44 per cent respectively), due to weeds. More than 50 per cent (52.18 per cent) reduction in grain yield was recorded in the un-weeded plot.

4.2.2.10. Harvest Index

Harvest index was computed using the data on grain yield and straw yield. Effect of weed management practices on harvest index was statistically analyzed and presented in Table 17.

Harvest index of wet seeded paddy was significantly affected by the weed management practices. Higher harvest index of 0.374was recorded in penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (T_2). Bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} fb HW at 35-40 DAS (0.368), ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS (0.366), HW twice at 20 and 40 DAS (0.358) and carfentrazone-ethyl @ 20 g ha^{-1} fb HW at 35-40 DAS (0.356) were at par with T_2. The proportion of economic yield out of the total biological yield was lower in weedy check (0.325). Harvest index of metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} fb HW at 35-40 DAS (0.327) and 2,4-D sodium salt fb HW at 35-40 DAS (0.343) were at par with the lowest value recorded.

Table 17. Effect of weed management practices on grain yield, straw yield weed index (WI) and harvest index (HI)

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	WI (%)	HI
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	5050.00	8678.33	12.12 (3.61)	0.368
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	5500.67	9201.67	4.32 (2.30)	0.374
T_3: ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	5750.00	9955.00	0.00 (1.00)	0.366
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	5061.33	9208.67	11.85 (3.55)	0.356
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	4310.67	8909.67	24.86 (5.06)	0.327
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	5148.67	9847.00	10.34 (3.33)	0.343
T_7: HW at 20 and 40 DAS	5432.67	9735.00	5.44 (2.50)	0.358
T_8: weedy check	2750.00	5692.00	52.18 (7.29)	0.325
SEm (±)	94.24	309.78	0.19	0.009
CD (0.05)	288.603	948.727	0.591	0.0280

The data were subjected to square root transformation $\sqrt{(x + 0.5)}$ and transformed values are given in paranthesis

4.2.2.11. Herbicide phytotoxicity

Visual symptoms of herbicide phytotoxicity were not observed in the crop. Observation taken on the crop after fifteen days of herbicide spray was also symptomless.

4.2.2.12. Pest and disease incidence

Incidence of rice bug (*Leptocorisa acuta*) at milky stage of the crop was scored (score 7) 12-25 per cent damage in the standard evaluation system (SES) developed by International Rice Research Institute (IRRI, 2002). The SES by International Rice Research Institute is given in Appendix II.

4.3. Chemical analysis

4.3.1. Nutrient content of crop

Effect of applied treatments on the NPK content of crop was statistically analyzed and presented in Table 18.

N, P and K content of crop showed no significant difference with the weed management practices. N content of crop ranged from 1.147 to 1.188 per cent, P content was found to vary between 0.242 to 0.250 per cent and K content ranged from 1.450 to1.469 per cent.

4.3.2. Nutrient content of weed

Effect of applied treatments on the NPK content of weed was statistically analyzed and presented in Table 19.

N, P and K content of weeds were not observed to differ significantly from each other based on the treatments applied. N content of *S. juncoides* was found to range between 0.839 and 0.896 per cent, P content ranged from 0.330 to 0.354 per cent and K content was found to range from 1.092 to 1.140 per cent.

Table 18. Effect of weed management practices on nutrient content of crop, %

Treatments	N	P	K
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	1.173	0.242	1.460
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	1.179	0.246	1.462
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	1.176	0.250	1.455
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	1.188	0.248	1.451
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	1.147	0.244	1.450
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	1.175	0.245	1.469
T_7: HW at 20 and 40 DAS	1.163	0.248	1.460
T_8: weedy check	1.171	0.248	1.469
SEm (±)	0.016	0.005	0.019
CD (0.05)	NS	NS	NS

Table 19. Effect of weed management practices on nutrient content of the weed, %

Treatments	N	P	K
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	0.863	0.346	1.106
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.859	0.349	1.092
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.848	0.354	1.112
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.849	0.346	1.098
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	0.839	0.342	1.117
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	0.852	0.341	1.110
T_7: HW at 20 and 40 DAS	0.847	0.351	1.125
T_8: weedy check	0.896	0.330	1.140
SEm (±)	0.011	0.013	0.021
CD (0.05)	NS	NS	NS

4.3.3. Nutrient uptake by crop

Statistically interpreted data on the effect of treatments over dry matter production and nutrient uptake by the crop are presented in Table 20.

Dry matter production and nutrient uptake of wet seeded broadcasted paddy were influenced by the weed management practices. Dry matter produced from ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS (T_3) treated plots were recorded to be higher with a dry matter production of 15.71 t ha^{-1}. Combined grain and straw yield obtained from HW at 20 and 40 DAS (15.17 t ha^{-1}) and 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS (14.99 t ha^{-1}) were at par with T_3.

4.3.3.1. N uptake

Uptake of N was higher (219.01 kg N ha^{-1}) in ethoxysulfuron @ 15 g ha^{-1} fb hand weeding at 35-40 DAS (T_3). N uptake by crops in plots treated with penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (205.71 kg ha^{-1}), HW twice at 20 and 40 DAS (177.72 kg ha^{-1}) and 2,4-D sodium salt @ 1 kg ha^{-1} fb HW at 35-40 DAS (176.25 kg ha^{-1}) were on a par with T_3. Lower crop uptake rate of N was recorded from weedy check (99.31 kg ha^{-1}).

4.3.3.2. P uptake

Higher P uptake of 39.32 kg ha^{-1} was recorded in T_3. Uptake of P by the crop in plots sprayed with 2,4-D sodium salt @ 1 kg ha^{-1} fb HW at 35-40 DAS (36.68 kg ha^{-1}), penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (36.12 kg ha^{-1}), HW twice at 20 and 40 DAS (36.04 kg ha^{-1}) and carfentrazone-ethyl @ 20 g ha^{-1} fb HW at 35-40 DAS (35.48 kg ha^{-1}) were on a par with the treatment that recorded higher P uptake. P uptake by the crop was lower in weedy check (20.94 kg ha^{-1}).

Table 20. Effect of weed management practices on dry matter production and nutrient uptake by the crop

Treatments	Dry matter (t ha^{-1})	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	13.73	161.08	33.19	200.55
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	14.70	205.71	36.12	214.89
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	15.71	219.01	39.32	228.55
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	14.27	167.80	35.48	206.92
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	13.22	155.56	32.22	191.77
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	14.99	176.25	36.68	220.30
T_7: HW at 20 and 40 DAS	15.17	177.72	36.04	221.37
T_8: weedy check	8.44	99.31	20.94	123.98
SEm (±)	0.32	15.84	1.31	5.42
CD (0.05)	0.982	48.497	3.998	16.598

4.3.3.3. K uptake

Crop uptake of K was higher in (T_3) with an uptake rate of 228.55 kg K ha^{-1}. Crop K uptake recorded from plots hand weeded twice at 20 and 40 DAS (221.37 kg ha^{-1}) and plots treated with 2,4-D sodium salt @ 1 kg ha^{-1} fb HW at 35-40 DAS (220.30 kg ha^{-1}) and penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (214.89 kg ha^{-1}) were at par with ethoxysulfuron @ 15 g ha^{-1} fb HW at 35-40 DAS. Lower K uptake by the crop was observed in weedy check (123.98 kg ha^{-1}).

4.3.4. Nutrient removal by weed

Statistically interpreted data on the effect of treatments over nutrient removal by the weed are presented in Table 21.

Nutrient removal by S. *juncoides* was found to be affected by the weed management practices tested.

4.3.4.1. N removal

N removal by the weed in ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) recorded lower value of 0.16 kg N ha^{-1}. All the treatments except weedy check were at par with T_3. N removal rates in T_2, T_7, T_6, T_4, T_1 and T_5 were 0.17, 0.24, 0.30, 0.34, 0.35 and 0.53 kg N ha^{-1} respectively. Weeds in the un-weeded control was removed 8.61 kg N ha^{-1} from the available N pool in the soil.

4.3.4.2. P removal

The lowest P removal of 0.07 kg ha^{-1} was recorded in plots that received an early post-emergence spray of ethoxysulfuron @ 15 g ha^{-1} or penoxsulam @ 22.5 g ha^{-1} both at 15 DAS fb HW at 35-40 DAS was the lowest value. All the treatments except weedy check were at par with T_2 and T_3. Weeds in the un-weeded control recorded a P removal of 3.13 kg ha^{-1}.

Table 21. Effect of weed management practices on nutrient removal by the weed, kg ha^{-1}

Treatments	N	P	K
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	0.35	0.14	0.45
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.17	0.07	0.22
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.16	0.07	0.20
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	0.34	0.14	0.44
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	0.53	0.22	0.71
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	0.30	0.12	0.40
T_7: HW at 20 and 40 DAS	0.24	0.10	0.31
T_8: weedy check	8.61	3.13	10.95
SEm (±)	0.22	0.07	0.29
CD (0.05)	0.674	0.213	0.895

4.3.4.3. K removal

Weed removal of K was lower in ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS recording a value of 0.20 kg K ha^{-1}. Except weedy check, all other treatments were on a par with T_3. Higher K removal of 10.95 kg ha^{-1} was observed in the un-weeded plot.

4.3.5. Available N, P, K and organic carbon status of soil after experiment

Effect of treatments on the available N, P, K and organic carbon status of soil are presented in Table 22.

Treatments compared for the efficacy in managing S. *juncoides* had no significant effect on available N, P, K and organic carbon status of soil after the experiment. Soil in the experimental field was low in available N (275.97 kg ha^{-1}) before the experiment. After the experiment, available N in the soil was markedly lowered with values ranging from 117.78 to 197.23 kg ha^{-1}.

Before the experiment available P status was high (39.20 kg ha^{-1}) and available K status was medium (240 kg ha^{-1}). After crop harvest, available P and K status of the soil varied from 29.84 to 34.37 kg ha^{-1} and 135.07 to 194.86 kg ha^{-1} respectively. Soil in the experimental field recorded high organic carbon content of 1.10 per cent before the experiment. After the experiment, organic carbon content was found to lower ranging from 0.97 to 1.07 per cent.

4.4. Economic analysis

4.4.1. Net income

Net income obtained from all the treatments are presented in Table 23.

Net income obtained from the treated plots varied with the applied weed management practices. Net income obtained from ethoxysulfuron @ 15 g ha^{-1} at 15

Table 22. Effect of weed management practices on available N, P, K and organic carbon status of the soil

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	188.86	33.74	178.90	1.00
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	134.51	32.64	188.53	1.03
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	197.23	30.77	194.86	1.07
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	167.84	33.42	138.43	1.04
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	176.20	34.37	135.07	1.01
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	159.59	33.58	170.05	1.00
T_7: HW at 20 and 40 DAS	147.05	31.55	142.99	0.97
T_8: weedy check	117.78	29.84	139.44	1.02
SEm (±)	19.28	1.04	16.10	0.04
CD (0.05)	NS	NS	NS	NS

DAS fb HW at 35-40 DAS (Rs 101475) was higher than all other treatments. Plots hand weeded twice at 20 and 40 DAS recorded a net income of Rs 83680. Lower net income of Rs 19264 was realized from the plots which did not receive any weed management treatments (weedy check).

4.4.2. Benefit: cost ratio

Benefit: cost ratio for wet seeded paddy was computed and the results are presented in Table 23.

Benefit: cost ratio of wet seeded broadcasted paddy was influenced by the weed management practices. Higher B: C ratio of 2.26 was obtained from plots treated with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS. The B: C ratio realized from hand weeded (at 20 and 40 DAS) plots was 1.93. Lower B: C ratio of 1.26 was recorded from weedy check.

4.5. Enzyme analysis

Dehydrogenase activity of soil in μg TPF g^{-1} of soil 24 h^{-1} after 15 days of herbicide spraying was statistically interpreted and presented in Table 24.

Soil dehydrogenase activity after 15 days of herbicide spray was influenced by the weed management treatments. Initial dehydrogenase activity of soil before spraying was recorded to be 168.96 μg TPF g^{-1} of soil $24h^{-1}$. Higher activity of dehydrogenase (203.42 μg TPF g^{-1} of soil $24h^{-1}$) was recorded in metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS (T_5). Dehydrogenase activity observed from plots treated with 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS (198.55 μg TPF g^{-1} of soil $24h^{-1}$), ethoxysulfuron @ 15 g ha^{-1} (191.58 μg TPF g^{-1} of soil $24h^{-1}$) and penoxsulam @ 22.5 g ha^{-1} (191.07 μg TPF g^{-1} of soil $24h^{-1}$) were recorded to be at par with T_5. Hand weeding at 20 and 40 DAS registered the lowest dehydrogenase activity of 141.82 μg TPF g^{-1} of soil $24h^{-1}$ while, weedy check recorded a dehydrogenase activity of 144.10 μg TPF g^{-1} of soil $24h^{-1}$.

Table 23. Effect of weed management practices on gross income, cost of cultivation, net income and B: C ratio

Treatments	Gross income (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Net income (Rs ha^{-1})	B: C ratio
T_1 : bensulfuron methyl+pretilachlor@60+ 600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	159542	82401	77141	1.93
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	172524	81821	90703	2.11
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	182025	80550	101475	2.26
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	162454	80576	81878	2.02
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	143694	80964	62730	1.77
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	167654	80266	87388	2.09
T_7: HW at 20 and 40 DAS	173626	89946	83680	1.93
T_8: weedy check	91710	72446	19264	1.26

Table 24. Effect of weed management practices on soil dehydrogenase activity (µg TPF g^{-1} of soil 24 h^{-1}) at 15 days after herbicide spraying

Treatments	µg TPF g^{-1} of soil 24 h^{-1}
T_1 : bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS fb HW at 35-40 DAS	171.67
T_2: penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	191.07
T_3: ethoxysulfuron @15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	191.58
T_4: carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS	154.96
T_5: metsulfuron methyl+ chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS	203.42
T_6: 2,4-D sodium salt @1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS	198.55
T_7: HW at 20 and 40 DAS	141.92
T_8: weedy check	144.10
SEm (±)	8.85
CD (0.05)	27.108

*Before spraying 168.96 µg TPF g^{-1} of soil 24 h^{-1}

Discussion

5. DISCUSSION

Schoenoplectus juncoides (Roxb.) Palla, commonly known as 'rock bulrush' has recently emerged as an increasingly troublesome sedge weed in the lowland paddy fields of Kerala. A field study was conducted at farmer's field in Ookkode, to develop an effective and economic management strategy for rock bulrush in wet seeded rice. As knowledge on weed biology is essential to formulate species specific weed management decisions, weed biology was also studied simultaneously. Results of the experiments are discussed in this chapter.

5.1. WEED BIOLOGY

Weed biology refers to the study of weeds in relation to its habit, habitat, propagation and stages of growth. Talaka and Rajab (2013) considered weed biology as the prerequisite for determining herbicide sensitive stage of the weed to formulate effective weed management strategies. In the present investigation, weed biology was studied by observing ten randomly selected sample plants ear marked in the weedy check plots of experimental field from November 2017 to March 2018.

5.1.1. Phenology of rock bulrush

Schoenoplectus juncoides has been documented to occur globally in direct seeded lowland rice. IRRI (2017) included *Schoenoplectus juncoides* (Roxb.) Palla as one among the twelve most troublesome weeds in the rice fields of South and South East Asia. However, there are no reports of *Schoenoplectus juncoides* becoming a major sedge or rush in lowlands of Kerala till date. Rock bulrush was observed to grow through six phenological stages to complete its life cycle. These stages included germination, seedling, flowering, spike maturity, lodging and seed maturity (Plate 4).

Germination of *Schoenoplectus juncoides* seeds commenced within 3 to 7 days of wet seeding; flowering in 22 days, spike maturity in 33 days and seed maturity in 68 days. The weed exhibited lodging behaviour one week after attaining spike


Plate 3. Experimental field infested with rock bulrush

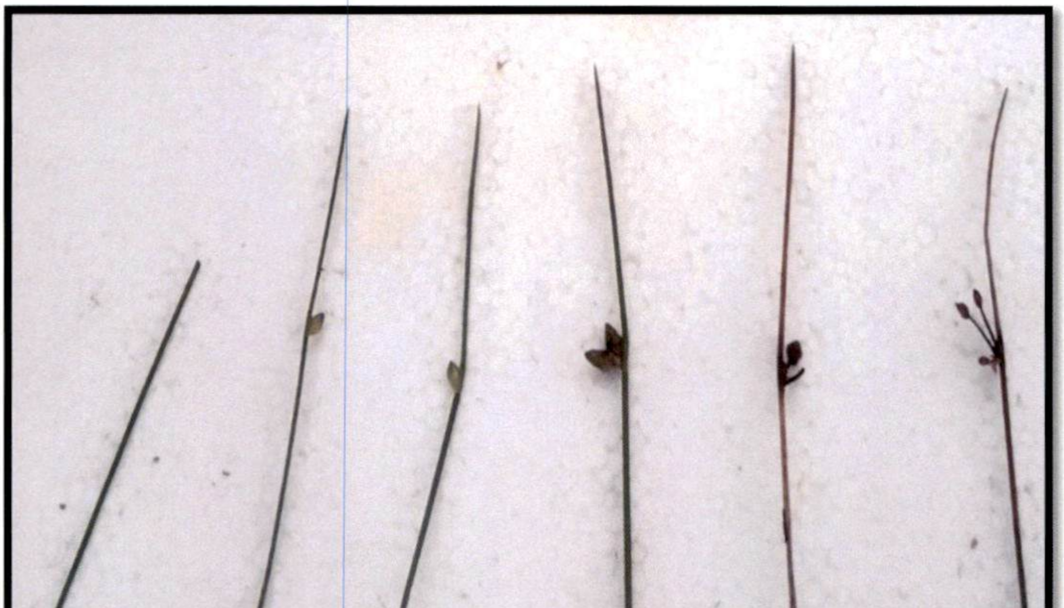


Plate 4. Stages of rock bulrush: seedling, flowering, spike maturity, seed maturity and drying

maturity which coincided with 40^{th} day of growth. Even after seed maturity, rock bulrush was found to inhabit the field for more than one month followed by drying of the aerial portion. Short time period for attaining reproductive maturity, prolific seed production and seed maturity were observed to ensure season long infestation of rock bulrush in the field. Aggressive growth of the weed throughout the crop's lifecycle was noticed by Mukherjee *et al.* (2008).

The weed was observed to be an annual in continuously puddled fields with an average duration of 106 days in wet seeded paddy. However, it had the potential to grow perennially through rhizomes as observed in fields that were left undisturbed. Khalid and Sadar-U-Siddiqui (2014) also described rock bulrush as an annual tufted sedge in the cultivated paddy fields with a perennial habit in the unattended wetlands.

During the field investigation, *Schoenoplectus juncoides* coexisted with the crop and also occupied the field bunds and water channels. Apart from lowlands, rock bulrush was also reported to inhabit the marshes, ditches, pond banks, river banks and waterlogged areas according to the observations made by Pal and Choudhury (2014). Donayre *et al.* (2016) reported copious growth of the weed in irrigated and rainfed lowland paddy fields.

5.1.2. Vegetative characteristics of rock bulrush

Schoenoplectus juncoides was observed to be an erect, tillering sedge with round stem that grew up to a height of 66.76 cm at maturity. According to NPPC (2017) height of rock bulrush ranged from 15 to 70 cm with scaly, light brown coloured leaf sheaths. Shoot of rock bulrush was hollow and circular in cross section unlike other sedges. Morphological structures for leaves, shoot and culm were the same for rock bulrush. Eickhoff (2009) also observed round, cylindrical stems for rock bulrush with lodging of heavy seed bearing culms. Vigorous tillering of the sedge was observed in the paddy field, with an average tiller production of 19.6 tillers $plant^{-1}$. Rock bulrush recorded a mean shoot dry weight of 1.82 g and dry matter of

2.81 g plant^{-1}. Average biomass production of the weed was 0.96 t ha^{-1} as observed in the weedy check plots.

Roots of rock bulrush were fibrous with rhizomes developing after the harvest of rice. Weed roots extended to a mean depth of 17.76 cm with dry weight of 0.99 g plant^{-1}. Deep, fibrous roots of the weed denoted the significance of increasing ploughing depth for effective management. Smaller rhizomes observed had a mean dry weight of 0.03 g plant^{-1}. Similar observations of rock bulrush producing shorter rhizomes were made by Le Bourgeois (2008). Root: shoot ratio on length basis was 0.27 and dry weight basis was 0.52. Thus, root length was 21 per cent the length of the weed at maturity and 34 per cent of the total dry matter plant^{-1} was contributed by the roots.

Puddling the field after each crop would destroy underground rhizomes but retain heavy weed seed bank in the soil. Watanabe *et al.* (1991) opined that the seed viability of *Schoenoplectus juncoides* may extend beyond a decade, making it unpractical to eliminate the soil weed seed bank. Sprouting of vegetative buds from the decayed remnants of the weed was observed throughout the crop growth. IRRI (2017) reported the regrowth of rock bulrush from vegetative buds and rhizomes in marshy unpuddled areas. Hence rock bulrush could be considered as a persistent weed in the lowlands owing to the production of seeds as well as rhizomes.

5.1.3. Reproductive characteristics of rock bulrush

Inflorescence of rock bulrush is botanically a spike which is sessile and laterally positioned (Plate 5). Number of spikes in individual tillers varied from 2 to 4 with a mean length of 1.24 cm and mean diameter of 1.56 cm. Khalid and Sadar-U-Siddiqui (2014) reported that *Schoenoplectus juncoides* could produce 1-3 sessile

Emerging spike Spikelet arrangement on spike (10x) Developing seed (10x)

Plate 5. Floral characteristics of rock bulrush

Seeds Vegetative buds Rhizomes

Plate 6. Propagules of rock bulrush

green spikes culm^{-1}. Number of spike bearing tillers in a plant varied from 6 to 16. On an average 33 spikes were produced by a single plant.

Seeds of *Schoenoplectus juncoides* resembled amaranth seeds with an initial cream colour, turning brown to black upon maturity with a mean seed length of 0.582 mm, width of 0.452 mm and thousand seed weight of 1.5 g (Plate 7). The seeds had a spiny apex with 4 to 6 bristles. As the seeds matured, they started shedding from the spike into the soil along with the glumes attached to it. Lodging of culms and spiny tip of seeds aided easy dispersal of rock bulrush seeds through water, clothes and implements (Plate 8). Seed surface appeared rough with bristles, helping in dispersal by sticking on to grains, straw, chaff, etc. Caton *et al.* (2010) reported the potential of rock bulrush as a seed contaminant in rice. Sprouting of vegetative buds occurred simultaneously with drying of spikes and seed dispersal. Under field conditions, infestation of rock bulrush was observed throughout the crop growing season. Complete drying of the weed occurred from 90th to 120th day with a mean duration of 106.10 days for completing the life cycle. General description of rock bulrush is tabulated and presented in Table 25.

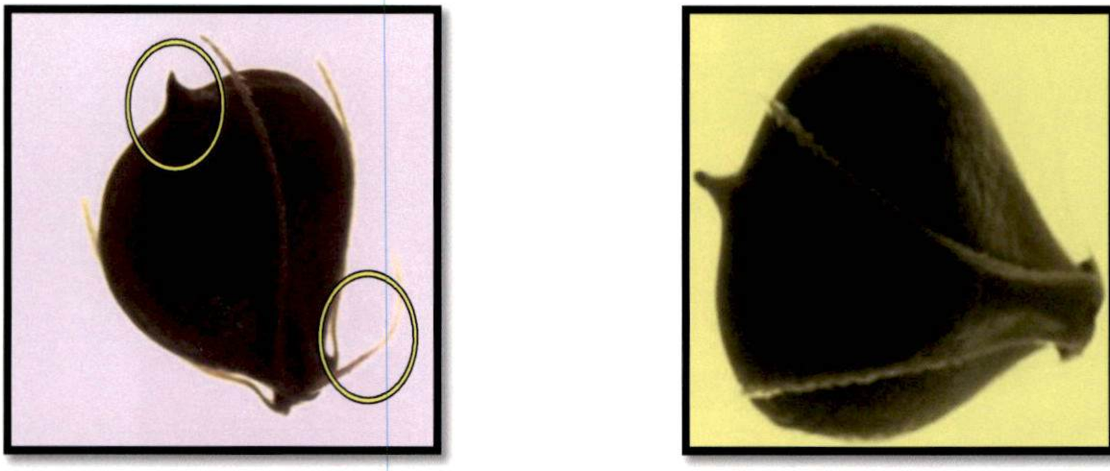
5.1.4. Propagation

Schoenoplectus juncoides propagated largely through sexual reproduction through seeds (Plate 6). Maximum seed production capacity of rock bulrush was estimated to be 20 spike^{-1} and 1120 plant^{-1}. IRRI (2017) reported the seed production capacity of rock bulrush as 1500 seeds plant^{-1}.

In the field, seed germination of rock bulrush commenced within 3 to 7 days of wet seeding and coincided with paddy germination, increasing the competition for nutrients, space, solar radiation and water at early stages of crop growth. Chiang (1983) observed significant influence of season in deciding the emergence time of *Schoenoplectus juncoides* and reported faster emergence during *rabi* season (2 days)

Table 25. General description of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla)

Characteristics	Description
Habit	Erect, strongly tillering annual growing to a height of about 66.76 cm at maturity with a perennial habit in undisturbed lowlands.
Habitat	Lowland paddy fields, bunds and irrigation channels.
Leaves	Leaves or culms or tillers were erect, light green in colour with two light brown leaf sheaths at the base tightly packed with each other.
Inflorescence	Sessile spike arising laterally from the culm. Number of spikes per tiller varied from 2 to 4.
Season of flowering	Throughout the crop growing season
Flowers	Sessile spikelets start maturing from the base to the tip. Maturation of spikes could be identified by the colour change of spike from green to straw brown colour.
Seeds	Obcordate in shape with 4 to 6 perianth bristles. Cream colour of seeds attained dark brown to black colour at maturity. Seed surface was rough when observed under the microscope.
Propagation	Mainly through seeds, vegetative buds and rhizomes
Seed dispersal	Clothes, implements, machineries. Lodging of mature spike bearing culms also aid in seed dispersal.



Seed with bristles and spiny apex   Rough bristles and seed surface under microscope (10x)

Plate 7. Seed characteristics of rock bulrush

Clothes   Lodging of seed bearing culms

Plate 8. Dispersal of rock bulrush seeds

compared to *kharif* (5 days). Hamamura (2002) explained the role of perianth lobe in serving as the major pathway of water imbibition for germination.

However, weed seeds collected after the crop season kept in petriplates with moistened filter paper failed to germinate under laboratory conditions of light, temperature and humidity. Failure in germination observed could be associated with seed dormancy exhibited by the weed. Development of seed dormancy after 20 to 25 days of flowering was observed by Ishikura and Soga (1978). Under field conditions, those seeds which germinated might be from the seed bank reserve deposited by earlier weed flush which must have overcome dormancy with time. Reports of Pons and Schroder (1986) suggested the requirement of anaerobic condition coupled with variations in temperature for seed germination of rock bulrush.

After the harvest of rice, *Schoenoplectus juncoides* developed small rhizomes after leaving the field undisturbed. These vegetative propagules ensured long term survival of the weed. Perennial nature of rock bulrush was also reported by Khalid and Sadar-U-Siddiqui (2014).

5.1.5. Nutrient composition and uptake of rock bulrush

The NPK content of *Schoenoplectus juncoides* was analyzed to be 0.90, 0.33 and 1.14 per cent respectively and the corresponding nutrient uptake by the weed as worked out from the weedy check plot was 8.61, 3.13 and 10.95 kg NPK ha^{-1} respectively. The weed had a higher K content which resulted in higher uptake of K per unit area. High K^+ uptake and stem succulence rendered saline tolerance to *Schoenoplectus juncoides* (Zahoor *et al.*, 2012). Besides, rock bulrush was reported to possess high potential for accumulating osmotic substances *viz.* proline, sugars, proteins and free amino acids (Mezni *et al.*, 2010) rendering it as a promising candidate for rehabilitating saline lowlands. However, the weed has not achieved much attention in these times in India due to lack of awareness.

5.2. MANAGEMENT OF ROCK BULRUSH

Weed management refers to all strategies practised in the field to maintain weeds below economic threshold level. According to Thapa and Jha (2002) maintaining the field devoid of weeds in the initial stages of growth has an important role in deciding the final yield. Though effective, hand weeding (HW) is an impractical method of weed control in wet seeded broadcasted rice owing to difficulty in identifying the weeds at initial stages of growth. Use of new generation herbicides is an attractive option for weed management due to lower application rates and mammalian toxicity. In the present investigation, application of pre-emergence, early-post emergence and post-emergence herbicides followed by hand weeding, was tested for their effectiveness in controlling *Schoenoplectus juncoides* in wet seeded rice. The pre-emergence herbicide, bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1}; early post-emergence herbicides, penoxsulam @ 22.5 g ha^{-1}, ethoxysulfuron @ 15 g ha^{-1} and carfentrazone-ethyl @ 20 g ha^{-1} and post-emergence herbicides *viz.* metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} and 2, 4-D sodium salt @ 1.0 kg ha^{-1} were tested. Herbicide application was later followed by a hand weeding at 35-40 DAS. Hand weeding twice at 20 and 40 DAS and weedy check were the control treatments in the experimental plots. Stages of the experiment are shown in Plate 9.

5.2.1. EFFECT ON WEEDS

5.2.1.1. Weed flora

Wet seeded rice was associated with a multitude of weeds belonging to the group of grasses, sedges and broad leaved weeds, throughout the cropping season

Seedling

Active tillering

Flowering

Harvest

Plate 9. Stages of the experiment

(Plate 10). At all stages of crop growth, rock bulrush (*Schoenoplectus juncoides*) co-occurred with the crop and dominated the field. Raj (2016) also reported the dominance of sedge species, especially *Schoenoplectus juncoides* in the rice fields of Nemom block of Thiruvananthapuram district. IRRI (2017) also listed *Schoenoplectus juncoides* as one among the twelve most troublesome weeds in the Asian rice fields.

Sedges dominated the field from crop emergence till the critical growth stages of rice. Sedges commonly associated with the crop in the field were *Fimbristylis miliacea*, *Cyperus difformis*, *Cyperus haspan*, *Cyperus exaltatus*, *Cyperus iria* and *Cyperus cyperoides*. Grasses such as *Eragrostis tenella* and *Digitaria sanguinalis* were observed during the later stages. *Echinochloa glabrescens* and *Oryza sativa f* sp. *spontanea* took over the field at 60 DAS. BLW were present at varying densities in the field and not found dominating at any stage of the crop. Common BLW associated with the system were *Ludwigia perennis*, *Lindernia rotundifolia*, *Limnocharis flava*, *Oxalis corniculata*, *Monochoria vaginalis* and *Alternanthera sessils*. The applied treatments were found to be effective in managing sedges and BLW during the cropping season, leaving behind grasses. However, underground propagules helped the perennial sedge weeds in propagation.

5.2.1.2. Weed density

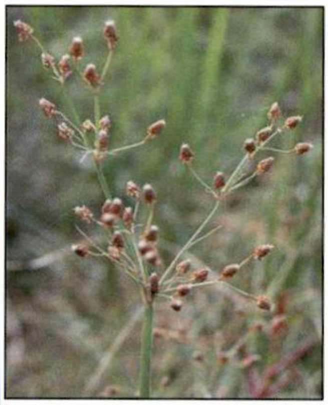
Weed density refers to the number of weeds per unit area. Intense weed growth observed in wet seeded paddy had a strong influence on the final yield. At 15 DAS, density of *Schoenoplectus juncoides* was the lowest (0.67 m^{-2}) in bensulfuron methyl + pretilachlor @ 60+ 600 g ha^{-1} at 4-7 DAS with a reduction in weed count to the tune of 98.35 per cent over weedy check. This could be attributed to its pre-emergence spray at 4-7 day after wet seeding. All other plots recorded higher densities of rock bulrush at that stage due to absence of any treatment application at that period of observation. Effect of the pre-emergence spray was evident up to 30 DAS. Reduction in weed count to the tune of 93.32 per cent at 30 DAS confirms the

Isachne miliacea

Oryza sative f sp. *spontanea*

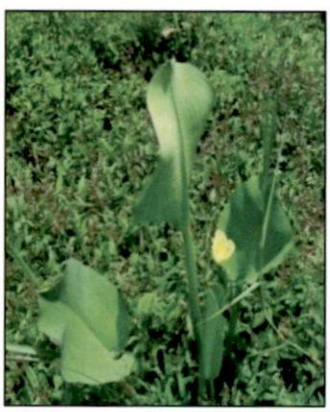
Echinochloa glabrescens

Cyperus iria



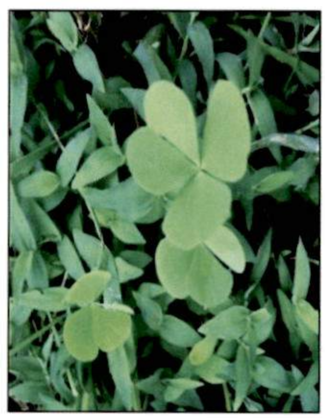
Fimbristylis miliacea

Cyperus difformis



Limnocharis flava

Ludwigia perennis



Oxalis corniculata

Plate 10. Weed flora in the experimental field

efficacy of bensulfuron methyl + pretilachlor in managing rock bulrush. Application of early post-emergence (15 DAS) and post-emergence herbicides (20 DAS) resulted in lower densities of rock bulrush at 30 DAS compared to weedy check. However, HW at 20 DAS was less effective (69 per cent) in reducing the population of rock bulrush. At the critical stages of crop-weed competition in wet seeded rice (45 and 60 DAS) ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS gave considerable reduction in weed density (Fig 3). Tall, robust plants in plots treated with ethoxysulfuron could effectively suppress weed growth. Son and Rutto (2002) observed ethoxysulfuron as an effective early post-emergence herbicide against sedges and BLW in cereals, especially rice. The duration of weed control got extended when application of ethoxysulfuron @ 15 g ha^{-1} at 15 DAS was coupled with HW at 35-40 DAS. Hence the combination of early post-emergence application of ethoxysulfuron and HW could give effective control of rock bulrush throughout the crop growing season. Ethoxysulfuron has been proved especially good for controlling the sedges belonging to *Scirpus* sp. (Sondhia and Dixit, 2012).

At all stages of crop, weedy check recorded higher densities of rock bulrush. Increase in number of weeds per unit area triggered the competition for nutrients, water, space and solar radiation. Apart from this, the lodging behavior exhibited by *Schoenoplectus juncoides* unfavourably affected crop growth when left unchecked. Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS effectively managed rock bulrush in wet seeded direct sown system.

5.2.1.3. Weed dry weight

Lower weed dry weight at 15 DAS was recorded in bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 DAS due to lesser number of weeds per unit area in the plots treated. In aerobic rice, Sunil *et al.* (2010) observed that the pre-emergence application of bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} fb HW at 40 DAS was effective in reducing the weed count and dry weight. At 30 DAS, carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS gave lower dry weight of rock bulrush and was at par with bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1}, penoxsulam @ 22.5 g ha^{-1}, ethoxysulfuron @ 15 g ha^{-1}, metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1}, 2,4- D sodium salt @ 1 kg $ha^{-1}$and HW twice at 20 and 40 DAS. Dry weights recorded were lower in all the plots except weedy check due to the timely application of all the treatments at 15 and 20 DAS. At 45 and 60 DAS, ethoxysulfuron fb HW recorded lower weed dry weights of 0.13 g m^{-2} and 1.83 g m^{-2} respectively (Fig 4). Findings of Saini and Angiras (2002) was in conformity with the result where, ethoxysulfuron @ 20 g ha^{-1} at 15 DAS gave effective management of BLW and sedges attributing to lower weed dry weight. Penoxsulam fb HW and HW twice at 20 and 40 DAS were statistically on a par with ethoxysulfuron fb HW. Pre-emergence application of penoxsulam (Chauhan and Seth, 2013) could be considered as an alternative or supplement to hand weeding.

Weed dry weight recorded at 45 and 60 DAS in plots treated with ethoxysulfuron fb HW at 35-40 DAS were 83.75 and 34.17 per cent lesser than the plots hand weeded twice at 20 and 40 DAS. This indicated that both ethoxysulfuron and penoxsulam fb HW were more effective in controlling rock bulrush than HW twice at critical period of crop-weed competition (20 and 40 DAS). Singh *et al*. (2008) reported the ineffectiveness of HW due to weed escape and re-growth. Dry weight of rock bulrush in weedy check plots showed a steady progression from 15 to 60 DAS recording dry weights of 14.11, 35.47, 70.11 and 96.05 g m^{-2}. Higher weed dry weight indicated higher biomass production by weeds in the system.

5.2.1.4. Weed control efficiency

Low dose high efficiency herbicides possess higher WCE as per the findings of Saha (2006). Higher WCE of 99.4 per cent with bensulfuron methyl+ pretilachlor

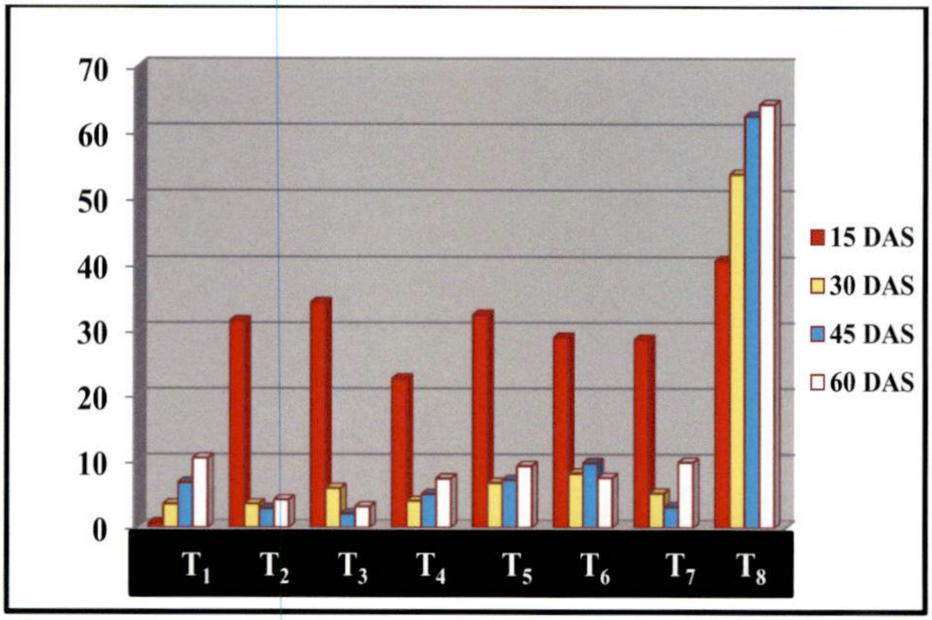


Fig 3. Effect of weed management practices on weed density at 15, 30, 45 and 60 DAS, number m^{-2}

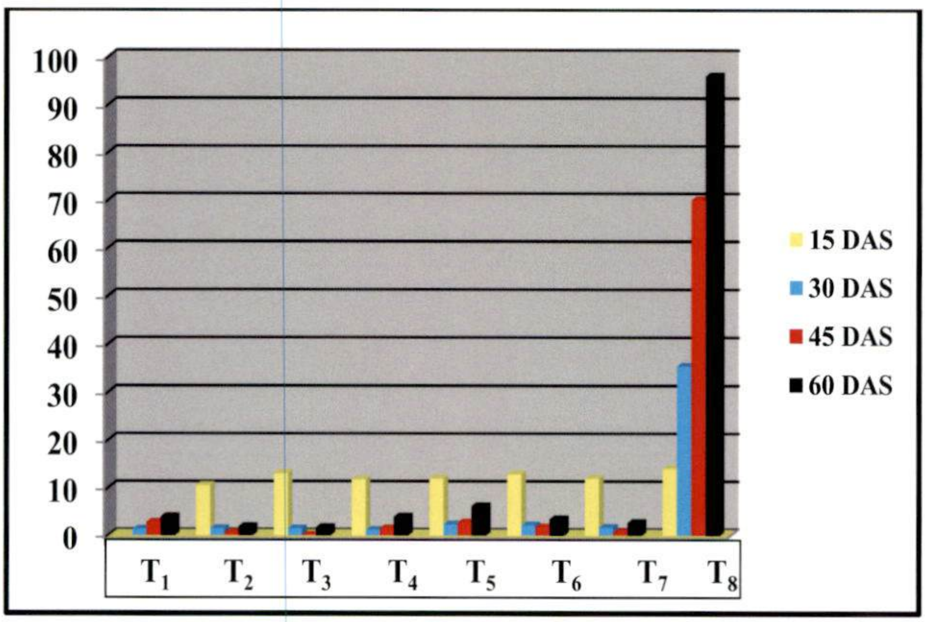


Fig 4. Effect of weed management practices on weed dry weight at 15, 30, 45 and 60 DAS, g m^{-2}

@ 60 + 600 g ha^{-1} at 15 DAS could be attributed to the lower weed count and dry weight. Arya and Ameena (2016) reported the superiority of pre-emergence application of bensulfuron methyl + pretilachlor @ 60 + 600 g ha^{-1} in terms of WCE in direct seeded dry sown rice in comparison with HW twice at 20 and 40 DAS. All the treatments except weedy check were found to be equally effective in controlling rock bulrush at 30 DAS as evidenced by the higher WCE. At critical stages of crop-weed competition (45 and 60 DAS), ethoxysulfuron fb HW provided higher weed control efficiencies of 99.82 and 98.07 per cent respectively (Fig 5). In Bangladesh, Ahmed and Bhuiyan (2010) reported higher WCE of ethoxysulfuron @ 150 g a.i. ha^{-1} fb HW in drum seeded and broadcasted paddy. Penoxsulam @ 22.5 g ha^{-1} fb HW and HW twice at 20 and 40 DAS were at par with ethoxysulfuron @ 15 g ha^{-1} fb HW.

5.2.1.5. Herbicide phytotoxicity on weeds

Herbicides control weeds through different modes and mechanisms of action. Symptoms of phytotoxicity on weeds vary with the active ingredient also. Spraying of ethoxysulfuron @ 15 g ha^{-1} and carfentrazone-ethyl @ 20 g ha^{-1} both at 15 DAS developed symptoms of withering and browning from tip downwards at 8-10 days after spraying. In plots treated with penoxsulam @ 22.5 g ha^{-1}, metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1}, 2,4- D sodium salt @ 1 kg ha^{-1}, first visible symptom was yellowing observed at 10 days after spraying followed by necrosis at 15 days after spraying. This was in conformity with the findings of Vencill (2002) where wilting and chlorosis followed by necrosis were observed with sulphonyl urea herbicides.

5.2.1.6. Nutrient removal by weed

Reduced weed dry weight in ethoxysulfuron @ 15 g ha^{-1} fb HW resulted in lower removal of 0.16, 0.07 and 0.20 kg NPK ha^{-1} respectively while, weedy check recorded higher nutrient removal of 8.61, 3.13 and 10.95 kg NPK ha^{-1} (Fig 6). Higher K removal by the weed was observed due to high K content of 1.14 per cent. In direct seeded rice, nutrient removal by the weeds were observed to be 34.8, 15.6 and 42.3 kg NPK ha^{-1} from un-weeded control as per the work of Singh *et al.* (2005). Higher nutrient removal by weeds reduced the crop nutrient uptake in the weedy check that was clearly reflected on the yield. Higher NPK removal triggered growth and related attributes of weeds helping them to grow robust and competent. Higher nutrient removal in weedy check plot was in conformity with the findings of Parameswari and Srinivas (2014).

5.2.2. EFFECT ON CROP

5.2.2.1. Growth and yield attributes of rice

Results of the experiment highlighted the need for an effective weed management strategy in wet seeded broadcasted rice. Weed interference was observed at all growth stages of rice, depriving the crop from taking up necessary resources required for optimum growth. Apart from the major weed of study - *Schoenoplectus juncoides*, thick growth of grasses, sedges and broad leaved weeds offered competition right from crop emergence.

In the study conducted, weed management practices were not found to affect crop height at 30 DAS. Hand weeding at critical stages of crop-weed competition (20 and 40 DAS), managed the weeds effectively and had a positive correlation with plant height at 60 DAS. Weed re-growth after hand weeding would occur at a slower pace, resulting in lower dry weights. Hussain *et al.* (2008) reported that HW twice at 20 and 40 DAS was capable of reducing weed dry weight and increasing the crop height. Lower crop-weed competition during critical stages would lead to robust growth of crops and confer competitive advantage in terms of optimal use of nutrients, water, sunlight and space. However at harvest, penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW

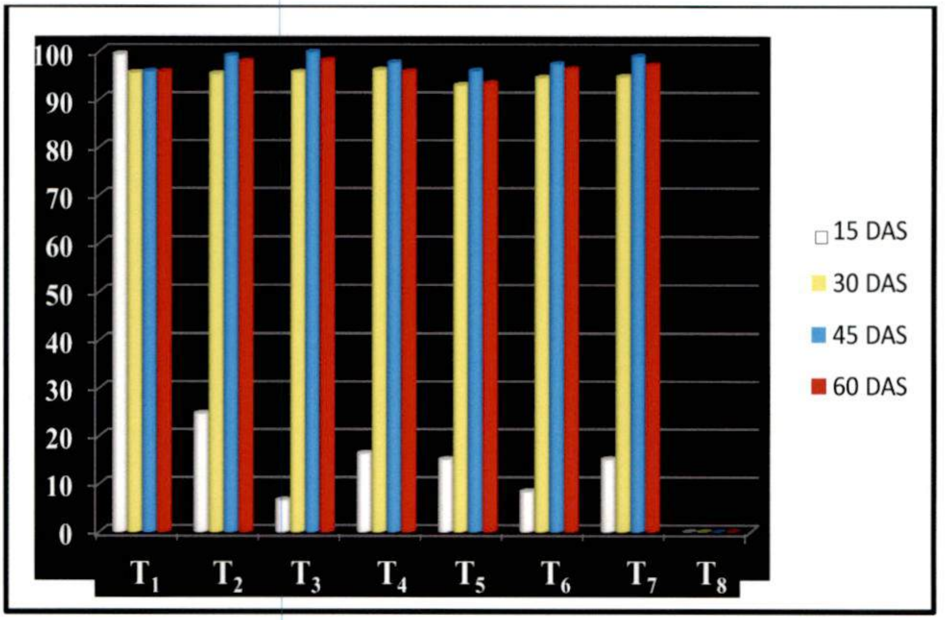


Fig 5. Weed control efficiency of treatments at 15, 30, 45 and 60 DAS, %

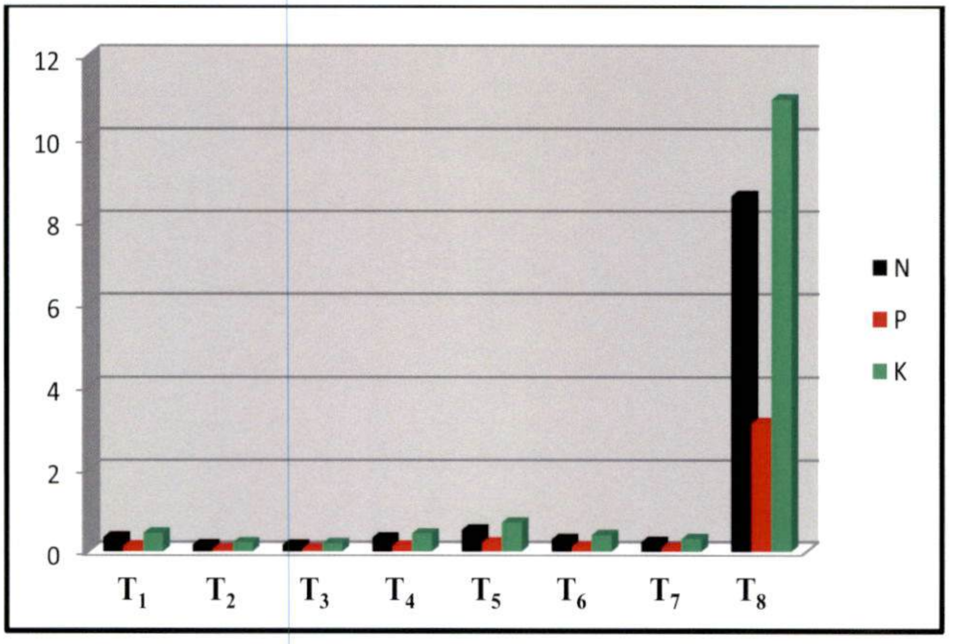


Fig 6. Effect of weed management practices on nutrient removal by the weed, kg ha^{-1}

at 35-40 DAS recorded taller plants (104.67 cm). Netam *et al.* (2018) also reported the superiority of penoxsulam @ 22.5 g ha^{-1} fb single HW at 35 DAS/ DAT in relation to the height of rice. It was found that herbicides were effective during initial stages and the efficacy improved with a follow up HW at 35-40 DAS. Further, pre-emergence herbicides, early post-emergence herbicides and hand weeding twice at 20 and 40 DAS were equally effective in increasing the crop height. Unchecked weed population in the weedy check plots conferred 6 per cent reduction in crop height. Sahu (2016) reported 14.25 per cent height reduction of rice plants in the un-weeded plots of direct seeded lowland paddy in comparison with hand weeded plots.

Though plant height decides the competence of crop, final yield is determined by the yield attributes like productive tillers m^{-2}, number of grains panicle^{-1}, number of filled grains panicle^{-1}, sterility percentage and thousand grain weight. Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35- 40 DAS (T_3) was significantly superior with respect to productive tillers m^{-2}, number of grains panicle^{-1} and number of filled grains panicle^{-1}. Early post-emergence spray of the herbicide, when given a follow up of HW at 35-40 DAS was found to prolong the effective period of weed control and helped in keeping the field weed-free especially at critical stages of crop growth. Saini and Angiras (2002) also reported the potency of ethoxysulfuron @ 20 and 30 g ha^{-1} as an early post-emergence herbicide against BLW and sedges in wet seeded system of rice. Hand weeded plots recorded 7.2, 13.8 and 14.4 per cent lesser number of panicles m^{-2}, grains panicle^{-1} and filled grains panicle^{-1} compared to T_3. This could be because *Schoenoplectus juncoides* escaped hand weeding due to its needle like leaf morphology that made it difficult to identify the weed during initial stages (20 DAS) in the cropped fields. Hence, the use of herbicides could be encouraged for effective management of rock bulrush. Uncontrolled weeds in the weedy check plots markedly reduced the productive tillers m^{-2}, number of grains panicle^{-1} and number of filled grains panicle^{-1} to the tune of 19.2, 27.5 and 32 per cent respectively. This was in conformity with the observations made by Singh (2012) in direct seeded rice, where 21.2 and 31 per cent reduction in productive tillers m^{-2} and number of grains $panicle^{-1}$ respectively were observed in plots with unchecked weed growth. Lowest number of panicles m^{-2} (308.67) observed in weedy check was at par with bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} fb HW at 35-40 DAS (317), penoxsulam @ 22.5 g ha^{-1} fb HW at 35-40 DAS (318.33) and metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} (331.67) fb HW at 35-40 DAS.

Sterility percentage and thousand grain weight were not significantly influenced by the weed management practices. Higher crop-weed competition leading to poor nutrient availability and uptake by the crop resulted in lower translocation of nutrients to the grain as evident from the higher spikelet sterility per cent in the un-weeded plots. Thousand grain weight was observed to be a variety related trait which was not determined by the treatments. Mondal *et al.* (2005) observed the variation of thousand grain weight depending on the variety used when they compared 17 *Aman* rice cultivars in the transplanted system.

Grain yield obtained from the plots treated with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW (5750 kg ha^{-1}) was higher and on a par with penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW (5500 kg ha^{-1}). Sondhia and Dixit (2012) observed an improvement in grain yield with early post-emergence application of ethoxysulfuron @ 15-20 g ha^{-1}. Reddy *et al*. (2000) reported ethoxysulfuron @ 30 g ha^{-1}, as an effective herbicide against the sedge sp. *Schoenoplectus supinus*, *Cyperus difformis* and *Cyperus iria* when applied at 10 DAT. The supremacy of ethoxysulfuron treated plots could be related to the productive $tillers^{-1}$, grains $panicle^{-1}$, filled grains $panicle^{-1}$ and higher fertility percentage. Rao *et al*. (2000) reported that grain yield is decided by the productive tillers m^{-2}, grains $panicle^{-1}$, fertility percentage and thousand grain weight. Further, the treatment also gave better weed control efficiency especially at critical stages of crop. Lower crop-weed competition in the major growth phases increased the grain yield in rice as per the findings of Mubeen *et al*. (2014). Yield reduction recorded in hand weeded control was 5.52 per cent (5432 kg ha^{-1}) in comparison with the superior treatment indicating the effectiveness of hand weeding. Mukherjee *et al.* (2008) also considered HW at critical stages (15 to 60 DAS) as effective in controlling weeds in wet seeded rice with only 0.44 to 3 per cent reduction in yield compared to the best treatment. Uncontrolled weed growth could cause a grain yield reduction of 52.2 and 49.4 per cent in comparison with ethoxysulfuron and hand weeding twice. Pandey (2009) also noticed lower grain yield in the plots with unchecked weed growth. Less panicles m^{-2}, grains $panicle^{-1}$ and filled $grains^{-1}$ in conjunction with increased spikelet sterility would lead to decreased yields. Mukherjee *et al.* (2008) explained the need for managing the weeds in wet seeded rice from 15 to 60 DAS. Maintaining the field weed-free at critical stages of crop growth has a decisive role on grain yield.

Higher straw yield was recorded by ethoxysulfuron @ 15 g ha^{-1} at 15 DAS (9955 kg ha^{-1}). All the treatments except bensulfuron methyl + pretilachlor, metsulfuron methyl + chlorimuron ethyl and weedy check, had a straw production at par with ethoxysulfuron @ 15 g ha^{-1} (Fig 7). Pre-emergence and post-emergence application of combination herbicides were found to be ineffective in increasing the straw yield. Straw yield could be related to the number of tillers m^{-2}. Straw yield reduction by 42.8 per cent in the weedy check plots could be associated with the lower crop stand and tiller number. Also, lodging of rock bulrush resulted in the lodging of surrounding rice plants, which in turn reduced the plant stand in the un-weeded plot. Lower straw yield in un-weeded control was reported by Arya (2015) in semi-dry system of rice cultivation.

Harvest index (HI) was found higher in penoxsulam fb HW (T_2). Though grain and straw yield recorded were the highest in ethoxysulfuron fb HW, proportion of economic yield out of the total biological yield was higher for penoxsulam. This could be due to the lower straw yield obtained in T_2. Post-emergence herbicides were not found to increase the harvest index even after giving a follow up HW at 35-40 DAS.

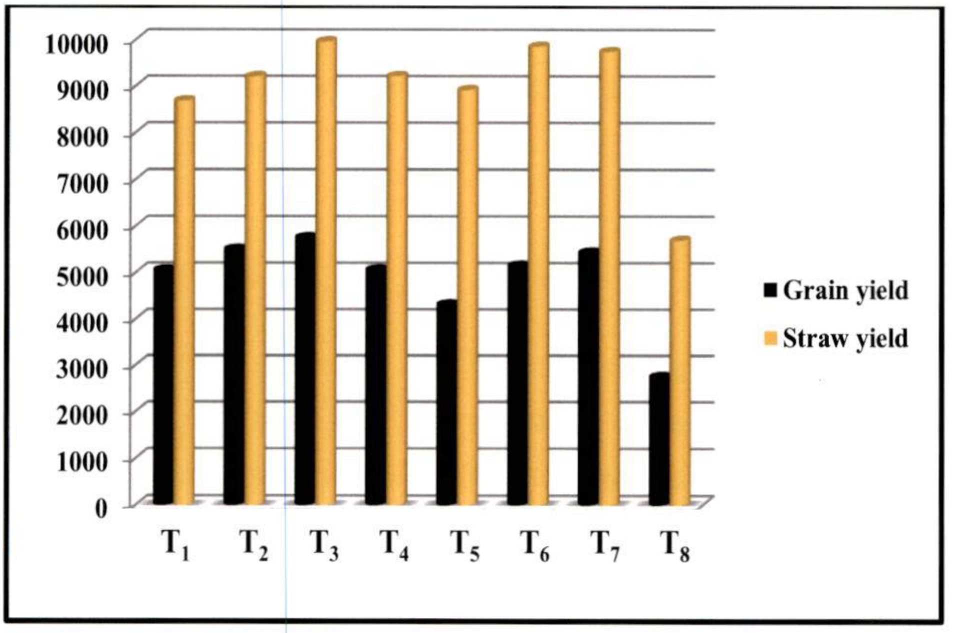


Fig 7. Effect of weed management practices on grain yield and straw yield, kg ha^{-1}

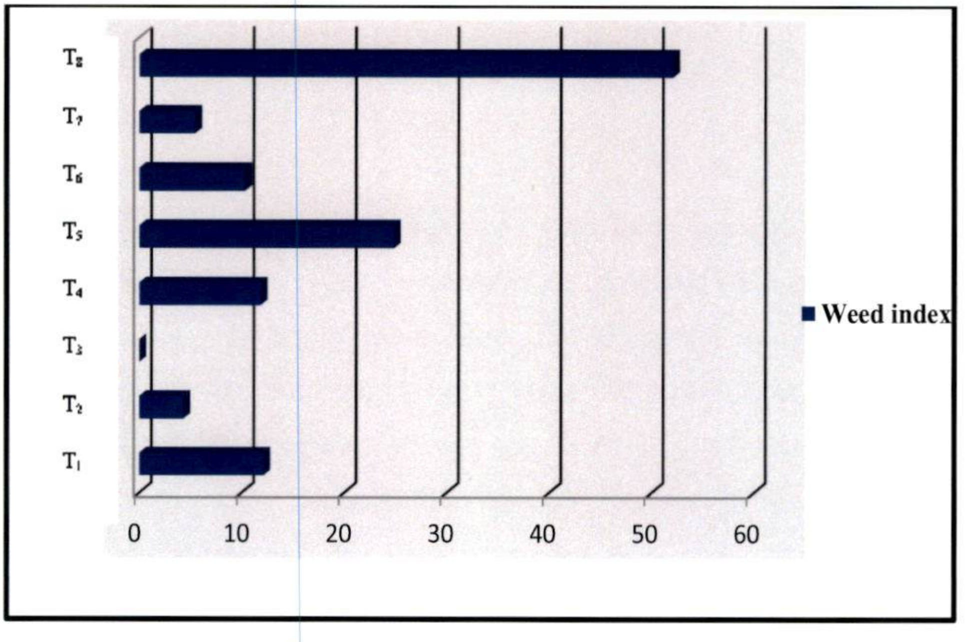


Fig 8. Effect of weed management practices on weed index, %

Lower grains yields combined with higher straw yields could have resulted in the low HI.

5.2.2.2. Weed index

Weed index (WI), a measure of yield reduction due to the presence of weeds was estimated to be 52.2 per cent in wet seeded broadcasted rice (Fig 8). Both vegetative and reproductive phases of crop were exposed to severe competition from weeds. Ramzan (2003) also reported a grain yield loss of more than half (53 per cent) in wet seeded rice due to unchecked weed growth. Maity and Mukerjee (2008) reported 61 per cent yield reduction in wet seeded rice due to uncontrolled weed growth. This signified the need for resorting to timely weed management strategies for realizing higher crop yields. Yield loss due to *Schoenoplectus juncoides* largely depended on its emerging intensity and cropping season. Higher competence of rock bulrush was observed in direct seeded rice. Sakamoto *et al.* (1982) reported 12-27 per cent yield loss in transplanted paddy in Japan at higher densities of rock bulrush.

5.2.2.3. Herbicide phytotoxicity on crop

Selectivity of herbicide should be the prima facie factor to be considered to avoid any toxicity on crop. Visual symptoms of herbicide phytotoxicity were not observed in rice after herbicide application. Pre-emergence spray of bensulfuron methyl + pretilachlor was followed by heavy rains which would have resulted in the absence of phytotoxicity symptoms on wet seeded rice. It could be inferred that the herbicides sprayed *viz*. bensulfuron methyl + pretilachlor, penoxsulam, ethoxysulfuron, carfentrazone-ethyl, metsulfuron methyl + chlorimuron ethyl and 2,4-D sodium salt were safe to the crop and damaging to the weeds at the specified concentration. Data on herbicide phytotoxicity over crop suggest that herbicides belonging to sulfonyl urea, aryl azolinone and chlorinated phenoxy groups are safe to rice. Ethoxysulfuron 60 WG @ 15, 17.5, 20 g ha^{-1} and ethoxysulfuron 15 WP @ 18.5 g ha^{-1} did not show phytotoxic symptoms in rice as per the findings of Pal *et al.* (2008). Rajagopal (2013) reported the pre-emergence application of bensulfuron methyl + pretilachlor safe in transplanted rice. Singh (2012) described carfentrazone-ethyl as a safe-to-apply herbicide in direct seeded rice. Reddy *et al.* (2016) reported penoxsulam 24 SC as safe to wet seeded rice when applied at 2 to 4 leaf stage of the weeds.

5.2.2.4. Nutrient uptake by crop

Nutrient composition of crop was not significantly influenced by weed management practices. However, the difference in dry matter production by crop registered higher uptake rates of 219.01, 39.32 and 228.55 kg NPK ha^{-1} in ethoxysulfuron fb HW (Fig 9). Limiting the weed growth below the damaging limits up to one-third of crop life cycle played an important role in increasing the dry matter production. Dry matter production recorded in ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS was the highest (15.71 t ha^{-1}). Higher grain and straw yield realized in the treatment as a result of higher weed control efficiency could be attributed to the dry matter production. Lower weed density would help the crop to have an upper hand over weeds in terms of competition. Better root activity of rice due to sparse interference from the weed roots would lead to increased nutrient uptake by crop. Rajkhowa *et al.* (2007) reported that increased root volume of rice associated with lower crop-weed competition, helped in higher uptake of nutrients and increased the grain yield. Lower nutrient uptake (99.31, 20.94 and 123.98 kg NPK ha^{-1}) was recorded from weedy check due to intense crop-weed competition at the rhizosphere level. Higher density of weed roots at varying depths would hinder crop uptake in turn reflecting on the yield. Arya (2015) also observed lower nutrient uptake rates in plots with uncontrolled weed growth.

5.2.2.5. Nutrient status of soil after experiment

Available N, P, K and organic carbon status of the soil was not significantly influenced by weed management practices. Before the experiment, soil was low in available N, high in available P, medium in available K and high in organic carbon. Compared to the initial values, available N, P and K status of the soil markedly reduced after the experiment and the per cent reduction ranged from ranged from 28.5 to 57.3 per cent, 12.3 to 23.8 per cent and 18.8 to 43.7 per cent respectively. Reduction in available N, P and K status of soil was observed to be 40.3, 13.2 and 28.4 per cent respectively in the weedy check compared to the highest values recorded. In the weedy check, 4.7 per cent reduction in organic carbon content of soil was recorded.

5.2.3. ECONOMICS OF CULTIVATION

Considering the economics of cultivation, ethoxysulfuron fb HW recorded higher gross income (Rs 1,82,025 ha^{-1}), net income (Rs 1,01,475 ha^{-1}) and B: C ratio (2.26). This could be due to the lower cost of herbicide in conjunction with higher grain and straw yield. The returns per one rupee spent would be Rs 2.26, for ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) and could be considered as a viable option for managing rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice. Though, conventional method of manual weeding was effective, herbicide application was easier, time and labour saving and economical compared to hand weeding (Rekha *et al.*, 2003). Gross income (Rs 1,73,626 ha^{-1}), net income (Rs 83,680 ha^{-1}) and B: C ratio (1.93) recorded from the hand weeded plots was lower compared to T_3. Yaduraju and Mishra (2008) reported that hand weeding failed to control sedges due to regeneration or escape of weeds in direct seeded rice. Weedy check recorded lower gross income, net income (Fig 10) and B: C ratio (Fig 11).

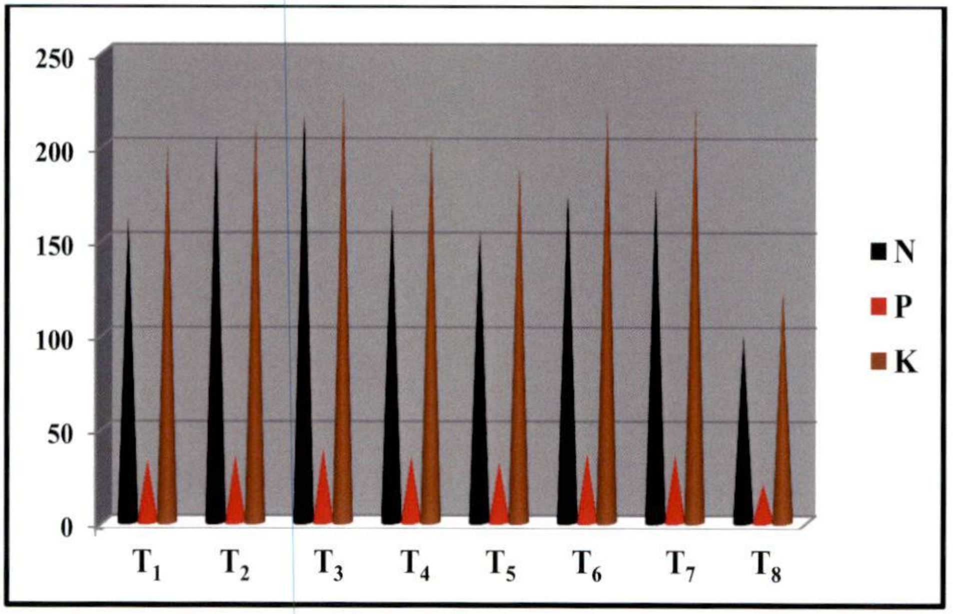


Fig 9. Effect of weed management practices on N, P and K uptake by the crop, kg ha^{-1}

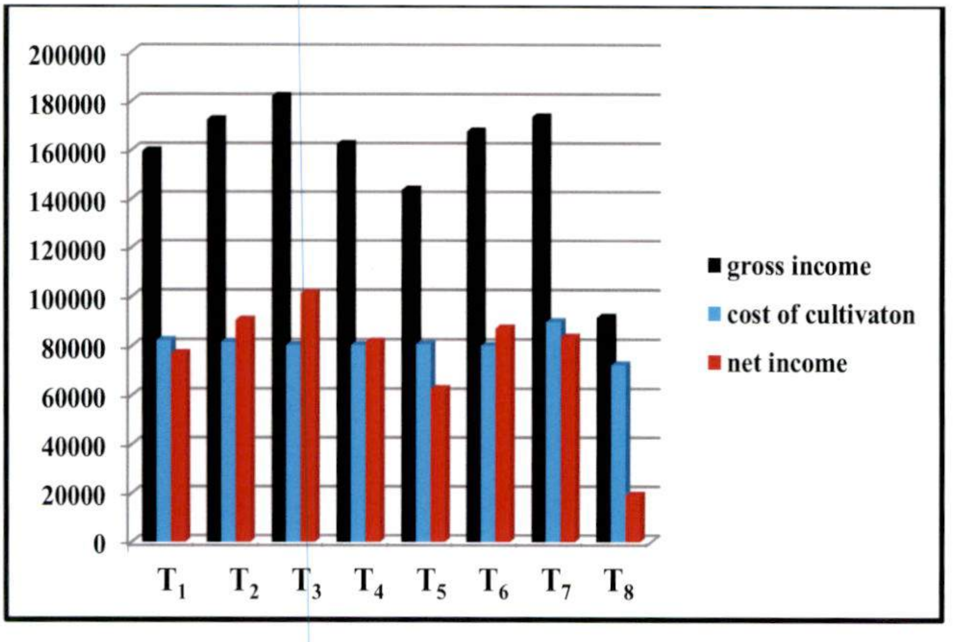


Fig 10. Effect of weed management practices on gross income, cost of cultivation and net income, Rs ha^{-1}

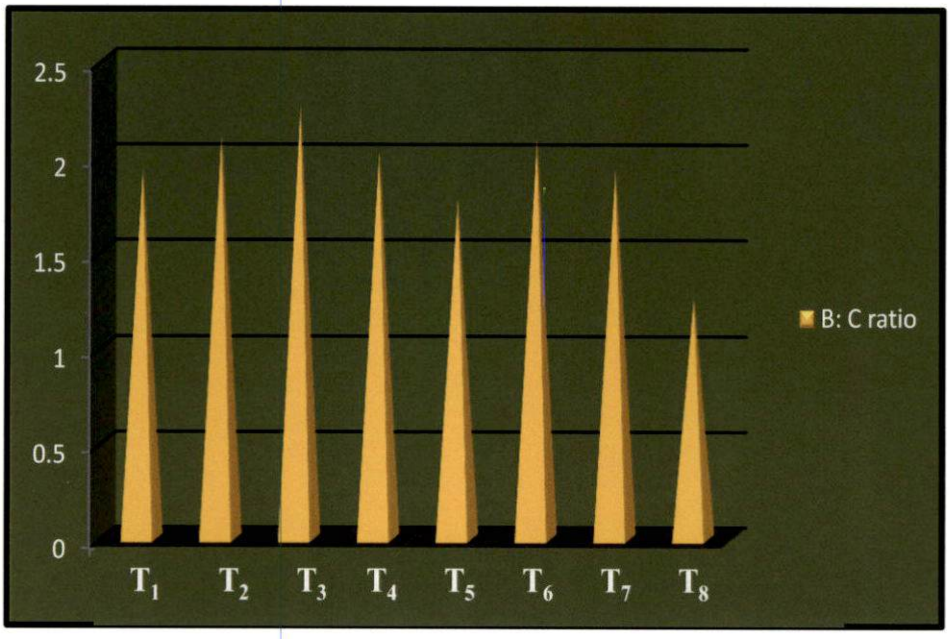


Fig 11. Effect of weed management practices on B: C ratio

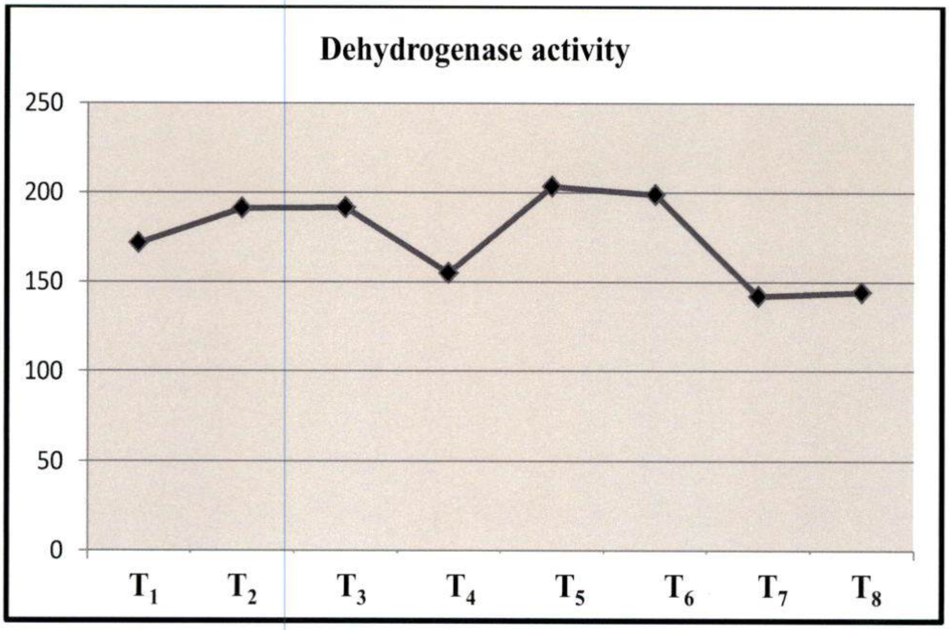


Fig 12. Soil dehydrogenase activity at 15 days after herbicide spraying, µg TPF g^{-1} of soil 24 h^{-1}

5.2.4. DEHYDROGENASE ACTIVITY

Activity of soil enzymes was determined by analyzing the dehydrogenase activity of soil after herbicide application. It is an index of microbial or biological activity in soil according to Burns (1978).

Soil dehydrogenase activity analyzed after 15 days of herbicide application indicated higher enzyme activity of 203.42 μg TPF g^{-1} soil $24h^{-1}$ in metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} fb HW (T_5). Sanyal *et al.* (2006) reported shorter half life for metsulfuron methyl + chlorimuron ethyl at all rates of application which makes it a safe herbicide. Rapid disintegration to safer limits helps in mainaining higher level of microbial activity in the plots treated with metsulfuron methyl + chlorimuron ethyl. Enzyme activities in penoxsulam @ 22.5 g ha^{-1} fb HW, ethoxysulfuron @ 15 g ha^{-1} fb HW and weedy check were statistically at par with T_5 (Fig 12). Lower dehydrogenase activity was recorded from hand weeding at 20 and 40 DAS. Reduced root activity in the hand weeded plot could have resulted in lower enzyme activity.

The study revealed that rock bulrush (*Schoenoplectus juncoides*), an erect tillering sedge with round stem having annual or perennial nature reproduce both by seeds and rhizomes with a biomass production of 0.96 t ha^{-1} if uncontrolled, with an average duration of 106 days in cultivated wetlands. The present investigation also revealed the need for adopting proper weed management practices especially at the critical stages of crop-weed competition for realizing better yield from wet seeded rice. Uncontrolled weed growth in the wet seeded system resulted in 52.18 per cent yield reduction in paddy. Rock bulrush could be effectively controlled by ethoxysulfuron @ 15g ha^{-1} or penoxsulam @ 22.5 g ha^{-1} both at 15 DAS fb HW at 35-40 DAS. Considering the economics, ethoxysulfuron @15g ha^{-1} at 15 DAS followed by hand weeding at 35-40 DAS could be adjudged as the most effective strategy for the management of *Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice.

Summary

6. SUMMARY

The present investigation entitled "Management of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) in wet seeded rice" was carried out in farmer's field at Ookkode, Thiruvananthapuram during *rabi* season (November 2017 to March 2018). The study was aimed at understanding the biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) and to develop an effective and economic strategy for its management in wet seeded rice.

Biology of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) was studied by observing ten randomly selected sample plants earmarked in the weedy check plots of the experimental field. In the experiment conducted for weed management, eight treatments were tested for its efficacy in controlling rock bulrush. The weed management practices tested were: T_1- bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 days after sowing (DAS) followed by (fb) hand weeding (HW) at 35-40 DAS; T_2- penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS; T_3- ethoxysulfuron @ 15 g ha^{-1}at 15 DAS fb HW at 35-40 DAS; T_4- carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS; T_5- metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS; T_6- 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS; T_7- HW twice at 20 and 40 DAS and T_8- weedy check. Pre-germinated seeds of the rice var. Sreyas were broadcasted in the puddled soil of the experimental field which was laid out in Randomized Block Design with all the treatments replicated thrice. Field work and lab analysis were conducted to achieve the objectives of the study. Salient findings of the experiment are summarized in this chapter.

- *Schoenoplectus juncoides* (Roxb.) Palla or rock bulrush,a wetland sedge weed belonging to the family Cyperaceae was observed to be an emerging weed in the lowland paddy fields and found to associate the crop throughout its life cycle.

- *Schoenoplectus juncoides* (Roxb.) Palla was observed to be an erect tillering sedge with upright culms.
- Rock bulrush was observed to grow through six phenological stages to complete its life cycle. These stages included germination, seedling, flowering, spike maturity, lodging and seed maturity.
- Germination of *Schoenoplectus juncoides* seeds commenced within 3 to 7 days of wet seeding; flowering in 22 days, spike maturity in 33 days and seed maturity in 68 days. The weed exhibited lodging behavior at 40 DAS, after spike maturity.
- Rock bulrush was found to grow copiously in the lowland paddy field, field bunds and associated water channels. The weed had an annual habit in the cultivated fields with an average duration of 106 days. Production of small rhizomes after crop harvest in the undisturbed field revealedthe perennial nature of the weed.
- *Schoenoplectus juncoides* had round, hollow stem growing upto a height of 66.76 cm at maturity and was vigorously tillering with an average tiller production of 19.6 tillers plant^{-1}.
- Roots of rock bulrush were fibrous and extended to a mean depth of 17.76 cm with dry weight of 0.99 g plant^{-1}. Small rhizomes produced after the harvest of rice had a mean dry weight of 0.03 g plant^{-1}.
- Average biomass production of the weed was 0.96 t ha^{-1} as observed in the weedy check plots.
- Inflorescence of rock bulrush was a sessile spike, positioned laterally on the culm. Number of spikes in individual tillers varied from 2 to 4 with an average of 33 spikes in a single plant.
- Seeds of *Schoenoplectus juncoides* had an initial cream colour, turning brown to black upon maturity with a mean seed length of 0.582 mm, width of 0.452

mm and thousand seed weight of 1.5 g. Average seed production capacity of the weed was estimated to be 862 seeds plant^{-1}.

- Upon maturation, seeds were found to shed from the spike into the soil along with the glumes attached to it. Lodging of culms and spiny tip of seeds aided easy dispersal of seeds through water, clothes and implements.
- Complete drying of rock bulrush occurred from 90th to 120th day with a mean duration of 106 days for completing the life cycle.
- Sprouting of vegetative buds occurred simultaneously with drying of spikes and seed dispersal.
- The nutrient content of *Schoenoplectus juncoides* was analyzed to be 0.90, 0.33 and 1.14 per cent NPK respectively and the corresponding nutrient uptake by the weed in weedy check plot was 8.61, 3.13 and 10.95 kg NPK ha^{-1} respectively.
- Uncontrolled weed growth in wet seeded broadcasted paddy had the potential to cause 52 per cent reduction in grain yield.
- Grain yield obtained from the plots treated with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW (5750 kg ha^{-1}) was higher and on a par with penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW (5500 kg ha^{-1}).
- Ethoxysulfuron@ 15 g ha^{-1} at 15 DAS fb HW recorded higher uptake of NPK i.e. 219.01, 39.32 and 228.55 kg ha^{-1}respectively.
- At the critical stages of crop-weed competition in wet seeded rice (45 and 60 DAS) ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS recorded lower weed density (2.09 and 3.15 weeds m^{-2} respectively).
- At 45 and 60 DAS, ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS recorded lower weed dry weights of 0.13 g m^{-2} and 1.83 g m^{-2} respectively.
- At critical stages of crop-weed competition (45 and 60 DAS), ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS provided higher weed control

efficiencies of 99.82 and 98.07 per cent respectively. Penoxsulam @ 22.5 g ha^{-1}at 15 DAS fb HW at 35-40 DAS (99.07 and 97.90 per cent respectively) and HW twice at 20 and 40 DAS (98.91 and 97.08 per cent respectively) were at par with ethoxysulfuron @ 15 g ha^{-1}fb HW.

- Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS had lower removalof 0.16, 0.07 and 0.20 kg NPK ha^{-1} respectively while,weedy check recorded higher nutrient removal of 8.61, 3.13 and 10.95 kg NPK ha^{-1}.
- Ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS recorded higher gross income (Rs 1,82,025 ha^{-1}), net income (Rs 1,01,475 ha^{-1}) and B:C ratio (2.26).
- Rock bulrush could be effectively controlled by ethoxysulfuron @15g ha^{-1}or penoxsulam @ 22.5 g ha^{-1} both at 15 DAS fb HW at 35-40 DAS.
- Considering the economics, ethoxysulfuron @15g ha^{-1} at 15 DAS followed by hand weeding at 35-40 DAS could be adjudged as the most effective strategy for the management of *Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice.

FUTURE LINE OF WORK

- Study on the allelopathic potential of rock bulrush (if any) against rice.
- Assessing the ability of rock bulrush in rehabilitating saline lowlands.
- Infesting capacity of rock bulrush in different systems of rice cultivation.

References

7. REFERENCES

Abtali, Y., Jafari, M. E., and Moussavi, M. R. 1995. Studies on damages caused by sedges in paddy field of Mazandaran. In: *Proceedings of the 12th Iranian Plant Protection Congress,* 2-7 September 1995, Karadj.

Ahmed, G. J. U. and Bhuiyan, M. K. A. 2010. Performance of weed management practices for different establishment methods of rice (*Oryza sativa* L.) in dry season. *Pakist. J. Weed Sci. Res.* 16(4): 393-402.

Ali, M. A. and Sankaran, S. 1984. Crop-weed competition in direct seeded lowland and upland bunded rice. *Indian J. Weed Sci.* 16: 90-96.

Ali, N., Durrani, S., Abbas, M., Ullah, I., Ishfaq, M., Akbar, N., Rehman, A., and Waheed, A. 2018. Different approaches in direct seeded rice system to avert weed infestation: Review. *Int. J. Sci. Eng. Res*. 9(6): 1538.

Aminpanah, H. 2015. Effects of spatial pattern and cultivar on weed control and grain yield in rice at reduced rates of herbicide. *Biosci. J.* 31(2): 460-469.

Andreoni, V., Cavalca, L., Rao, M. A., Nocerino, G., Bernasconi, S., Dell'Amico, E., Colombo, M., and Gianfreda, L. 2004. Bacterial communities and enzyme activities of PAHs polluted soils. *Chemo*. 57: 401-412.

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(1/2): 42-44.

Arya, S. R. and Ameena, M. 2016. Efficacy of new generation herbicides for weed management in semi dry rice. *J. Trop. Agric*. 54(1): 55- 59.

Arya. S. R. 2015. Herbicide based weed management for semi dry rice (*Oryza sativa* L.). M.Sc. (Ag) thesis. Kerala Agricultural University, Thrissur, 167p.

Athaulla, P., Kamatha, K. V. S., Hanumanathapppa, M., Bhanuprakash, H. R., and Sridara, S. 2017. Efficacy of pre and post emergent herbicides in rice at coastal zone of Karnataka. *Int. J. Curr. Microbiol. Appl. Sci.* 4: 142-146.

Aurora, M. B. and De Datta, S. K. 1992. Weed management in rice. *Weed Abstr*. 41: 495-508.

Azmi, M., Shukor, J. A., and Najib, M. Y. 2007. Critical period for weedy rice control in direct seeded rice. *J. Trop. Agric. Food Sci.* 35(2): 333-339.

Balasubramanian, P. and Palaniappan, S. P. 2001. *Principles and Practices of Agronomy.* Agrobios, New Delhi, 364p.

Balasubramanian, V. and Hill, J. K. 2000. Direct seeding of rice in Asia: emerging issues and strategic research needs for the 21st century. In: *Annual workshop at Directorate of Rice Research*, Hyderabad, Andhra Pradesh, 540p.

Banerjee, H. 2000. Studies on bio-efficacy of some herbicides in transplanted summer rice (*Oryza sativa* L.). M.Sc. (Ag) thesis, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, 105p.

Barooah, C. and Ahmed, I. 2014. *Plant Diversity Of Assam - A Checklist Of Angiosperms And Gymnosperms*, Assam Science and Technology Council, Guwahati, 585p.

Barrett, S. H. 1983. Crop mimicry in weeds. *Econ. Bot.* 37: 255-282.

Bayer, A. G. 2017. How to fight weeds and maximize yields in rice systems [on line]. Available: https://www.iwm.bayer.com/-/media/bcsinter/wsiwm/.../iwmricebrochure .pdf. [20 August 2017].

Begon, M., Harper, J. L., and Townsend, C. R. 1996. *Ecology: Individuals, Populations and Communities* (3rd Ed.). Blackwell Science, Oxford, 384p.

Bhagat, R. M., Bhuiyan, S. I., and Moody, K. 1996. Water, tillage and weed interactions in lowland tropical rice: A review. *Agric. Water Manag.* 31: 165-184.

Bhatt, M. D., Tewarl, A., and Singh, S. P. 2009. Floristic composition of weeds in paddy fields in Mahendranagar, Nepal. *Ecoprint* 16**:** 15-19.

Biswas, M., Parveen, S., Shimozawa, H., and Nakagoshi, N. 2005. Effects of *Azolla* species on weed emergence in a rice paddy ecosystem. *Weed Biol. Manag.* 5(4): 176-183.

Borghohain, M. and Upadhyaya, L. P. 1980. Efficiency of butachlor, propanil and 2, 4-D in controlling weeds in upland rice. *Indian J. Weed Sci.* 12(2): 145-150.

Bouman, B. 2009. How much water does rice use? *Manag.* 69: 115-133.

Bouyoucos, C. J. 1962. Hydrometer method improved for making particle size analysis of soil. *Agron. J.* 54: 464-465.

Brown, H. M. and Cotterman, J. C. 1994. Recent advances in sulfonylurea herbicides. In: Stetter, J. and Eding, W. (eds), *Herbicides Inhibiting Branched Chain Amino Acid Biosynthesis.* Springer-Verleg, Berlin, Germany, 47-81.

Bruhl, J. J .1995. Sedge genera of the world: relationships and a new classification of the Cyperaceae. *Aust. Syst. Bot*. 8(2): 125–305.

Buhler, D. D., Liebman, M., and Obrycki, J. J. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Weed Sci.* 48: 274 - 280.

Burns, R.G. 1978. Enzyme activity in soil: some theoretical and practical considerations. In: Bums, R.G. (ed.), *Soil Enzymes*. Academic, London, pp. 295–340.

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

Caton, B. P., Hill, J. E., and Johnson, D. E. 2010. *A Practical Field Guide to Weeds of Rice in Asia* (2nd Ed.), International Rice Research Institute, Los Banos, Philippines, 58p.

Chakraborty, D., Ladha, J. K., Rana, D. S., Jat, M. L., Gathala, M. K., Yadav, S., Rao, A. N., Ramesha, M. S., and Raman, A. 2017. A global analysis of alternative tillage and crop establishment practices for economically and environmentally efficient rice production. *Sci. Rep.* 7(1): 9342.

Chandar, S. and Pandey, J. 1996. Effect of herbicide and nitrogen on yield of scented rice (*Oryza sativa*) under different rice cultures. *Indian J. Agron.* 41(2): 209-214.

Chander, S. and Pandey, J. 2001. Effect of rice (*Oryza sativa*).culture, nitrogen and weed control on nitrogen competition between scented rice and weeds. *Indian J. Agron.* 46(1): 68-74.

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

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): 1-13.

Chauhan, B.S. and Opena, J. 2013. Weed management and grain yield of rice sown at low seeding rates in mechanized dry seeded systems. *Field Crops Res.* 141: 9-15.

Cheema, Z. A., Khichi, A. H., and Khaliq, A. B. D. U. L. 2005. Feasibility of reducing herbicide dose in combination with sorgaab for weed control in transplanted fine rice (*Oryza sativa* L.). *Int. J. Agric. Biol.* 7(6): 892-894.

Chiang, M. Y. 1983. Emergence, growth and reproduction of eleven paddy weeds in two seasons. *Weed Sci. Bull.* 4: 1-18.

Chung, I. M., Kim, J. T., and Kim, S. H. 2006. Evaluation of allelopathic potential and quantification of momilactone A, B from rice hull extracts and assessment of inhibitory bioactivity on paddy field weeds. *J. Agric. Food Chem.* 54: 2527-2536.

Cochran, W. C. and Cox, G. H. 1965. *Experimental Designs*. John Wiley and Sons Inc., New York, 225p.

Dave, A. K. and Sahu, R. K. 2006. Effect of different tillage and weeding methods on yield of rainfed transplanted rice in Bastar region. *J. Agric. Issues* 11 (1): 25-29.

Dawe, D. 2005. Increasing water productivity in rice-based systems in Asia - past trends, current problems and future prospects. *Plant Prod. Sci.* 8: 221-230.

Deivasigamani, S. 2016. Study of bio-efficacy and phytotoxicity of new generation herbicides on triafamone and ethoxysulfuron in direct seeded rice (*Oryza sativa*). *Int. J. App. Sci.* 3(2): 106-112.

Devi, B. R. and Singh, Y. 2018. Influence of nitrogen and weed management practices on growth ad yield of direct seeded rice (*Oryza sativa* L.). *Int. J. Curr. Microbiol. Appl. Sci.* 7(1): 2566-2574.

Dhakal, M., Sah, S. K., McDonald, A., and Regmi, A. P. 2015. Perception and economics of dry direct seeded rice in Terai of Nepal. *J. Asian Earth Sci.* 16: 103-111.

Donald, C. M. and Hanohlin, J. 1976. Biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron.* 28: 361-405.

Donayre, D. K. M., Martin, E. C., Santiago, S. E., and Lee, J. T. 2016. *Weeds in Irrigated and Rainfed Lowland Rice fields in the* Philippines. Philippine Rice Research Institute, Philippines, 156p.

Dorji, S., Lhamo, K., Chophyll, K., and Tobgye, K. 2013. Weeds of transplanted rice in western Bhutan. *Bhutan J. Renew. Nat. Res.* 9: 43-50.

Dutta, A., Patra, B. C., Jana, P., and Mandal, N. 2005. Effect of fertility levels and weed management practices on growth, yield attributes and yield of direct seeded rice in the rainfed and lateritic belt of West Bengal. In: *First International Weed Science Seminar on Innovative Approaches for Ecosafety Weed Management*, 21-24 January 2005, Kolkata, India, p. 69.

Ehsanullah, Anjum, S. A., Ashraf, U., Rafiq, H., Tanveer, M., and Khan, I. 2014. Effect of sowing dates and weed control methods on weed infestation, growth and yield of direct seeded rice. *Philipp. Agric. Sci.* 97(3): 307-312.

Eickhoff, D. 2009. Native plants of Hawaii- Schoenoplectiella juncoides [on line]. Available: http://nativeplants.hawaii.edu/plant/view/Schoenoplectiella_juncoides. [8 January 2018].

EPPO Global Database. 2004. Schoenoplectiella juncoides [on line]. Available: https://gd.eppo.int/taxon/SCPJU. [03 March 2018].

FAO [Food and Agriculture Organization]. 2016. FAO statistical database [on line]. Available: http://faostat3.fao.org/browse/FB/CC/E [03 March 2018]

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

Ghimiray, M., Chhetri, M., and Dukpa, W. 2009. *Field Manual: Rice Production Practices for Low Altitude Belt*. Council for RNR Research of Bhutan, Ministry of Agriculture, 38p.

Ghosheh, H. Z., Holshouser, D. L., and Chandler, J. M. 1996. The critical period of Johnson grass (*Sorghum halepense*) control in field corn (*Zea mays*). *Weed Sci.* 44: 944-947.

Gill, H. S. and Vijayakumar. 1969. Weed index–a new method for reporting weed control trial. *Indian J. Agron.* 14(1): 96-98.

Gnanavel, I. and Kathiresan, R. M. 2002. Sustainable weed management in rice-rice cropping system. *Indian J. Weed Sci.* 34(3/4): 192-196.

Goetghebeur, P. 1998. Cyperaceae. In: Kubitzki, F., Huber, H., Rudall, P. J., Stevens, P. S., and Stützel, T. (eds), *The Families and Genera of Vascular Plants*. Springer-Verlag, Berlin, 190p.

GoK [Government of Kerala]. 2017. Second advanced estimate of area, production and yield of principal crops [on line]. Available: http://www.ecostat.kerala.gov.in/index.php/publications. [10 November 2017].

Hamamura, K. 2002. The characteristic of the water imbibition of seeds of *Scirpus juncoides* Roxb. var. ohwianus T. Koyama. *J. Weed Sci. Technol.* 47(3): 161-167.

Harper, J. L. 1977. *Population Biology of Plants.* Academic press, San Diago, 892p.

Hayasaka, E. 2002. Taxonomic revision of the genus *Schoenoplectus* (Cyperaceae), with special reference to nutlet micromorphology. Ph.D thesis, Tohoku University, Sendai, 309p.

Hiroomi, A., Katsunori, I., and Yoshio, T. 1999. Eating behaviour of Aigamo ducks in paddy field. *J. Weed Sci. Technol.* 44(1): 1-8.

Ho, N. K. 1994. Integrated weed management in Malaysia: some aspects of the Muda irrigated scheme's approach and experience. In: Sastroutomo, S. S. and Auld, B. A. (eds), *Workshop on Appropriate Weed Control in Southeast Asia*, Kuala Lumpur, Malaysia, 17-18 May 1994, pp. 83-97.

Hooda, I. S. 2002. Weed management in organic rice. In: *Development of Basic Standard for Organic Rice Cultivation, 1st RDA/ARNOA International Conference,* 12-15 November 2002, RDA and Dankook University, Korea.

Hossain, M. N., Uddin, M. R., Salam, M. A., Sarker, U. K., Ferdousi, S., and Uddin, M. J. 2017. Allelopathic potential of mustard crop residues on weed management and performance of transplant Aman rice. *J. Bangladesh Agric. Univ.* 15(2): 133-139.

Hussain, S., Ramzan, M., Akhter, M., and Aslam, M. 2008. Weed management in direct seeded rice. *J. Anim. Plant Sci.* 18(2): 86–88.

IRRI [International Rice Research Institute]. 2002. *Standard Evaluation System for Rice.* International Rice Research Institute, Los Banos, Philippines, 56p.

IRRI [International Rice Research Institute]. 2017. *Schoenoplectus juncoides* [on line]. Available:http://www.knowledgebank.irri.org/training/fact-sheets/item/schoenoplectus-juncoides [10 November 2017].

Ishikura, N. and Soga, Y. 1978. Studies on the ecology and control of the perennial weed *Scirpus* in paddy fields- seed ripening of *Scirpus juncoides* Roxb. var. *ohwianus* T. Koyama and changes in germinability with seed ripening. *Weed Res.* 23(1): 19-23.

Iwasaki, K., Watajima, T., and Hagimoto, H. 1981. Wintering abilities of three *Scirpus* taxa and their control. *Res. Lab. Agric. Chem. Div.* 26(2): 104-110.

Jabran, K., Farooq, M., Khan, H. E., Shahid, M.B., and Jnlee, D. 2012. Efficient weed control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. *Int. J. Agric. Biol.* 14: 901-907.

Jabusch, T. W. and Tjeerdema, R. S. 2005. Chemistry and fate of triazolopyrimidine sulfonamide herbicides. *Rev. Environ. Contam. Toxicol.* 193: 31-52.

Jackson, M. L. 1973. *Soil Chemical Analysis.* Prentice Hall of India Pvt. Ltd., New Delhi, 498p.

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.

Janiya, J. D. 2002. Weed management in major crops in the Philippines. In: *Weed Science Society of the Philippines*, Los Baños, Laguna, Philippines, 17-37.

Johnson, D. E. 1996. Weed management in small holder paddy production in the tropics [on line]. Available: http://ipm.world.umn.edu/chapters/johnson.htm. [10 Jan. 2010].

Johnson, D. E., Wopereis, M. C. S., Mbodj, D., Diallo, S., Powers, S., and Haefele, S. M. 2004. Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. *Field Crops Res.* 85: 31-42.

Jung, J. and Choi, H. 2011. Taxonomic Study of Korean *Scirpus* L. (Cyperaceae) II: pattern of phenotypic evolution inferred from molecular phylogeny. *J. Plant Biol.* 54(6): 409-424.

Juraimi, A., Mohamad, M., Begum, M., Anuar, A., and Azmy, M. 2009. Critical period of weed competition in direct seeded rice under saturated and flooded conditions. *J. Trop. Agric. Sci. 32*(2): 305–316.

Kabdal, P., Pratap, T., and Yadav, V. R. 2018. Weed management in transplanted rice- A review. *Int. J. Curr. Microbiol. Appl. Sci.* 7(4): 1660-1669.

Kamoshita, A., Araki, Y., and Nguyen, Y. T. 2014. Weed biodiversity and rice production during the irrigation rehabilitation process in Cambodia . *Agric. Ecosyst. Environ.* 194: 1-6.

Kashin, J. 2014. Herbicide application timing of *Scirpus juncoides* var. *ohwianus* for for control of sorghum plant bug *Stenotus rubrovittatus*, Hemiptera, Miridae. *Jpn. J. Appl. Entomol. Zool.* 58(3): 263-268.

Kathirvelan, P. and Vaiyapuri, V. 2003. Relative efficacy of herbicides in transplanted rice. *Indian J. Weed Sci.* 35(3/4): 257-258.

KAU (Kerala Agricultural University). 2011. *Package of Practices Recommendations: Crops* (14th Ed.). Kerala Agricultural University, Thrissur, 360p.

Khalid, S. and Sadar-U-Siddiqui. 2014. Weeds of Pakistan: Cyperaceae. *Pakist. J. Weed Sci. Res.* 20(2): 233-263.

Khaliq, A. and Matloob, A. 2011. Weed crop competition period in three fine rice cultivars under direct seeded rice culture. *Pakist. J. Weed Sci. Res.* 17: 229–243.

Khan, M. A. K., Bhuiyan, S. I., and Undan, R. C. 1992. Assessment of direct seeded rice in an irrigated system in the Philippines. *Bangladesh Rice J.* 3(1/2): 14-20.

Kim, J. G., Lee, S. B., Lee, K. B., Lee, D. B., and Kim, J. D. 2001. Effect of applied amount and time of rice bran on the rice growth condition. *Korean J. Environ. Agric.* 20(1): 15-19.

Kolay, S. 2007. Weed management in transplanted kharif rice and ecophysiological studies on competition between rice and *Ludwigia parviflora* (Roxb.). Ph.D thesis, Institute of Agriculture, Visva-Bharati, Sriniketan, 121p.

Kraehmer, H., Jabran, K., Mennan, H., and Chauhan, B. S. 2016. Global distribution of rice weeds- A review. *Crop Prot.* 80: 73-86.

Kumar, S., Angiras, N. N., Rana, S. S., and Sharma, N. 2008. Efficacy of new herbicides to manage weeds in transplanted rice. *Himachal J. Agric. Res.* 34(1): 18-21.

Kumar, S., Chaudhuri, S., and Maiti, S. K. 2013. Soil dehydrogenase enzyme activity in natural and mine soils-A review. *Middle-East J. Sci. Res.* 13(7): 898-906.

Kumar, S., Pandey, N., Kumar, A., Singh, A. K., Gopal, T., and Kumar, D. 2018. Effect of establishment methods and weed management practices on economics of direct seeded rice (*Oryza sativa* L.). *Int. J. Curr. Microbiol. Appl. Sci.* 7(4): 1473-1480.

Kumar, V. and Ladha, J. K. 2011. Direct seeding of rice: recent developments and future research needs. *Adv. Agron.* 111: 297-413.

Kurmi, K. and Das, G. R. 1993. Effect of herbicides on 'weed control in transplanted rice. In: *Proceedings of Indian Society of Weed Science International Symposium*, 18-20 November 1993, Hisar, India. Indian Society of Weed Science, pp. 27-29.

Kuyeonchung, Songdukyong, Leesangbok, Seongkiyoung, and Parkjeonghua. 2002. Changes of weed biodiversity in rice cultivation system. *Korean J. Weed Sci*. 22: 254-258.

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: *Programme and Abstracts, 24th APWSS Conference*, 22-25 October 2013, Padjadjaran University Convention Hall, Bandung, West Java, Indonesia, pp.97.

Le Bourgeois, T., Carrara, A. M., Dodet, W., Dogley, A., Gaungoo, P., Grard, Y., Ibrahim, E., Jeuffrault, G., Lebreton, P., Poilecot, J., Prosperi, J. A., Randriamampianina, A. P., Andrianaivo, and Théveny, F. 2008. *Schoenoplectiella juncoides* (Roxb.) Lye [on line]. Available: http://portal.wikwio.org/biodiv/species/ show/285. [30 June 2018].

Leck, M. A. and Schütz, W. 2005. Regeneration of Cyperaceae, with particular reference to seed ecology and seed banks. *Perspect. Plant Ecol. Evol. Syst.*7: 95-133.

Lee, I. Y., Ji, S. H., Jung, K. I., Park, N. I., Kwon, O. S., and Park, J. E. 2005. Effect of recycled paper mulching on weeding efficacy and rice growth in the transplanted rice field. *Korean J. Weed Sci.* 25: 98-102.

Luo, X., Liao, J., Hu, L., Zang, Y., and Zhou, Z. 2016. Improving agricultural mechanization level to promote agricultural sustainable development. *Trans Chinese Soc. Agric. Eng* 32(1): 1-11.

Madhukumar, V., Murthy, K. N., Prashanth, R., Kumbar, B., and Dinesha, M. S. 2013. Relative efficacy of different herbicides for weed control in aerobic rice (*Oryza sativa* L.). *Inter. J. Sci. Nat.* 4(3): 473-477.

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.

Maity, S. K. and Mukerjee, P. K. 2008. Integrated weed management in dry seeded rice (*Oryza sativa*). *Indian J. Agron.* 53(2): 116-120.

Manandhar, Sailaza, Bharat, B., Shrestha, Hair, D., and Lekhak. 2007. Weeds of paddy field at Kirtipur, Kathmandu. *Sci. World* 5(5):100-106.

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

Matloob, A., Khaliq, A., and Chauhan, B. S. 2015. Weeds of rice in Asia: problems and opportunities. *Adv. Agron.* 130: 291–336.

Mercado, B. L. 1979. *Introduction of Weed Science.* Southeast Asia Regional Center for Graduate Study and Research in Agriculture (SEARCA), College Laguna, Philippines, 292 p.

Mesquita, M. L., de Andrade, L. A., and Pereira, W. E. 2013. Floristic diversity of the soil weed seed bank in a rice-growing area of Brazil: *in situ* and *ex situ* evaluation. *Acta Bot. Brasilica.* 27(3): 465-471.

Mezni, M. A., Albouchi, E., Bizid, and Hamza, M. 2010. Minerals uptake, organic osmotica contents and water balance in alfalfa under salt stress. *J. Phytol.* 2: 1-12.

Mishra, A. K., Khanal, A. R., and Pede, V. O. 2017. Is direct seeded rice a boon for economic performance? Empirical evidence from India. *Food Policy* 73: 10-18.

Miyahara, M. 1968. Effects of cultural practices on the weed community in paddy fields. *J. Weed Sci. Technol.* 7: 22-28.

Mondal, M. M. A., Islam, A. F. M. S., and Siddique, M. A. 2005. Performance of 17 modern transplant aman cultivar in the north region of Bangladesh. *Bangladesh J. Crop. Sci*. 16: 23-29.

Moody, K. 1990. Post-plant weed control in direct seeded rice. In: *Rice Symposium*; 25-27 September 1990. Malaysian Agricultural Research and Development Institute, Penang, Malaysia.

Mubeen, K., Amit, J., Hussain, M., Siddiqui, M. H., Zahoor, F., Shehzad, M., and Khalid, M. 2014. Effects of seeding time and competition period on weeds, growth and yield of direct seeded fine rice (*Oryza sativa* L.). *Acad. J. Interdisciplinary Stud.* 3(5): 55.

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.

Nath, C. P. and Pandey P. C. 2013. Evaluation of herbicides on grain yield and nutrient uptake in rice (*Oryza sativa* L.). *Bioinfolet* 10(1): 282-287.

Netam, C. R., Rameshwari, N., Qureshi, A., Kunti, B., and Netam, A. K. 2018. Influence of various weed management approaches on weed dynamics in rice under different crop establishment methods. *Int. J. Curr. Microbiol. App. Sci.* 7(3): 1551-1557.

NPPC [National Plant Protection Centre]. 2017. *Scirpus juncoides*- Cyperaceae [on line]. Available:http://www.nppc.gov.bt/wp-content/uploads/2016/07/8.-Scirpus-juncoides.pdf. [10 November 2017].

Pal, H. and Choudhury, M. D. 2014. Taxonomic status of cyperaceae of Southern Assam. *Pleione* 8(1): 149 - 157.

Pal, S., Banerjee, H., and Mandal, N. N. 2009. Efficacy of low dose of herbicides against weeds in transplanted *kharif* rice (*Oryza sativa* L.). *J. Plant Prot. Sci.* 1(1): 31-33.

Pandey, S. 2009. Effect of weed control methods on rice cultivars under the system of rice intensification (SRI). M.Sc.(Ag) thesis, Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal, 185p.

Parameswari, Y. S. and Srinivas, A. 2014. Influence of weed management practices on nutrient uptake and productivity of rice under different methods of crop establishment. *J. Rice Res.* 7(1/2): 110-121.

Pignotti, L. 2003. *Scirpus* L. and related genera (Cyperaceae) in Italy. *Webbia* 58(2): 281-400.

Pignotti, L. and Mariotti, L. 2004. Micromorphology of *Scirpus* (Cyperaceae) and related genera in south-west Europe. *Bot. J. Linn. Soc.* 145(1): 45-58.

Pons, T. L. and Schroder, H. F. 1986. Significance of temperature fluctuation and oxygen concentration for germination of the rice field weeds *Fimbristylis littoralis* and *Scirpus juncoides*. *Oecol.* 68(2): 315-319.

Prasad, K. S. and Raveendran, K. 2011. Diversity of weed flora associated with rice crop in Kasaragod district, Kerala, South India. *Int. J. Plant Sci.* 6(1): 49-54.

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

Puniya, R., Pandey, P. C., and Bisht, P. S. 2007. Performance of trisulfuron, trisulfuron + pretilachlor and bensulfuron-methyl in transplanted rice (*Oryza sativa* L.). *Indian J. Weed Sci.* 39(1/2): 120-122.

Raj, S. K. 2016. Herbicide mixtures for weed management in direct seeded puddled rice (*Oryza sativa* L). Ph.D thesis. Kerala Agricultural University, Thrissur, 315p.

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.

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

Rajagopal, K. 2013. Evaluation of new generation herbicides in transplanted rice (*Oryza sativa* L.). M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur,113p.

Rajkhowa, D. J., Deka, N. C., Borah, N., and Barua, I. C. 2007. Effect of herbicides with or without paddy weeder on weeds in transplanted. *Indian J. Agron.* 52(2):107-110.

Ramesha, Y. M., Bhanuvally, M., Gaddi, A. K., Krishamurthy, D., and Umesh, M. R. 2017. Efficacy of herbicides against weeds in transplanted rice (*Oryza sativa* L.). *Int. J. Plant Soil Sci.* 18(1): 1-8.

Ramzan, M. 2003. Evaluation of various planting methods in rice-wheat cropping system. *Rice Crop Rep.* 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: 250-255.

Rao, A. N. and Chauhan, B. S. 2015. Weeds and weed management in India – A Review. In: Rao, V. S., Yaduraju, N. T., Chandrasena, N. R., Hassan, G., and Sharma, A. R. (eds), *Weed Science in the Asian-Pacific Region*, Indian Society of Weed Science, Jabalpur, India. pp. 87-118.

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. N., Wani, S. P., Gajanan, S., Anantha, K. H., and Ladha, J. K. 2017. Weed management role in increasing crop yield and doubling rice farmer's income in India-An analysis. In: *Biennial Conference of the Indian Society of Weed Science on "Doubling Farmer's Income by 2022"*, 1-3 March 2017, Udaipur, Rajasthan.

Rao, B. B., Modh, C. H. I., and Murthy, R. 2000. Influence of time of planting on grain yield of scented rice. *Crop Res.* 20: 179-181.

Rao, V.S. 2000. *Principles of Weed Science*. Oxford and IBH publishing Co., New Delhi, 555p.

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

Reddy, C. N., Reddy, N. P., and Davy, M. P. 2000. Evaluation of fenoxyprop-p-ethyl and ethoxysulfuron in transplanted rice. *Indian J. Weed Sci.* 32(1/2): 105- 107.

Reddy, M. B. G., Guruprasad, G. S., Shivayogayya, P. M. D., Gowdar, S. B., and Sridhar, D. J. 2016. Bioefficacy of penoxsulam 24% SC herbicide against weeds in direct seeded rice under puddled conditions. *J. Farm Sci*. 29(3): 337-339.

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

Rekha, K. B., Raju, M. S., and Reddy, M. D. 2002. Effect of herbicides in transplanted rice. *Indian J. Weed Sci.* 24(1/2): 123-125.

Saha, S. 2006. Comparative study on efficacy of sulfonyl urea herbicides and traditional recommended herbicides in transplanted rice. *Indian J. Agron.* 51(4): 304-306.

Saha, S. and Rao, K. S. 2009. Efficacy of sulfonylurea herbicides for broad-spectrum weed control in wet direct sown summer rice. *Oryza* 46(2): 116-119.

Sahid, I., Faezah, Z. N., and Ho, N. K. 1995. Weed populations and their buried seeds in rice fields of the Muda area, Kedah, Malaysia. *Trop. Agric. Sci.* 18(1): 21-28.

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, Bhubaneshwar, 72p.

Saini, J. P. and Angiras, N. 2002. Evaluation of ethoxysulfuron against broad leaved weeds and sedges in direct seeded puddled rice. *Indian J. Weed Sci.* 34(1): 36-38.

Sakamoto, S., Eto, H., Umeki, Y., Murakoso, K., and Kajimoto, A. 1982. Influence of the method of paddy field management after the harvest on the change of the perennial weed community in the early season rice culture in the warm region (of Japan), 2: The kinds of succeeding crops and the ridging method. *J. Weed Sci. Technol.* 27: 264-271.

Sanodiya, P., Singh, M. K., and Lawate, P. 2017. Impact of integrated weed management on weed flora, growth attributes and yield of direct seeded rice (*Oryza sativa* L.). *J. Pharma. Phytochem.* 958-961

Sansa, S., 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.

Sanyal, N., Pramanik, S. K., Pal, R., and Chowdhury, A. 2006. Laboratory simulated dissipation of metsulfuron methyl and chlorimuron ethyl in soil and their residual fate in rice, wheat and soyabean at harvest. *J. Zhejiang Univ. Sci.* 7: 202-208.

Sasidharan, N. 2017. *Indian Medicinal Plants And Indian Biodiversity Portal*. Kerala Forest Research Institute, Peechi. 702p.

Satapathy, B. S., Duary, B., Saha, S., Pun, K. B., and Singh, T. 2017. Effect of weed management practices on yield and yield attributes of wet direct seeded rice under lowland ecosystem of Assam. *Oryza* 54(1): 29-36.

Sathyamoorthy, K. and Kandasamy, O. S. 1998. Critical period of crop weed competition in different rice culture (lowland transplanted and wet seeded rice). In: *Summary and Research Achievements-1998*, AICRPWC (ICAR), Coimbatore Centre, Tamil Nadu Agricultural University, Coimbatore, India.

Selvam, P. P. and Krishnan, R. 1992. Crop-weed competition in direct sown lowland samba rice varieties. In: *Annual Conference ISWW*, Chaudhary Charan Singh Haryana Agricultural University, Hisar, 3-4 March 1992. pp.10.

Serrano, F. B. 1975. *Twenty-six Years of Rice Research and Development.* National Research Council of the Philippines, Diliman, Quezon City, Philippines, 122p.

Shultana, R., Biswas, J.C., Mamun, M.A.A., and Nahar, L. 2016. Fertilizer and weed management options for direct wet seeded rice in dry season. *Bangladesh Rice J.* 20(1): 65-75.

Singh, A. 2012. Studies on the efficiency of carfentrazone ethyl in direct seeded rice. M.Sc. (Ag) thesis, Banaras Hindu University, Varanasi, 104p.

Singh, A., Nandal, D. P., Punia, S. S., and Malik, P. 2018. Integrated weed management in direct seeded rice in Trans Indo-Gangetic plains of India- A review. *J. Appl. Nat. Sci.* 10(2): 779-790.

Singh, G., Singh, O. P., Kumar, V., and Kumar, T. 2008. Effect of methods of establishment and tillage practices on the productivity of rice (*Oryza sativa*) -wheat (*Triticum aestivum*) cropping system. *Indian J. Agric. Sci.* 78: 163-166.

Singh, S., Singh, G., Singh, V. P., and Singh, A. P. 2005. Effect of establishment methods and weed management practices on weeds and rice in rice-wheat cropping system. *Indian J. Weed Sci.* 37: 51-57.

Singh, Y., Singh, V. P., Singh, G., Yadav, D. S., Sinha, R. K. P., Johnson, D. E., and Mortimer, A. M. 2011. The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice-wheat system in the Indo-Gangetic plains. *Field Crops Res.* 121(1): 64-74.

Smith, S. G. and Hayasaka, E. 2002. New combinations within North American *Schoenoplectus smithii* and *S. purshianus* (sect. *Actaeogeton, Cyperaceae*) and comparison with eastern Asian allies. *Novon* 12: 106–111.

Son, C. Y. and Rutto, K. L. 2002. Are herbicides essential for paddy control in East Asia? *Pakist. J. Biol. Sci.* 5: 1352-1362.

Sondhia, S. and Dixit, A. 2012. Bioefficacy and persistence of ethoxysulfuron in rice. *Oryza.* 49(3): 178-182.

Subbiah, D. V. and Asija, G. L. 1956. Rapid procedure for estimation of available nitrogen in soil. *Curr. Sci.* 25: 259-260.

Sunil, C. M., Sekara, B. G., Murthy, K. N. K., and Shankaralingappa, B. C. 2010. Growth and yield of aerobic rice as influenced by integrated weed management practices. *Indian J. Weed Sci.* 42 (3/4): 180-183.

Suresh, C. and Singh, O. S. 2003. Herbicidal effect on yield attributing characters on rice in direct seeded puddled rice. *Agric. Sci. Digest* 23: 75-76.

Talaka, A. and Rajab, Y. S. 2013. Weed biology and ecology - a key to successful weed management and control. *J. Agric. Vet. Sci.* 2(3): 11-14.

Tanaka, I. 1976. Climatic influence on photosynthesis and respiration of rice plants. *Clim. Rice* 223-247.

Tao, Y., Chen, Q., Peng, S., Wang, W., and Nie, L. 2016. Lower global warming potential and higher yield of wet direct seeded rice in Central China. *Agron. Sustain. Dev.* 36(2): 24.

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

Thapa, C. B. and Jha, P. K. 2002. Paddy crop-weed competition in Pokhara, Nepal. *Geobios*. 29(1): 51-54.

Upadhayay, U. C. and Sivanand, K. 1985. *A Practical Manual on Weed Control*. Oxford and IBP publishing Co. Pvt. Ltd., New Delhi. 280p.

USDA [United States Department of Agriculture]. 2018. World rice production, consumption and stocks [on line]. Available: http://apps.fas.usda.gov/psdonline/psd home.aspx [03 March 2018].

Ushiki, J., Kawana, Y., and Morita, H. 2008. Germination and survival of paddy weed seeds after soil sterilization with hot water. *J. Weed Sci. Technol.* 53(4): 167-172.

Vaishya, R. D. and Tomar, S. K. 2000. Weed control in puddled seeded rice (*Oryza sativa* L.) with herbicides. *Indian J. Agron.* 45(2): 334-337.

Vangsaroj, P. and Chinawong. 1982. Weeds in deep water rice and their control. *Thailand J. Weed Sci.* 1(2): 40-49.

Vencill, W. K. 2002. *Herbicide Handbook* (8th Ed.). Weed Science Society of America, Lawrence, USA, 493p.

Watanabe, H. and Miyahara, M. 1989. Seed dormancy of some lowland weeds of *Scirpus* buried in paddy soil. In: *Proceedings, 12th Asian-Pacific Weed Science Society Conference*, National Agriculture Research Centre, Tsukuba, Ibaraki, Japan, p.305.

Watanabe, H., Miyahara, M., and Shibayama, H. 1991. Seasonal changes in seed dormancy and emergence of *Scirpus juncoides* Roxb. subsp. *juncoides* in paddy fields. *Weed Res*. 36: 362-371.

Wersal, R. M. and Madsen, J. D. 2012. Combinations of diquat and carfentrazone ethyl for control of floating aquatic plants. *J. Aquat. Plant Manag.* 50: 46-48.

Yadav, D. B., Punia, S. S., and Yadav, A. 2010. Efficacy of bispyribac-sodium, azimsulfuron and penoxsulam for post emergence weed control in transplanted rice. In: *Biennial conference on "Recent Advances in Weed Science Research-2010"*, 25-26 February 2010, Raipur, Chattisgarh, p. 65.

Yaduraju, N. T. and Mishra, J. S. 2008. Sedges in rice culture and their management. 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. International Rice Reaearch Institute, Los Banos, Philippines, 191-203.

Yaduraju, N. T., Sharma, A. R., and Rao, A. N. 2015. Weeds in Indian agriculture: problems and prospects to become self-sufficient. *Indian Farming* 65: 2-6.

Yano, O. and Hoshino, T. 2005. Molecular phylogeny and chromosomal evolution of Japanese *Schoenoplectus* (Cyperaceae), based on ITS and ETS 1f sequences. *Acta Phytotaxon. et Geobot. 56*(2): 183-195.

Zahoor, I., Ahmad, S. A., Hameed, M., Nawaz, T., and Tarteel, A. 2012. Comparative salinity tolerance of *Fimbristylis dichotoma* (L.) Vahl and *Schoenoplectus juncoides* (Roxb.) Palla, the candidate sedges for rehabilitation of saline wetlands. *Pakist. J. Bot.* 44: 1-6.

Appendices

Appendix I. Weather data of the experimental field (November 2017 to March 2018)

Standard week	Month and date		Rainfall (mm)	Temparature (⁰C)		RH (%)		Sunshine hours	Evaporation (mm)
				Max.	Min.	Max.	Min.		
45	November	11	1.0	30.4	25.0	96	76	8.0	3.0
46		12-18	0.0	31.6	24.1	94.3	74.1	8.2	4.0
47		19-25	22.7	31.1	23.9	94.0	80.7	4.8	2.9
48		26-02	41.2	29.5	22.5	97.1	92.0	1.1	1.5
49	December	03-09	9.4	31.3	23.2	95.1	77.4	8.0	3.3
50		10-16	0.9	31.4	24.1	95.1	78.9	5.7	2.6
51		17-23	0.0	32.4	23.8	94.3	74.1	8.8	3.9
52		24-31	0.0	32.6	23.7	93.3	74.1	9.4	4.1
1	January	01-07	0.0	31.8	22.1	94.1	72.4	9.2	4.1
2		08-14	0.0	31.3	21.7	93.4	79.8	8.2	4.0
3		15-21	0.0	32.2	21.6	93.7	73.3	8.8	3.9
4		22-28	0.0	31.7	21.5	93.7	71.1	7.7	4.0
5		29-04	0.0	31.7	22.8	92.7	72.6	9.1	3.9
6	February	05-11	0.0	32.4	24.2	94.6	74.4	9.0	4.0
7		12-18	0.0	32.6	23.7	93.9	75.6	9.1	3.9
8		1925	0.0	32.5	23.1	92.1	77.9	9.1	4.1
9		26-04	0.0	33.5	24.1	90.4	73.7	9.6	4.3
10	March	05-11	0.0	32.9	24.1	93.9	74	8.9	4.1
11		12-16	1.18	33.2	24.4	92.2	76.4	7.3	3.94

Appendix II.

SES (Standard Evaluation System for Rice) SCORE CHART

Scale	Damaged grains per panicle (%)
0	No damage
1	Less than 3
3	4-7
5	8-15
7	12-25
9	26-100

MANAGEMENT OF ROCK BULRUSH (*Schoenoplectus juncoides* (Roxb.) Palla) IN WET SEEDED RICE

by

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Abstract of the thesis

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ABSTRACT

An investigation entitled "Management of rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) in wet seeded rice" was conducted at College of Agriculture, Vellayani during 2016 to 2018. The major objectives were to study the biology of the weed rock bulrush (*Schoenoplectus juncoides* (Roxb.) Palla) and to develop an effective and economic method for its management in wet seeded rice.

Field experiment was undertaken in farmer's field at Nemom block, Thiruvananthapuram during *rabi* season (November 2017 to March 2018). Weed biology was studied by observing sample plants in weedy check plots starting from the emergence of the weed. The experiment was laid out in Randomized Block Design with 8 treatments replicated thrice. The weed management practices tested were: T_1- bensulfuron methyl + pretilachlor @ 60+600 g ha^{-1} at 4-7 days after sowing (DAS) followed by (fb) hand weeding (HW) at 35-40 DAS; T_2- penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS; T_3- ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS; T_4- carfentrazone-ethyl @ 20 g ha^{-1} at 15 DAS fb HW at 35-40 DAS; T_5- metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAS fb HW at 35-40 DAS; T_6- 2,4-D sodium salt @ 1 kg ha^{-1} at 20 DAS fb HW at 35-40 DAS; T_7- HW twice at 20 and 40 DAS and T_8- weedy check. Pre-germinated seeds of var. Sreyas (MO 22) were broadcasted in the puddled soil following all cultural practices as per KAU PoP (KAU, 2011) except weed management.

Study on weed biology revealed that the weed behaved as annual/perennial depending on field situation, with an average duration of 106 days in continuously cultivated fields. Phenology of rock bulrush revealed that the weed took 5 days for seed germination, 22 days for flowering, 33 days for spike maturity and 68 days for seed maturity after wet seeding of rice. The weed exhibited a lodging

behaviour after spike maturity. Seeds were observed to be the main propagule however, vegetative buds and rhizomes also helped in propagation. Lodging after spike maturity and spiny apex of seeds were found to facilitate seed dispersal. The weed was observed to be a prolific seed producer (862 seeds plant^{-1}) with a biomass production of 0.96 t ha^{-1} as worked out from weedy check plots. The nutrient content of the weed was analyzed to be 0.90, 0.33 and 1.14 per cent NPK respectively.

Among the weed management practices tested, ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (T_3) was significantly superior to all other treatments with respect to number of productive tillers m^{-2} (382), number of grains panicle^{-1} (134.27), filled grains panicle^{-1} (115.85), grain yield (5750 kg ha^{-1}) and straw yield (9955 kg ha^{-1}). Grain yield recorded in penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS (5500.67 kg ha^{-1}) was on par with T_3. These treatments also recorded higher B: C ratios of 2.26 and 2.11 respectively.

At 45 and 60 DAS, lower weed density (2.09 and 3.15 respectively) and weed dry weight (0.13 and 1.83 g m^{-2} respectively) were recorded for ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS. Higher weed control efficiencies of 99.82 and 98.07 per cent were obtained in plots treated with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS during critical stages of crop weed competition (45 and 60 DAS). Penoxsulam @ 22.5 g ha^{-1} at 15 DAS fb HW at 35-40 DAS was on par with T_3 at 45 and 60 DAS recording weed control efficiencies of 99.07 and 97.90 per cent respectively. Uncontrolled weed growth in wet seeded broadcasted rice could cause a yield reduction of 52.18 per cent. Higher crop uptake (kg ha^{-1}) of N (219.01), P (39.32) and K (228.55) were recorded in T_3 and it was statistically on par with T_2, T_6 and T_7. The weed removal of N, P and K (8.61, 3.13 and 10.95 kg ha^{-1} respectively) were also lower with ethoxysulfuron @ 15 g ha^{-1} at 15 DAS fb HW at 35-40 DAS.

Schoenoplectus juncoides was observed to be an emerging sedge weed in the cultivated wet lands with round upright culms having annual or perennial nature, reproducing by seeds or rhizomes with a biomass production of 0.96 t ha^{-1}, if uncontrolled. The weed could be effectively controlled by ethoxysulfuron @ 15g ha^{-1} or penoxsulam @ 22.5 g ha^{-1} both at 15 DAS fb HW at 35-40 DAS. Considering the economics, ethoxysulfuron @15g ha^{-1} at 15 DAS followed by hand weeding at 35-40 DAS could be adjudged as the most effective strategy for the management of *Schoenoplectus juncoides* (Roxb.) Palla in wet seeded rice.

സംഗ്രഹം

നെല്ലിന്റെ ചേറ്റുവിത രീതി അവലംബിക്കുമ്പോൾ വളരുന്ന മട്ടിപുല്ല് അഥവാ മണപുല്ല് (ഷീനോപ്ലെക്ട്സ് ജൺകോയ്ഡ്സ്) എന്ന കോര വർഗത്തിൽപ്പെട്ട കളയുടെ നിയന്ത്രണമാർഗം കണ്ടെത്താൻ 2017- 2018 കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി. തിരുവനന്തപുരം ജില്ലയിലെ ഊക്കോട് പഞ്ചായത്തിലെ വയലിൽ 2017 നവംബർ മുതൽ 2018 മാർച്ച് വരെയുള്ള കാലയളവിൽ, മങ്കൊമ്പ് നെല്ല് ഗവേഷണ കേന്ദ്രത്തിൽ വികസിപ്പിച്ചെടുത്ത ശ്രേയസ് എന്ന ഇടത്തരം ദൈർഘ്യമുള്ള നെല്ലിനം ഉപയോഗിച്ചാണ് പ്രസ്തുത പഠനം നടത്തിയത്. നെല്ല് വിതച്ച് 1 ആഴ്ച്ചയ്ക്കുള്ളിലും 15 ദിവസങ്ങൾക്കുശേഷമുള്ള കളനാശിനിപ്രയോഗവും കൈകൾക്കൊണ്ടുള്ള കള പറിച്ചുനീക്ക ൽ രീതിയും (35-40 ദിവസങ്ങൾക്കുശേഷം) സംയോജിച്ചുള്ള വ്യത്യസ്തമായ മാർഗങ്ങളാണ് പരീക്ഷിച്ചത്.

റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണ രൂപകൽപ്പനയിൽ നടത്തിയ ഈ പഠനത്തിൽ എട്ടു വ്യത്യസ്ത കളനിയന്ത്രണ മാർഗങ്ങളുടെ നിയന്ത്രണമികവാണ് പരീക്ഷിച്ചത്. ബെൻസൽഫ്യൂറോൺ മീതൈൽ + പ്രെറ്റിലാക്ലോർ 60 + 600 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 4-7 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_1), പെനോക്സുലാം 22.5 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 15 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_2), എതോക്സിസൽഫ്യൂറോൺ 15 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 15 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_3), കാർഫെൻട്രസോൺ ഈതൈൽ 20 ഗ്രാം ഹെക്ടറിന് എന്ന

തോതിൽ വിതച്ച് 15 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_4), മെറ്റ്സൾഫ്യൂറോൺ മീതൈൽ + ക്ലോറിമൂറോൻ ഈതൈൽ 4 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 20 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_5), 2, 4-ഡി സോഡിയം സാൾട്ട് 1 കിലോ ഗ്രാം എന്ന തോതിൽ വിതച്ച് 20 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_6), രണ്ടു തവണ കളപറിച്ചുനീക്കൽ - വിതച്ച് 20 ദിവസത്തിനുശേഷവും 40 ദിവസത്തിനു ശേഷവും (T_7), കളകൾ നീക്കംചെയ്യാത്ത വീഡി ചെക്ക് (T_8) എന്നീ രീതികളാണ് പഠനവിധേയമാക്കിയത്.

ഷീനോപ്ലെക്ട്സ് ജൺകോയ്ഡ്സ് എന്ന കളയുടെ ജീവിതചക്രവും പഠനവിധേയമാക്കി.

റോക്ക് ബുൾറഷ് അഥവാ ഷീനോപ്ലെക്ട്സ് ജൺകോയ്ഡ്സ് എന്ന കോരവർഗ്ഗത്തിൽപ്പെട്ട ഈ പുല്ല്, തുടർച്ചയായി കൃഷിയിറക്കുന്ന വയലുകളിൽ ഒരു വാർഷികകളയായും, കൃഷിയിറക്കാതെ തരിശ്ശിട്ടിരുന്ന വയലുകളിൽ ഒരു വറ്റാത്തകളയായും കാണപ്പെടുന്നതായായും പഠനഫലങ്ങൾ സൂചിപ്പിക്കുന്നു. വിത്തിലൂടെയും മൂലകാണ്ഡത്തിലൂടെയും മുകുളങ്ങളിലൂടെയും പ്രവർധനം നടത്തുന്ന ഈ കള നെല്ലിന്റെ

ജീവിതാവളർച്ചകാലത്തിലുടനീളം കാണപ്പെടുന്നു. അനിയന്ത്രിതമായ വളർച്ച അനുവദിച്ചാൽ ഹെക്ടറിൽ 0.96 ടൺ ജൈവ അവശിഷ്ടം ഉൽപ്പാദിപ്പിക്കാൻ മട്ടിപ്പുല്ലിന് സാധിക്കും.

ചേറ്റുവിതയിൽ മട്ടിപ്പുല്ല് നിയന്ത്രണത്തിനായി നടത്തിയ ഗവേഷണ പഠനത്തിൽ എതോക്സിസൾഫ്യൂറോൺ 15 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ചു 15 ദിവസത്തിനുശേഷവും

തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_3), പെനോക്സുലാം 22.5 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ചു 15 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_2) എന്നീ നിയന്ത്രണ രീതികൾ തുല്യഫലപ്രാപ്തി രേഖപ്പെടുത്തി. എന്നാൽ, സാമ്പത്തിക ലാഭം കൂടി കണക്കിലെടുക്കുമ്പോൾ എതോക്സിസൾഫ്യൂ-റോൺ ഹെക്ടറൊന്നിനു 15 ഗ്രാം എന്ന തോതിൽ വിതച്ച് 15 ദിവസങ്ങൾക്കുശേഷവും തുടർന്ന് കളപറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (T_3) അവലംബിക്കുന്നത് മട്ടിപ്പുല്ലിന്റെ (ഷീനോപ്ലെക്ട്സ് ജൺകോയ്ഡ്സ്) നിയന്ത്രണത്തിനും നെല്ലിന്റെ മികച്ച വിളവിനും ഏറ്റവും മികച്ച രീതിയാണെന്ന് പഠനഫലങ്ങൾ സൂചിപ്പിച്ചു.