BIOLOGY AND MANAGEMENT OF *Sacciolepis interrupta* (Willd.) Stapf IN RICE

By

PUJARI SHOBHA RANI

(2016-21-015)

Department of Agronomy

COLLEGE OF HORTICULTURE

KERALA AGRICULTURAL UNIVERSITY

VELLANIKKARA, THRISSUR – 680656

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THESIS

Submitted in partial fulfillment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled **"Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

P. Shobha

Vellanikkara

Date: 09.10.2020

Pujari Shobha Rani

(2016-21-015)

CERTIFICATE

Certified that this thesis entitled **"Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice"** is a bonafide record of research work done independently by **Mrs. Pujari Shobha Rani (2016-21-015)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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

Vellanikkara
Date: 9-10-2020

CERTIFICATE

We, the undersigned members of the advisory committee of **Mrs. Pujari Shobha Rani (2016-21-015)**, a candidate for the degree of **Doctor of Philosophy in Agriculture** with major field in **Agronomy**, agree that this thesis entitled **"Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice"** may be submitted by **Mrs. Pujari Shobha Rani** in partial fulfillment of the requirement for the degree.

9-10-2020

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

9/10/2020

Dr. P. Prameela
(Member, Advisory committee)
Professor
Department of Agronomy
College of Horticulture, Vellanikkara

09.10.2020

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

9/10/2020

Dr. T. Girija
(Member, Advisory committee)
Professor and Head
Dept. of Plant Physiology
College of Horticulture, Vellanikkara

9/10/2020

Dr. K. Sreelakshmi
(Member, Advisory committee)
Assistant Professor (Agronomy)
Krishi Vigyan Kendra
Pattambi

EXTERNAL EXAMINER

Dr. D. Subramanyam
09/10/2020
Professor
Department of Agronomy
S.V. Agricultural College
Acharya N.G. Ranga Agricultural University, Tirupati

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Pujari Shobha Rani

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Introduction

1. INTRODUCTION

Weeds are one of the main threats to biodiversity and agriculture, and under changing climatic regime, management of this threat will be an increasing challenge in two ways, firstly, the spectrum of weed species will change and secondly, some weeds will become more invasive. Changing climatic conditions affect arable weeds in various ways, and in order to persist in a local habitat, species have to respond to changes of the environment (Pautasso *et al*., 2010).

Climate change affects the various geographic range expansions of weeds like migration or introduction to new areas, acclimation and adaptation. Migration of weeds to areas with favorable climate alters their distribution, leading to range shift, where the weeds possess appropriate propagules or seed distribution mechanisms (Kubisch *et al*., 2013). So apart from impacting the crop productivity, climate change also affects weed management especially herbicide efficacy, and subsequently can affect development of herbicide- resistant weeds and new weeds.

Change in the method of crop establishment from transplanting of seedlings to direct-seeding in response to rising production costs, especially for labour and mechanization has led to shift in weed flora in rice ecosystems. The adoption of direct-seeding has resulted in a change in the relative abundance of weed species like *Echinochloa* spp., *Ischaemum rugosum*, *Cyperus difformis* and *Fimbristylis miliacea* which are widely adapted to conditions of DSR (Rao *et al*., 2007).

Shift in the crop establishment method from transplanting to direct sowing of pre germinated seeds and increased dependence on herbicides. New weeds invade rice fields because of human interventions and they adapt and acclimatize in new environments. Effective control of these newcomers becomes a challenging issue. One such a newcomer is *Sacciolepis interrupta*.

S. interrupta is a tropical grass which mimics rice crop at early stages and of late has been appearing as a major weed in many rice growing areas. It is widespread in tropical and temperate warmer regions and is distributed in Asia and Africa. In

India, it is reported in rice growing areas of eastern India and Kerala. In the context of climate change, the occurrence and spread of *S. interrupta,* is a matter of concern in the rice tracts of Kerala.

The major rice growing tracts of Kerala are ‘Palakkad’, ‘Kuttanad’, ‘Pokkali’, and ‘Kole’ lands. Direct seeding of rice, particularly dry seeding is a common practice in Palakkad district of Kerala, which accounts for more than 45% of total rice production of the state (Thomas, 2011). *S. interrupta* was initially seen as a minor weed in the semi dry rice growing areas of Palakkad. However, extremely fast growth habit and multiple methods of propagation have led to its new status as a troublesome weed. It is also now reported in both wet seeded and transplanted rice. A study by Renu (1999) concluded that competition from *S. interrupta* alone could reduce the rice grain yield by 50%.

Experiences so far have indicated that the weed has the potential to develop into a serious menace, and drastically affect the production and productivity of rice. The intensity of occurrence of *S. interrupta* in Palakkad and other important rice growing tracts of the state, *viz., Kole* lands in Thrissur district and Kuttanad in Alleppey and Ernakulum districts, has not been assessed. Hence, a detailed survey was needed to assess the distribution and occurrence of this weed in the major rice growing tracts of Kerala. The problem of *S. interrupta* assumes significance as more and more farmers resort to direct seeding mainly because of uncertainty of timely receipt of rains and also to avoid the hassles of transplanting.

Weed biology, germination and emergence pattern is related to study of weeds in relation to their geographic distribution, habitat, growth and population dynamics of weed species and communities (Rao, 1999).

S. interrupta is a tropical grass weed, and it is commonly called as, ‘Cup scale grass’ and as ‘*Pollakala*’ in Malayalam, meaning a weed that is hollow, belongs to the family Poaceae and is an annual or perennial herb. *S. interrupta* is reported to flower and fruit year round when vegetatively propagated and the flowers are pollinated by insects. It can be distinguished from other species of *S. interrupta* by its robust, spongy, floating culms and larger spikelets. Its rhizomatous structure, rooting from lower nodes, makes it a perennial plant and it further grows and multiplies as separate individuals simultaneously with rice, owing to mimicry with rice seedlings (Clayton *et al*., 2006).

Understanding weed biology, germination pattern with respect to different environmental, edaphic and management factors which offers useful keys to formulate weed management strategies. For example, it defines the susceptible stages for weed control. This helps the farmers to control weeds effectively and reduces inputs for crop cultivation.

Among the various weed management approaches in direct seeded rice, management by use of herbicides is promising as it is easy, quick, economical and feasible compared to manual weeding which is laborious and costly (McErlich and Boydston, 2013). Many herbicides are being used successfully both as pre-emergence and post-emergence sprays for weed control in rice. New generation herbicides have different chemical composition with very low off residue buildup and low mammalian toxicity. Efficacy of different pre and post-emergence herbicides, has to be tested individually as well as in an integrated manner to develop an effective recommendation for control of the weed before it reaches alarming proportions.

With this view, the research programme entitled "Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice" was conducted with the following objectives:

- To study the distribution of *S. interrupta* in major rice tracts of Kerala.
- To study the biology of *S. interrupta* with respect to growth rate, days taken for attaining different growth stages, seed production potential and dry matter accumulation.

- To study the germination ecology of *S. interrupta* under different moisture regimes.
- To test the bioefficacy of different pre-emergence and post-emergence herbicides for management of *S. interrupta*.
- Development of an effective recommendation for management of *S. interrupta* in rice.

Review of literature

2. Review of literature

Rice (*Oryza sativa* L.) is a major food crop in Asia, and many other tropical and sub-tropical countries in the world, and 90 per cent of this crop is grown and consumed in Asia. Traditionally, rice is grown mainly by transplanting seedlings but due to water scarcity and high labour cost, there is a shift from transplanting to direct seeding (Pandey and Velasco, 2005). In direct seeded rice, weeds act as a major constraint in production and crop suffers the competition from early stages of growth, which drastically affects the grain yield (Choubey *et al.*, 2001). For achieving higher yield and productivity, effective early weed management is imperative in direct seeded rice.

A shift in crop establishment method from transplanting to direct seeding brings about more competitive weed flora requiring revised weed management approaches for effective control. A weed-free period for the first 15-45 days after sowing (DAS) is considered as critical for effective weed management to avoid loss in yield in dry direct-seeded rice (Chauhan and Johnson, 2011; Singh *et al.,* 2012).

Under the present changing climatic scenario, where dry periods are becoming longer and more frequent, new weeds have the potential to become a major menace in food crops. Effective control of these newcomers, becomes a challenging issue. One such a newcomer is *S. interrupta,* the occurrence of which was earlier confined to semi dry rice growing areas. However, because of fast growth and multiple ways of survival, it has now been reported in wet seeded as well as transplanted rice. In a quantitative weed survey in the rice fields of *Kole* lands of Kerala, *S. interrupta* accounted for a relative density of 2.46 per cent (Latha and Jaikumaran, 2015). The problem of *S. interrupta* assumes significance as more and more farmers resort to direct seeding mainly because of uncertainty of timely receipt of rains and also to avoid the hassles of transplanting.

Among the various weed management approaches in direct seeded rice, management by use of herbicides is promising as it is easy, quick, economical and feasible compared to manual weeding which is laborious and costly (McErlich and Boydston, 2013). Many herbicides are being used successfully both as pre-emergence and post-emergence sprays for weed control in rice. New generation herbicides have different chemical compositions with very low off residue buildup and low mammalian toxicity.

In this background a brief review on various aspects of weed shift under changing climatic conditions, biology and scenario of weed shift of *S. interrupta* in rice ecosystem, weed spectrum in semi dry rice, critical period of weed competition in rice, herbicidal management of grassy weeds in rice and their influence on yield attributes and yield of rice under dry seeded conditions have been discussed in this chapter

2.1 Climate change and weeds

Weeds are one of the main threats to biodiversity and agriculture and under the changing climatic spectrum, management of this threat will be an increasing challenge in two ways, firstly, the suite of weed species will change and secondly, some weeds will become more invasive. Changing climatic conditions affect arable weeds in various ways, and in order to persist in a local habitat, species have to respond to changes of the environment (Woodward and Cramer, 1996). These responses leads to three distinct kinds of shifts like range shift, niche shift and trait shift acting at landscape, community, and population scales respectively (Lavorel and Garnier, 2002; Pautasso *et al*., 2010).

Climate change affects the various geographic range expansions like migration or introduction to new areas, acclimation and adaptation. Migration of weeds with a favorable climate alters their distribution leading to range shift, where the weeds possess appropriate propagule or seed distribution mechanisms (Kubisch *et al.*, 2013). Acclimation of weeds by their phenotypic plasticity without any evolutionary adjustments helps them either to tolerate or avoid the changes in climate leading to performance of the weeds beyond the species' ecological optimum (Lavorel and Garnier, 2002). As a consequence, the fitness and the competitive ability of the weeds are either reduced or enlarged (Barrett, 2000). Consequently, the realized niche is being altered, which leads to niche shifts. Adaptation of weeds by evolution of new properties or by optimization of existing ones, which are driven by natural selection, result in trait shifts, which acts at population scale, and are prominent at morphological, physiological, and genetic processes at the individual plant scale (Tungate *et al*., 2007).

Apart from affecting the crop productivity, climate change also affects weed management especially herbicide efficacy, and subsequently effects development of herbicide- resistant weeds and new weeds. Various environmental factors like carbon dioxide, temperature, relative humidity, precipitation and soil moisture, and wind influence efficacy, retention and performance of the applied herbicide (Upasani and Barla, 2018).

2.1.1 Weed response to elevated CO_2

Atmospheric CO_2, temperature, and water or nutrient availability are important abiotic factors that directly affect weed physiology and growth. Elevated CO_2 levels could affect the growth rates of crops and weeds by altering temperature, precipitation, and radiation patterns. Increased CO_2 levels will directly affect photosynthetic activity and crop ability to compete with surrounding weed species, which could modify weed distribution patterns (Chandrasena, 2009). Many C_3 weeds have shown significant increases in growth, with substantial decreases in the yields of competing crops, because of increased CO_2. Ziska (2000) reported a 65 % increase in the biomass of a C_3 weed, common lambsquarters (*Chenopodium album* L.), with an analogous reduction in seed yield of soybean by 39 % at elevated CO_2 concentrations. Similarly, elevated CO_2 was found to increase the seed yield and biomass of weedy or wild rice compared with cultivated rice as the competitive density increased, indicating greater reduction in the yields of cultivated rice in the presence of C_3 weeds in future CO_2 concentrations (Ziska *et al*., 2010).

2.1.2 Weed response to increased temperature

Increased temperature has greater effect on plant phenological development than elevated CO_2 (Lee, 2011). It was also reported that with an increase of 4^0C temperature there was an advancement of emergence timing of *Chenopodium album* and *Setaria viridis* by 26 and 35 days, and flowering time by 50 and 31.5 days respectively. Biomass accumulation by annual grass species was more pronounced in C_3 and C_4 plant species during their reproductive phase as compared with the vegetative phases by increased temperatures. However, the increased temperature offset the benefits of elevated CO_2 by reducing the reproductive output. Apart from weed growth, the uptake and translocation of herbicides in plants and their persistence in soil is also affected by rising temperatures (Rodenburg *et al*., 2011).

2.1.3 Weed response to variation in rainfall

A change in rainfall patterns would favor hydromorphic weeds while prolonged drought spells will benefit C_4 over C_3 weeds. A change from transplanting to direct seeding of rice, in relation to water saving, resulted in increased weed competition and changed weed dynamics (Matloob *et al*., 2015). Chauhan and Abugho (2013) reported that *Amaranthus spinosus* and *Leptochloa chinensis* (L.) *Nees* survived under water stress conditions and produced a significant number of tillers/branches and leaves even at the lowest soil water content.

2.2 Weed spectrum in semi dry rice

Direct seeded rice can be grown under both rainfed upland and irrigated or flooded conditions. The distribution of weeds in paddy fields is largely determined by environmental factors that are influenced by rice competition. Kim and Park (1996) reported that many weeds have wide range of environmental tolerance and broad geographical distribution. Approximately 350 species in over 150 genera and 60 plant families are recorded as rice weeds, of which grasses are ranked as first, followed by sedges and broadleaf weeds (Holm *et al*., 1977). According to

Kuyeonchung *et al*. (2002) cultivation methods strongly influence weed diversity and species distribution. Species composition and diversity varied widely with changes in cultivation methods (Tomita *et al*., 2003). Gowda *et al*. (2009) reported that more than 50 weed species are reported to cause yield losses in DSR, the loss ranging from 30 per cent to 98 per cent.

Among different group of weeds, grass weeds are most influential in reducing grain yield, followed by broad-leaved weeds and sedges (DeDatta *et al*., 1968). Azmi and Baki (1995) estimated that the yield loss caused by grasses, broadleaved weeds and sedges was 41, 28 and 10 per cent, respectively.

In direct seeded rice *Echinochloa crus-galli*, *Echinochloa colona*, *Eleusine indica*, *S. interrupta*, *Eclipta alba*, *Ludwigia parviflora*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* were reported as the major weed species (Verma *et al*., 2004). In dry seeded rice, *Echinochloa colona* (30.8 per cent), *Echinochloa crus-galli* (15.8 per cent), *Ischaemum rugosum* (26.4 per cent), *Commelina diffusa* (7.6 per cent) and others (8.9 per cent) were identified as most dominating weed species by Bahar and Singh (2004). Singh *et al*. (2005) reported that *Echinochloa crus-galli*, *Echinochloa colona*, *Leptochloa chinensis*, *Cyperus rotundus*, *Cyperus difformis*, *Fimbristylis dichotoma*, *Commelina benghalensis* and *Cyanotis axillaris* were the dominating weed flora.

After the introduction of DSR, weeds such as *Echinochloa crus-galli* (L.) Beauv. and *Leptochloa chinensis*, which were apparently unfamiliar to rice fields earlier, became widespread and dominant (Azmi *et al*., 2005). *Cynodon dactylon*, *Eragrostis gangeticum*, *Setaria glauca*, *Dactyloctenium aegypticum*, *Cyperus rotundus*, *Cyperus iria*, *Cyperus compressus*, *Fimbristylis miliacea*, *Oldenlandia corymbosa*, *Ludwigia parviflora*, *Borreria hispida*, *Desmodium triflorum*, *Scoparia dulcis*, *Sida rhombifolia*, *Phyllanthus niruri*, *Alysicarpus vaginalis* and *Cleome viscosa* were the major weed flora in rainfed upland rice as reported by Saha *et al*. (2005).

Singh *et al*. (2007a) reported that weeds associated with dry-seeded rice included grasses like *Dactyloctenium aegyptium*, *Echinochloa crus-galli, Echinochloa colonum*, *Leptochloa chinensis,* and major broadleaved weeds were *Commelina benghalensis, Caesulia axillaris*, *Eclipta prostrata*, *Euphorbia hirta*, *Portulaca oleracea*, *Trianthema portulacastrum* and *Lindernia* spp. Among the different weed flora in rice fields of Guntur, Andhrapradesh, Rao *et al.* (2008) found that *Echinochloa colonum* (36 per cent), *Dinerba retroflexa* (6 per cent), *Panicum repens* (3 per cent), *Cynodon doctylon* (5 per cent), *Cyperus rotundus* (5 per cent), *Corchorus acutangulus* (10 per cent), *Eclipta alba* (10per cent), *Cleome viscosa* (6 per cent), *Phyllanthus niruri* (7 per cent), *Celosia argentia* (5per cent), *Digera arvensis* (4 per cent) and *Trianthema portulacastrum* (3 per cent) were dominant.

Mishra and Singh (2008) reported that major weeds associated with dry seeded rice in Jabalpur were *Echinochloa colonum* (31.5 per cent), *Phyllanthus niruri* (26.5 per cent), *Commelina communis* (17.8 per cent), *Cyperus iria* (9.9 per cent), *Alternanthera sessilis* (5.9 per cent), *Dinebra retroflexa* (5.1 per cent), *Physalis minima* (1.8 per cent) and *Caesulia axillaris* (1.2 per cent).

It has been reported that *Cyperus difformis*, *Cyperus iria*, *Sphenoclea zeylanica*, *Echinochloa crus-galli*, *Echinochloa colona*, *Fimbristylis miliacea* and *Eclipta alba* were the dominant weed species in DSR (Hussain *et al*., 2008; Singh and Singh, 2010). Tiwari *et al*. (2010) reported that *Echinochloa crus-galli*, *Echinochloa colona*, *Commelina benghalensis*, *Monochoria vaginalis* and *Ludwigia perennis* were problematic weeds in DSR. Balasubramanian *et al*. (2010) identified *Echinochloa colona* and *Panicum repens* under grasses, *Cyperus difformis* and *Fimbristylis miliacea* under sedges, *Eclipta alba*, *Marselia quadrifolia*, *Ammania baccifera* and *Ludwigia parviflora* under broad-leaved weeds as major weeds in DSR. According to Muthukrishnan *et al*. (2010) in Tamil Nadu, weeds of major concern in DSR included *Ischaemum rugosum*, *Leptochloa chinensis*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Cyperus iria*, *Fimbristylis miliacea* and *Cyperus difformis.*

Naresh *et al.* (2011) identified the weeds associated with direct seeded rice (DSR) as *Brachiaria* spp., *Cynodon dactylon, Dactyloctenium aegyptium, Digitaria ciliaris, Echinochloa colonum, Echinochloa crus-galli, Eragrostis japonica, Ischaemum rugosum, Leptochloa chinensis, Paspalum distichum, Sorghum halepense, Ageratum conyzoides, Amaranthus viridis, Ammania auriculata, Caesulia axillaris, Commelina benghalensis, Convolvulus arvensis, Corchorus* spp., *Digera muricata, Eclipta prostrata, Euphorbia hirta, Euphorbia microphylla, Lindernia crustacea, Ludwigia* spp., *Phyllanthus fraternus, Parthenium hysterophorus, Portulaca oleracea, Trianthema portulacastrum, Eleusine indica, Panicum repens, Digitaria sanguinalis, Eragrostis tenella, Commelina diffusa, Celosia argentea, Alternanthera sessilis, Marsilea quadrifolia, Monochoria vaginalis, Sphenoclea zeylanica, Physalis minima, Ammania baccifera, Fimbristylis miliacea, Echinochloa* spp, *Leptochloa chinensis,Caesulia axillaris, Brachiaria* spp., *Dactyloctenium aegyptium, Physalis minima, Cyperus difformis, Cyperus iria, Fimbristylis quinquangularis, Scirpus supinus, Cucumis* spp. and *Digera muricata.*

The major weed flora in direct sown rice in Punjab as reported by Walia *et al*. (2012) were *Cyperus rotundus, Cyperus iria* and *Cyperus compressus* among sedges, *Digitaria sanguinalis, Echinochloa* spp., *Eleusine aegyptiacum, Leptochloa chinensis* and *Eragrostis* spp. among grasses and *Ammania baccifera* and *Caesulia axillaris* among broad-leaved weeds.

Mahajan *et al*. (2013) conducted a survey in Punjab, and reported that dominant weed species in DSR fields were *Cyperus iria* (L.), *Echinochloa colona* (L.), *Eragrostis* spp., *Leptochloa chinensis* (L.), *Digitaria sanguinalis* (L.), *Dactyloctenium aegyptium* (L.), *Cyperus rotundus* (L.), and *Eleusine indica* (L.). Singh *et al*. (2013) reported that major weed species in direct seeded rice were *Echinochloa colona* (L.), *Echinochloa crus-galli* (L.), *Dactyloctenium aegyptium* (L.), among grasses, sedges included *Cyperus* spp. and broad-leaved weeds dominating were *Caesulia axillaris* (L.), *Ammania baccifera* (L.), *Eclipta alba* (L.) and *Phyllanthus niruri* (L.), and in the year 2010 the composition of grasses, broad-leaved and sedges was 35.5, 33.5 and 30.9 per cent, and 37.7, 32.0 and 30.1 per cent during 2011, respectively. Chauhan and Abugho (2013) identified the major weeds in dry seeded rice as cleome (*Cleome rutidospermum* Dc.), bermuda grass (*Cynodon dactylon* L.), purple nutsedge (*Cyperus rotundus* L.), crow foot grass [*Dactyloctenium aegypticum*(L.) Willd.], southern crab grass [*Digitaria ciliaris* (Retz.) Koel.], jungle rice [*Echinochloa colona* (L.) Link], goosegrass [*Eleusine indica* (L.) Gaertn.], chinese sprangletop [*Leptochloa chinensis* (L.) Nees], common purslane (*Portulaca oleracea* L.) and horse purslane (*Trianthema portulacastrum* L.).

Jacob *et al*. (2014) reported that among grasses, *Echinochloa crus-galli* and *Echinochloa stagnina* (17 per cent) and *Leptochloa chinensis* (28 per cent), in dicots *Ludwigia parviflora* (12 per cent) and among sedges, *Fimbristylis miliacea* (14 per cent), *Cyperus iria* and *Cyperus difformis* (21 per cent) were dominant in the rice fields of Alapad *Kole* lands of Kerala.

Chauhan *et al.* (2015) identified that *Cleome rutidosperma*, *Cyperus iria*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Echinochloa colonum*, *Eclipta prostrata*, *Eleusine indica*, *Leptochloa chinensis*, and *Trianthema portulacastrum* were the major weed flora found in rice at Las Banos,Philippines. Duary *et al.* (2015a) revealed that throughout the cropping period of rice, *Echinochloa colonum* and *Digitaria sanguinalis* among the grasses, *Cyperus difformis* and *Cyperus iria* among the sedges and *Ludwigia parviflora* among the broadleaved weeds were predominant.

Punia *et al*. (2016) studied 28 weed species (7 grassy, 7 sedges and 14 broadleaved) that were found to infest rice fields in Haryana. Grassy weeds *Echinochloa colonum* and *Echinochloa glabrescens*, *Ammania baccifera* among broad-leaved weeds, and *Cyperus rotundus* and *Cyperus difformis* among sedges were present predominantly in all the districts. Lipishmita (2016) reported that the weed flora in direct-seeded aerobic rice of sandy loam soils of Raipur, Chhattisgarh was dominated by grasses *viz.*, *Echinochloa colonum*, *Ischaemum rugosum* and *Leptochloa chinensis*, broad-leaved weeds *viz.*, *Aeschynomene indica*, *Alternanthera* *triandra*, *Cyanotis axillaris*, *Commelina benghalensis*, *Eclipta alba*, *Ludwigia parviflora*, *Spilanthes acmella* and *Marsilia quadrifolia,* and sedges *viz*., *Cyperus iria*, *Fimbristylis miliacea* and *Cyperus difformis* in direct-seeded aerobic rice.

Parameswari and Srinivas (2017) reported that major weed flora in direct seeded rice were *Cynodon dactylon, Panicum* spp., *Cyperus rotundus, Cyperus iria, Cyperus difformis, Echinochloa colonum, Ammania baccifera* and *Eclipta alba.* Singh *et al.* (2017) observed the major weeds associated with dry seeded rice in Haryana to be *Cyperus difformis, Cyperus rotundus, Leptochloa chinensis, Echinochloa glabrescens, Eclipta alba* and *Ammania* spp.

Liu-qing *et al*. (2007) reported remarkably increased infestation of *Alternanthera philoxeroides* Mart. in rice fields of China over the last 20 years. It showed that some new weed species or weeds that were not necessarily adapted for rice fields otherwise exhibited a pronounced DSR distribution and dominance. Consequently, the implementation of DSR might lead to changes in the number of weed species encountered (narrow-leaved vs. broad-leaved) and their relative densities and proportions, resulting in a whole new scenario of intra and interspecific competition.

2.3 Crop-weed competition in semi dry rice

Grasses are most competitive in rice, followed by sedges, and least competitive are the broad-leaved plants (Umapathi *et al*., 2000). Rice and rice weeds have similar requirements for growth and development, and they compete for limited resources such as nutrients, moisture, light, space etc. Weeds dominate the crop habitat, reducing the realized yield of rice. Among the weeds, grasses pose serious competition for soil, water and nutrients apart from that for CO_2 and light. Sedges, as their root systems are fibrous, primarily compete for nutrients, whereas broadleaved weeds pose less competition for nutrients with rice because of their deep root systems.

Balasubramaniyam and Palaniappan (2001) reported that weeds could deprive the crops of 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg. Weed infestation depleted the soil nitrogen, phosphorus and potassium by 24.7, 5.8 and 63.4 kg/ha respectively, in one season (Sharma, 2007).

In semi-dry rice growing areas of Kerala where *S. interrupta* predominated, a yield loss of 73-86 per cent due to uncontrolled weed growth was reported (AICRP-WC, 1992; Sreedevi and Thomas, 1993). Rice yield was reduced by 34 per cent when the density of *S. interrupta*plants was 5/m^2 (AICRP-WC, 1997). Renu (1999) reported that competition from *S. interrupta* alone could reduce the rice grain yield by 50 per cent.

Shiji (2001) investigated the quantum of loss which occurred in rice due to different densities of *S. interrupta* and *Isachne miliacea*. Different weed densities were maintained in the experimental plots by thinning and the competition effects were assessed. The threshold level for beginning weeding operation was found to be 2/m^2 in the case of *S. interrupta*.

2.4 Critical period of weed competition in semi dry rice

Critical period of crop weed competition (CPWC) is the shortest time span during crop growth when weeding results in highest economic returns. CPWC is pre and post weed growth period that does not affect crop yield (Zimdahl, 2004). Singh *et al*. (2008) reported that the critical period of weed competition is longer for direct seeded rice *i.e.* 15 to 45 DAS. One of the important alternative weed management strategies for minimizing labour requirements for weeding operations, improving herbicide use efficiency and maximizing economic returns is a critical period based weed control approach.

In DSR, 15 and 45 DAS are considered as CPWC (Sahai *et al*., 1983; Singh *et al*., 1987; Rao and Nagamani, 2007). Acccording to Juraimi *et al*. (2009), the CPWC under saturated conditions was found to be between 2 and 71 DAS and 15 and 73 DAS under flooded conditions. Chauhan and Johnson (2011) showed that the CPWC varied as a function of row spacing and was 18-52 DAS and 15-58 DAS for a 15 cm and 30 cm spaced DSR field respectively. Anwar *et al.* (2012) assessed the CPWC in rice on the basis of 10 per cent yield loss (90 per cent weed-free rice yield) and suggested that crop should be kept weed-free from 21 to 43 DAS for achieving higher rice yields and net benefits.

Approximately sigmoid is the relationship between the period of weed competition (time of removal) and the related rice yield reduction (Murphy *et al*., 2002). El-Desoki (2003) reported that weed competition after 20 days of rice seeding resulted in a significant reduction in the number of panicles and grain yield per unit area, and an increase in yield was proportional to the weed-free period. According to Bhat *et al*. (2008), rice crop recorded greater plant height (70.63 cm) and accumulation of dry matter (1289 g m^{-2}) in weed free plots due to improved plant growth resulting from reduced weed competition at critical crop growth stages. Infestation of weeds up to 15 DAS and maintaining weed-free condition up to 60 or 75 DAS resulted in grain yields which were comparable to those of plots kept weed-free throughout the growing season (Singh, 2008).

In dry seeded rice, 4-6 weeks might elapse between sowing and permanent flood establishment and controlling weeds during this period was critical to optimize grain yield (Rao *et al*., 2007). The first 30 to 60 days after sowing should be considered to be a critical period for rainfed lowland rice competition (Moorthy and Saha, 2005). Johnson *et al*. (2004) conducted field trials of dry-seeded irrigated rice in the Senegal River delta and revealed that 95 per cent weed-free rice yield could be achieved by controlling weeds between 0 and 32 DAS in the wet season, and between 4 and 83 DAS in the dry season. Hasanuzzaman *et al*. (2009) reported that the losses in rice yield ranged between 15 and 20 per cent normally and in severe cases yield losses might exceed 50 per cent, depending on the species and the intensity of the weeds.

2.5 Biology, occurrence of *S. interrupta* in rice ecosystem

S. interrupta commonly known as 'cup scale grass' is a C_4 grass belonging to the family Poaceae, native to tropical Asia and tropical Africa. In India, it is distributed in rice growing areas of eastern India and Kerala. In Kerala, the occurrence of *S. interrupta* was earlier confined to semi- dry rice, but now it has been reported in wet seeded as well as transplanted rice. *S. interrupta* has annual or perennial habit, propagating by both seeds and rhizomes. It has decumbent spongy culms and grows to a height of 1.5 m. It is reported to flower and fruit year round and flowers are pollinated by insects. It can be distinguished from other species of *S. interrupta* by its robust, spongy, floating culms and larger spikelets. Its rhizomatous structure, rooting from lower nodes, makes it a perennial plant and it further grows and multiplies as separate individuals simultaneously with rice, owing to mimicry with rice seedlings (Clayton *et al*., 2006).

Weed species replace each other by succession and vary significantly in composition and dominance of species from one rice ecosystem to another (Kosaka *et al*., 2006; Juraimi *et al*., 2011). *S. interrupta* was initially seen as a minor weed in the semi dry rice growing areas of Palakkad. However, extremely fast growth habit and multiple methods of propagation has led to the weed infesting both wet seeded and transplanted rice (Latha and Jaikumaran, 2015).

Renu *et al*. (2006) reported that stale seedbed technique, a cultural-preventive measure was very effective in controlling *S. interrupta* and increasing yield and yield attributing characters of rice, as well as straw yield and uptake of nutrients.

2.6 Management of weeds in direct seeded rice

Weed management is a system approach whereby whole land use planning is done in advance to minimize the invasion of weeds in aggressive forms so as to give crop plants a very strong competitive advantage over the latter.

2.6.1. Non-chemical weed management

a. Hand weeding (HW)

Hand weeding is one of the traditional and most effective methods of weed control in controlling weeds in rice crop. Beltran *et al*. (2012) reported that hand weeding was the efficient method of weed control if weed infestation was less and labour expenses were economical.

According to Verma *et al*. (2004), hand weeding at 20 and 40 DAS resulted in lower weed population (15.2 m^2), lower weed dry weight (2.05 t ha^{-1}), higher WCE (90.6 per cent) and higher grain yield (3.66 t ha^{-1}) in direct seeded rice. Viren *et al*. (2005) reported that in direct seeded rice under rainfed conditions, all the weed control methods efficiently reduced weed growth and were significantly better than unweeded control, and WCE was highest (71.25 per cent) with power weeder followed by hand weeding thrice (70.55 per cent). Hasanuzzaman *et al.* (2009) observed that hand weeding twice controlled the weeds most effectively and produced significantly higher yield and yield contributing characters. Hand weeding at 15, 30 and 50 DAS recorded higher WCE (97.07 per cent), lower weed index (2.75 per cent) and higher grain yield of 3.45 kg ha^{-1} (Maity and Mukherjee, 2011).

Akbar *et al.* (2011) reported that HW thrice at (4, 6 and 8 weeks after sowing) during cropping period reduced the weed count and infestation by 95 per cent, and 30 per cent increase in grain yield was obtained compared to weedy check. Similarly Mubeena *et al*. (2014) reported that that HW thrice (2, 4 and 6 WAS) decreased the weed density by 90 per cent and increased grain yield by 77 per cent in aerobic rice.

b. Stale seedbed (SSB) Method

According to Jordan and Bollich (2002), stale seedbed is the principle of flushing out or removing germinal weed seeds before planting the main crop, thereby depleting the soil seed bank in the surface layer of soil and thus reducing the subsequent weed seedling emergence. Stale seedbed is a low cost weed control and productivity improving system in lowland rice and is helpful in lowering the weed flora infestation and improving the efficacy of other weed control methods especially herbicides (John and Mathew, 2001). Azmi and Johnson (2001) suggested out the important factors determining the success of SSB method *i.e.* seed bed preparation, water management and duration of SSB. SSB is an efficient method to manage weedy rice as reported by Chen (2001).

SSB is a cultural weed preventive technique where the soil is ploughed three to six weeks prior to sowing, thereby providing a favorable environment for germination of weeds seeds which are brought up to the top layer. Irrigating the soil before and after preparation of SSB also improved the rate of weed seeds germination and subsequent killing by natural tillage or by application of chemicals (Hill *et al*., 2006; Marahattta *et al*., 2017).

Pandey *et al.* (2009) revealed that SSB plots were superior in lowering the weed density and dry weight and increasing grain yield as compared to traditional sowing. Sindhu *et al*. (2011) reported that SSB+ paraquat application reduced the weed density compared to SSB+ hoeing, and grain yield was higher in SSB treated plots than normal sown plots. Bhurer *et al.* (2013) stated that SSB *fb* PE application of pendimethalin 30 EC@ 1 kg ha^{-1} *fb* bispyribac application as post-emergence @ 25 g ha^{-1} at 20 DAS was best alternative for hand weeding, recording higher net returns per unit investment.

According to Arya (2015) SSB technique showed reduction in biomass of weedy rice from 63.72 per cent to 39.83 per cent during first year and 76.99 to 58.27 during second year in a study in direct seeded wetland rice.

2.6.2 Chemical weed management

Herbicide acceptability increased rapidly after 1980 due to ease of use and lack of expensive labour requirements. Because of their success in reducing weed competition, simple usage, low economic cost and less manpower, herbicides looked better than other approaches (Ishaya *et al*., 2007). Most researchers working on weed management in direct seeded rice suggested that herbicide could be considered a viable alternative or substitute to hand weeding (Mahajan *et al*., 2009). As weed and rice seedlings emerge simultaneously in DSR, the use of herbicides became even more important, as some weeds like jungle rice, barnyard grass, weedy rice and *S. interrupta* were morphologically similar to rice (Chauhan, 2012).

1. Management through pre-emergent herbicides

Pre-emergence herbicides like pretilachlor, butachlor, pendimethalin, bensulfuron methyl, pyrazosulfuron ethyl and oxyfluorfen were effective in control of major grass weeds in rice including *S. interrupta* for 3-4 weeks (AICRP-WC, 2015).

a. Oxyfluorfen

Oxyfluorfen (23.5 per cent EC) is a 2-chloro-1-(3-ehtoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene belonging to the diphenyl-ether group of herbicide. It is a pre-emergence herbicide used in a variety of field crops to combat annual and perennial broad-leaved weeds. Its mode of action was by free radical formation, inhibiting protoporphyrinogen oxidase (Protox), which is the enzyme that transformed protoporphyrinogen IX to protoporphyrin IX, thereby causing necrosis in the plants (WSSA, 1994).

Effect of oxyfluorfen on weeds

Oxyfluorfen @ 150-200 g ha^{-1} could effectively control rice weeds such as grasses, sedges and broad-leaved weeds in paddy at 4 DAT (Abraham *et al*., 2010). Prakash (1994) reported that lower weed count (3.6 m^2), lower weed dry weight (5.0 g/ m^2) and higher grain yield (5100 kg ha^{-1}) were reported in direct seeded puddled rice by pre- emergence application of oxyfluorfen.

Kathiresan and Manoharan (2002) reported that application of oxyfluorfen at 0.125 kg ha^{-1} + hand weeding recorded lower weed population (17.6 m^2) and weed dry weight (12.2 g m^2) in semi dry rice. Pre-emergence application of oxyfluorfen at

0.2 kg ha^{-1} resulted in lower weed dry weight and higher grain yield in semi dry rice (Rao *et al*., 2007). ARWR (2011) also reported similar results on effectiveness of oxyfluorfen in rice by pre-emergence application at 400 g ha^{-1}, recording lower weed density, dry weight and higher WCE at 20 and 40 DAS.

According to Abraham and Menon (2015) application of oxyfluorfen 23.5per cent EC at 150 g ha^{-1} followed by one hand weeding at 30 DAS resulted in a higher weed control efficiency (90 per cent) in wet seeded rice.

Effect of oxyfluorfen on crops

Highest leaf area index, dry matter accumulation, number of productive tillers and grain yield (5345 kg ha^{-1}) in rice were obtained by application of oxyfluorfen at 0.125 kg ha^{-1} (Kathiresan and Manoharan, 2002). Pre-emergence application of oxyfluorfen @ 0.2 kg ha^{-1} resulted in lower weed biomass (8.08 g m^{-2}) and higher grain yield (13.35 q ha^{-1}) in direct seeded upland rice (Porwal, 1999). According to Pellerin and Webster (2004), use of pre-emergence herbicide, oxyfluorfen alone or supplemented with hand weeding provided a fair degree of weed control in semi dry rice.

According to Singh *et al*. (2005) application of oxyfluorfen in direct seeded rice effectively reduced *Panicum maximum* population as well as leading to lower weed count (14.7 m^{2}), weed dry weight (4.4 g m^{-2}) and higher grain yield (4.3 t ha^{-1}). In direct seeded rice, pre-emergence application of oxyfluorfen at 0.2 kg ha^{-1} resulted in lower weed dry weight and higher grain yield (Rao *et al*., 2007).

Application of oxyfluorfen @ 0.15 kg a.i ha^{-1} followed by hand weeding at 20 DAS effectively controlled weeds in rice (variety Aiswarya) and produced highest grain and straw yield (Reshma, 2014). Oxyfluorfen at 200 g ha^{-1} as pre-emergence herbicide recorded lower weed density and dry weight, and increased the grain yield and straw yield by 5709 to 6645 and 7102 to 7327 kg ha^{-1}, respectively in transplanted rice (Priya *et al*., 2017).

b. Pretilachlor

Pretilachlor, commercially available as Rifit ®, 50 EC is a pre-emergence herbicide, used for control of grasses, sedges and some broad-leaved weeds in rice. It belongs to the chemical class, chloroacetanilide that inhibits growth and reduces cell division in weeds.

Effect of pretilachlor on weeds

Pretilachlor with safener effectively controls all the weed species in rice crop (Peerzada *et al*. 2016). Pretilachlor effectively controls different weed species like *Echinochloa* spp, *L. chinensis*, *Cyperus* spp, *Fimbristylis miliacea*, *Scirpus* spp, *Monochoria vaginalis* and *Ludwigia* sp. (Allard and Zoschke, 1990). Pretilachlor + safener as PE at 500 g a.i ha^{-1} effectively controlled grassy weeds (Singh *et al*., 2008). Application of 2,4-D + pretilachlor at the rate of 300g/ha each, effectively controlled weeds like *C. rotundus*, *E. colona*, *L. chinensis*, *Marsilea quadrifolia*, *Eclipta alba* and *Sphenoclea zeylanica* and recorded lowest weed densities of 6-4 weeds/m^2.

Ghuman *et al*. (2008) reported that application of pretilachlor at 0.75 g a.i ha^{-1} effectively reduced weed dry matter and increased grain yield of rice. According to Arunvenkatesh and Velayatham (2010), application of pretilachlor at 0.45 kg a.i ha^{-1} as pre-emergence + one hand weeding between 30 to 35 DAS registered higher weed control efficiency.

Pre-emergence application of pretilachlor 1.0 kg ha^{-1} and pretilachlor 0.75 kg ha^{-1} with one hand weeding at 45 DAT offered better weed control and increased yield in rice (Suganthi *et al*., 2010). Awan *et al.* (2015) reported that pre-emergence application of pretilachlor with safener at 0.6 kg ha^{-1} controlled various grasses like *E. crus-galli* and *E. colona* with weed control efficiency of 100 per cent.

Effect of pretilachlor on crop

Pretilachlor 50 EC @ 0.75 kg ha^{-1} applied at 3-5 days after transplanting brought about lowest weed density, weed dry weight, highest weed control efficiency of 79.73 and 90.23 per cent, and lowest weed index values of 3.95 and 14.52, higher number of panicles m^{-2} (381 and 278), panicle weight (3.70 and 3.80 g), grain (4.96 and 4.23 t ha^{-1}), and straw yields (6.61 and 5.81 t ha^{-1}) in 2007 and 2008, respectively compared to other treatments (Prakash *et al*., 1995).

Pre-emergence application of pretilachlor + safener at 0.45 kg ha^{-1} followed by one hand weeding at 45 DAS resulted in less weed count, more nutrient uptake and highest grain yield in direct sown rice (Parthipan *et al*., 2013). According to Parameswari and Srinivas (2017) pre-emergence application of pretilachlor 600 g ha^{-1} + bensulfuron methyl 60 g ha^{-1} followed by one mechanical weeding at 30 DAS registered the highest B:C ratio compared to other weed management practices.

c. Pendimethalin

Pendimethalin, commercially available as Stomp® 30 per cent EC is a pre-emergence herbicide belonging to dinitroaniline class, used to control annual grasses and certain broadleaf weeds. It inhibits cell division and cell elongation.

Effect of pendimethalin on weeds

Pre-emergence or pre-plant incorporation of pendimethalin effectively controls grases up to 60 days after sowing (Punia *et al*., 2005). Several studies suggested the importance of pendimethalin in reducing weed density (Valverde and Gressel, 2005). Pre-emergence application of pendimethalin @ 0.75 kg ha^{-1} followed by post-emergence application of bispyribac sodium @ 20 g ha^{-1} recorded less weed dry weight (0.17 t ha^{-1}) (Walia *et al*., 2008).

A study conducted by Khaliq *et al.* (2011a) showed that the pre-emergence application of pendimethalin followed by the post-emergence application of bispyribac-sodium or penoxsulam resulted in 80 per cent reduction in density of different grass weeds in direct-seeded rice. According to Khaliq and Matloob (2012), the density of jungle rice reduced largely with pre-emergence application of pendimethalin. Nayak *et al*. (2014) reported that pre-emergence application of pendimethalin at 1 kg ha^{-1} suppressed the weed growth, especially that of grasses upto 20 days after sowing in direct-seeded rice.

Raj *et al.* (2016) also reported the high efficacy of pendimethalin followed by bispyribac sodium against *Echinochloa colona*, whereas in the same study, pendimethalin 1 kg ha^{-1} reduced the density of *Echinochloa colona* in rice field at 30 and 90 days after transplanting. Pendimethalin followed by hand weeding achieved high grass weed control in rice throughout the season (Peerzada *et al*., 2016).

Effect of pendimethalin on crop

Application of pendimethalin 1.0 kg ha^{-1} as PE recorded more number of tillers, panicle length, panicle weight, spikelet panicle and 1000 grain weight (Singh and Namdeo, 2004). Chakraborti *et al.* (2017) reported that pre-emergence application of pendimethalin @ 1.0 kg ha^{-1} + 1 hand weeding at 30 DAS resulted in more number of panicles m^{-2} (324.17 and 335.10), number of filled grains panicle^{-1} (65.23 and 69.66) and grain yield (3.30 and 3.59 t ha^{-1}) in the years 2013 and 2014 respectively. Singh *et al*. (2017) concluded that pre-emergence application of pendimethlin @ 1000 g ha^{-1} *fb* post-emergence application of bispyribac-sodium @ 25 g ha^{-1} resulted in minimum weed density compared to other herbicidal treatments at 45 DAS.

d. Oxadiargyl

Oxadiargyl, commericially available as Topstar® 80 WP, is a broad-spectrum herbicide very effective for the control of grasses, sedges and some broad-leaved weeds in rice. It belongs to the class oxadiazoles and inhibits protophosphyrinogen IX oxidase, the enzyme that converts from Protox to Proto, leading to necrosis in weeds.

Effect of oxadiargyl on weeds

Pre-emergence application of oxadiargyl resulted in lowest weed density and dry weight (Sharma *et al*., 2004). Pre-emergence application of oxadiargyl at 75 g ha^{-1} effectively controlled the weeds at early stage of crop growth (Jadhav *et al*., 2009; Yadav *et al*., 2009). Application of oxadiargyl @ 70 and 80 g ha^{-1} effectively controlled *Echinochloa crus-galli* and *Echinochloa colona* respectively (Singh *et al*., 2004; Kumar *et al*., 2004). According to Subramanian *et al*. (2006), among various weed management practices, application of oxidiargyl at 75 g ha^{-1} *fb* one hand weeding at 40 DAT brought about the lowest density and dry weight of weeds with higher weed control efficiency comparable to hand weeding twice at 20 and 40 DAT.

Naseeruddin and Subramanyam (2013) reported that pre-emergence application of oxadiargyl @ 75 g ha^{-1}+ post-emergence application of azimsulfuron @ 30 g ha^{-1}, or pre-emergence application of oxadiargyl alone @ 75 g ha^{-1} effectively reduced the total density and dry weight of weeds in drum seeded rice. Ahmed and Chauhan (2014) concluded that application of oxadiargyl followed by ethoxysulfuron in *Boro* season and oxadiargyl followed by one hand weeding resulted in highest weed control efficiency and higher yield of rice.

Effect of oxadiargyl on crops

Among the different herbicidal treatments, application of oxadiargyl @ 70 g ha^{-1} resulted in higher number of panicles, 1000 grain weight and grain yield of rice (Kumar *et al*., 2004). In the opinion of Ramana *et al*. (2008), pre-emergence application of oxadiargyl at 80 g ha^{-1} + mechanical weeding with star weeder improved weed control, and resulted in higher grain and straw yield and B:C ratio. The treatment pre-emergence application of oxadiargyl @ 75 g ha^{-1} recorded highest number of filled grains $panicle^{-1}$, 1000 grain weight and grain yield of rice, and was on par with hand weeding twice at 20 and 40 DAT (Yadav *et al*., 2009; Kiran and Subramanyam, 2010).

Highest harvest index was achieved by pre-emergence application of oxadiargyl 70 g ha^{-1} + one hand weeding treatment (Hasanuzzaman *et al*., 2009). Application of oxadiargyl as pre-emergence at 100 g per ha followed by post-emergence application of bispyribac sodium at 25 g per ha produced higher yield and net returns due to better weed control in direct seeded rice (Rana *et al*., 2016). According to Kumar *et al*. (2017), highest grain (39.76 q ha^{-1}) and straw (63.24 q ha^{-1}) yield was obtained by pre-emergence application of oxidiargyl + one hand weeding compared to other treatments.

2. Post-emergence herbicides

Post-emergence herbicides like fenoxaprop-p-ethyl, metamifop and cyhalofop-butyl were very effective against *Echinochloa colona*, *S. interrupta* and *Leptochloa chinensis*. Bispyribac-sodium was effective against all weeds except *Leptochloa chinensis* (Abraham and Jose, 2014). Penoxsulam was effective against broad-leaved weeds and sedges and gave reasonable control of grass weeds like *Echinochloa colona* and *S. interrupta*. All herbicides significantly reduced the count and dry matter production of weeds, but complete control was not achieved (Duary *et al*., 2015b).

a. Cyhalofop-butyl

Cyhalofop-butyl, available as Clincher® 10 EC, is an aryloxy phenoxy propionate(AOPP) herbicide developed for post-emergence control of grass weeds in dry as well as wet seeded rice. It is a phloem mobile, systemic herbicide that inhibits Acetyl Co-A carboxylase enzyme activity (Sharma *et al*., 2004).

Effect of Cyhalofop-butyl on weeds

Choubey *et al*. (2001) reported that application of cyhalofop-butyl @ 80g/ha was effective in controlling *Echinochloa colona* and grass weeds. According to Saini *et al*. (2001), cyhalofop-butyl @ 90g/ha + 0.3 per cent surfactant effectively controlled weeds in transplanted rice and reduced total dry matter of *Echinochloa* sp.

Sequential application of cyhalofop-butyl @ 90g/ha followed by 2,4-D @ 1kg/ha reduced the total weed biomass and resulted in 89.6 per cent weed control efficiency (WCE) (Angiras and Attri, 2002).

Cyhalofop-butyl as post-emergence herbicide was a very effective herbicide against barnyard grass as reported by Scott (2003) and when applied at 120g/ha, it effectively controlled grassy weeds (Singh *et al*., 2008). Saini (2005) reported that cyhalofop-butyl @ 120g/ha applied 15 DAS followed by 2,4-D @ 1kg/ha applied 20 DAS recorded lower total weed dry weight and higher WCE.

According to Sangeetha *et al*. (2009) cyhalofop-butyl spray at 15 DAS followed by one HW at 45 DAS resulted in lower weed density and was on par with HW twice at (20 and 45 DAS). Kiran *et al*. (2010) opined that cyhalofop-butyl alone as post-emergence application was ineffective in controlling broad-leaved weeds. A study conducted in the rice fields at *Kole* lands of Kerala by Jacob *et al*. (2014) suggested that cyhalofop-butyl at 80 g ha^{-1} was very effective against grass weeds when applied at 20 DAS.

Effect of Cyhalofop-butyl on crop

Cyhalofop-butyl applied at 120g/ha (15 DAS) followed by 2,4-D at 1 kg/ha (20 DAS) recorded more number of panicles/m^2, longer panicle length, more number of grains/panicle and 1000 grain weight (Saini, 2005). Angiras and Attri (2002) reported that cyhalofop-butyl @ 90g/ha recorded more number of panicles and higher grain yield of rice (4.5 t/ha). According to Sangeetha *et al*. (2009), application of cyhalofop-butyl (15 DAS) + one HW (45 DAS) resulted in more panicles/m^2, filled grains/panicle and yield, which was on par with HW twice at 20 and 45 DAS.

b. Bispyribac-sodium

Bispyribac-sodium, a pyrimidinyl carboxy herbicide, is a broad spectrum herbicide, effective in controlling many annual and perennial grasses, sedges and broad-leaved weeds in rice fields (Yun *et al*., 2005).

Effect of bispyribac-sodium on weeds

Bispyribac-sodium is a pyramidinyl carboxy herbicide applied @ 25.0 g ha^{-1} at 15 or 25 DAT, which effectively controlled many annual and perennial grasses, sedges and broad-leaved weeds in rice field (Yadav *et al*., 2009).

Post-emergence application of bispyribac-sodium @ 30.0 g ha^{-1} produced higher grain yield in rice (Walia *et al*., 2008) and similar results were obtained by Hussain *et al*. (2008) who reported bispyribac-sodium as the best weedicide with higher weed control efficiency of 90.5 per cent and higher paddy yield. Veeraputhiran and Balasubramanian (2010) suggested that for achieving higher weed control efficiency and lower weed index, application of bispyribac-sodium at 25.0 g ha^{-1} was effective in rice.

According to Yadav *et al*. (2010), bispyribac-sodium applied @ 15 or 25 DAT was effective against grass weeds but control of broad-leaved weeds and sedges was more when applied at 15 DAT. According to Khaliq *et al*. (2011a), application of bispyribac-sodium suppressed the grass weeds and total weed count and density by more than 80 per cent. Bispyribac-sodium 10 SC @ 25 g ha $^{-1}$ effectively controlled all categories of weeds causing lowest biomass of weeds in rice, and also with no observed phytotoxicity even at higher dose of the herbicide (Ghosh *et al*., 2013).

Effect of bispyribac sodium on crops

The highest number of grains per panicle (119.73) was recorded in the treatment with post-emergence application of bispyribac sodium (Begum *et al*., 2009). Yadav *et al*. (2009) obtained 41 per cent increase in grain yield with application of bispyribac-sodium @ 25g/ha at 15-25 DAT. Higher grain yield was obtained by application of bispyribac sodium @ 25g/ha on 20 DAT (ARWR, 2011).

Highest weed control efficiency (WCE) was obtained with bispyribac sodium when applied @ 30 g ha^{-1}, particularly against *Echinochloa crus-galli* (Mehta *et al*., 2010). Singh *et al*. (2016) reported that sequential application of pendimethalin as PE *fb* bispyribac sodium+azimsulfuron as post-emergence, resulted in higher grain yield

(3.5 t ha^{-1}). Ajaysingh *et al*. (2017) also found similar results and reported that pre-emergence application of pendimethalin @ 1000 g ha^{-1} *fb* bispyribac-sodium @ 25 g ha^{-1} brought about higher number of productive tillers m^{-2}, filled grains $panicle^{-1}$ and grain yield than weedy check.

c. Penoxsulam

Penoxsulam, commercially available as Granite® 24 EC, is broad spectrum post-emergence herbicide with ALS inhibiting mode of action that impedes the biosynthesis of branched chain of amino acids like valine, leucine and isoleucine required for protein synthesis, leading to the rapid cessation and growth of plant cells (Kogan *et al*., 2011).

Effect of penoxsulam on weeds

Penoxsulam @ 22.5 g ha^{-1} resulted in highest reduction in density of broad-leaved weeds and sedges and the density and dry weight of grassy weeds decreased with increased dose of penoxsulam (Mishra *et al*., 2007). Yadav *et al.* (2008) reported that penoxsulam at 25.0 g ha^{-1} as pre-emergence (3 DAT) and 20.0-22.5 g ha^{-1} as post-emergence (10-12 DAT) resulted in efficient control of weeds, bringing about grain yield similar to that in weed free plots of transplanted rice.

According to Singh *et al*. (2009), penoxsulam was effective against *Echinochloa* species and *Cyperus difformis* when compared to other herbicides like butachlor and pretilachlor and recorded lower weed dry matter. Malik *et al*. (2011) reported that no phytotoxicity symptoms were observed in rice treated with penoxsulam. Khaliq *et al*. (2011b) found similar results, and when penoxsulam was used at its label dose there was maximum suppression in individual and total weed count at 30 DAT.

Penoxsulam@ 25.0 g ha^{-1} applied as early post-emergence (0-5 DAT) was most effective in reducing weed growth and gave maximum grain and straw yield, lowest dry weight of weeds, and highest herbicidal efficiency (Prakash *et al*., 2013).

Penoxsulam @ 25 g ha^{-1} resulted in lower density and dry weight of weeds and higher WCE over weedy check plots (Sasna and Syriac, 2014). According to Saranraj *et al*. (2018), PE application of penoxsulam @ 22.5 g ha^{-1} + hand weeding at 30 DAT resulted in highest WCE, grain yield and lowest weed index.

Effect of penoxsulam on crops

Penoxsulam @ 22.5 g ha^{-1} applied at 10 DAT was found most effective in controlling weeds and maximizing rice grain yield (Mishra *et al*., 2007). According to Singh *et al*. (2007a) lower dose of penoxsulam (22.5 g ha^{-1}) applied as early post-emergence (8-12 DAT) resulted in higher number of panicles m^{-2} and grain yield. According to Pal *et al*. (2009) penoxsulam at 22.5 g ha^{-1} applied at 8-12 DAT was most effective and resulted in lowest weed index (5.61per cent) and higher grain (3.53 t ha^{-1}) and straw yield (4.73 t ha^{-1}).

Ravikiran (2018) reported similar results with Penoxsulam @ 22.5 g ha^{-1} resulting in highest grain yield and B: C ratio. Application of penoxsulam @ 35 g ha^{-1} at 10 DAS *fb* one HW at 35 DAS brought about improved morphological characters and chlorophyll content in upland rice (Sanodiya and Singh, 2017). Penoxsulam@ 22.5 g ha^{-1} *fb* one hand weeding resulted in highest plant height, more number of tillers $hill^{-1}$, dry matter accumulation and LAI (Netam *et al*., 2018).

d. Fenoxaprop-p-ethyl

Fenoxaprop-p-ethyl is commercially available as Rice star® 6.9 EC, is a new post-emergence herbicide belonging to the chemical group, aryl oxy phenoxy propionate (AOPP) that inhibits Acetyl Co-A carboxylase enzyme and is effective against rice grass weeds.

Effect of fenoxaprop-p-ethyl on weeds

Fenoxaprop-p-ethyl @ 56.25 g ha^{-1} applied at 10 DAT effectively controlled *Echinochloa colona, Echinochloa crus-galli*, *Leptochloa chinensis* and *Ischaemum rugosum* (Singh *et al*., 2004). Katiyar and Kolhe (2006) reported that weed density, frequency and abundance were highly affected by fenoxaprop-p-ethyl + ethoxy sulfuron at 45+10g/ha (15 DAS). Fenoxaprop-p-ethyl at 50g/ha could be used as post-emergence spray for the control of grass weeds (Singh *et al*., 2008). Mallick *et al*. (2009) opined that application of fenoxaprop-p-ethyl resulted in gradual decrease of weed density and dry weight of grasses.

Application of fenoxaprop-p-ethyl @ 60g/ha followed by one HW resulted in highest weed control efficiency (WCE) of 95.5 percent and lowest weed index (Kumar *et al*., 2010). According to Tiwari *et al.* (2010), the highest WCE was obtained on mixing of fenoxaprop-p-ethyl (0.06 kg/ha) with ethoxysulfuron (0.015 kg/ha). Menon and Prameela (2015) suggested that the post-emergence application of fenoxaprop-p-ethyl@ 60 g ha^{-1} reduced the grass weed population in wet seeded rice of *Kole* lands, Kerala.

Effect of fenoxaprop-p-ethyl on crops

Application of fenoxaprop-p-ethyl @ 90g/ha (20 DAS) recorded higher grain yield as well as yield attributing characters (Saini and Angiras, 2002). Singh *et al*. (2004) reported that fenoxaprop-p-ethyl at 56.25 g/ha applied at 10 days recorded grain yield of 6798 kg/ha which was on par with hand weeding. Dixit and Varshney (2008) observed that post-emergence application of fenoxaprop-p-ethyl resulted in more number of panicles/m^2 (236) and grains/panicle (71). More number of panicles/m^2 (228) with lesser weed dry weight (15.3 g/m^2) and higher yield (4.3 t/ha) was obtained by application of fenoxaprop-p-ethyl @ 60g/ha followed by one HW.

According to Sreedevi *et al.* (2009), greater plant height and dry matter were obtained by application of fenoxaprop-p-ethyl. Fenoxaprop-p-ethyl (0.06 kg/ha) mixed with ethoxysulfuron (0.015 kg/ha) as post-emergence spary produced higher grain yield (Tiwari *et al*., 2010).

e. Triafamone+ ethoxysulfuron

Triafamone+ ethoxysulfuron available as Council® activ, is the latest post-emergent rice herbicide, which is highly effective in control of weeds. Council® activ is taken up by leaves and is metabolised by N-demethylation and this metabolite strongly inhibits acetolactate synthase (ALS) in the plants.

Effect of triafamone+ethoxysulfuron on weeds

Post-emergence application of ready mix mixture of triafamone + ethoxysulfuron 60 g ha^{-1} recorded lower weed count and weed dry count and weed dry matter and was on par with hand weeded plots (Kailkhura *et al*., 2015). Deivasigamani (2016) reported that the herbicide triafamone + ethoxysulfuron at (200 g/ha and 225 g/ha), triafamone as post-emergence at 15 DAT (225 g/ha) and two hand weedings at 20 and 40 DAT recorded zero weed counts.

According to Menon *et al*. (2016) lowest weed dry matter production (8.44 g/m^2) and highest weed control efficiency (74.65 %) was recorded in post-emergence application of premix triafamone + ethoxysulfuron @ 60 g ha^{-1} at 15 DAT, and was on par with weed free plots. Triafamone + ethoxysulfuron was found to be relatively more effective against *Leptochloa chinensis* and *Ludwigia parviflora*, and not so effective against *Echinochloa* spp.

Das (2018) reported that post-emergence application of triafamone + ethoxysulfuron (PoE), recorded lower weed density, weed dry weight throughout the cropping period and had lowest weed index (WI) of 5.70 per cent and highest weed control efficiency (WCE) of 79.80 % at harvest.

Effect triafamone + ethoxysulfuron on crops

Highest grain yield of 5375 and 5165 kg ha^{-1} was observed with two treatments of triafamone + ethoxysulfuron (200 g/ha and 225 g/ha). Triafamone + ethoxysulfuron was superior at all doses to butachlor, pyrazosulfuron ethyl and cyhalofop-butyl in direct seeded rice (Deivasigamani, 2016). Menon *et al*. (2016)

found that two hand weedings at 25 and 45 DAT recorded highest grain yield (6917 kg ha^{-1}) followed by triafamone + ethoxysulfuron 60 g ha^{-1} at 15 DAT (5958 kg ha^{-1}).

Highest number of effective tillers/m^2 (250), fertile grains/panicle (75), 1000 grain weight (24.8 g) and grain yield (4.64 t ha^{-1}) was attained by application of triafamone + ethoxysulfuron (PoE) among different herbicide treatments (Das, 2018).

f. Cyhalofop-butyl+ penoxsulam

Cyhalofop-butyl+ penoxsulam is commericially available as Vivaya®, a post-emergence, broad-spectrum, systemic herbicide that controls grasses, broad-leaved and sedge weeds in rice. It inhibits two plant enzymes, Aceto Lactate Synthase (ALS), essential for the synthesis of branched chain amino acids and Acetyl co-enzyme A carboxylase (ACCase), pre-cursor of fatty acid synthesis in targeted grassy weeds.

Effect Cyhalofop-butyl+ penoxsulam on weeds

Cyhalofop-butyl+ penoxsulam when applied at the four-leaf stage effectively controlled 89 to 100 per cent barnyard grass, chinese sprangletop and jungle rice. It was concluded that six-leaf stage is best for improving the herbicide efficacy. A study conducted by Abraham and Menon (2015) revealed that combination of penoxsulam + cyhalofop-butyl at 150 g ha^{-1} resulted in superior control of all types of weeds, and higher grain and straw yields of wet seeded rice compared to other herbicides.

Peerzada *et al.* (2016) concluded that the combination of penoxsulam plus cyhalofop-butyl could achieve broad-spectrum control of grasses, sedges and broadleaved weeds. Pratap *et al*. (2016) reported that post-emergence application of penoxsulam+ cyhalofop-butyl at 150 g ha^{-1} recorded lower dry weight of weeds than weedy check.

Effect of Cyhalofop-butyl+ penoxsulam on crops

Herbicide combination containing cyhalofop-butyl+ penoxsulam increased rice productivity in direct seeded, water seeded and transplanted rice production system (Lap *et al*., 2013). Kailkhura *et al.* (2015) reported that herbicidal combinations of pre-emergence application of pendimethalin@ 1000 g/ha *fb* post-emergence application of bispyribac-sodium@ 25 g/ha and post-emergence application of readymix of penoxsulam +cyhalofop-butyl@ 135 g/ha were found to be most effective in controlling weed infestation with the highest weed control efficiency and grain yield. A study conducted by Hossain and Malik (2017) revealed that early post-emergence application of penoxsulam + cyhalofop-butyl as ready-mix was effective in controlling total weed population, and resulted in highest number of effective tillers/m^2, number of grains/panicle and grain yield of transplanted rice.

The above review broadly covers the research carried out on control of grassy weeds in rice. However, very little information is available on the weed *S. interrupta* on ecological requirements of the plant and its adaptation to various rice ecosystems. Specific response of *S. interrupta* to commonly used herbicides is also not known. The present research aims to fill this knowledge gap in order to achieve a viable strategy for management of *S. interrupta.*

Material and methods

3. MATERIAL AND METHODS

The research programme was carried out during 2016-2019 to study the biology, particularly the growth, reproduction, propagation, dormancy and germination requirements, of *S. interrupta* occurring in major rice tracts of Kerala. It was also aimed to study the efficacy of different pre and post-emergence herbicides and integrated weed management approaches for controlling *S. interrupta*, so as to develop an effective recommendation for management of the weed. The whole research work consisted of three parts:-

Part I: Studies on distribution and morphology of *S. interrupta* in major rice tracts of Kerala. Seeds were collected from major rice tracts along with soil samples and sown in pots, and observations on growth and morphological characters were recorded.

Part II: Biology of *S. interrupta* was studied by conducting experiments on methods of propagation and germination. Different experiments were conducted to study the effect of ideal field conditions, seasonal variations, depth of burial and seed longevity on the germination of *S. interrupta*.

Part III: Field experiments were conducted to manage *S. interrupta* in rice. Efficacy of different pre-emergence and post-emergence herbicides was studied in separate experiments for two years (2017 and 2019), and a third experiment was conducted in 2019 by integrating the best of pre and post-emergence treatments to identify an effective management strategy.

3.1. Details of study area

The study was focused on major rice tracts of Kerala, *viz.*, *Kuttanad*, *Kole* and Palakkad.

a) *Kuttanad*

Kuttanad is the rice bowl of Kerala, and is located in the districts of Alappuzha and Kottayam. The region is serviced together with the Vembanad lake by four rivers: Achenkovil, Pampa, Manimala and Meenachil. The area is located at a latitude of 9˚27' North and a longitude of 76˚25' East and is approximately 0.5 to 2 meters below mean sea level. *Kuttanad* soils are categorized into three categories based on their chemical characteristics: *Kari*, *Karappadom* and *Kayal* soils. Texture of the soil is silty clay, with a pH of around 3.5 to 4.5. The soil is low in fertility, but it is rich in organic matter. In wetlands, rice is cultivated in two seasons, *viz*., (May-June to September- October) and (November-December to March-April).

b) *Kole* lands

The *Kole* lands are spread through the districts of Thrissur and Malappuram, covering more than 13,000 ha. The area lies between the latitudes of 10˚20' to 10˚40' North, and longitudes of 75˚58' to 76˚11' East and is located 0.5 m to 1 m below mean sea level. The soil pH ranges from 2.6 to 6.3, and the electrical conductivity from 0.16 to 15 dS m^{-1} and the texture varies from sandy loam to clayey. The *Kole* lands are very productive. The soil is high in organic carbon and available phosphorus, and medium in nitrogen and potassium. Rice is cultivated only in one season, *i.e.*, September-October to February-March, and the land remains submerged for the rest of the year. Farmers, however, raise a second crop during the period from February to April in favorable locations.

c) Palakkad rice tract

Palakkad rice tract, known as the rice granary of Kerala, is located between the latitudes of 10˚21' to 11˚14' North, and longitudes of 76˚02' to 76˚45' East. The soil is laterite and low in available nitrogen, phosphorus, potassium and organic carbon. The pH of the soil is around 5. The rice lands in Palakkad plains are double cropped. The first crop is mainly grown under semi-dry situation. In second season, the system followed is transplanted rice under puddled condition. It depends on canal irrigation water from Malampuzha, Vaalayar, Mangalam, Pothundi, Gayathri and Chithrapuzha irrigation projects.

3.2. Climate and weather

Kuttanad, *Kole* lands and Palakkad rice tract have tropical monsoon climate with more than 80 per cent of the rainfall distributed through south-west and north-east monsoon showers. During 2018 August, the State received about 27.5% more rainfall than usual and faced its worst floods in nearly 100 years.

3.3. Experiments

Part 1. Survey and morphological study of different morphotypes of *S. interrupta* in major rice tracts of Kerala.

To study the distribution of *S. interrupta*, a survey was conducted in three major rice growing tracts of Kerala *i.e*., *Kuttanad*, *Kole* and Palakkad. In *Kuttanad* and *Kole*, the survey was conducted from December to March, and in Palakkad tract from April to June in 2017-18 and 2018-19, being the periods of most appropriate representation of majority of weed species in the respective tracts. For each rice tract, based on the dominance of the weeds, various indices on density of individual weeds were worked out and different characters of morphotypes recorded.

Sampling was done using quadrat of 0.5 x 0.5 m in the surveyed areas, with the quadrat being randomly placed in a total of 15 spots in each location.

From the data collected, cluster analysis was done using Euclidean distance as similarity index, to differentiate between the eleven morphological characters of different morphotypes collected from the surveyed locations. For this analysis statistical package 'Minitab Version 19' was used and associated dendrogram was obtained. To find out the components which were important for clustering the *S. interrupta* types, principal component analysis (PCA) was done with the same package.

Observations

a) Phytosociological observations of weeds

Species- wise count of all weeds was recorded from different locations by collection using quadrat technique. Sampling was done using quadrat of 0.5 x 0.5 m in the surveyed area with the quadrat being randomly placed in each location and a total of 15 quadrats were sampled. Data of each year were pooled for each locality and average counts of different weeds were worked out. Based on the data collected, phytosociological observations on density (d), relative density (RD), abundance (a), frequency (f), relative frequency (RF) and summed dominance ratio (SDR) or importance value index (IVI) of individual weeds were worked out for each rice tract (*Kuttanad*, *Kole* and Palakkad) as per methods suggested by Misra (1968) and Raju (1977).

a. **Density**

$$\frac{\text{Total no. of individuals of the species in all quadrats}}{\text{Total no. of quadrats sampled}}$$

b. **Abundance**

$$\frac{\text{Total no. of individual of the species in all quadrats}}{\text{Total no. of quadrats in which the species occurred}}$$

c. **Weed frequency**

$$\frac{\text{Number of quadrats where a particular weed species occurred}}{\text{Total no. of quadrats sampled}} \times 100$$

d. **Relative density (RD)**

$$\frac{\text{Total no. of individuals of the given species}}{\text{Total no. of individuals of all the species}} \times 100$$

e. Relative frequency (RF)

$$\frac{\text{No. of occurrence of a species}}{\text{No. of occurrence of all the species}} \times 100$$

f. Relative abundance (RA)

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

g. **Summed dominance ratio (SDR)**

$$\frac{\text{Importance value index (IVI) of given species}}{\text{Total number of indices taken}} \times 100$$

b) Habitat analysis

Habitat analysis in the rice tracts was done using indices like

1. Species richness (R): the total number of species which occurred in the field.

2. **Species diversity (H):** measured by the Shannon-Wiener diversity index *i.e.,* $H = Pi \log Pi$, in which Pi is the proportion of individual numbers of the i^{th} *species* to the total individual number of each species in the quadrats. Thus, $Pi = Ni/N$, of which N is the total individual number of each weed species and Ni is the individual number of the i^{th} species (Shannon and Weaver, 1963).

3. Degree of community dominance (D): measured by the Simpson diversity index, where $D = 1\text{-}Pi^2$ (Simpson, 1949).

4. Community evenness (J): was measured by the evenness index (Pielou index), where $J = H/logR$ (Pielou, 1969).

c) Characters of morphotypes at flowering

1. Plant height: Heights of 10 plants from each location were measured from the base of the plant to the tip of the tallest leaf or panicle at the flowering stage and recorded in centimeters.

2. Number of tillers per plant: Total numbers of tillers per plant were counted after full heading. Observations were recorded from five plants in each location.
3. Number of panicles per plant: Number of panicles per plant was recorded from 10 plants in each location.
4. Growth form: Growth form of the plant was recorded as erect or prostrate.
5. Leaf arrangement and size: Leaf arrangement of different *S.* morphotypes was recorded and length and width of three leaves of each plant were recorded.
6. Panicle characters:
   a. Panicles were classified according to branching and angle of primary branches and distribution of spikelets as: a) compact, b) intermediate, and c) open
   b. Panicle length was recorded in centimetres from the base to the tip of the panicle
   c. Spikelet length: The length of spikelet was recorded in millimetres.
   d. Spikelet width: The spikelet width at the widest point was recorded in millimetres.

d) Content of major nutrients in *S. interrupta* morphotypes

From each location 10 plants were collected, first air dried for three days and then oven dried at 70± 5˚C to constant weight, ground to powder and contents of major nutrients were analysed in the laboratory by standard procedures (Jackson, 1958). Total N content of plant samples was determined by Microkjeldhal digestion and distillation method. Plant sample was digested in a diacid mixture and P content was determined by Vanadomolydophosphoric yellow colorimetric method. Intensity of yellow color was read using Spectronic 20 spectrophotometer at 470nm. Potassium content in the diacid plant digest was estimated by reading in a flame photometer.

e) Soil chemical properties

Soil samples were collected from each surveyed locations and analysed in the laboratory, to find the association with between soil properties on dominance and occurrence of *S.* morphotypes. The methods used for physico-chemical analysis of soil are detailed below.

Methods for soil physico-chemical analysis

Sl. No.	**Soil property**	**Method used**
1	pH	1: 2.5 soil: water ratio, Potentiometry (Jackson, 1958)
2	EC	1: 2.5 soil: water ratio, Conductometry (Jackson, 1958)
3	Organic C (%)	Walkley and Black method (Jackson, 1958)
4	Available N (kg/ha)	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg/ha)	Bray-1 extractant ascorbic acid reductant method (Watnabe and Olsen, 1965)
6	Available K (kg/ha)	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)

Part 2 Biology of *S. interrupta*

Observations were recorded on plant growth stages of *S. interrupta.* Different experiments were conducted on methods of propagation and germination to determine the growth and spread of *S. interrupta.*

a) Biology

To study the plant phenophases, plants of *S. interrupta* in the experimental field were tagged and observations were noted.

Observations recorded were

1. Time of normal seed germination under field conditions, observations was done for one year.

2. Duration of growth stages (vegetative, reproductive and maturity): Mean number of days taken from emergence to flowering, flowering to seed formation and for seed maturation were noted.

3. Days to first flowering: Mean number of days taken from emergence to flowering was noted.

4. No. of tillers/sq.m: Observations were recorded from 10 plants and total numbers of tillers per sq.m were counted after full heading.

5. No. of panicles/plant: Number of panicles per plant was recorded from 10 plants in each location.

6. Seed production capacity: Number of seeds per panicle were counted. From this, total number of seeds per plant was derived.

7. 1000 seed weight (g): Weight of 1000 seeds was measured

8. Incidence of pests and diseases: Incidence of pests and diseases, if any, during the growing period were noted down.

9. Content of major nutrients: Plants were collected at flowering stage and contents of N, P and K were estimated.

b) Methods of propagation

To assess the regeneration capacity of *S.*, different plant parts like seeds, culm cuttings with nodal roots and root clumps were grown in pots in three replicates, and germination of seeds, as well as regeneration capacity of vegetative propagules was assessed in the most suited condition of growth.

c) Germination studies

I. Laboratory studies

Seeds of *S. interrupta* were collected from areas of severe infestation in different rice growing tracts of Kerala, in the months of August and September. A composite sample was made by pooling seeds from many plants, and stored in air tight containers for further studies. Seeds were collected in three consecutive years *i.e.* 2016, 2017 and 2018, to compare the viability of newly shed (fresh), seeds collected earlier (old seeds) as well as full matured, and physiologically matured seeds. Laboratory experiments were conducted during 2017 and 2018 in Department of Agronomy, College of Horticulture, Vellanikkara, Kerala Agricultural University. As seeds of *S. interrupta* were observed to show dormancy, various dormancy breaking treatments were tried. The methodology followed is given below.

1. Seed viability studies

Fresh and six month old seeds of *S. interrupta* were soaked in water for 12 h for full imbibition and crushed with mortar and pestle to expose the embryo for easy staining. 25 crushed seeds of both types were placed separately in petri plates lined with moist filter paper in three replicates and 0.5 % tetrazolium solution (Tz) was added. Embryos were tested for pink staining.

2. Effect of scarification treatments on germination

Fresh and six months old seeds (twenty-five per type, in three replicates) were subjected to different scarification treatments like mechanical scarification *i.e.*, breaking seed coat by rubbing with sand paper, and acid scarification using diluted sulphuric acid (10 % and 50 %), concentrated sulphuric acid, and 1% solution each of nitric acid, perchloric acid and potassium hydroxide, for varying periods (5 min to 1 hour). Then seeds were washed thrice in running water and allowed to germinate in petri dishes at room temperature. Thermal scarification by placing seeds in boiling water for short interval (3-10 min) was also tested.

3. Effect of temperature and light on germination

Seeds of *S. interrupta,* both fresh and one year old, were taken and soaked for 24 h in water. One set of each type (50 seeds per sample) was placed in petri dishes filled with sterilized moist sand, and another in petri dishes lined with moist filter paper, incubated at 28^0C, 33^0C and 38^0C in an incubator under continuous light, continuous dark, and alternate light and dark conditions for 14 days each and germination rate was calculated.

II. Pot culture studies

To understand the germination behaviour of *S. interrupta,* soil was collected from areas of infestation, and solarized for one month for conducting pot culture studies. Completely randomized experimental design was adopted for these experiments. The details of material and methodology adopted were as follows:

1. Ideal conditions for germination

Seeds of *S. interrupta* (50 seeds) were sown in pots simulating three field situations, T_1-upland (moist conditions maintained by irrigating on alternate days for a period of one month), T_2- lowland with continuous flooding (puddled soil flooded throughout for a period of one month), and T_3- lowland conditions with alternate flooding and draining (puddled soil flooded for 10 days alternated with five days without flooding for a period of one month). Factorial combinations of the three treatments in the presence and absence of rice seeds were maintained in five replicates, with four pots in each treatment per replication for a period of one month, and emergence and establishment of *S. interrupta* were recorded.

2. Seasonal variations in germination

Non scarified fresh and six month old viable seeds (twenty five of each type) of *S. interrupta*, were placed in pots and tested for germination at weekly intervals upto four weeks. Subsequently the test was repeated at monthly intervals for 12 months. Seeds with one mm emerged radical were considered as germinated.

3. Effect of depth of burial

Samples of 25 seeds of *S. interrupta* were placed at 0 (surface), 2, 5, 10 and 15 cm depths in soil in pots, and germination and emergence were observed at weekly intervals. Each treatment was replicated three times.

4. Study on seed longevity

Seeds of both rice and *S. interrupta*, and *S. interrupta* alone were placed in plastic net bags (25 seeds per bag) and buried in pots at depths of 0, 2, 4 and 8 cm from the surface and filled with soil. The treatments consisted of eight factorial combinations, with four sowing depths in the presence or absence of rice in three replicates. Buried bags were taken out, seeds were sown in pots and germination was recorded at biweekly intervals for all treatments for a period of one year.

Based on the observations as detailed above, seedling vigour index was calculated by multiplying germination (%) and total seedling length (cm). The seed lot showing the higher seedling vigour index was considered to be more vigorous (Abdul-Baki and Anderson, 1973).

Part 3. Management of *S. interrupta* in rice

The field trial of the research programme was conducted during May to October, 2017 and 2019 at a farmers' field in Chithali, in Palakkad district. The soil of the experimental area is laterite and sandy clay in texture with pH of 5.8. The physico-chemical characteristics of the soils are presented in Table 1. The rice variety Jyothi (PTB 39), a red kernelled, short duration variety of 110-115 days duration was used for the trial. The variety is suitable for direct seeding and transplanting during both first (*Virippu*) and second crop (*Mundakan*) seasons.

Table 1. Physico-chemical characteristics of soil before the experiment

Particulars	Value	Method used
A) Particle size analysis		
Sand (%)	37.2	International Pipette Method (Piper, 1966)
Silt (%)	22.3	
Clay (%)	40.5	
B) Chemical composition		
pH	5.8	1: 2.5 soil water ratio, Potentiometry (Jackson, 1958)
Organic C (%)	0.85	Walkley and Black method (Jackson, 1958)
Available N (kg/ ha)	189.25	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ ha)	24.45	Bray-1 extractant ascorbic acid reductant method (Watnabe and Olsen, 1965)
Available K (kg/ ha)	191.56	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)

A. Experimental details

Two separate experiments, one with pre-emergence and other with post-emergence herbicides, was conducted in *Virippu* season to manage *S. interrupta* in dry seeded rice. These experiments were done in 2017 and were repeated in 2019. In the second year (2019), the best three treatments from each of the above two experiments conducted in 2017 was selected, integrated and a third experiment was conducted. In the first year (2017), two separate experiments were conducted with seven pre-emergence herbicides and eight post-emergence herbicides. In the second year (2019), in addition to these, a third experiment with eight integrated weed management treatments were conducted. All the experiments were laid out in randomized block design (RBD) (Fig. 1, 2 and 3). The treatments details are given below in Tables 2, 3 and 4. Weather data during the conduct of study is represented in figure 4.

B. Field operations

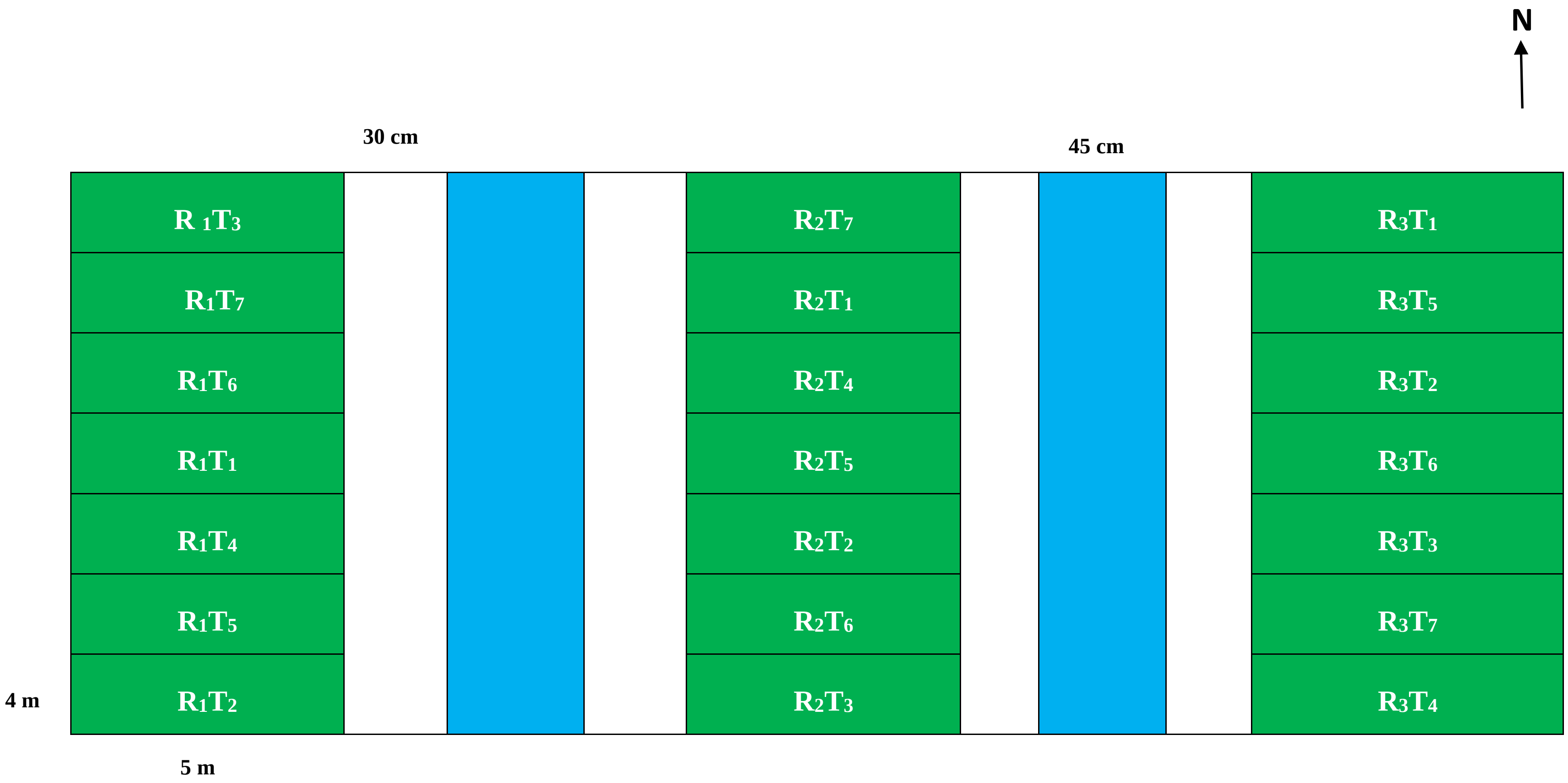
Land preparation, sowing and fertilizer application

The area was ploughed and levelled. The plot size adopted was 20 m^2. Plots of size 5m x 4m were formed by taking bunds of 30 cm width and 30 cm height. After levelling, fertilizers to supply NPK @ 90:35:45kg/ha were applied. Urea, factamphos and muriate of potash were used for supplying the nutrients. Full dose of P was applied basally. N and K were applied in three equal splits at land preparation, maximum tillering and panicle initiation stages. After basal fertilizer application, the seeds were broadcasted at the rate of 250 g/plot (125 kg/ha).

In hand weeded treatment, hand weeding was done at 20 and 45 DAS. Herbicides were sprayed at 2, 6, 15 and 20 DAS (as per treatments) using knapsack sprayer of 13L capacity fitted with a flood jet nozzle at the recommended doses (Table 2, 3 and 4). Visual phytotoxicity rating on crop and weeds was done on third and seventh day after spraying. Symptoms of injury were graded from 0-5 using the toxicity scale as per Thomas and Abraham (2007) given in Table 5.

Harvesting

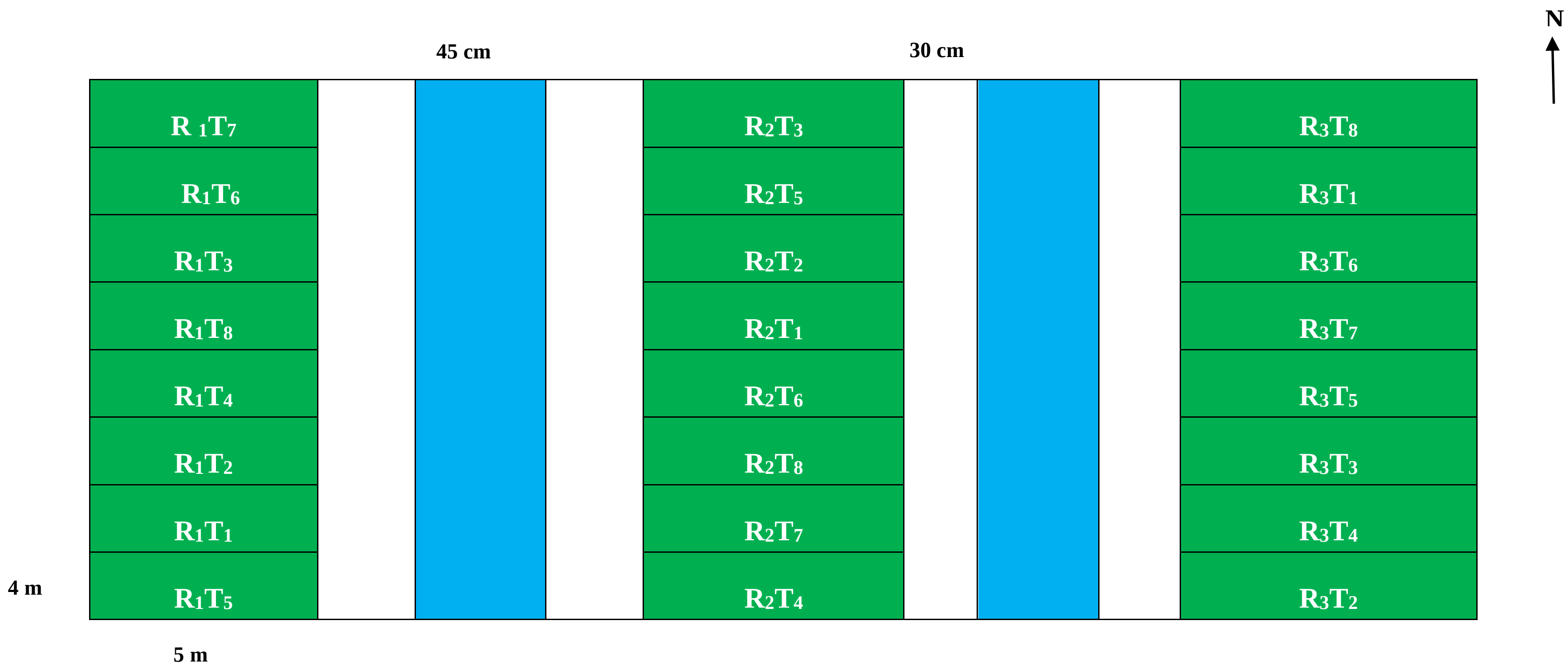
The first season crops of experiments 1 and 2 were harvested on 1st of October 2017 and second season crop of experiments 1, 2 and 3 were harvested on 28th and 29th September 2019, after the grains were fully matured. Threshing was done manually and the produce was cleaned, dried and weighed and the yield was expressed in kg/ha.



Treatments

T_1- Oxyfluorfen, **T_2**- Pretilachlor, **T_3**- Pendimethalin, **T_4**- Oxadiargyl, **T_5**- Stale seedbed, **T_6**- Hand weeding, **T_7**- Unweeded control

Figure 1. Layout of the experiment 'Management of *Sacciolepis interrupta* with pre-emergence herbicides'

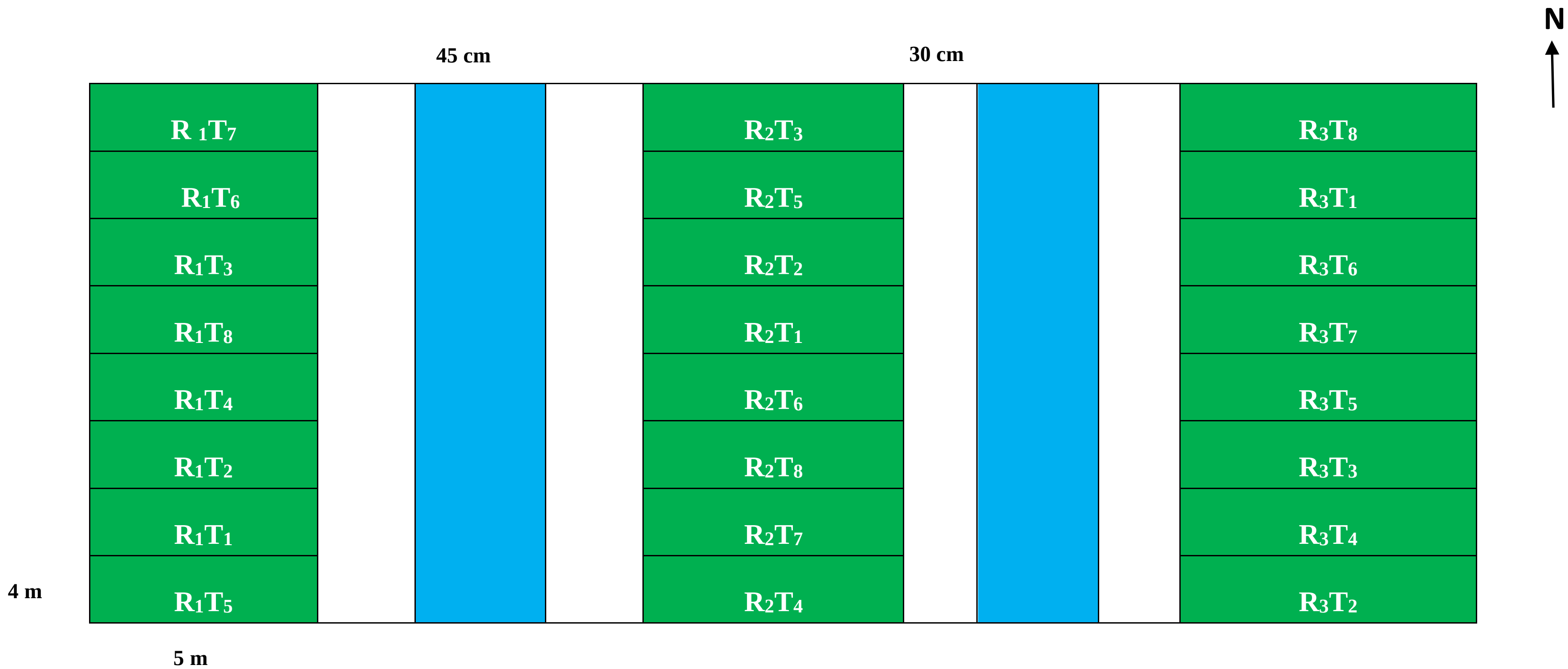


Treatments

T_1- Cyhalofop-butyl, **T_2**- Bispyribac-sodium, **T_3**- Penoxsulam, **T_4**- Fenoxaprop-p-ethyl,

T_5- Triafamone+ethoxysulfuron, T_6- Cyhalofop-butyl+penoxsulam, T_7- Hand weeding, T_8- Unweeded control

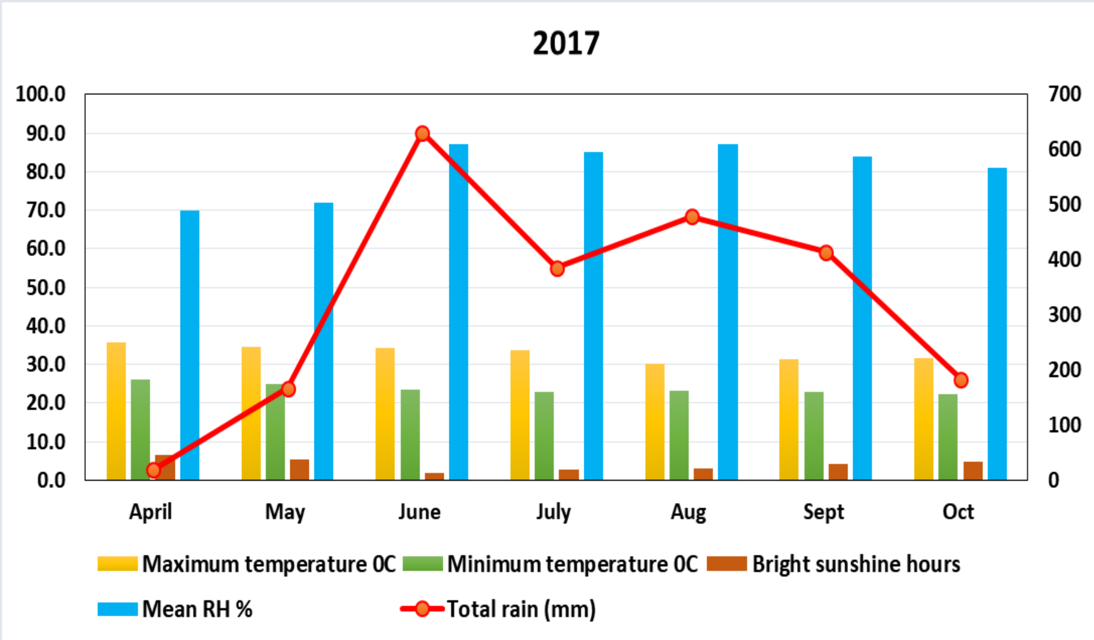
Figure 2. Layout of the experiment 'Management of *Sacciolepis interrupta* with post-emergence herbicides'



Treatments

T_1- SSB+ fenoxaprop-p-ethyl**,** **T_2**- SSB+Cyhalofop-butyl, T_3**-** SSB+ hand weeding@ 45 DAS**,** **T_4**- Oxyfluorfen+ fenoxaprop-p-ethyl **T_5**- Oxyflourfen+ cyhalofop-butyl, **T_6**- Oxyfluorfen+hand weeding@ 45 DAS, **T_7-** Hand weeding **T_8-** Unweeded control

Figure 3. Layout of the experiment 'Integrated management of *Sacciolepis interrupta*'



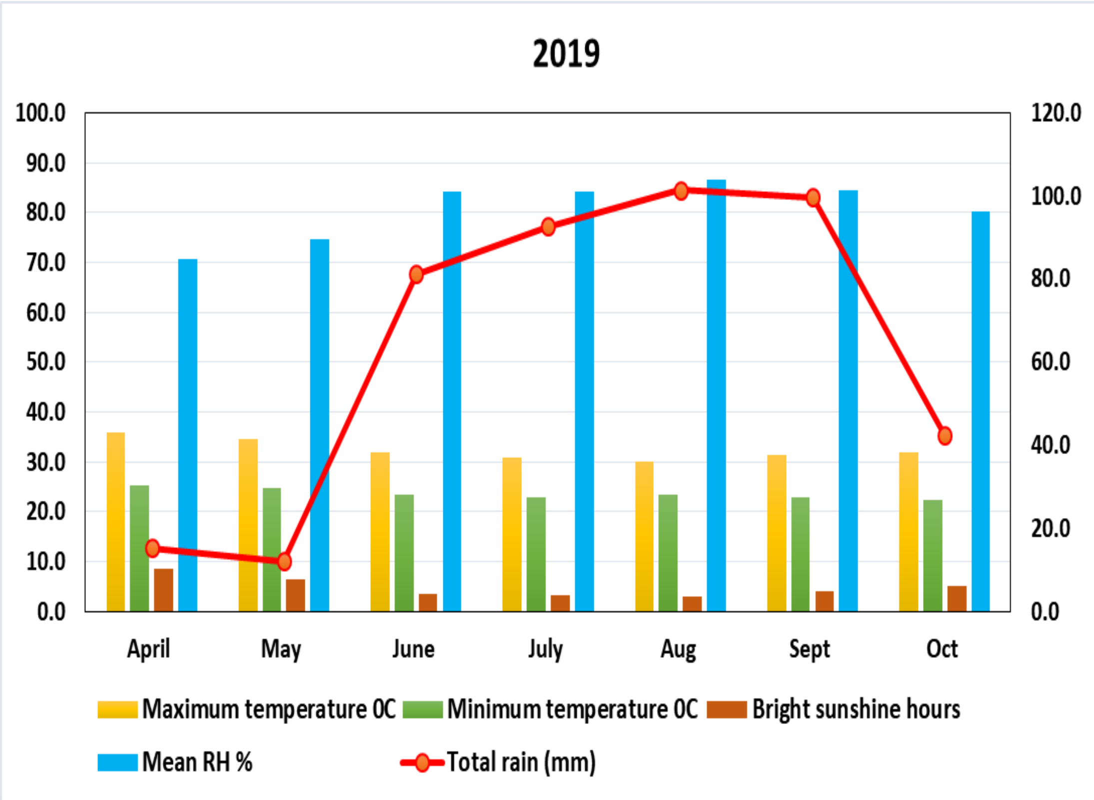


Figure 4. Weather data during the period of study (2017 and 2019)

Table 2. Pre-emergence herbicide treatments (Experiment I)

Sl. No.	Herbicide	Trade name	Formulation	Dose (kg/ha)	Time of application (DAS)
T_1	Oxyfluorfen	Goal	23.5 EC	0.15	6
T_2	Pretilachlor	Rifit	50 EC	0.75	6
T_3	Pendimethalin	Stomp	30 EC	1.50	6
T_4	Oxadiargyl	Topstar	80 WP	0.10	2
T_5	Stale seed bed*	-	-	-	-
T_6	Hand weeding	-	-	-	20 & 45
T_7	Unweeded control	-	-	-	-

Table 3. Post-emergence herbicide experiment treatments (Experiment II)

Sl. No.	Herbicide	Trade name	Formulation	Dose (kg/ha)	Time of application (DAS)
T_1	Cyhalofop-butyl	Clincher	10 EC	0.080	20
T_2	Bispyribac sodium	Nominee gold	10 EC	0.025	20
T_3	Penoxsulam	Granite	24 EC	0.025	20
T_4	Fenoxaprop–p–ethyl	Legacee	6.9 EC	0.060	20
T_5	Triafamone + ethoxysulfuron (commercial formulation)	Council activ	20+10%	0.067	15
T_6	Cyhalofop-butyl+ penoxsulam (commercial formulation)	Vivaya	6% OD	0.15	20
T_7	Hand weeding	-	-	-	20 & 45
T_8	Unweeded control	-	-	-	-

EC- Emulsifiable concentrate WP- Wettable powder OD- Oil dispersible DAS-Days after sowing

*Stale seed bed technique involved ploughing the land prior to sowing and forming seed beds which were irrigated and left as such for 3 weeks. The weed seeds which were germinated in this period were destroyed by spraying glyphosate @ 0.8 kg/ha. Rice was dry sown on the next day.

Table 4. Integrated weed management treatments (Experiment III)

Sl. No.	Treatments
T_1.	Stale seed bed + Fenoxaprop–p–ethyl @ 0.06 kg/ha at 20 DAS
T_2	Stale seed bed + Cyhalofop-butyl @ 0.15 kg/ha at 20 DAS
T_3	Stale seed bed + Hand weeding at 45 DAS
T_4	Oxyfluorfen @ 0.15 kg/ha at 6 DAS + Fenoxaprop–p–ethyl @ 0.06 kg/ha at 20 DAS
T_5	Oxyfluorfen @ 0.15 kg/ha at 6 DAS + Cyhalofop-butyl @ 0.15 kg/ha at 20 DAS
T_6	Oxyfluorfen @ 0.15 kg/ha at 6 DAS + Hand weeding at 45 DAS
T_7	Hand weeding at 20 & 45 DAS
T_8	Unweeded control

Table 5. Response of crop to herbicides

Rating	Effect on crop
0	No injury
1	Slight injury
2	Moderate injury
3	Severe injury
4	Very severe injury
5	Complete destruction

i. Observations

Observations on weeds

1. Count of weeds emerged/survived: Species- wise weed count was recorded using a 50 cm x 50 cm (0.25 m^2) quadrat. The quadrat was placed randomly in each plot and all the weed species inside were uprooted and counted at 30 and 60 DAS and at harvest, and were recorded in number/m^2.

2. Re-growth: Re- growth pattern of *S. interrupta,* if any, was noted at 30 days after spraying.

3. Dry matter production of weeds: Weeds uprooted from the quadrat were cleaned, air dried and then oven dried at 80±50^0C and dry weights were recorded in g/m^2 at 30 and 60 DAS and at harvest.

4. Weed Control Efficiency (WCE) and Weed Index (WI): WCE was calculated as per formula of Mani and Gautham (1973) and WI was calculated as per formula of Gill and Vijayakumar (1969) and expressed in percentage.

$$\textbf{WCE} = \frac{\text{*WDMP in control plot} - \text{WDMP in treatment plot}}{\text{WDMP in control plot}} \times 100$$

*WDMP= Weed Dry Matter Production

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

Observations on crop

1. Plant height: Heights of 10 plants were measured in cm from ground level to the tip of the longest leaf at 30 DAS, 60 DAS and at harvest and the mean values were calculated.

2. Tiller production: Number of tillers in each experimental plot at 30 DAS, 60 DAS and at harvest was counted and recorded using quadrat of 0.5m x 0.5m ($0.25m^2$). From count in 0.25 m^2 the number in one square metre was worked out.

3. Number of panicles: Number of panicles in each plot was counted and recorded using a 0.25 m^2 quadrat. From count in 0.25 m^2 the number in one square metre was worked out.

4. Number of filled grains per panicle: Grains collected from ten randomly selected panicles were separated into filled grains and chaff. Average number of filled grains for a single panicle was then worked out.

5. Thousand grain weight: One thousand grains were counted from the produce of each plot and their weight was recorded in grams.

6. Grain and straw yield: Crop was harvested from each plot area, threshed, winnowed and weight of grain and straw was recorded separately and expressed in kg/ha.

ii. Chemical analysis

Soil analysis

Primary nutrients *viz.,* available N, available P and available K were estimated in soil samples collected by the standard sampling procedures.

Plant analysis

N, P and K contents of weeds (at 30 DAS and 60 DAS) and of rice (at 60 DAS) were analyzed by standard procedures (Jackson, 1958). Total N content of plant samples was determined by Microkjeldhal digestion and distillation method. Plant sample was digested in a diacid mixture and the P content was determined by Vanadomolydophosphoric yellow colorimetric method. Intensity of colour was read using Spectronic 20 spectrophotometer at 470 nm. Potassium content in the diacid digest was estimated by making up the volume and directly reading in a flame photometer. The nutrient removal by weeds (at 30 DAS and 60 DAS) and of rice (at 60 DAS) was calculated as the product of nutrient content and the plant dry weight and expressed in kg/ha.

iii. Economics of weed control

The prevailing labour charge in the locality, costs of inputs and treatment costs were taken together and gross expenditure was computed and expressed in Rupees per hectare. Value of paddy and straw at current local market prices were considered as total receipts for computing gross return, partial budgeting and expressed in Rupees per hectare. Benefit/cost ratio was worked out by dividing the gross return with total expenditure.

iv. Data analysis

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

Results

4. RESULTS

4.1. Distribution and morphology of *Sacciolepis interrupta*

Surveys were conducted in the major rice tracts of Kerala *viz., Kole*, *Kuttanad*, and Palakkad to study the distribution and morphology of *S. interrupta*. In *Kuttanad* and *Kole,* the survey was conducted from December to March, 2017-18 and in Palakkad tract from April to May, 2018-19. The surveyed locations are depicted in Plate 1. From areas of severe infestation of *S. interrupta* in the rice tracts, ten plant samples and matured seeds were collected from each location (Plate 2 and 3). Soil samples from each location were also analyzed in the laboratory.

A. Weed phytosociological observations

The results of the study indicated that *S. interrupta* was a serious weed in all the three major rice tracts of Kerala.

I. *Kole* rice tract

S. interrupta dominated in Pullazhi, Manakkody, Alappad blocks of *Kole* lands. The rice fields were flooded during the entire cropping period in the surveyed localities. In *Kole* tract, a total of 11 weed species were recorded and out of these the highest density, frequency, relative density, relative frequency and summed dominance ratio were recorded for *S. interrupta* and weedy rice. In case of abundance *S. interrupta* and *Leptochloa* were abundant than other weed species (Table 6).

II. *Kuttanad* rice tract

S. interrupta was found to be dominating in the blocks of Veeyapuram (two locations) and Kidangara (one location) of *Kuttanad* rice tract. *S. interrupta* was observed in the rice field bunds, marshy areas and stream banks. *Echinochloa crus-galli* was seen to be the dominant weed in the surveyed areas of *Kuttanad*, with highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio out of 12 species, followed by *S. interrupta* and *Salvinia molesta* (Table 7).

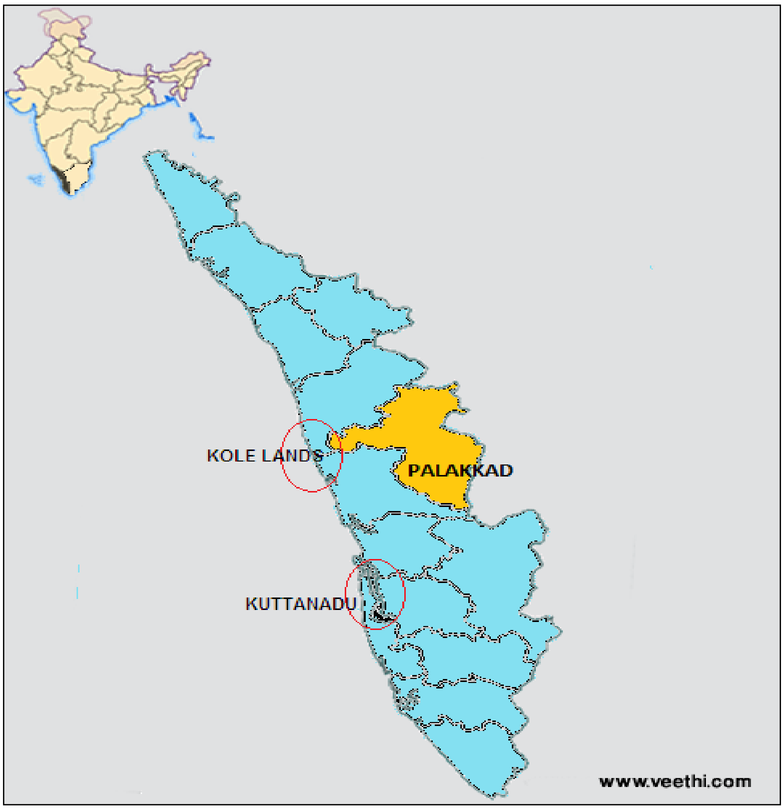


Plate 1. Map of Kerala showing the study locations

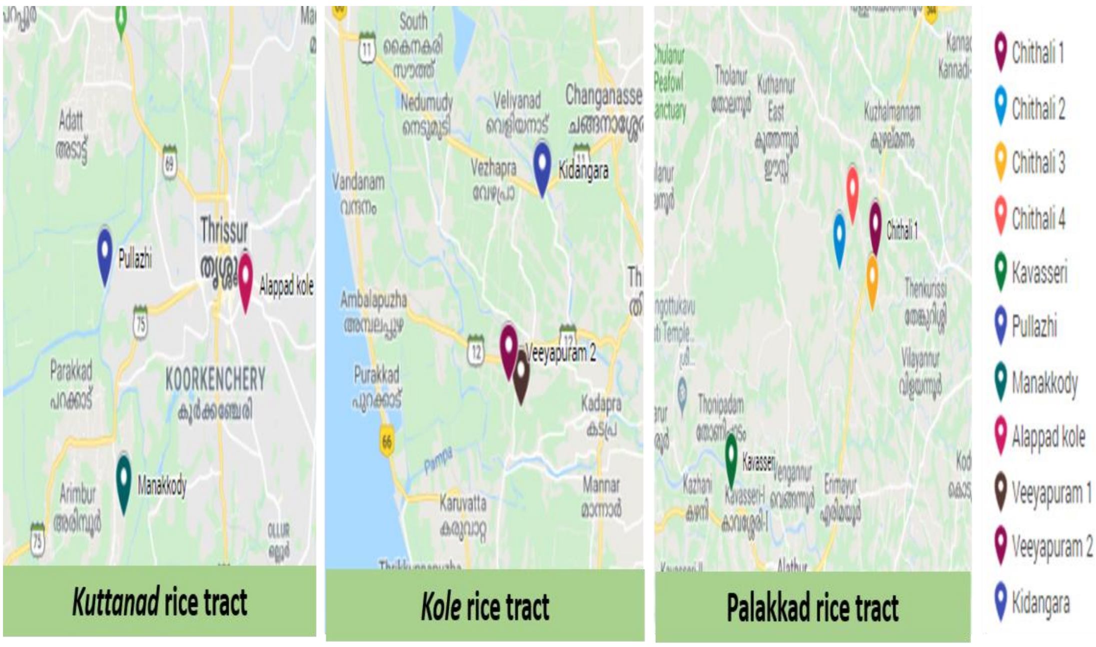


Plate 2. Locations from where *S. interrupta* was collected

Plate 3. Collection of *S. interrupta* morphotypes from different rice tracts of Kerala

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

Sl. No.	Species	Density (No./m^2)	Frequency (%)	Abundance (No./m^2)	RD (%)	RF (%)	RA (%)	SDR
1	*Echinochloa colona*	2.7	70.0	3.9	10.6	9.2	15.2	11.7
2	*Salvinia molesta*	1.5	50.0	3.0	5.9	6.6	11.8	8.1
3	*Monochoria vaginalis*	1.5	70.0	2.1	5.9	9.2	8.4	7.9
4	*Cyperus haspan*	2.5	60.0	4.2	9.8	7.9	16.4	11.4
5	*Sacciolpeis interrupta*	4.9	100.0	4.9	19.3	13.2	19.3	17.2
6	*Leptochloa chinensis*	3.3	70.0	4.7	13.0	9.2	18.6	13.6
7	*Oryza sativa* f. *spontanea*	3.6	90.0	4.0	14.2	11.8	15.7	13.9
8	*Ludwigia parviflora*	0.9	60.0	1.5	3.5	7.9	5.9	5.8
9	*Limnocharis flava*	0.9	50.0	1.8	3.5	6.6	7.1	5.7
10	*Isachne miliacea*	2.2	80.0	2.8	8.7	10.5	10.8	10.0
11	*Kyllinga monocephala*	1.4	60.0	2.3	5.5	7.9	9.2	7.5

Table 7. Distribution and dominance of weed species in surveyed areas of *Kuttanad* tract

Sl. No.	Species	Density (No./m^2)	Frequency (%)	Abundance (No./m^2)	RD (%)	RF (%)	RA (%)	SDR
1	*Echinochloa crus-galli*	3.0	73.3	4.1	15.8	15.5	21.5	17.6
2	*Oryza sativa* f. *spontanea*	1.4	46.7	3.0	7.4	7.2	15.8	10.1
3	*Cyperus iria*	1.5	80.0	1.8	7.7	7.6	9.6	8.3
4	*Cyperus haspan*	0.5	40.0	1.3	2.8	2.8	7.0	4.2
5	*Salvinia molesta*	2.7	73.3	3.7	14.4	14.1	19.6	16.0
6	*Monochoria vaginalis*	1.5	53.3	2.8	7.7	7.6	14.5	9.9
7	*Fimbristylis miliacea*	1.5	46.7	3.1	7.7	7.6	16.5	10.6
8	*Leptochloa chinensis*	1.5	66.7	2.3	8.1	7.9	12.1	9.4
9	*Schoenoplectus juncoides*	0.9	46.7	1.9	4.6	4.5	9.8	6.3
10	*Alternathera sessilis*	0.7	46.7	1.6	3.9	3.8	8.3	5.3
11	*Digitaria ciliaris*	1.1	40.0	2.7	5.6	5.5	14.0	8.4
12	*Sacciolepis interrupta*	2.7	66.7	4.1	14.4	14.1	21.6	16.7

RD- Relative density, RF- Relative frequency, RA- Relative abundance, SDR- Summed dominance ratio

III. Palakkad *rice tract*

S. interrupta was found to be distributed in the main paddy cultivating blocks of Palakkad district *viz*., different locations of Chithali block and Kavasseri. In the surveyed fields rice was cultivated under direct seeding. Details of surveyed areas with severe infestation of *S. interrupta* or morphotypes identified from each location are presented in Table 8. Chithali block had severe infestation of *S. interrupta* and wide variation was exhibited in the morphological characters of *S. interrupta* indicating the existence of morphotypes. In surveyed areas of Palakkad, a total of 15 weed species dominated and out of them, *S. interrupta* recorded highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio, followed by *Leptochloa chinensis*. Other common weeds identified in the surveyed fields were *Echinochloa colona*, *Ludwigia parviflora*, *Isachne miliacea*, etc.

b) Habitat analysis

Habitat analysis was carried out in the major rice tracts of Kerala *i.e. Kole*, *Kuttanad* and Palakkad and expressed in terms of weed vegetation. Comparison of weed vegetation analysis indices in different rice tracts of Kerala showed the highest weed species richness (R) of 15 in Palakkad tract compared to other two tracts, showing the dominance of weeds, primarily *S. interrupta,* under dryland and direct seeded conditions. Simpson diversity (D), Shannon-Wiener diversity (H) and Evenness (J) indices were highest in *Kuttanad* and *Kole, i.e.,* 0.9, 2.3 and 0.95, and 0.8, 2.2 and 0.9 respectively, whereas in Palakkad tract it was 0.7, 1.5 and 0.5 respectively, showing a high degree of domination of one species in Palakkad tract and a larger diversity of weed species in other two tracts (Table 9).

c) Characters of morphotypes at flowering

S. interrupta was found to occur in all the surveyed locations. The weed inhabited cultivated rice fields, field bunds, irrigation channels, marshy areas and stream banks. Incidence was also noted in uncultivated fields. The observations taken from each location are furnished in Tables 10, 11 and 12.

Table 8. Distribution and dominance of weed species in surveyed areas of Palakkad tract

Sl. No.	Species	Density (No./m^2)	Frequency (%)	Abundance (No./m^2)	RD (%)	RF (%)	RA (%)	SDR
1	*Echinochloa colona*	1.9	70.0	2.7	5.9	9.0	8.4	7.4
2	*Leptochloa chinensis*	2.7	80.0	3.4	8.4	10.3	10.5	9.3
3	*Fimbristylis miliacea*	1.0	40.0	2.5	3.1	5.1	7.8	4.1
4	*Eclipta alba*	1.0	50.0	2.0	3.1	6.4	6.2	4.8
5	*Ludwigia parviflora*	1.8	70.0	2.6	5.6	9.0	8.0	7.3
6	*Lindernia crustacean*	0.4	20.0	2.0	1.2	2.6	6.2	1.9
7	*Commelina diffusa*	1.0	30.0	3.3	3.1	3.8	10.4	3.5
8	*Cyanotis axillaris*	1.4	60.0	2.3	4.3	7.7	7.2	6.0
9	*Leucas aspera*	0.8	30.0	2.7	2.5	3.8	8.3	3.2
10	*Scoparia dulcis*	1.0	40.0	2.5	3.1	5.1	7.8	4.1
11	*Isachne miliacea*	1.8	60.0	3.0	5.6	7.7	9.3	6.6
12	*Spilanthes calva*	1.0	50.0	2.0	3.1	6.4	6.2	4.8
13	*Sacciolpeis interrupta*	13.6	100.0	13.6	42.2	12.8	42.2	27.5
14	*Schoenoplectus juncoides*	1.5	40.0	3.8	4.7	5.1	11.6	4.9
15	*Cyperus iria*	1.3	40.0	3.3	4.0	5.1	10.1	4.6

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

Indices	*Kole*	*Kuttanad*	Palakkad
Species richness (R)	11.0	12.0	15.0
Simpson diversity (D)	0.8	0.9	0.7
Shannon-Wiener diversity (H)	2.2	2.3	1.5
Evenness (J)	0.9	0.9	0.5

i. Vegetative characters

S. interrupta plants grew more vigorously in *Kole* areas compared to all other locations. In *Kuttanad* rice tract the weed registered lowest plant height, where it was greatest (108.6 cm and lowest (69.0 cm) in *Kole* and *Kuttanad* tracts respectively (Table 10). Number of tillers per plant were higher in *Kuttanad* (9.4/plant) and it was lowest in Palakkad tract (4.0/plant). In *Kole* tract number of tiller ranged from 7-9 tillers per plant.

Leaf length and width of *S. interrupta* was low in Palakkad tract. Greatest leaf length and leaf width of 40.6 cm and 1.4 cm was recorded in *Kole* areas whereas medium leaf length and leaf width were observed in *Kuttanad* compared to other two tracts. Higher dry matter production (4.2 g/plant) was observed in *Kole*, while it was lowest in *Kuttanad* tract (1.2g/plant) as seen in Table 11 and Plate 4.

ii. Panicle characters

The panicles of *S. interrupta* were green to purple in colour, and growth form was erect and compact in all the locations. The weed in *Kuttanad* tract had higher number of panicles per plant and number of spikelets per panicle (6-8 tillers/plant and 311-348 spikelets/panicle) and lowest number of panicles and number of spikelets per panicle were seen in plants from Palakkad tract (2-4 panicles/plant per plant and 256-291 spikelets/panicle). Length of the panicle was more in plants from *Kole* tract (23.2 cm) and shortest panicle was seen in Palakkad tract (10.2 cm) (Table 11 and Plate 5).

iii. Spikelet characters

S. interrupta had the ability to produce numerous seeds from a single plant. The seeds were very small, oval to oblong shaped, and light brown to dark brown in colour when mature. Spikelet characters of different locations is represented in Table 12. Length of the spikelet was greater in the plants from *Kole* tract (4.7 mm) whereas the width of the spikelet was more in *Kuttanad* tract (1.7 mm), showing that the spikelets were elongated and narrow in *Kole* tract and short and wider in *Kuttanad* tract. Plants in palakkad tract plants had medium panicle length and width. Although

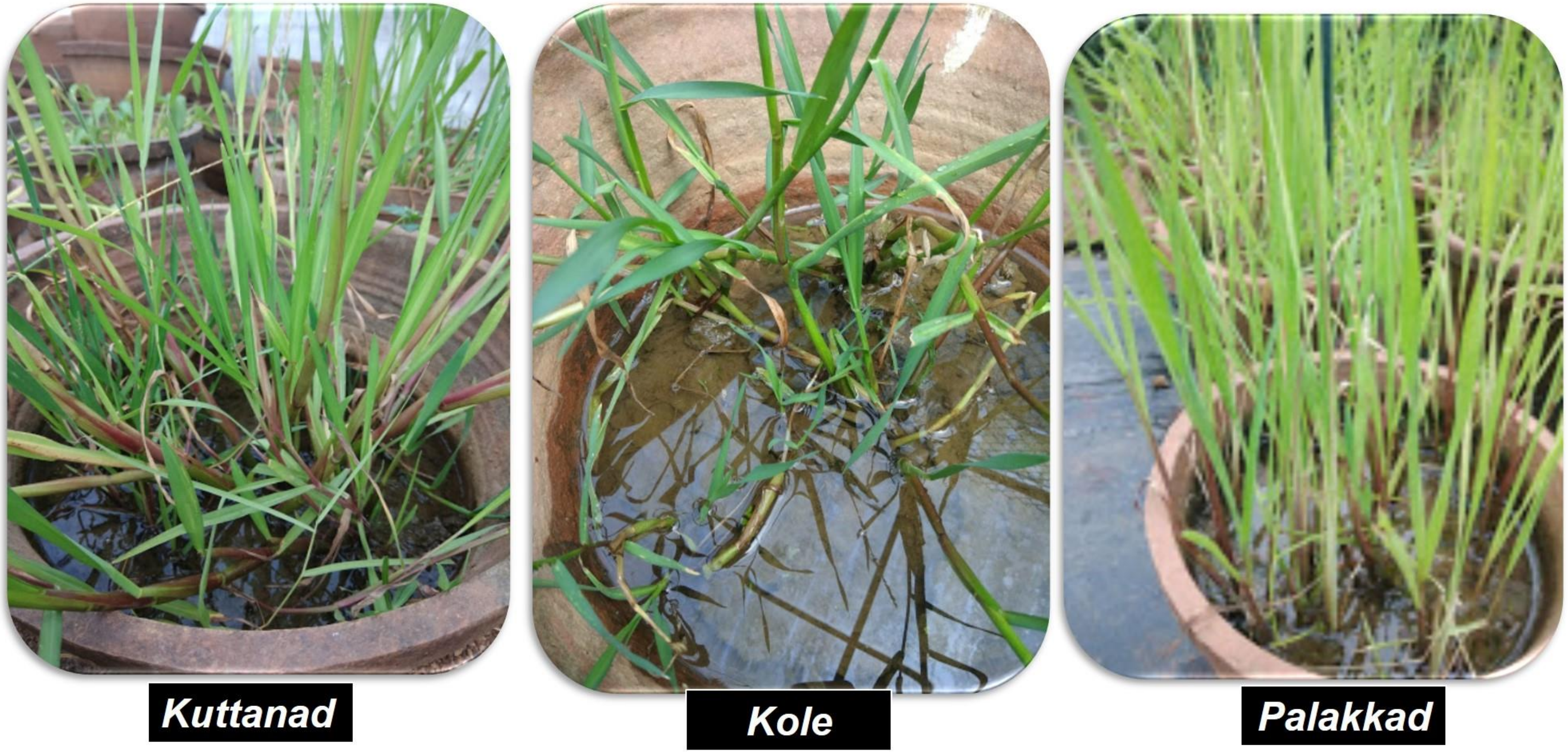


Plate 4. Vegetative characters of *S. interrupta* morphotypes

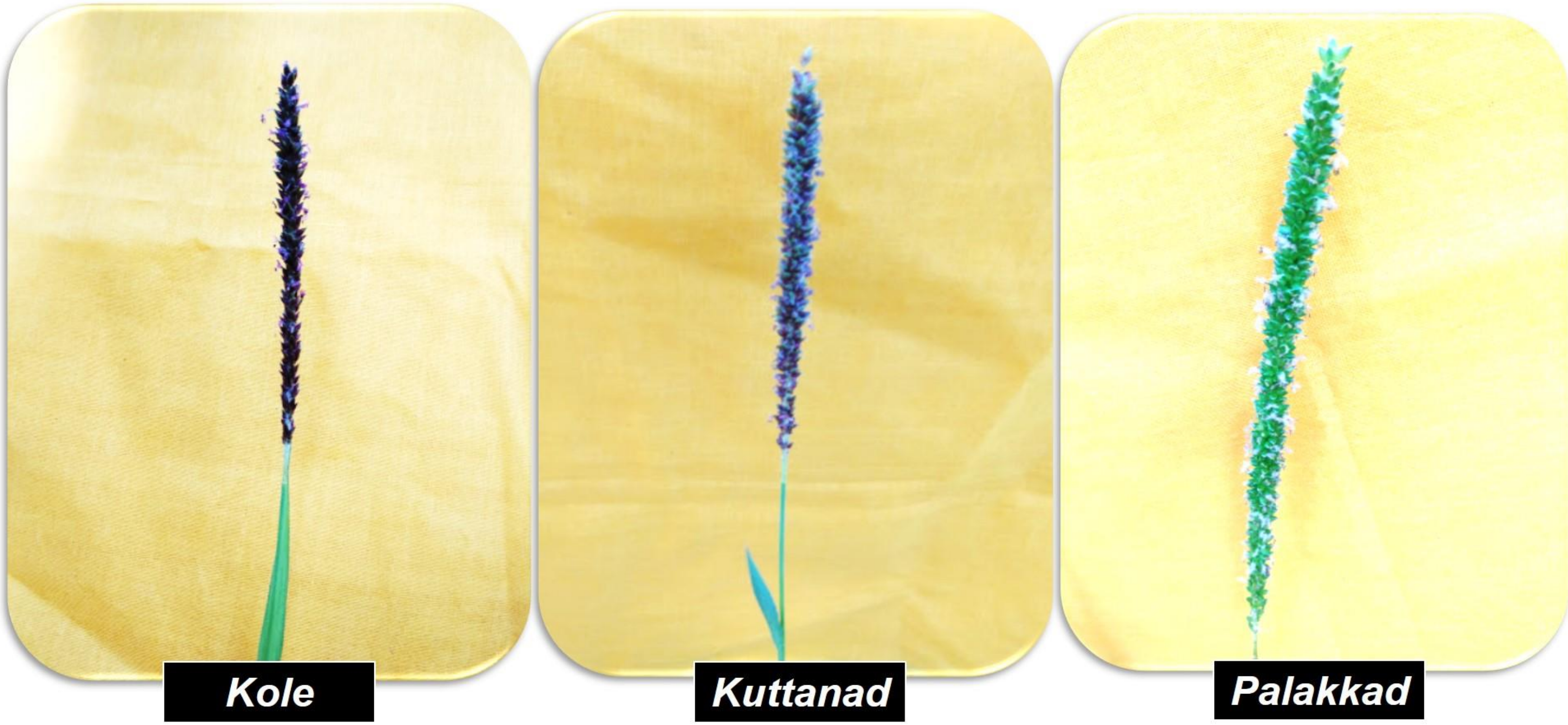


Plate 5. Panicle characters of *Sacciolepis* morphotypes

the total dry matter production of the plants in *Kuttanad* tract was lower, a single panicle contained up to 893-1217 seeds in *Kuttanad*, while the number was 713 to 863 and 312 to 623 seeds in *Kole* and Palakkad tract, respectively.

iv. Flowering of spikelets

The manner of flowering of spikelets in the inflorescence was seen to be non-uniform in all the locations. Flowering began from random position on the inflorescence, and progresses in the same manner. There was no distinct pattern in flower opening, which was probably the reason for the weed being given the species name '*interrupta*'

v. Leaf anatomy

Transverse sections of leaves of *S. interrupta* morphotypes were taken and images were taken with a capturing device attached to light microscope using Leica Application Suite (LAS) software for image digitization (Plate 6 and 7).

C_4 photosynthesis is generally closely associated with a suite of leaf properties known as 'Kranz anatomy'. Kranz anatomy can be defined as two distinct concentric layers of chlorenchyma cells formed by a bundle sheath cells containing mostly chloroplasts, surrounded by a small number of mesophyll cells in the outer layer.

S. interrupta morphotypes showed typical Kranz anatomy with arenchyma cells. The micrographs from the surveyed locations were categorized into green and purple type, showed similar distinct horizontal layers of mesophyll cells in its leaves. Bundle-sheath and mesophyll cells form concentric circles around the vasculature. Vascular bundles were observed both in the adaxial and abaxial regions and in the vertical partitions. The upper epidermis was made of two layers of rectangular cells and the lower epidermis consisted of cylindrical cells. The spongy parenchyma consisted of aerenchyma chambers, some of which were filled with bundles of parenchyma cells.

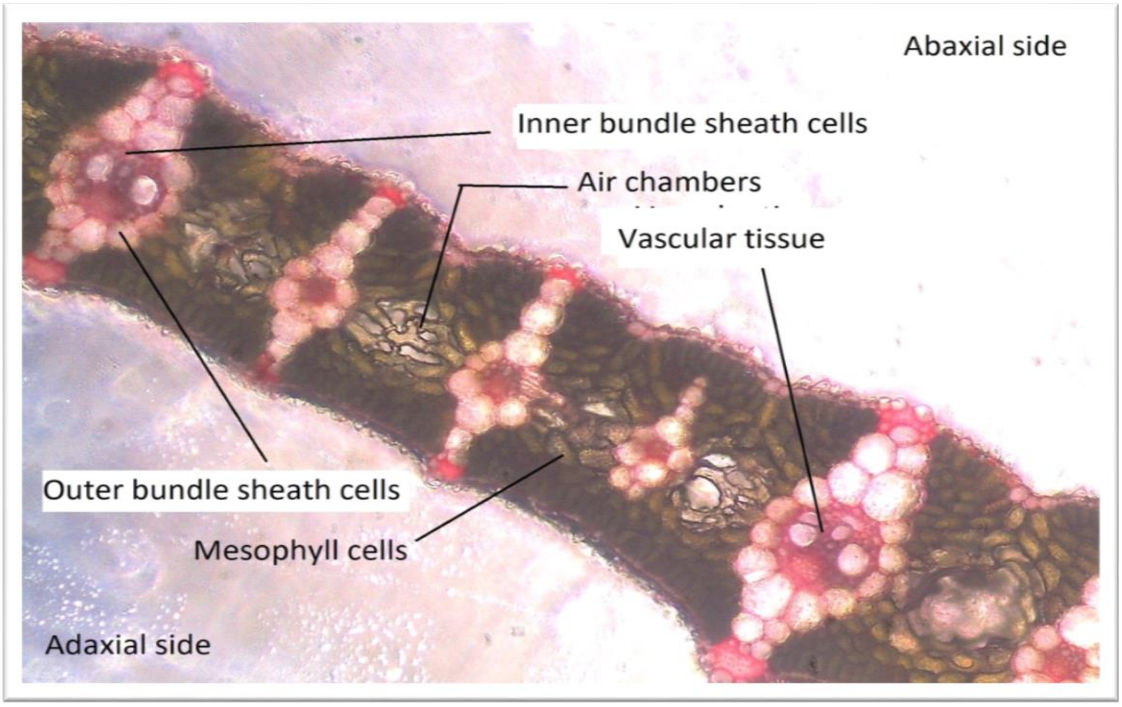


Plate 6. Micrograph of transverse section of *Sacciolepis* green panicle types

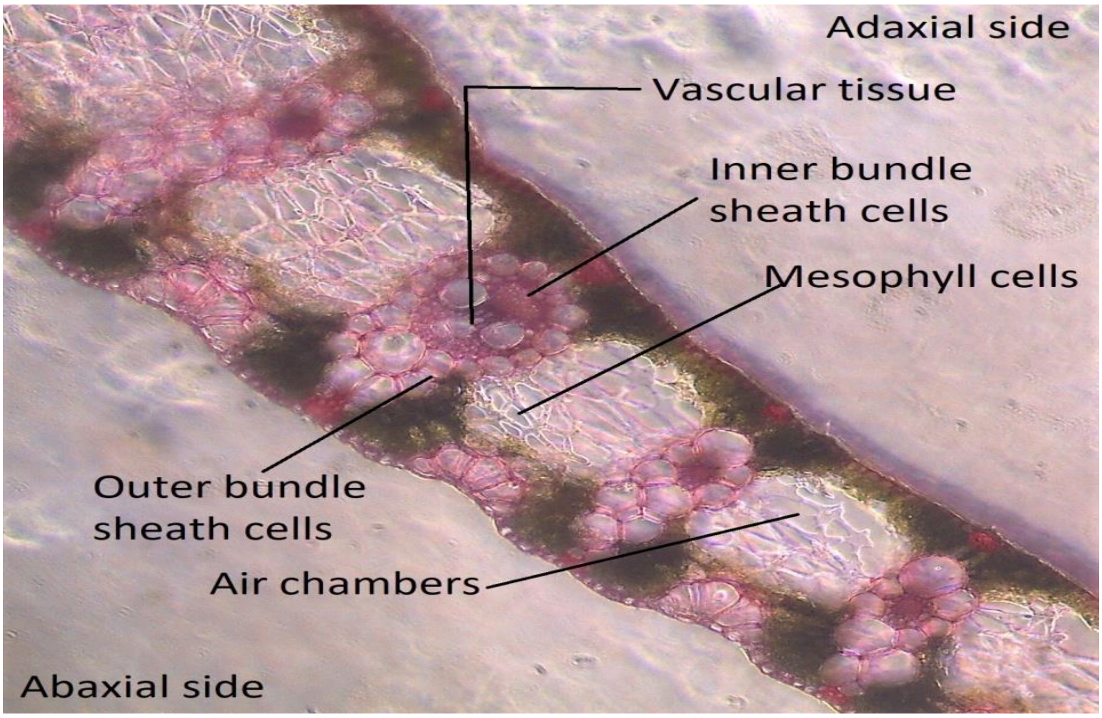


Plate 7. Micrograph of transverse section of *Sacciolepis* purple panicle types

Table 10. Morphological vegetative characters of *S. interrupta* in different locations

Location		Plant height (cm)		No. of tillers/plant		Leaf length (cm)		Leaf width (cm)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Kole	Pullazhi	95.6±4.71	(87-113)	8.4±0.40	(7-9)	39.2±0.96	(37-42)	1.1±0.08	(1.2-1.4)
	Manakkody	101.6±3.54	(94-112)	8.2±0.37	(7-9)	40.6±0.67	(39.42)	1.3±0.03	(1.1-1.3)
	Alappad	108.6±4.66	(98-121)	8.0±0.31	(8-9)	38.4±0.50	(38-40)	1.4±0.02	(1.1-1.3)
Palakkad	Chithali 1	86.6±1.63	(82-91)	5.6±0.24	(5-6)	18.6±1.20	(16-23)	0.4±0.03	(0.4-0.5)
	Chithali 2	91.0±2.25	(83-97)	6.0±0.54	(4-6)	19.4±0.92	(17-22)	0.7±0.04	(0.3-0.4)
	Chithali 3	91.2±1.98	(86-97)	6.6±0.24	(6-7)	19.2±0.48	(18-21)	0.5±0.03	(0.4-0.6)
	Chithali 4	94.0±3.14	(88-106)	5.6±0.24	(5-6)	19.6±0.67	(18-22)	0.7±0.02	(0.3-0.5)
	Kavasseri	94.2±1.39	(91-99)	6.8±0.37	(6-8)	20.6±0.67	(19-23)	0.6±0.03	(0.4-0.6)
Kuttanad	Veeyapuram 1	70.0±1.87	(64-75)	9.0±0.31	(8-10)	31.0±1.09	(28-34)	1.2±0.02	(1.2-1.3)
	Veeyapuram 2	74.2±1.98	(72-81)	8.6±0.24	(8-9)	29.4±1.63	(26-35)	1.3±0.04	(1.2-1.4)
	Kidangara 1	69±3.04	(61-78)	9.4±0.50	(8-11)	28.2±0.86	(26-31)	1.2±0.03	(1.2-1.4)
	Kidangara 2	75.2±2.13	(69-81)	9.0±0.54	(7-11)	30.2±0.73	(28-32)	1.3±0.02	(1.3-1.6)

Table 11. Morphological panicle characters of *S. interrupta* in different locations

Location		No. of panicles/plant		Panicle length (cm)		No. of spikelets/panicle		Dry matter/plant (g)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Kole	Pullazhi	5.4±0.40	(4-6)	21.2±0.58	(20-23)	318.6±6.17	(311-342)	2.52±0.08	(2.61-2.82)
	Manakkody	5.0±0.44	(4-6)	20.8±0.37	(20-22)	322.2±2.81	(316-331)	3.63±0.09	(2.94-3.72)
	Alappad	5.2±0.20	(5-6)	23.2±0.58	(22-25)	328.2±7.05	(324-348)	4.21±0.08	(3.81-4.23)
Palakkad	Chithali 1	3.8±0.20	(3-4)	8.75±0.74	(8-12)	275.4±4.15	(261-285)	1.46±0.07	(1.36-1.52)
	Chithali 2	3.4±0.24	(3-4)	10.4±0.50	(9-12)	280.8±3.56	(272-291)	1.51±0.08	(1.39-1.62)
	Chithali 3	3.2±0.37	(2-4)	11.0±0.54	(10-13)	277.0±4.67	(261-289)	1.72±0.09	(1.52-1.77)
	Chithali 4	2.8±0.37	(2-4)	10.2±0.58	(9-14)	270.8±5.47	(256-283)	1.76±0.08	(1.51-1.71)
	Kavasseri	2.6±0.24	(2-3)	10.6±0.81	(9-13)	268.0±1.73	(263-272)	1.49±0.05	(1.56-1.72)
Kuttanad	Veeyapuram 1	6.6±0.24	(6-7)	16.8±0.37	(16-18)	386.2±2.57	(381-396)	1.37±0.07	(1.31-1.78)
	Veeyapuram 2	7.4±0.24	(7-8)	16.6±0.66	(15-18)	378.4±7.30	(362-405)	1.41±0.08	(1.32-1.62)
	Kidangara 1	7.2±0.20	(6-8)	15.8±0.37	(15-17)	397.6±6.25	(391-415)	1.21±0.07	(1.16-1.42)
	Kidangara 2	7.0±0.30	(6-8)	15.8±0.66	(14-18)	391.2±4.55	(981-407)	1.32±0.08	(1.24-1.44)

Table 12. Morphological spikelet characters of *S. interrupta* in different locations

Location		Length of spikelet (mm)		Width of spikelet (mm)		No. of seeds/plant	
		Mean	Range	Mean	Range	Mean	Range
Kole	Pullazhi	4.72±0.03	(4.6-4.8)	1.08±0.04	(0.9-1.1)	793.2±30.8	(713-862)
	Manakkody	4.74±0.02	(4.7-4.8)	1.12±0.02	(1.1-1.2)	789.2±24.0	(739-863)
	Alappad	4.76±0.05	(4.7-4.8)	1.2±0.031	(1.1-1.3)	750.4±16.5	(724-815)
Palakkad	Chithali 1	3.18±0.03	(3.1-3.2)	1.34±0.05	(1.2-1.5)	587.6±41.6	(486-572)
	Chithali 2	3.22±0.03	(3.1-3.3)	1.36±0.04	(1.3-1.5)	514.0±29.4	(438-612)
	Chithali 3	3.22±0.02	(3.2-3.3)	1.36±0.02	(1.3-1.4)	437±38.1	(312-513)
	Chithali 4	3.22±0.05	(3.1-3.4)	1.40±0.03	(1.4-1.5)	509.4±35.8	(389-615)
	Kavasseri	3.32±0.03	(3.2-3.4)	1.36±0.02	(1.3-.14)	580.2±20.57	(503-623)
Kuttanad	Veeyapuram 1	4.26±0.06	(4.1-4.5)	1.7±0.03	(1.6-1.8)	1141.2±24.99	(1073-1217)
	Veeyapuram 2	4.32±0.05	(4.2-4.5)	1.6±0.03	(1.5-1.6)	1023.8±66.38	(893-1196)
	Kidangara 1	4.34±0.05	(4.2-4.5)	1.7±0.03	(1.6-1.8)	1115.4±52.80	(912-1214)
	Kidangara 2	4.22±0.05	(4.1-4.4)	1.6±0.02	(1.6-1.7)	1091.2±23.24	(1012-1146)

v. Cluster analysis of *S. interrupta* morphotypes

Using Euclidean distance as similarity index, cluster analysis was done to differentiate between the eleven morphological characters of different morphotypes collected from the surveyed locations. Principal component analysis (PCA) was carried out to find out the components which were important for clustering the *S. interrupta* types. Based on morphological characters, fifteen morphotypes of *S. interrupta* were categorized from the three surveyed rice tracts (Table 13). *S. interrupta* was classified into six groups by cluster analysis at 66.67 % similarity level. Group 1 included 4 types *i.e.*, type 1, 8, 12 and 9. Group 2 included 4 types *i.e.*, 4, 10, 5 and 6. Type 11 and 2 occupied separate groups (Group 3 and Group 4 respectively). Group 5 included four types 3, 15, 7 and 13. Group 6 included type 14 (Plate 8).

Scree plot of principal component analysis (PCA) indicated that first two PCA corresponded to whole percentage variance in the data, as they possessed Eigen value of >1 (Plate 9). PC1 and PC2 together accounted for 81.7% of total variations of which PC1 accounted for 61.90 % and PC2 accounted for 19.80 %.

PC1 was related to all morphological characters except width of spikelets and PC2 was related to characters like plant height, panicle length, leaf length, leaf width and dry matter production/plant. PC1 was more positively contributed by six morphological characters in the order plant height, panicle length, length of spikelet, leaf length, leaf width, dry matter production/plant.

PC2 was more positively contributed by dry matter production/plant, panicle length, plant height, leaf length and leaf width (Table 14). The scree plot between PC1 and PC2, which together contributed more than 81% of total variation, showed that *S. interrupta* types included in different groups showed distinguishable variations in morphological characters.

Table 13. Location details of *S. interrupta* morphotypes in surveyed areas

Location		**Latitude (^{0}N)**	**Longitude (^{0}E)**	***S. interrupta* morphotypes**	**Code no.**
Palakkad	Chithali 1	10°41'40.8"	76°35'23.4"	Green variegated	1
	Chithali 2	10°41'41.0"	76°35'00.1"	Green variegated	2 & 3
	Chithali 3	10°41'40.9"	76°35'01.7"	Green variegated	4
	Chithali 4	10°41'40.4"	76°35'02.0"	Green variegated	5
	Kavasseri	10°38'01.6"	76°31'07.2"	Green variegated	6
***Kole* lands**	Pullazhi	10°31'32.1"	76°10'16.0"	Purple variegated	7
	Manakkody	10°29'08.5"	76°10'10.9"	Purple variegated	8 & 9
	Alappad	10°31'00.8"	76°13'25.1"	Purple variegated	10 & 11
Kuttanad	Veeyapuram 1	9°21'04.1"	76°28'10.0"	Green-purple variegated	12
	Veeyapuram 2	9°21'04.2"	76°28'10.2"	Green-purple variegated	13
	Kidangara 1	9°25'02.6"	76°29'32.2"	Green-purple variegated	14
	Kidangara 2	9°24'55.7"	76°29'37.6"	Green-purple variegated	15

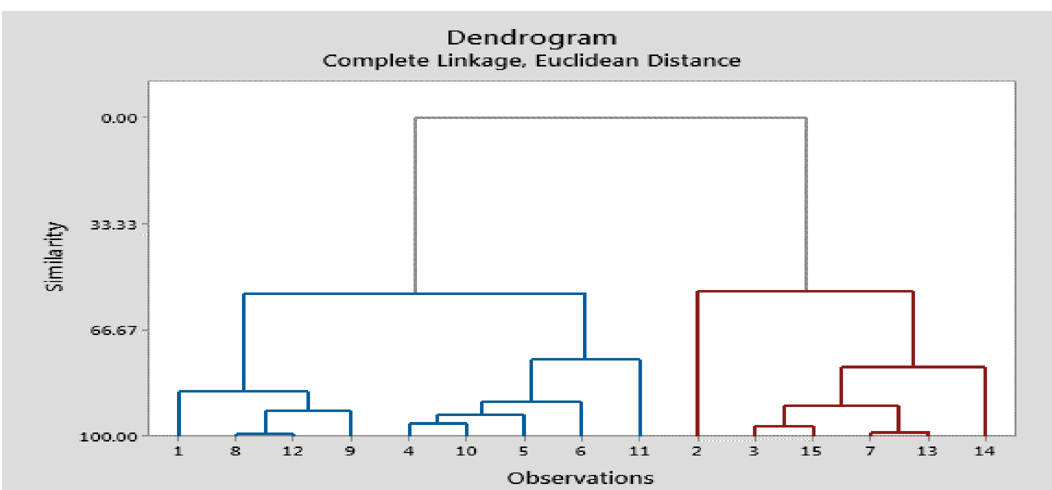


Plate 8. Dendrogram from hierarchical cluster analysis for dissimilarity among fifteen morphotypes of *S. interrupta*

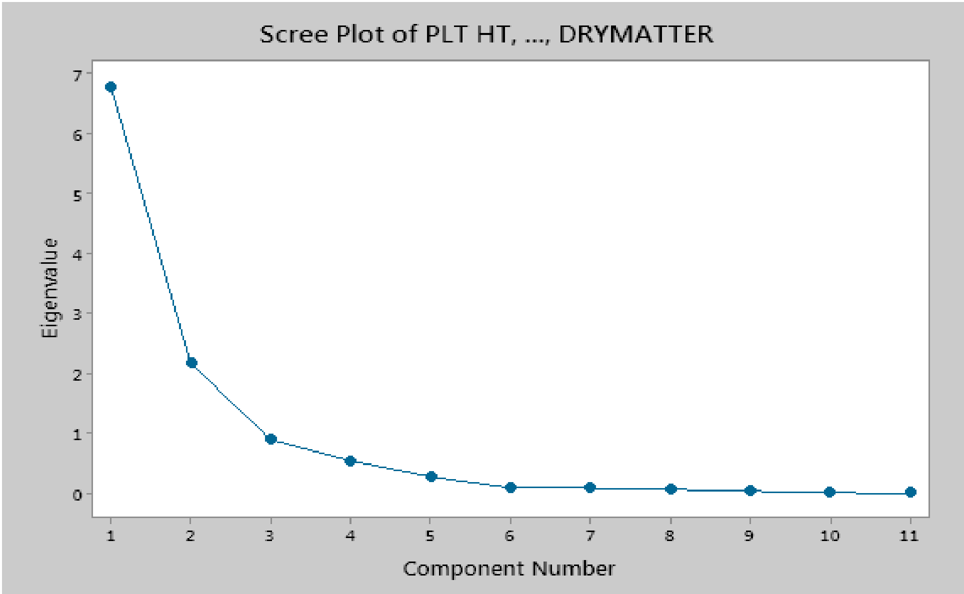


Plate 9. Scree plot showing the Eigen values in response to the morphological characters of *S. interrupta*

The first component data is efficient in grouping and separating one group from others. Group A referred to the morphotypes from Palakkad having green coloured panicles, oblong spikelets, medium stature and narrow light green leaves (green variegated). Group B contained morphotypes from *Kole* tract having purple coloured panicles, enlongated spikelets, tall stature and narrow dark green leaves (purple variegated), and *Kuttanad* tract types were categorized into Group C having bicoloured green and purple panicles, oblong to bulged spikelets, short stature, profuse tillering and with broad dark green leaves (green-purple variegated).

Majority of group B morphotypes were differentiated from group A by the first component, PC1, which is depicted on right hand side of scree plot. Group A occurs on left hand side, while Group C is placed intermediary on the scree plot (Plate 10).

Table 14. PCA values of morphological characters of *S. interrupta*

Sl No.	Morphological observations	PC1	PC2
1	Plant height	0.367	0.115
2	No of tillers	0.274	-0.190
3	No. of panicles	0.162	-0.490
4	Panicle length	0.362	0.124
5	No. of spikelets	0.166	-0.324
6	Seeds per plant	0.203	-0.549
7	Length of spikelets	0.362	-0.105
8	Width of spikelets	-0.244	-0.429
9	Leaf length	0.375	0.073
10	Leaf width	0.349	0.054
11	Drymatter production per plant	0.334	0.291

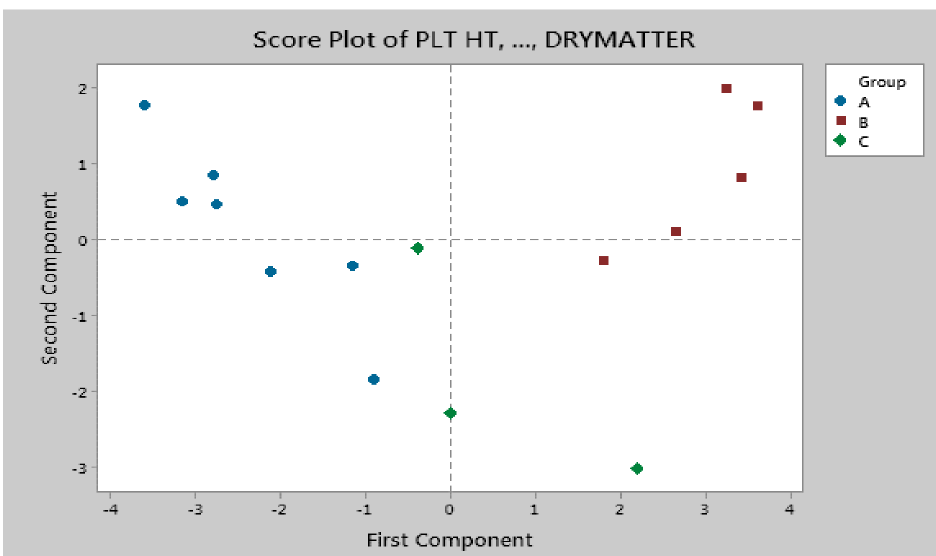


Plate 10. Scree plot of first two PC indicating the variability in morphological characters of *S. interrupta*

d) Contents of major nutrients in *S. interrupta* morphotypes

The contents of major nutrients was highest in *Kuttanad* tract with 1.75, 0.24 and 2.8 per cent N, P and K respectively. In plants of Palakkad tract, the content of N was lower (0.68 %) whereas P (0.10 %) and K (1.83 %) were higher than *Kole*. *Kole* tract had comparatively high N content of (1.24 %), P (0.07%) and K (1.73%) (Table 15).

e) Soil chemical properties

The soil chemical properties of surveyed locations are given in Table 16. All the surveyed areas had acidic soil pH and the soil from *Kole* and Palakkad rice tracts recorded higher pH 6.02-6.65. The acid sulphate soils of *Kuttanad* registered lower pH (4.37-4.42). Electrical conductivity was highest for *Kole* (0.54 mS/m) soil and lowest for Palakkad soil (0.021 mS/m).

The soil collected from *Kuttanad* was rich in organic carbon (4.43 per cent), while it was less than one per cent for Palakkad soil. The highest available nitrogen content was recorded from Kidangara region (476.3-526.4 kg/ha) in *Kuttanad*, but the other locations in *Kuttanad* registered low to medium range of available nitrogen (186.9-246.4 kg/ha). Palakkad soil was observed to be low in available nitrogen (100.8-156.8 kg/ha) and available potassium (87.4-294.6 kg/ha) whereas in *Kole* tract available nitrogen was in medium range (201.6-246.4 kg/ha) while available potassium was low (178.4-252 kg/ha). The available phosphorus content was in medium range (10.0-20.0 kg/ha) for all the surveyed locations.

f) Correlation between morphological characters and soil chemical properties

Severe infestation of *S. interrupta* group A (green variegated) was observed in saturated soils of Palakkad with near neutral pH, low organic carbon and low nutrient status. Group B (purple variegated) dominated in acidic pH, medium organic carbon containing and submerged soils of *Kole* lands, and group C (green-purple variegated) morphotypes were prominent in highly acidic and nutrient rich submerged soils of *Kuttanad*.

Table 15. Contents of major nutrients in *S. interrupta* morphotypes in surveyed locations

Location		**N (%)**	**P (%)**	**K (%)**
Kole	Pullazhi	1.12±0.01	0.07±0.008	1.62±0.08
	Manakkody	0.96±0.04	0.04±0.009	1.73±0.07
	Alappad	1.24±0.02	0.06±0.006	1.66±0.03
Palakkad	Chithali 1	0.84±0.03	0.08±0.006	1.79±0.08
	Chithali 2	0.96±0.02	0.10±0.008	1.76±0.07
	Chithali 3	0.74±0.04	0.09±0.060	1.82±0.07
	Chithali 4	0.68±0.03	0.08±0.070	1.54±0.04
	Kavasseri	0.84±0.02	0.13±0.006	1.83±0.08
Kuttanad	Veeyapuram 1	1.38±0.04	0.19±0.007	2.40±0.07
	Veeyapuram 2	1.29±0.02	0.22±0.004	2.30±0.04
	Kidangara 1	1.75±0.03	0.24±0.008	2.60±0.07
	Kidangara 2	1.64±0.02	0.16±0.007	2.80±0.04

Table 16. Chemical properties of soil of surveyed locations

Location	pH	EC (mS/m)	Organic carbon (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Soil moisture level
Kole							
Pullazhi	5.02	0.32	1.67	201.6	12.25	178.4	Submerged
Manakkody	6.02	0.54	2.13	235.2	10.24	241.9	-do-
Alappad	5.99	0.53	2.22	246.4	13.74	252.0	-do-
Average	5.68	0.46	2.01	227.73	12.08	224.1	-do-
Palakkad							
Chithali 1	5.58	0.04	0.52	100.8	17.74	87.4	Saturated
Chithali 2	5.80	0.05	0.62	112.0	18.49	91.8	-do-
Chithali 3	5.57	0.04	0.58	100.8	20.74	88.5	-do-
Chithali 4	5.65	0.03	0.69	116.8	18.74	98.0	-do-
Kavasseri 2	6.26	0.02	0.90	156.8	15.49	294.6	-do-
Average	0.03	0.66	117.44	18.24	132.1	0.03	-do-
Kuttanad							
Veeyapuram 1	4..42	0.14	2.86	186.9	11.20	193.7	Submerged
Veeyapuram 2	4.37	0.19	3.56	246.4	13.50	213.9	-do-
Kidangara 1	4.38	0.17	4.43	526.4	11.25	222.9	-do-
Kidangara 2	4.61	0.21	5.13	476.3	10.50	242.8	-do-
Average	0.18	4.00	359.00	11.61	218.3	0.18	-do-

4.2 Biology of *S. interrupta*

Biology of *S. interrupta* was studied by observing ten tagged plant samples in the experimental field. The observations recorded for a period of one year from April 2017 to May 2018 are furnished below.

4.2.1 Biology

I. Morphological characters

a. Habit

S. interrupta has annual or perennial, erect or creeping or geniculate habit with rooting at lower nodes, and nodes are glabrous in nature (Plate 11).

b. Habitat

It is commonly seen in the semi dry rice growing areas, as well as wetland rice fields. Apart from that it is seen on field bunds, marshy areas and stream banks.

c. Leaves

Leaves are lanceolate or rounded at base and apex is acute or acuminate ranging from 15 to 50 cm in length and 0.4 to 4 cm in width, either glabrous or sparsely pilose.

d. Inflorescence

Inflorescence is an erect, compact, terminal panicle about 8 to 30 cm long and is either interrupted or spiciform type. The spikelets are ovate or lanceolate either green coloured or green coloured with violet variegations and about 2.1 to 4.8 cm long (Plate 12).

e. Period/ season of flowering

July to September is the peak period of flowering in *S. interrupta*

Plate 11. ***Sacciolepis interrupta*** **vegetative stage**

Plate 12. Inflorescence of ***Sacciolepis interrupta***

f. Flower

Each spikelet has two glumes and two lemmas. The glumes are unequal in length, outer glume is short 1-2.5 * 1mm, while the inner glume is as long as the spikelet. Each lemma contains one floret, outer lemma is short 1-2 * 0.2 mm and florets are either sterile or staminate. Inner lemma is long 2-3.5 * 1-2 mm, ovate to oblong in shape and contains fertile florets which are either monosexual or bisexual. Palea of outer lemma (sterile floret) is very much reduced, while palea of inner lemma (fertile floret) is well developed and is 1.5 to 3.5 mm long, elliptic or 2-keeled and hyaline. Fertile floret has three stamens and anthers which are dorsifixed, and are either violet or purple or white in colour and the ovary has a bifid style, and a plumose pink or white coloured stigma (Plate 13).

g. Anthesis and Pollination

Flowering usually begins from tip and continues until middle of panicle on first night. Timing of anthesis is between 4.00 am to 9.30 pm. Each spikelet has three flowering phases, spikelet opening, pollination and closing, and flowering phase completes in 3 to 4 hours.

The opening phase takes 60 to 75 minutes, and the spikelet remains open for 60 minutes. Pink colour stigma flows out of the whorl of flower, and during this time, between the stigmas, 3 violet or white coloured anther lobes emerge and shed the pollen. The anthers elongate to a length greater than the stigma and they collapse mostly on the stigma after rapid desiccation. Then the spikelets close rapidly, with the vestiges of anther and stigma remaining trapped outside the spikelet. These remnants of anthers turn from violet to pale white, signifying spikelet opening and fertilization. The spikelets are opened only once.

h. Seeds

Spikelets turn dark green to brown colour as they mature, and the seeds are 2 to 2.5 mm long and ovoid in shape, with light brown colouration.

i. Propagation and spread

S. interrupta is propagated sexually by seeds and vegetatively by root clumps or by culm cuttings.

Seeds are shed and dispersed by wind and water. Seeds exhibit dormancy for a period of six to nine months (September to April), and germinate under favourable high temperature conditions (May to August).

S. interrupta can be propagated vegetatively throughout the year either by rooted clumps or by culm cuttings. The culms produce new roots from the nodes placed below the soil and continue to grow as new plants.

II. Duration of growth stages

S. interrupta has three general growth phases: vegetative, reproductive, and ripening (Table 17 and Plate 14).

a. Germination

Germination in *S. interrupta* occurs when the first shoots and roots start to emerge from the seed and the plant begins to grow. To germinate, *S. interrupta* seeds need to absorb a certain amount of water and be exposed to a temperature range of 35-40 °C. This breaks the dormancy of the seed. When germinated in flooded soil, the shoot is the first to emerge from the seed, with the roots developing when the first shoot has reached the air. If the seed is germinated in non-flooded soil, the root is the first to emerge from the seed and then the shoot. It usually takes seven to nine days after sowing.

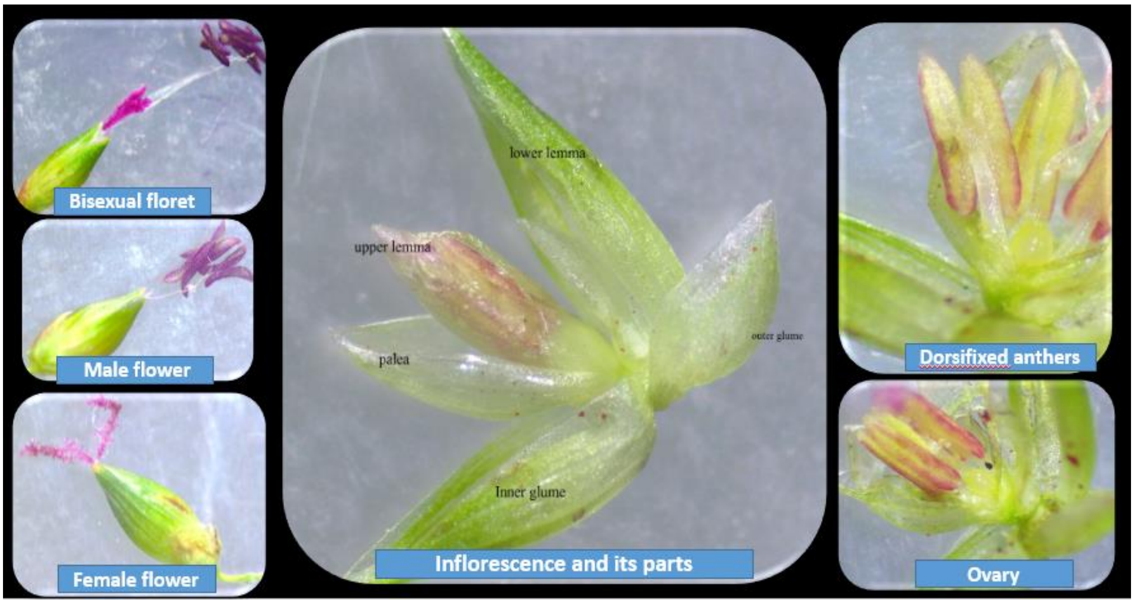


Plate 13. Floral biology of *Sacciolepis interrupta*

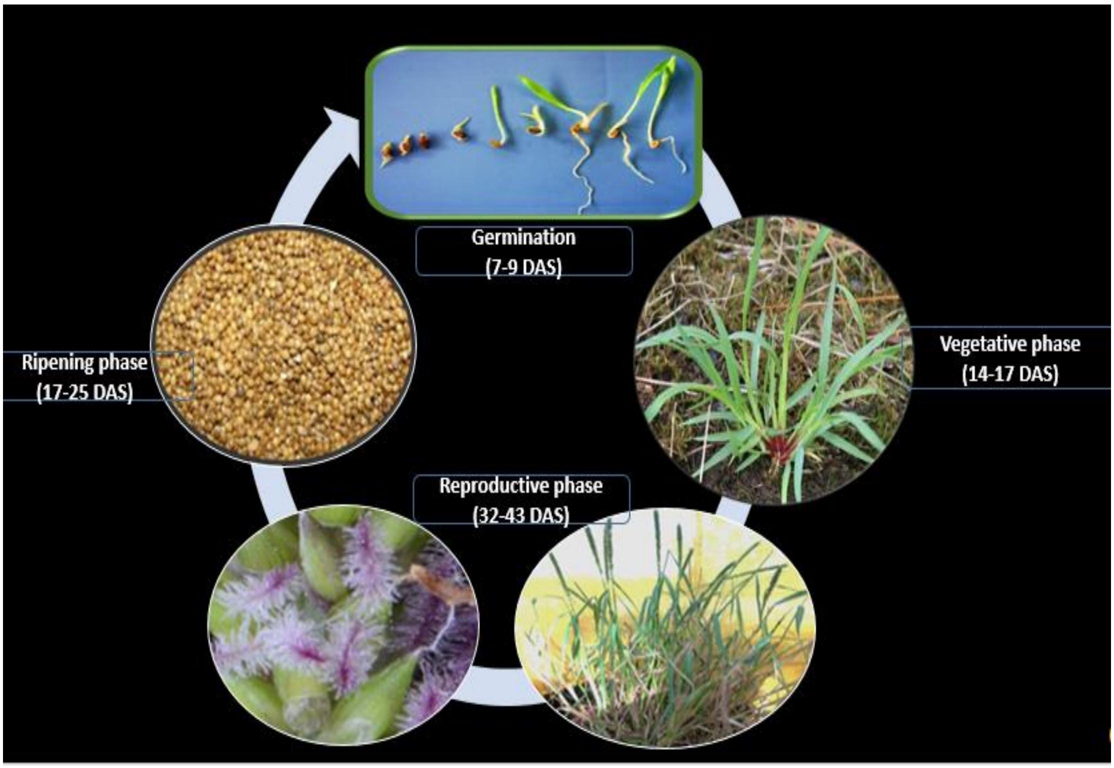


Plate 14. Ontogeny of *Sacciolepis interrupta*

b. Vegetative phase

Vegetative phase is characterized by the development of tillers and leaves, and a gradual increase in plant height. It takes around 29 to 35 days. Early vegetative phase begins as soon as the seed germinates into a seedling and ends at tillering. Seedling stage starts right after the first root and shoot emerge, and lasts until just before the first tiller appears. During this stage, seminal roots and up to five leaves develop. Stem begins to lengthen late in the tillering stage and stops growing in height just before panicle initiation, which is the signal for the end of the vegetative phase.

c. Reproductive phase

First sign in reproductive phase is a bulging of the leaf sheath at the base of the plant that conceals the developing panicle, called the 'booting' stage just like in rice. Then the tip of the developing panicle emerges from the stem and continues to grow. Flowering begins a day after heading is completed and days to first flowering is about 57-62 DAS. As the flowers open they shed their pollen and pollination occurs. Flowering continues for about 6 days. The reproductive phase ranges from 13 to 19 days depending on climatic conditions.

d. Ripening phase

Ripening phase starts at the end of flowering and ends when the grain is mature. This stage usually takes 17 to 24 days. Rainy days or low temperatures may lengthen the ripening phase, while sunny and warm days may shorten it.

III Biometric characters

In rice fields of the experimental area, plant height of *S. interrupta* ranged from 70-112 cm (Table 18). Leaves were green to dark green and pubescent, and number ranged from 3 to 7. The size of the leaves ranged from 19 to 78 cm length and 0.4 to 3.8 cm width. The tiller number ranged from 3 to 6 and the number of panicles were 3 to 4 per plant. Length of panicle ranged from 8 to 30 cm and there were about 33 to 310 spikelets per panicle. Spikelets ranged about 2.1 to 4.8 cm long. The total seed production capacity per plant ranged between 121 and 872 and seed weight per plant was between 182 to 1065 g. 1000 seed weight of *S. interrupta* seeds ranged from 2.2 to 4.2 g. Content of major nutrients in *S. interrupta* plants was worked out at the time of flowering and the content of N, P and K ranged from 0.7-1.6, 0.07-0.18 and 1.7-2.7 per cent respectively.

4.2.2 Methods of propagation

Regeneration capacity of *S. interrupta* was assessed in different plant parts. It was observed that *S. interrupta* can propagate by different methods. Seeds, culm cuttings and root clumps were observed to be on par in germination and regeneration capacity. Morphological characters like branching, tillering, leaf length, and leaf width were found to be better in vegetatively propagated plants compared to seed propagated ones, whereas plant height was greater in seed propagated (Table 19 and Plate 15).

Table 17. Ontogeny of *S. interrupta*

Characters	Range	Average	SEm
Days to germination	7-9	8	0.27
Days to tillering	14-17	16	0.34
Days to panicle initiation	15-18	17	0.33
Days to booting	9-14	11	0.51
Days to 1st flowering after heading	3-4	3	0.15
Days to flowering	5-7	6	0.27
Days to grain filling	10-14	12	0.41
Days to maturity	7-11	9	0.31

Plate 15. Different methods of propogation of *Sacciolepis interrupta*

Table 18. Biometric characters of *S. interrupta*

Characters	Range	Average	SEm
Plant height (cm)	70-112	86	4.47
No. of leaves/plant	3-7	5	0.51
Length of leaf (cm)	19-78	48	5.43
Width of leaf (cm)	0.4-3.8	3	0.35
No. of tillers/ plant	3-6	5	0.50
No. of panicles/ plant	3-4	3	0.16
Length of panicle (cm)	8-30	17	2.34
No. of spikelets/ panicle	33-310	140	28.73
Length of spikelet (cm)	2.1-4.8	4	0.27
No. of seeds/ plant	121-872	454	70.39
Seed weight/ plant (g)	182-1065	681	105.59
1000 seed weight (g)	2.2-4.2	3	0.22
N content at flowering (%)	0.7-1.6	1.1	0.12
P content at flowering (%)	0.07-0.18	0.13	0.012
K content at flowering (%)	1.7-2.7	2.2	0.096

Table 19. Effect of propagules on morphological characters of *S. interrupta* at 80 DAS

Sl. No.	Characters	Propagule		
		Seeds	Culm cuttings	Root clumps
1	Plant height(cm)	112-127	68-72	83-87
2	No. of tillers (Nos./plant)	2-3	4-6	4-6
3	Leaf length (cm)	24-27	29-32	34-37
4	Leaf width (cm)	0.7-0.9	1.4-1.6	1.3-1.4

4.2.3 Germination Studies

The results of germination studies conducted with newly shed seeds and six months old seeds and physiologically matured seeds are detailed below

I. Laboratory studies

i. Seed viability studies

Fresh seeds as well as six month old seeds when tested showed pink colour staining. Among both lots, fresh seeds were more viable and showed higher proportion of stained embryos compared to the old seeds (Plate 16).

ii. Effect of scarification treatments on germination

Both fresh and six month old seeds showed zero germination when experiments were conducted from September to April, and all the scarification treatments including hot water treatment, failed to induce germination. But when the experiments were conducted during May to August, it resulted in very good germination. The response of fresh seeds to scarification treatments was higher compared to six month old seeds.

Among the different treatments, concentrated sulphuric acid treatment for 5 to 30 min resulted in 80 % germination in fresh seeds, and perchloric acid (1 %) recorded highest germination percentage of 64 % in old seeds compared to untreated seeds, which had lowest rate of germination in both the cases (Table 20).

iii. Effect of temperature and light on germination

Germination of *S. interrupta* seeds was influenced by the interaction between temperature and light. Light strongly stimulated germination, while darkness completely inhibited germination of *S. interrupta*. Maximum germination (68 %) occurred when seeds were exposed to higher temperature of 38^0C and continuous light for a period of 14 days. With the same temperature under alternate light and dark conditions, a germination of 54.7 % was recorded. At lower temperatures there was no influence of light on germination and germination percentage was zero (Table 21 and Plate 17). *S. interrupta* seeds germinated at higher temperatures both under continuous light as well as alternate light and dark conditions, indicating a positive photoblastic response of weed under high temperature regimes.

II Pot culture studies

i. Ideal conditions for germination

S. interrupta seeds under continuous submergence showed higher germination and emergence compared to the condition simulating upland situation. In the treatment lowland with continuous flooding, highest emergence of *S. interrupta* was recorded at 7, 14 and 30 days after sowing, followed by lowland conditions with alternate flooding and drying, and the emergence was lowest under upland conditions.

Burial along with rice was found to significantly reduce the germination of *S. interrupta* at all dates of observation. The interaction effect was significant and had highest seedling emergence of 27, 37 and 35 was observed at 7, 14 and 30 DAS respectively in lowland condition with continuous flooding, in the absence of rice seeds. However, comparing the effect of sowing with and without rice seeds, the rate of germination was low when *S. interrupta* was sown along with rice seeds and it was higher in absence of rice seeds (Table 22 and Plate 18).

ii. Seasonal variations in germination

Monthly observations on germination of non-scarified fresh and six month old seeds of *S. interrupta*, showed 0 % germination in initial three months *i.e.*, from January to March, as well as in the last four months *i.e.*, September to December. Germination improved from the 3rd week of April onwards in fresh seeds and from 1st week of May in case of old seeds. Germination percentage was highest in the 3rd of June for both fresh and old seeds (92 % and 80 % respectively) (Table 23).

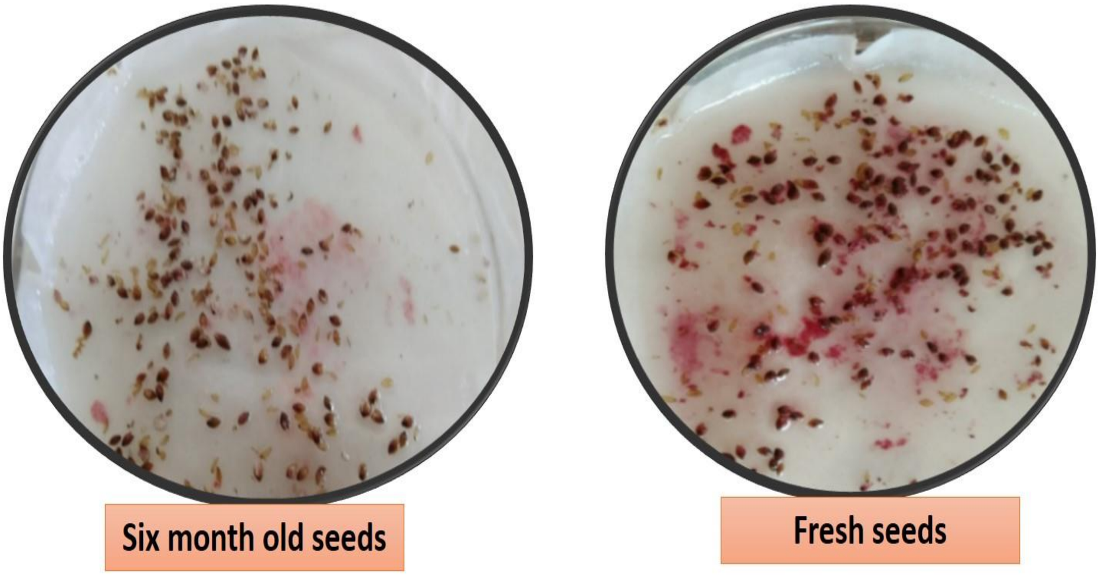


Plate 16. Seed viability studies

Plate 17. Effect of light and temperature on germination of *Sacciolepis interrupta*

Plate 18. Ideal conditions for germination of *Sacciolepis interrupta*

Table 20. Effect of seed scarification treatments on germination of *S. interrupta*

Sl. No.	Treatments	Germination % of fresh seeds		Germination % of six month old seeds	
		Sep – April	May- Aug	Sep- April	May -Aug
T_1	Breaking seed coat	0	68	0	48
T_2	Sulphuric acid (10%)	0	72	0	60
T_3	Sulphuric acid (50%)	0	72	0	60
T_4	Sulphuric acid (Conc)	0	80	0	60
T_5	Nitric acid (1%)	0	64	0	52
T_6	Per chloric acid (1%)	0	64	0	64
T_7	Potassium hydroxide (1%)	0	64	0	48
T_8	Boiling water (100^{0}C)	0	72	0	52
T_9	Control	0	64	0	36

Table 21. Effect of temperature and light on germination of *S. interrupta*

Temperature (^{0}C)	Mean germination %		
	Continuous light	Continuous dark	Alternate light and dark
28	0	0	0
33	46.7	0	0
38	68	0	54.7

Table 22. Effect of soil moisture status on emergence of *S. interrupta*

Treatments	7 DAS	14 DAS	30 DAS
FACTOR- I			
T_1- Upland	3	4	4
T_2- Lowland with continuous flooding	21	31	29
T_3- Lowland with alternate flooding and draining	12	21	18
CD (0.01)	2.18	1.70	1.91
FACTOR- II			
S_1- *S. interrupta* with rice seeds	9	14	13
S_2- *S. interrupta* without rice seeds	16	23	21
CD (0.01)	1.78	1.38	1.62
INTERACTION			
T_1S_1- *S. interrupta* with rice seeds in upland condition	2	2	2
T_1S_2- *S. interrupta* without rice seeds in upland condition	4	6	6
T_2S_1- *S. interrupta* with rice seeds in lowland under continuous flooding	15	24	22
T_2S_2- *S. interrupta* without rice seeds in lowland under continuous flooding	27	37	35
T_3S_1- *S. interrupta* with rice seeds in lowland under alternate flooding and draining	9	16	14
T_3S_2- *S. interrupta* without rice seeds in lowland under alternate flooding and draining	15	26	23
CD (0.01)	2.26	2.40	2.81

iii. Effect of depth of burial

Emergence of *S. interrupta* decreased as the depth of seed placement in soil increased (Table 24 and Plate 19). The per cent of seedling emergence decreased drastically beyond the placement depth of 5 cm with 12 % germination. About 72 % of seeds germinated when seeds were placed on the surface (0 cm) and it was 44 % at 2 cm depth by end of 4 weeks after sowing.

iv. Study on seed longevity

When the effect of seed longevity on germination of *S. interrupta* seeds was tested through the year, it was found to be highest in the month of June (23^{rd} to 25^{th} standard week) compared to other months. Highest germination in *S. interrupta* was recorded in the month of June (88 %) irrespective of the depth of seed burial. In *S. interrupta* germination rate was highest in 23^{rd} standard week in the treatment $T_{4,}$ *i.e*., burial at 8 cm depth along with rice seeds (Table 25 and Plate 20).

Germination in *S. interrupta* was found to increase from 15^{th} standard week *i.e*., 1^{st} week of May, and was highest during 23^{rd} standard week *i.e*., June, and declined thereafter and reached zero by end of 33^{rd} standard week *i.e*., 4^{th} week of August. Significantly higher germination percentage was observed when seeds were placed deep at 8 cm and 4 cm depth, as compared to 2 cm and surface buried seeds.

The presence of rice seeds significantly improved germination of *S. interrupta*, and was highest in the 23^{rd} standard week. Interaction effects also revealed significantly higher germination when buried at deeper depths with rice seeds. At both 23^{rd} and 25^{th} standard weeks, highest germination was observed when buried at 8cm depth along with rice seeds.

Table 23. Seasonal variations in germination (%) of *S. interrupta*

Month	1st week		2nd week		3rd week		4th week	
	New seeds	Six month old seeds	New seeds	Six month old seeds	New seeds	Six month old seeds	New seeds	Six month old seeds
Jan	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0
Apr	8	0	12	8	20	8	20	12
May	68	48	68	60	80	60	88	72
June	80	68	88	80	92	80	92	72
July	68	48	68	32	60	24	48	20
Aug	48	32	48	32	32	24	24	24
Sep	12	0	8	0	8	0	0	0
Oct	0	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0

Table 24. Effect of depth of burial in germination (%) of *S. interrupta*

Depth \ Weeks	1st week	2nd week	3rd week	4th week
0 cm	32	60	62	72
2 cm	28	32	36	44
5 cm	2	4	8	12
10 cm	0	0	0	4
15 cm	0	0	0	2

Plate 19. Effect of depth of burial on germination of *Sacciolepis interrupta*

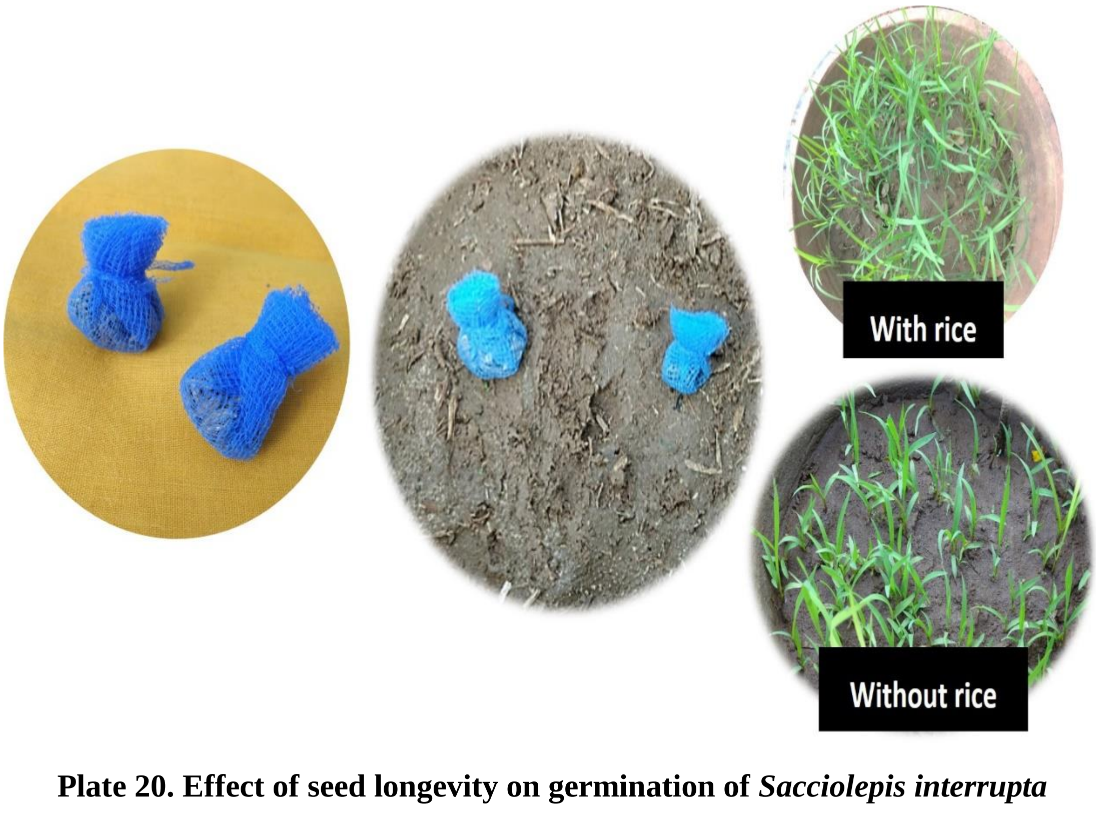


Plate 20. Effect of seed longevity on germination of *Sacciolepis interrupta*

Table 25. Effect of depth of seed burial in soil with and without rice seeds on germination of *S. interrupta*

Treatments	Seeds germinated (No.)		
	23rd Std wk	25th Std wk	27th Std wk
FACTOR- I			
T_1- 0 cm	9	8	7
T_2- 2 cm depth	10	9	8
T_3- 4 cm depth	15	14	13
T_4- 8 cm depth	19	18	16
CD (0.01)	1.51	1.39	1.43
FACTOR- II			
S_1- *S. interrupta* with rice seeds	15	14	12
S_2- *S. interrupta* without rice seeds	11	10	9
CD (0.01)	1.07	0.98	1.01
INTERACTION			
T_1S_1- *S. interrupta* with rice seeds at 0 cm depth	9	8	6
T_1S_2- *S. interrupta* without rice seeds at 0 cm depth	8	7	7
T_2S_1- *S. interrupta* with rice seeds at 2 cm depth	11	10	9
T_2S_2- *S. interrupta* without rice seeds at 2 cm depth	9	8	6
T_3S_1- *S. interrupta* with rice seeds at 4 cm depth	17	16	15
T_3S_2- *S. interrupta* without rice seeds at 4 cm depth	13	12	11
T_4S_1- *S. interrupta* with rice seeds at 8 cm depth	22	20	18
T_4S_2- *S. interrupta* without rice seeds at 8 cm depth	16	15	14
CD (0.01)	2.14	1.97	2.02

4.3. Management of *Sacciolepis interrupta* in rice

The field trial of the research programme to manage *Sacciolepis interrupta* (Willd.) Stapf in rice was conducted from May to October, 2017 and 2019 at a farmers' field in Chithali, in Palakkad district. The data from the observations after statistical analysis are presented below. The various field operations carried out in experimental fields are depicted in Plate 21.

4.3.1. Management through pre-emergence herbicides

General view of the pre-emergence experimental plot is given in Plate 22.

1.1 Weeds

Observations on the weed spectrum, species-wise weed count (no.), weed dry weight (kg/ha), and nutrient removal by weeds (kg/ha), for 2017 and 2019 are given below.

Weed spectrum

The experiment was laid out in a site where high infestation of *S. interrupta* was observed every year. The details of the major weeds present in the field during 2017 and 2019 are given in Table 26.

The grass weeds comprised of mainly *S. interrupta*, *Oryza sativa* f. *spontanea*, *Leptochloa chinensis* and *Echinochloa crus-galli*. The sedges present were *Fimbristylis miliacea* and *Cyperus iria*. The main broad leaved weeds (BLWs) were *Cyanotis axillaris* and *Commelina diffusa*.

A. Phytotoxicity rating

Phytotoxicity scoring of both weeds as well as crop was done at third and seven days after spraying (Table 27). Injury symptoms were graded from 0-5 using toxicity scale as per Thomas and Abraham (2007). Among various herbicides applied

Plate 21. Various field operations carried out in experimental fields

FIRST YEAR

SECOND YEAR

Plate 22. General view of the pre-emergence experimental plot

pretilachlor, oxyfluorfen showed phytotoxicity on rice at seven days after spraying. The rating given was '1' indicating the phytotoxicity on crop.

Whitening of leaf tips of crop were noted. However, the crop recovered within a weeks after spraying and no phytotoxic symptoms were seen on crop. As expected, all herbicides showed phytotoxic effect on weeds with scoring and drying of leaves ranging from 2 to 4 indicating moderate control to very good control after spraying.

Table 26. Major weeds in pre-emergence experimental field in 2017 and 2019

Sl no.	Common name	Scientific name	Family
1	Cup scale grass	*Sacciolepis interrupta*	Poaceae
2	Weedy rice	*Oryza sativa* f. *spontanea*	Poaceae
3	Barnyard grass	*Echinochloa crus-galli*	Poaceae
4	Jungle rice	*Echinochloa colona*	Poaceae
5	Chinese sprangletop	*Leptochloa chinensis*	Poaceae
6	Hoorah grass	*Fimbristylis miliacea*	Cyperaceae
7	Yellow nut sedge	*Cyperus iria*	Cyperaceae
8	Water primrose	*Ludwigia perennis*	Onagraceae
9	Hard slitwort	*Lindernia crustacean*	Scrophulariaceae
10	Creeping Cradle Plant	*Cyanotis axillaris*	Commelinaceae
11	Spreading dayflower	*Commelina diffusa*	Commelinaceae

Table 27. Phytotoxicity rating at three and seven days after spraying of pre-emergence herbicides

Treatments	Score on crop		Score on weeds	
	3rd day	7th day	3rd day	7th day
T_1 - Oxyfluorfen	0	0	3	4
T_2 - Pretilachlor	0	1	2	4
T_3 - Pendimethalin	0	0	2	3
T_4 - Oxadiargyl	0	0	3	4

B. Weed density

Data on effect of pre-emergence herbicide treatments on species-wise weed count at 30 DAS, 60 DAS and at harvest for the years 2017 and 2019 are given in Table 28 and 29, respectively.

In 2017, *S. interrupta*, *Oryza sativa* f. *spontanea*, *Echinochloa* spp, *Fimbristylis miliacea* and *Commelina diffusa* were the main weed species, and among them *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest. The treatment unweeded control (T_7) recorded the highest weed density for all the species. The population of *S. interrupta* in 2017 was lowest in hand weeded plot (T_6), followed by stale seed bed (T_5) at 30 DAS, 60 DAS and at harvest. Unweeded control (T_7) had the highest density of 28, 105 and 231/m^2 at 30 DAS, 60 DAS and at harvest respectively.

In 2019 the main weeds were *S. interrupta*, *Oryza sativa* f. *spontanea*, *Echinochloa* spp, *Cyperus* spp, and *Cyanotis axillaris*, and among them *Saaciolepis interrupta* was found to be the most dominating at 30, 60 DAS and at harvest. Comparing with 2017, the type of grass species remained the same, but the population of different sedges and BLWs had altered and in place of *Fimbristylis miliacea*, *Cyperus* spp was the dominating sedge, and *Cyanotis axillaris* was the dominant BLW in place of *Commelina diffusa*. Unweeded control (T_7) recorded the highest density of all the species. Population of *S. interrupta* in 2019 was the lowest in the hand weeded plot (T_6)

i.e., 0, 6 and 11/m^2, followed by stale seed bed (T_5) at 30 DAS, 60 DAS and at harvest respectively. Unweeded control (T_7) recorded the highest weed density of 32, 91 and 244/m^2 at 30 DAS, 60 DAS and at harvest respectively.

The effect of the pre-emergence herbicide treatments on total weed count (no./m^2) at 30 DAS is represented in Table 30. Lowest number of total weeds per m^2 was observed in hand weeding (T_6), stale seed bed (T_5) and oxyfluorfen (T_1) applied plots followed by oxadiargyl applied plot (T_4) in both years.

S. interrupta, was the dominant weed present in the field in both the years. Population of sedges was low while count was higher in second year compared to first year with *Cyanotis axillaris* being the most dominant BLW in the second year. Highest weed count was recorded in unweeded control and lowest was in hand weeding. During both first and second years considering the population of grasses, hand weeded (T_6), stale seed bed (T_5) and oxyfluorfen (T_1) treatments recorded lowest density and highest value was in unweeded control (T_7) plots.

The pooled data revealed that unweeded control had significantly higher density of sedges, while all other treatments were on par. Hand weeding was significantly better in controlling BLWs, followed by application of oxyfluorfen and pretilachlor, while unweeded control had highest density.

Table 28. Effect of pre-emergence herbicides on weed species density (no./ m^2) in 2017

Treatments	*S. interrupta*			*Oryza sativa* f. *spontanea*			*Echinochloa* spp			*Fimbristylis miliacea*			*Commelina diffusa*		
	30	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**
T_1 - Oxyfluorfen	1.28^{c*} (2)	3.91^{de} (15)	7.39^{c} (55)	1.82^{b} (3)	2.71^{c} (7)	3.46^{b} (12)	0.88^{b} (0)	1.34^{bc} (1)	1.34^{bc} (1)	0.88^{b} (0)	1.17^{abc} (1)	1.34^{ab} (1)	0.71^{c} (0)	1.58^{b} (2)	1.05 (1)
T_2 - Pretilachlor	1.28^{c} (2)	4.93^{c} (24)	8.12^{b} (66)	1.63^{bc} (3)	2.64^{c} (7)	3.46^{b} (12)	1.17^{b} (1)	1.46^{b} (2)	1.46^{b} (2)	0.88^{b} (0)	1.27^{ab} (1)	1.27^{abc} (2)	0.71^{c} (0)	1.39^{bc} (2)	1.17 (1)
T_3 - Pendimethalin	2.21^{b} (5)	5.77^{b} (33)	8.35^{b} (70)	1.41^{c} (2)	2.99^{b} (9)	3.74^{ab} (14)	0.88^{b} (0)	1.00^{bc} (1)	1.00^{bc} (1)	1.34^{b} (1)	1.56^{bc} (2)	1.68^{a} (2)	2.53^{a} (6)	1.68^{b} (2)	1.64 (2)
T_4 - Oxadiargyl	1.52^{c} (2)	4.43^{cd} (20)	6.43^{d} (41)	1.82^{b} (3)	2.71^{c} (7)	3.96^{a} (16)	1.05^{b} (1)	1.34^{bc} (1)	1.34^{bc} (1)	1.34^{b} (1)	1.29^{ab} (1)	1.00^{bcd} (2)	0.88^{c} (0)	1.34^{bc} (1)	1.44 (2)
T_5 - Stale seed bed	1.14^{c} (1)	3.56^{e} (13)	4.31^{e} (19)	1.82^{b} (3)	2.65^{c} (7)	2.77^{c} (8)	0.71^{b} (0)	0.88^{c} (0)	0.88^{c} (00	0.88^{b} (0)	0.88^{bc} (1)	0.88^{cd} (1)	0.88^{c} (0)	1.05^{cd} (1)	1.34 (1)
T_6 - Hand weeding	1.00^{c} (1)	2.58^{f} (7)	3.73^{f} (14)	1.52^{c} (2)	1.91^{d} (4)	2.58^{c} (7)	0.88^{b} (0)	1.05^{bc} (1)	0.88^{c} (0)	0.88^{b} (0)	0.71^{c} (1)	0.71^{d} (1)	0.71^{c} (0)	0.71^{d} (0)	1.52 (2)
T_7 - Unweeded control	5.31^{a} (28)	10.22^{a} (105)	15.21^{a} (231)	2.15^{a} (5)	3.51^{a} (12)	4.00^{a} (16)	2.26^{a} (5)	2.30^{a} (5)	2.30^{a} (5)	2.02^{a} (4)	1.64^{a} (5)	1.64^{a} (5)	1.57^{b} (2)	4.10^{a} (16)	1.56 (2)
SEm	0.57	0.94	1.42	0.09	0.18	0.21	0.19	0.17	0.18	0.16	0.12	0.14	0.25	0.42	0.08
CD(0.05)	0.58	0.59	0.51	0.27	5.58	0.32	0.54	0.57	0.55	0.55	0.53	0.41	0.56	0.48	-

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

Table 29. Effect of pre-emergence herbicides on weed species density (no./ m^2) in 2019

Treatments	*S. interrupta*			*Oryza sativa* f. *spontanea*			*Echinochloa* spp.			*Cyperus* spp			*Cyanotis axillaris*		
	30	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**	**30**	**60**	**H**
T_1 - Oxyfluorfen	1.56^{cd} (2)	4.86^{c} (24)	6.80^{c} (46)	1.81^{ab} (3)	3.05^{b} (9)	3.60^{b} (13)	0.88^{b} (0)	1.17^{b} (1)	1.17^{b} (1)	0.88^{b} (0)	1.17^{b} (1)	1.17^{b} (1)	0.88^{b} (0)	2.41^{b} (6)	3.81 (15)
T_2 - Pretilachlor	2.53^{de} (6)	5.88^{b} (35)	7.42^{bc} (55)	1.82^{ab} (3)	2.94^{b} (9)	3.50^{b} (12)	1.34^{b} (1)	1.46^{b} (2)	1.46^{b} (2)	0.88^{b} (0)	1.27^{ab} (1)	1.26^{ab} (1)	0.88^{b} (0)	2.08^{bc} (4)	3.40 (12)
T_3 - Pendimethalin	2.32^{bc} (5)	6.08^{b} (37)	7.57^{b} (57)	1.82^{ab} (3)	3.00^{b} (9)	3.74^{b} (14)	0.88^{b} (0)	1.00^{b} (1)	0.99^{b} (1)	1.34^{b} (1)	1.64^{a} (2)	1.64^{a} (2)	1.00^{b} (1)	1.58^{cd} (2)	2.43 (6)
T_4 - Oxadiargyl	1.86^{bcd} (3)	4.35^{c} (19)	5.57^{d} (31)	1.63^{bc} (3)	3.11^{b} (10)	3.69^{b} (14)	1.17^{b} (1)	1.34^{b} (1)	1.34^{b} (1)	1.34^{b} (1)	0.99^{bc} (1)	0.99^{bc} (1)	0.88^{b} (0)	1.52^{cd} (2)	2.55 (7)
T_5 - Stale seed bed	1.34^{de} (1)	3.19^{d} (10)	4.11^{e} (17)	1.63^{bc} (3)	3.21^{b} (10)	3.69^{b} (14)	0.88^{b} (0)	0.88^{b} (0)	0.88^{b} (0)	1.17^{b} (1)	0.88^{bc} (0)	0.88^{bc} (0)	1.05^{b} (1)	1.44^{d} (2)	2.36 (6)
T_6 - Hand weeding	0.71^{e} (0)	2.43^{e} (6)	3.26^{f} (11)	1.28^{c} (2)	2.38^{c} (6)	2.63^{c} (7)	0.88^{b} (0)	0.88^{b} (0)	0.88^{b} (0)	0.88^{b} (0)	0.71^{c} (0)	0.71^{c} (0)	0.71^{b} (0)	0.71^{e} (0)	2.55 (7)
T_7 - Unweeded control	5.66^{a} (32)	9.54^{a} (91)	15.60^{a} (244)	2.15^{a} (5)	3.86^{a} (15)	4.36^{a} (19)	2.26^{a} (5)	2.30^{a} (5)	2.16^{a} (5)	2.02^{a} (4)	1.64^{a} (2)	1.64^{a} (2)	2.88^{a} (8)	4.10^{a} (16)	5.01 (25)
SEm	0.61	0.88	1.53	0.10	0.16	0.19	0.19	0.19	0.19	0.15	0.14	0.14	0.62	0.41	0.15
CD(0.05)	0.78	0.66	0.71	0.35	0.41	0.46	0.54	0.66	0.66	0.59	0.43	0.43	0.29	0.62	-

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

Data on effect of pre-emergence herbicide treatments on total weed count at 60 DAS are presented in Table 31. By 60 DAS, weed population increased in all treatments. However, the lowest total weed count was noticed in hand weeded plots, which recorded significantly lower weed population (11 no./m^2) followed by stale seed bed treatment (17 no./m^2). The highest total weed density (144 no./m^2) was registered in unweeded control plot, followed by pendimethalin (T_3) applied plots (49 no./m^2). In hand weeded plot, the count of grasses was higher compared to sedges and BLWs. Hand weeding resulted in significantly lower density of grasses (10 no./m^2), while the effect was not so prominent with respect to sedges and BLWs. The stale seed bed treatment continued to be the next best treatment (14 no./m^2), followed by oxyfluorfen (23 no./m^2) and oxadiargyl (25 no./m^2), which were on par. Pretilachlor and pendimethalin were not so effective in controlling grasses at 60 DAS.

At harvest stage, hand weeded plot (T_6) as well as stale seed bed plots (T_5) had lowest density of grasses (18 and 22 no./m^2 respectively). Hand weeding registered superior weed control with respect to sedges and BLWs. The population of grasses, sedges as well as BLWs were significantly higher in unweeded control plot. Treatment effects were conspicuous and the total weed population was very low in treated plots compared to unweeded control. Hand weeding (T_6) and stale seed bed (T_5) plots resulted in lowest total weed count (23 no./m^2 and 27 no./m^2), while with regard to herbicide treatments, oxadiargyl (T_4) performed better and had significantly lower weed count (50 no./m^2) followed by oxyfluorfen (T_1) (64 no./m^2) compared to unweeded control (T_7) (282 no./m^2) (Table 32).

Table 30. Effect of pre-emergence herbicides on total weed density (no./ m^2) at 30 DAS

Treatments	Grasses			Sedges			BLWs			Total		
	1st year	**2nd year**	**Pooled**	**1st year**	**2nd year**	**Pooled**	**1st year**	**2nd year**	**Pooled**	**1st year**	**2nd year**	**Pooled**
T_1 – Oxyfluorfen	1.58^c (3)	1.81^{cd} (3)	1.66^{cd} (3)	0.88^c (0)	0.88^b (0)	0.88^b (0)	0.88^c (0)	0.88^c (0)	0.88^{de} (0)	1.81^d (4)	1.88^c (3)	1.66^{de} (4)
T_2 – Pretilachlor	1.67^c (3)	3.06^b (9)	2.43^{bc} (6)	0.88^c (0)	0.88^b (0)	0.88^b (0)	0.71^{bc} (0)	1.18^{bc} (1)	1.00^{cde} (1)	1.81^d (11)	3.25^b (3)	2.43^c (7)
T_3 – Pendimethalin	2.61^b (7)	2.71^b (7)	2.61^b (7)	1.46^b (2)	1.34^b (1)	1.46^b (2)	3.24^b (10)	1.90^b (3)	2.73^b (7)	4.31^b (12)	3.41^b (19)	2.61^b (15)
T_4 – Oxadiargyl	1.82^c (3)	2.24^{bc} (5)	2.06^{bcd} (4)	1.46^b (2)	1.34^b (1)	1.46^b (2)	1.05^{bc} (1)	1.17^{bc} (1)	1.34^{cd} (1)	2.38^c (7)	2.62^{bc} (6)	2.06^c (6)
T_5 - Stale seed bed	1.28^c (2)	1.66^{cd} (2)	1.49^d (2)	1.05^{bc} (1)	1.17^b (1)	1.17^b (1)	1.23^{bc} (1)	1.29^{bc} (1)	1.46^c (1)	1.82^d (5)	2.10^c (3)	1.49^{cd} (4)
T_6 - Hand weeding	1.28^c (2)	1.05^d (1)	1.28^d (1)	0.88^c (0)	0.88^b (0)	0.88^b (0)	0.71^c (0)	0.71^c (0)	0.71^e (0)	1.41^d (1)	1.00^d (2)	1.28^e (2)
T_7 - Unweeded control	6.13^a (38)	6.45^a (41)	6.29^a (40)	2.26^a (5)	2.02^a (4)	2.26^a (4)	3.53^a (12)	3.53^a (12)	3.53^a (12)	7.37^a (57)	7.53^a (54)	6.29^a (56)
SEm	0.55	0.61	0.57	0.19	0.15	0.26	0.36	0.36	0.40	0.71	0.73	0.71
CD(0.05)	0.82	0.64	0.55	0.54	0.59	0.59	0.90	0.90	0.54	0.48	0.66	0.50

*√x+0.5 transformed values, original values in parentheses.

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

Table 31. Effect of pre-emergence herbicides on total weed density (no./ m^2) at 60 DAS

Treatments	Grasses			Sedges			BLWs			Total		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	4.42^{de} (20)	5.19^{c} (27)	4.82^{c} (23)	1.56^{bc} (2)	1.46^{bc} (2)	1.56^{bc} (2)	1.58^{c} (2)	2.59^{b} (6)	2.19^{bc} (4)	4.86^{d} (24)	5.85^{c} (34)	5.38^{d} (29)
T_2 – Pretilachlor	5.41^{c} (29)	6.24^{b} (39)	5.86^{b} (34)	1.43^{c} (2)	1.56^{bc} (3)	1.49^{c} (2)	1.54^{c} (2)	2.41^{b} (6)	2.06^{bc} (4)	5.79^{c} (34)	6.78^{b} (46)	6.31^{c} (40)
T_3 – Pendimethalin	6.07^{b} (37)	6.39^{b} (41)	6.26^{b} (39)	2.18^{ab} (4)	2.24^{ab} (5)	2.24^{ab} (5)	2.47^{b} (6)	2.66^{b} (7)	2.60^{b} (6)	6.84^{b} (47)	7.05^{b} (50)	6.95^{b} (49)
T_4 – Oxadiargyl	5.00^{cd} (25)	4.96^{c} (25)	5.00^{c} (25)	1.74^{bc} (3)	1.79^{bc} (3)	1.81^{bc} (3)	1.34^{c} (1)	2.12^{b} (4)	1.84^{c} (3)	5.38^{cd} (29)	5.42^{c} (30)	5.41^{d} (29)
T_5 - Stale seed bed	3.87^{ef} (15)	3.45^{d} (12)	3.70^{d} (14)	1.46^{c} (2)	1.44^{bc} (2)	1.56^{bc} (2)	1.05^{cd} (1)	1.94^{bc} (3)	1.68^{cd} (2)	4.16^{e} (17)	3.95^{d} (16)	4.06^{e} (17)
T_6 - Hand weeding	3.32^{f} (11)	2.94^{d} (9)	3.16^{e} (10)	1.17^{c} (1)	1.17^{c} (1)	1.17^{c} (1)	0.71^{d} (0)	1.17^{c} (1)	1.05^{d} (1)	3.46^{f} (12)	3.11^{e} (10)	3.29^{f} (11)
T_7 - Unweeded control	11.19^{a} (125)	10.53^{a} (111)	10.88^{a} (118)	2.79^{a} (7)	2.79^{a} (7)	2.79^{a} (7)	4.30^{a} (18)	4.85^{a} (23)	4.60^{a} (21)	12.27^{a} (151)	11.67^{a} (136)	11.98^{a} (144)
SEm	0.93	0.84	0.88	0.21	0.21	0.19	0.46	0.43	0.42	1.04	0.96	0.99
CD(0.05)	0.66	0.57	0.41	0.67	0.86	0.73	0.60	0.90	0.67	0.61	0.65	0.47

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

Table 32. Effect of pre-emergence herbicides on total weed density (no./ m^2) at harvest

Treatments	Grasses			Sedges			BLWs			Total		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	7.62^{c} (58)	7.09^{c} (50)	7.37^{c} (54)	1.77^{bc} (3)	1.56^{bc} (2)	1.67^{bc} (2)	1.05 (1)	3.93^{b} (16)	2.87^{b} (8)	7.83^{c} (61)	8.18^{b} (67)	8.02^{c} (64)
T_2 – Pretilachlor	8.37^{b} (70)	7.68^{bc} (59)	8.04^{b} (65)	1.68^{bc} (3)	1.68^{bc} (3)	1.68^{bc} (3)	1.17 (1)	3.74^{b} (14)	2.76^{bc} (8)	8.60^{b} (74)	8.62^{b} (74)	8.64^{b} (74)
T_3 – Pendimethalin	8.62^{b} (74)	7.87^{b} (62)	8.27^{b} (68)	2.24^{ab} (5)	2.24^{ab} (5)	2.24^{ab} (5)	1.64 (2)	3.23^{bc} (11)	2.55^{bcd} (7)	9.02^{b} (81)	8.65^{b} (75)	8.85^{b} (78)
T_4 – Oxadiargyl	6.95^{d} (48)	6.16^{d} (38)	6.58^{d} (43)	1.79^{bc} (3)	1.79^{bc} (3)	1.79^{bc} (3)	1.44 (2)	2.96^{c} (9)	2.36^{cd} (5)	7.28^{c} (53)	6.90^{c} (48)	7.09^{d} (50)
T_5 - Stale seed bed	4.75^{e} (23)	4.57^{e} (21)	4.67^{e} (22)	1.44^{bc} (2)	1.44^{bc} (2)	1.44^{bc} (2)	1.34 (1)	2.70^{c} (7)	2.16^{d} (4)	5.05^{d} (26)	5.35^{d} (29)	5.25^{e} (27)
T_6 - Hand weeding	4.42^{e} (20)	4.04^{e} (16)	4.28^{e} (18)	1.17^{c} (1)	1.17^{c} (1)	1.17^{c} (1)	1.52 (2)	2.72^{c} (8)	2.23^{d} (5)	4.74^{d} (23)	4.89^{d} (24)	4.86^{e} (23)
T_7 - Unweeded control	15.91^{a} (253)	16.32^{a} (267)	16.13^{a} (260)	2.79^{a} (7)	2.79^{a} (7)	2.79^{a} (7)	1.56 (2)	5.65^{a} (32)	4.16^{a} (17)	16.20^{a} (263)	17.34^{a} (301)	16.79^{a} (282)
SEm	1.40	1.47	1.43	0.20	0.20	0.20	-	0.39	0.26	1.40	1.51	1.45
CD(0.05)	0.38	0.59	0.48	0.87	0.85	0.85	NS	0.74	0.49	0.47	0.65	0.37

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

Population of grasses was very high compared to sedges and BLWs and the treatments followed the same trend as total weed count with respect to density of grasses. Density of sedges was low, and there was no variation in the count of BLWs during the first year whereas in the second year, the count of BLWs was higher and it was highest in unweeded control (T_7) (32 no./m^2) followed by oxyfluorfen (T_1) (16 no./m^2), pretilachlor (T_2) (14 no./m^2) and pendimethalin (T_3) (11 no./m^2) applied plots.

C. Weed dry matter production

The data on weed dry matter production at 30 DAS, 60 DAS and at harvest are shown in Table 33. As observed from pooled data, at 30 DAS dry weight of weeds was the highest (17.30 g/m^2) in unweeded control (T_7) which differed significantly from all other treatments and was followed by the pendimethalin (T_3) treated plots (5.43g/m^2). The lowest weed dry weight at 30 DAS was observed in hand weeding (0.0) which was followed by oxyfluorfen (T_1), oxadiargyl (T_4), pretilachlor (T_2) and stale seed bed (T_5) plots. All the herbicide applied plots were on par with respect to weed dry weight at 30 DAS, except for pendimethalin treated plot.

At 60 DAS, weed dry weight was comparatively lower in all the treatments compared to unweeded control. Weed dry weight was recorded in hand weeded plot (T_6) (5.01 g/m^2) followed by stale seed bed (T_5) (10.55 g/m^2) as seen from the pooled means. The highest weed dry matter production was observed in unweeded control (101.94 g/m^2) which was significantly lower in all other treatments, and was followed by pendimethalin (T_3) (41.32 g/m^2).

At the time of harvest, weed dry weight was the lowest (16.16 g/m^2) in hand weeded plot followed by 21.64 g/m^2 in stale seed bed. The treatment oxadiargyl (T_4) was the next best followed by oxyfluorfen and pretilachlor treatments. However, there was an increase in weed dry weight from 101.94 g/m^2 at 60 DAS to 169.80 g/m^2

at harvest in unweeded plot, and this treatment produced significantly higher dry matter of weeds.

D. Nutrient removal by weeds

Data on the effects of pre-emergence herbicides on nutrient removal (nitrogen, phosphorus and potassium) by weeds at 30 and 60 DAS are presented in Tables 34 and 35. The highest removal of N, P and K was recorded by unweeded control plot (T_7) which was significantly superior to all other treatments.

As observed from pooled data, at 30 DAS, highest N removal of 3.39 kg/ha was observed in unweeded control followed by pendimethalin treatment which had a removal of 1.22 kg/ha. The treatments pretilachlor and oxadiargyl were at par and registered lower values of nutrient removal ranging between 0.48 -0.56 kg/ha. By 60 DAS, N removal increased to 14.26 kg/ha in unweeded control and lowest removal of 0.38 kg/ha was recorded in hand weeded plot. A removal of 5.51 kg/ha was noticed in pendimethalin treatment which was in tune with the high dry matter production registered in this treatment.

At 30 DAS, highest P uptake by weeds was noticed in unweeded control with 0.51 kg/ha followed by pendimethalin applied plot (0.18 kg/ha) whereas there was very low removal of phosphorus by weeds in herbicide applied plots as seen from pooled data. By 60 DAS, the treatments oxyfluorfen and oxadiargyl were on par with removal of 0.38 and 0.39 kg/ha respectively and the lowest removal rate was registered in hand weeding and stale seed bed which was on par with removal of 0.08 and 0.21 kg/ha respectively. Pendimethalin treated plot however, registered a comparatively higher P removal of 0.61 kg/ha and was on par with pretilachlor (0.54 kg/ha).

The same trend as in the case of N and P was observed in the case of K removal as evident in the pooled data. At 30 DAS, highest K removal of 4.10 kg/ha was observed in unweeded control which was statistically superior to other treatments. The treatment pendimethalin recorded next higher removal (1.36 kg/ha). K removal increased to 13.86 kg/ha in unweeded control by 60 DAS and the lowest removal was in hand weeded plot (0.49 kg/ha). The treatments pretilachlor and pendimethalin were on par in K removal with removal values of 4.45 and 4.35 kg/ha respectively.

Both at 30 and 60 DAS, lowest uptake of major nutrients was observed in hand weeded plots, followed by stale seed bed treatment. Among herbicide treatments, oxyfluorfen had lowest values for nutrient uptake by weeds, except in the case of K at 60 DAS, where oxadiargyl treated plots registered lowest uptake values.

1.2 Crop growth and yield parameters

A. Plant height

Data regarding the effect of various pre-emergence herbicides on plant height of rice at 30 DAS and 60 DAS are given in Table 36. At 30 DAS, taller plants were observed in stale seed bed plot (T_5) (40.68 cm) which was on par with oxadiargyl (T4) (38.75 cm) and the lowest height of 19.93 cm was in unweeded control (T_7).

Hand weeded plot (T_6) recorded greatest plant height of 63.72 cm at 60 DAS, followed by the treatments stale seed bed (52.83 cm) and oxadiargyl (57.82 cm) which were on par with each other. Unweeded control recorded lowest plant height of 31.06 cm. At harvest stage also, plant height followed the same trend and hand weeded plot (T_6) recorded a higher plant height of 114.68 cm, which was followed by stale seed bed (91.93 cm), oxyfluorfen (83.44 cm), oxadiargyl (82.33 cm), and pendimethalin (81.44 cm) which were all on par. Lowest plant height was observed for unweeded control (T_7) (48.63 cm).

Table 33. Effect of pre-emergence herbicides on weed dry weight (g/m^2) at 30 DAS, 60 DAS and at harvest

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T$_1$ – Oxyfluorfen	1.48^{c} (1.77)	1.35^{d} (1.33)	1.42^{c} (1.55)	4.33^{d} (18.80)	4.73^{c} (22.37)	4.53^{d} (20.58)	8.61^{c} (74.43)	7.61^{c} (58.03)	8.13^{cd} (66.23)
T$_2$ – Pretilachlor	1.05^{c} (0.67)	2.01^{bc} (3.57)	1.61^{c} (2.12)	4.72^{cd} (22.40)	6.14^{b} (37.89)	5.48^{c} (30.14)	8.81^{c} (77.80)	8.31^{b} (68.97)	8.56^{c} (73.39)
T$_3$ – Pendimethalin	2.68^{b} (6.77)	2.14^{b} (4.10)	2.43^{b} (5.43)	6.47^{b} (41.93)	6.37^{b} (40.70)	6.42^{b} (41.32)	10.14^{b} (103.17)	7.94^{bc} (63.13)	9.12^{b} (83.15)
T$_4$ – Oxadiargyl	1.30^{c} (1.23)	1.84^{bc} (2.90)	1.60^{c} (2.07)	4.96^{c} (24.70)	4.53^{c} (20.74)	4.75^{d} (22.72)	8.84^{c} (78.73)	6.43^{d} (41.41)	7.74^{d} (60.07)
T$_5$ - Stale seed bed	1.50^{c} (2.13)	1.69^{cd} (2.47)	1.65^{c} (2.30)	3.03^{e} (9.23)	3.44^{d} (11.87)	3.24^{e} (10.55)	4.70^{d} (22.13)	4.60^{e} (21.14)	4.65^{e} (21.64)
T$_6$ - Hand weeding	0.89^{c} (0.28)	0.71^{e} (0.00)	0.80^{d} (0.14)	2.32^{f} (5.40)	2.14^{e} (9.61)	2.24^{f} (5.01)	3.98^{d} (15.87)	4.06^{f} (16.46)	4.02^{f} (16.16)
T$_7$ - Unweeded control	4.43^{a} (19.23)	3.98^{a} (15.37)	4.21^{a} (17.30)	9.44^{a} (89.03)	10.71^{a} (114.85)	10.10^{a} (101.94)	12.49^{a} (156.07)	13.55^{a} (183.52)	13.03^{a} (169.80)
SEm	0.47	0.38	0.41	0.89	0.62	0.96	1.13	1.18	1.13
CD(0.05)	0.75	0.39	0.42	0.59	1.04	0.52	1.07	0.38	0.55

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

Table 34. Effect of pre-emergence herbicides on nutrients removal by weeds at 30 DAS (kg/ha)

Treatments	N			P			K		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	0.17^{cd}	0.28^{d}	0.23^{d}	0.04^{c}	0.03^{d}	0.03^{d}	0.18^{cd}	0.41^{d}	0.30^{d}
T_2 – Pretilachlor	0.14^{cd}	0.82^{c}	0.48^{c}	0.03^{c}	0.08^{c}	0.06^{cd}	0.17^{cd}	1.09^{bc}	0.63^{c}
T_3 – Pendimethalin	1.35^{b}	1.09^{b}	1.22^{b}	0.21^{b}	0.14^{b}	0.18^{b}	1.43^{b}	1.30^{b}	1.36^{b}
T_4 – Oxadiargyl	0.31^{c}	0.81^{c}	0.56^{c}	0.05^{c}	0.10^{c}	0.07^{c}	0.28^{cd}	0.95^{c}	0.61^{c}
T_5 - Stale seed bed	0.27^{cd}	0.14^{de}	0.20^{d}	0.05^{c}	0.02^{d}	0.04^{d}	0.29^{c}	0.23^{de}	0.26^{de}
T_6 - Hand weeding	0.00^{d}	0.00^{e}	0.00^{e}	0.00^{c}	0.00^{e}	0.00^{e}	0.00^{d}	0.00^{e}	0.00^{e}
T_7 - Unweeded control	3.41^{a}	3.36^{a}	3.39^{a}	0.69^{a}	0.34^{a}	0.51^{a}	3.37^{a}	4.83^{a}	4.10^{a}
SEm	0.46	0.43	0.46	0.09	0.04	0.07	0.48	0.62	0.54
CD(0.05)	0.28	0.17	0.13	0.06	0.04	0.02	0.28	0.30	0.28

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

Table 35. Effect of pre-emergence herbicides on nutrients removal by weeds at 60 DAS (kg/ha)

Treatments	N			P			K		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	2.18[c]	2.37[c]	2.28[de]	0.44[cd]	0.33[cd]	0.38[cd]	2.98[bc]	2.81[c]	2.89[c]
T_2 – Pretilachlor	2.06[c]	5.00[b]	3.53[c]	0.51[cd]	0.54[b]	0.53[bc]	3.14[bc]	5.77[b]	4.45[b]
T_3 – Pendimethalin	5.60[b]	5.42[b]	5.51[b]	0.80[b]	0.43[bc]	0.61[b]	3.66[b]	5.03[b]	4.35[b]
T_4 – Oxadiargyl	2.69[c]	2.44[c]	2.57[cd]	0.54[c]	0.24[de]	0.39[cd]	2.54[c]	2.13[c]	2.34[cd]
T_5 - Stale seed bed	0.71[d]	1.63[cd]	1.17[ef]	0.29[de]	0.13[ef]	0.21[de]	1.01[d]	1.53[cd]	1.27[de]
T_6 - Hand weeding	0.29[d]	0.48[d]	0.38[f]	0.10[e]	0.05[f]	0.08[e]	0.41[d]	0.56[d]	0.49[e]
T_7 - Unweeded control	10.25[a]	18.25[a]	14.26[a]	2.87[a]	1.93[a]	2.40[a]	10.53[a]	17.18[a]	13.86[a]
SEm	1.31	2.29	1.78	0.36	0.24	0.29	1.25	2.15	1.69
CD(0.05)	0.89	1.54	1.20	0.23	0.16	0.19	0.92	1.48	1.19

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

Table 36. Effect of pre-emergence herbicides on plant height (cm) of rice at different growth stages

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	41.13^{bc}	28.73^{b}	13.27^{cd} (34.93)	60.73^{b}	43.33^{c}	52.03^{d}	81.00^{c}	85.89^{b}	83.44^{bc}
T_2 – Pretilachlor	34.73^{c}	29.67^{b}	12.67^{d} (32.20)	61.93^{ab}	43.70^{c}	52.82^{cd}	76.49^{c}	75.51^{c}	76.00^{c}
T_3 – Pendimethalin	42.30^{ab}	28.27^{b}	13.29^{cd} (35.28)	65.20^{ab}	47.53^{c}	56.37^{bc}	79.14^{c}	83.74^{bc}	81.44^{bc}
T_4 – Oxadiargyl	47.87^{a}	29.63^{b}	14.52^{ab} (38.75)	61.23^{ab}	54.40^{b}	57.82^{b}	79.25^{c}	85.40^{b}	82.33^{bc}
T_5 - Stale seed bed	46.93^{ab}	34.43^{a}	15.58^{a} (40.68)	61.13^{ab}	54.53^{b}	57.83^{b}	91.99^{b}	91.87^{b}	91.93^{b}
T_6 - Hand weeding	46.07^{ab}	30.97^{b}	14.40^{bc} (38.52)	66.13^{a}	61.30^{a}	63.72^{a}	104.39^{a}	124.97^{a}	114.68^{a}
T_7 - Unweeded control	26.56^{d}	13.30^{c}	7.13^{e} (19.93)	36.67^{c}	25.45^{d}	31.06^{e}	47.20^{d}	50.06^{d}	48.63^{d}
SEm	2.92	2.55	1.04	3.81	4.37	3.94	6.60	8.39	7.51
CD(0.05)	6.72	3.27	1.16	5.27	6.58	4.11	8.37	8.53	13.91

* R (weighted MSE) transformed values, original values in parentheses.

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

B. Number of tillers

The data on tiller count/m^2 are presented in Table 37. It was observed that hand weeded plot recorded significantly higher number of tillers/m^2 at all stages of observation and was significantly superior to all other treatments. At 30 DAS, significantly higher number of tillers/m^2 (186.17 no./m^2) was recorded by the hand weeded plot (T_6), and the second highest number of tillers/m^2 was recorded by stale seed bed treatment (T_5) (176.17 no./m^2). Lowest tiller number per m^2 was seen in unweeded plot (64.67 no./m^2). At 60 DAS also the hand weeding treatment recorded significantly higher number of tillers/m^2 (400.00 no./m^2) followed by oxadiargyl (T_4) (285.50 no./m^2) and stale seedbed treated plots (T_5) (289.33 no./m^2). At harvest stage, significantly higher tiller count (236.67 no./m^2) was recorded in hand weeded plot (T_6) followed by stale seed bed (179.33 no./m^2) and lowest was in unweeded control (63.00 no./m^2) followed by the treatments pendimethalin (84.33 no./m^2) and pretilachlor (91.33 no./m^2).

C. Yield attributes

Data on the effect of pre-emergence herbicides on yield attributes are given in Table 38.

1. Number of panicles

It is clear from the pooled data in Table 37 that number of panicles per square metre was significantly higher in hand weeded treatment (221.67/m^2) (T_6) and lowest was noticed in unweeded control (48.83/m^2) (T_7) and the values were significantly different from other treatments. The value was significantly higher in stale seed bed (160.00/m^2) compared to herbicide treatments. Oxadiargyl and oxyfluorfen were the best herbicide treatments with respect to panicles/m^2 and were statistically superior to other herbicide treatments.

Table 37. Effect of pre-emergence herbicides on tiller production (no. /m^2) of rice

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	145.67^c	118.00^b	131.83^c	269.33^b	199.00^d	234.17^d	108.67^b	118.00^d	113.33^d
T_2 – Pretilachlor	133.33^d	108.67^b	121.00^d	215.33^{cd}	215.67^c	215.50^e	95.67^c	86.33^e	91.33^e
T_3 – Pendimethalin	115.33^e	92.67^c	104.00^e	188.00^d	204.00^{cd}	196.00^f	86.33^c	81.67^e	84.33^e
T_4 – Oxadiargyl	144.33^{cd}	108.33^b	126.33^{cd}	236.00^c	335.00^b	285.50^b	114.00^b	165.67^c	140.00^c
T_5 - Stale seed bed	191.33^b	161.00^a	176.17^b	297.00^b	281.67^b	289.33^b	168.00^a	190.33^b	179.33^b
T_6 - Hand weeding	204.67^a	167.67^a	186.17^a	344.33^a	455.67^a	400.00^a	175.00^a	297.67^a	236.67^a
T_7 - Unweeded control	81.33^f	48.00^d	64.67^f	146.67^e	77.00^e	111.83^g	64.67^d	60.67^f	63.00^f
SEm	16.02	15.41	15.68	25.35	45.43	33.37	15.56	31.26	23.02
CD(0.05)	11.14	10.58	7.65	28.94	16.19	15.18	11.57	14.91	9.50

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

Table 38. Effect of pre-emergence herbicides on yield attributes of rice

Treatments	Panicles (No./m²)			Filled grains/panicle (No.)			1000 grain weight (g)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	90.67^{d}	99.33^{d}	95.00^{d}	75.33^{bc}	72.00^{c}	72.33^{b}	26.93^{b}	26.30^{ab}	26.62^{b}
T_2 – Pretilachlor	83.67^{de}	72.00^{e}	77.83^{e}	71.00^{c}	48.67^{e}	67.33^{b}	26.00^{c}	25.87^{b}	25.94^{c}
T_3 – Pendimethalin	75.67^{e}	71.00^{e}	73.33^{e}	53.33^{d}	57.67^{d}	64.67^{b}	25.63^{cd}	26.63^{a}	26.13^{c}
T_4 – Oxadiargyl	101.67^{c}	148.33^{c}	125.00^{c}	71.33^{c}	78.67^{c}	76.00^{b}	26.73^{b}	25.27^{c}	26.01^{c}
T_5 - Stale seed bed	147.67^{b}	172.33^{b}	160.00^{b}	77.67^{b}	87.67^{b}	71.67^{b}	27.10^{ab}	26.40^{ab}	26.76^{ab}
T_6 - Hand weeding	159.33^{a}	284.00^{a}	221.67^{a}	84.33^{a}	107.00^{a}	89.67^{a}	27.70^{a}	26.50^{a}	27.09^{a}
T_7 - Unweeded control	57.00^{f}	40.67^{f}	48.83^{f}	40.67^{e}	25.00^{f}	31.00^{c}	25.30^{d}	24.80^{c}	25.06^{d}
SEm	14.27	31.45	22.57	15.76	10.19	6.80	0.32	0.26	0.25
CD(0.05)	9.59	12.94	7.82	4.39	8.21	12.75	0.69	0.56	0.47

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

2. Filled grains per panicle and test weight

The number of grains per panicle ranged from 31 to 90. It was observed from the pooled data that highest number of 90 grains/panicle was recorded in hand weeded control (T_6) followed by all other treatments except unweeded control, which were comparable.

The test weight (1000 grain weight) was in the range of 25 to 27 g, with unweeded treatment recording the lowest value and hand weeding along with stale seed bed resulting in the highest value. Among herbicide treatments, oxyfluorfen treatment resulted in the highest value of 26.62 g.

3. Grain yield, straw yield and harvest index

Details of grain yield, straw yield and harvest index as influenced by pre-emergence herbicide application are given in Table 39.

In the 1^{st} year, significantly higher grain yield of 4172 and 3744 kg/ha was recorded in the treatments hand weeding (T_6) and stale seed bed (T_5), respectively whereas in the 2^{nd} year it was significantly higher under hand weeding treatment (4743 kg/ha) followed by stale seed bed (3893 kg/ha). The pooled data showed highest grain yields of 2979 and 2924 kg/ha were recorded in oxyfluorfen (T_1) and oxadiargyl (T_4), respectively among the herbicide treated plots, followed by the treatment pretilachlor (T_2) (2226 kg/ha) and it was lowest in pendimethalin (1725 kg/ha). The unweeded control produced significantly lower grain yield of 962 kg/ha

In the 1^{st} year, the yields of rice straw were highest (5305 and 5058 kg/ha) in the hand weeded and stale seed bed plots, respectively, while in the 2^{nd} year significantly higher value was observed in hand weeded plot (5941 kg/ha) than in the stale seed bed treatment (5264 kg/ha). Pooled data also showed the same trend. Among the herbicide treated plots, highest straw yields (4286 kg/ha and 4100 kg/ha) were recorded in oxyfluorfen (T_1) and oxadiargyl (T_4) treatments, respectively and this was followed by pretilachlor (T_3) (3435 kg/ha). The lowest yield of 1805 kg/ha was obtained in unweeded control.

Significantly higher values of harvest index were observed in the treatments hand weeding (0.44) and stale seed bed (0.43) which were on par. Among herbicide treatments, oxyfluorfen application resulted in highest harvest index of 0.41.

D. Nutrient uptake by rice

The data on nutrient uptake by rice (Table 40) at 60 DAS revealed that highest N, P and K uptake was in hand weeded treatment with 37.89 kg/ha, 6.26 kg/ha and 52.80 kg/ha respectively. Stale seed bed followed by oxadiargyl treatments resulted in second highest N and K uptake, where as second highest P uptake was in stale seed bed followed by oxyfluorfen plots. The treatments that showed lowest N, P, K uptake values were unweeded control followed by pretilachlor and pendimethalin.

E. Weed Index (WI) and Weed Control Efficiency (WCE)

Weed control efficiency at 30 and 60 DAS, is represented in Table 41 for both the years. The higher WCE was calculated with hand weeding (99.27%) followed by oxyfluorfen (91.08 %) at 30 DAS similar trend was noticed at 60 DAS. Highest weed control efficiency of 90.40 % and 87.10 % was obtained in hand weeded and stale seed bed plots respectively, followed by oxadiargyl (63.35 %) and oxyfluorfen (60.43 %). As observed from the pooled data the treatment unweeded control showed highest weed index of 77.76 % compared to other treatments, followed by pendimethalin (64.14 %) and pretilachlor (49.16 %) (Table 42).

G. Economics of cultivation

Among different treatments maximum B:C ratio of 2.0 was obtained in stale seedbed plot with a net profit of Rs. 67,581 and Rs. 73,355 during first and second year respectively. Hand weeding treatment also produced a net profit of Rs. 55,737 and Rs. 76,560 in 1st and 2nd year respectively but B:C ratio was 1.5 and 1.7 in respective years due to high cost of cultivation and least B:C ratio of 0.7 and 0.4 was noted in unweeded control (Table 43).

Oxyfluorfen resulted in maximum profit of Rs. 43,092 in first year and 40,117 during second year, among the herbicide treatments and registered a B:C ratio of 1.6 and 1.5 during 1st and 2nd year respectively. Oxadiargyl was second best after oxyfluorfen with a B:C ratio of 1.5 during both years. Partial budgeting reveals that the additional returns due to weed management was the highest for stale seedbed during first year and in second year it was higher in hand weeding and stale seedbed. In terms of additional returns due to weed management, many herbicidal treatments were inferior to stale seedbed and hand weeding, as the net returns was lower (Table 44).

Table 39. Effect of pre-emergence herbicides on grain and straw yield (kg/ha) of rice

Treatments	Grain yield			Straw yield			HI		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	3052^{b}	2905^{c}	2979^{c}	4227^{b}	4344^{c}	4286^{c}	0.42^{ab}	0.40^{b}	0.41^{c}
T_2 – Pretilachlor	2590^{b}	1863^{d}	2226^{d}	3744^{c}	3125^{d}	3435^{d}	0.41^{b}	0.37^{c}	0.39^{d}
T_3 – Pendimethalin	1654^{c}	1796^{d}	1725^{e}	2745^{d}	3201^{d}	2973^{e}	0.38^{c}	0.36^{c}	0.37^{e}
T_4 – Oxadiargyl	2893^{b}	2953^{c}	2924^{c}	4097^{bc}	4103^{c}	4100^{c}	0.41^{b}	0.42^{ab}	0.42^{bc}
T_5 - Stale seed bed	3744^{a}	3893^{b}	3819^{b}	5058^{a}	5264^{b}	5161^{b}	0.43^{a}	0.43^{ab}	0.43^{ab}
T_6 - Hand weeding	4172^{a}	4743^{a}	4458^{a}	5305^{a}	5941^{a}	5624^{a}	0.43^{a}	0.44^{a}	0.44^{a}
T_7 - Unweeded control	1253^{c}	669^{e}	962^{f}	2214^{e}	1396^{e}	1805^{f}	0.36^{c}	0.32^{d}	0.35^{f}
SEm	396.03	519.71	454.11	427.09	569.53	493.10	0.02	0.01	0.01
CD(0.05)	463.75	362.79	265.60	430.83	504.80	376.27	0.03	0.02	0.01

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

Table 40. Effect of pre-emergence herbicides on uptake of nutrients (kg/ha) by rice at 60 DAS

Treatments	N			P			K		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	21.21[a]	25.10[cd]	23.16[c]	4.17[b]	3.42[c]	3.80[c]	38.43[a]	24.77[bc]	31.60[cd]
T_2 – Pretilachlor	12.77[b]	17.35[de]	15.06[d]	2.07[c]	1.96[de]	2.01[d]	25.30[b]	18.99[cd]	22.14[d]
T_3 – Pendimethalin	8.31[bc]	15.79[e]	12.05[d]	1.80[c]	1.85[e]	1.83[d]	14.74[c]	16.38[d]	15.56[d]
T_4 – Oxadiargyl	22.13[a]	29.17[bc]	25.65[bc]	2.59[c]	2.95[cd]	2.77[d]	34.25[ab]	32.29[b]	33.27[bc]
T_5 - Stale seed bed	26.06[a]	36.97[b]	31.52[ab]	5.35[a]	5.02[b]	5.19[b]	42.11[a]	34.69[b]	38.40[b]
T_6 - Hand weeding	26.79[a]	48.98[a]	37.89[a]	4.87[ab]	7.64[a]	6.26[a]	43.03[a]	62.57[a]	52.80[a]
T_7 - Unweeded control	5.24[c]	3.31[f]	4.27[e]	0.64[d]	0.36[f]	0.50[e]	6.64[c]	3.36[e]	5.00[e]
SEm	3.28	5.66	4.40	0.66	0.90	0.76	5.35	7.05	5.94
CD(0.05)	5.84	8.14	6.94	0.99	1.08	1.02	10.25	9.26	9.56

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

Table 41. Effect of pre-emergence herbicides on weed control efficiency (WCE %) at 30 and 60 DAS

Treatments	30 DAS (%)			60 DAS (%)		
	1st year	**2nd year**	**Pooled**	**1st year**	**2nd year**	**Pooled**
T_1 – Oxyfluorfen	90.80	91.35	91.08	78.88	80.52	79.70
T_2 – Pretilachlor	96.52	76.77	86.65	74.84	67.01	70.93
T_3 – Pendimethalin	64.79	73.32	69.06	52.90	64.56	58.73
T_4 – Oxadiargyl	93.60	81.13	87.37	72.26	81.94	77.10
T_5 - Stale seed bed	88.92	83.93	86.43	89.63	89.66	89.65
T_6 - Hand weeding	98.54	100.00	99.27	93.93	91.63	92.78
T_7 - Unweeded control	0.0	0.0	0.0	0.0	0.0	0.0

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

Table 42. Effect of pre-emergence herbicides on weed control efficiency (WCE) and weed index (WI) at harvest

Treatments	WCE			WI		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 – Oxyfluorfen	52.49	68.38	60.43	26.35	38.70	32.54
T_2 – Pretilachlor	50.12	62.38	56.25	37.70	60.63	49.16
T_3 – Pendimethalin	33.48	65.56	49.52	60.25	62.03	61.14
T_4 – Oxadiargyl	49.26	77.45	63.35	30.44	37.37	33.89
T_5 - Stale seed bed	85.74	88.46	87.10	10.46	17.83	14.14
T_6 - Hand weeding	89.77	91.03	90.40	0.00	0.00	0.00
T_7 - Unweeded control	0.00	0.00	0.00	69.71	85.80	77.76

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

Table 43. Effect of pre-emergence herbicides on economics of cultivation (Rs./ha)

Treatments	Total cost (Rs./ha)	Total income (Rs./ha)		Net returns (Rs./ha)		B:C ratio	
		1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 – Oxyfluorfen	75,242/-	1,18,334/-	1,15,359/-	43,092/-	40,117/-	1.6	1.5
T_2 – Pretilachlor	74,205/-	1,01,754/-	76,864/-	27,549/-	2,659/-	1.4	1.0
T_3 – Pendimethalin	75,825/-	67,991/-	75,701/-	- 7,835/-	- 125/-	0.9	1.0
T_4 – Oxadiargyl	74,529/-	1,12,936/-	1,14,607/-	38,407	40,078/-	1.5	1.5
T_5 - Stale seed bed	76,500/-	1,44,081/-	1,49,855/-	67,581	73,355/-	1.9	2.0
T_6 - Hand weeding	1,02,000/-	1,57,737/-	1,78,560/-	55,737	76,560/-	1.5	1.7
T_7 - Unweeded control	72,000/-	52,650/-	29,929/-	- 19,350	- 42,071/-	0.7	0.4

Table 44. Economics of weed control by partial budgeting (Rs./ha)

Treatments	Additional cost for WM* (Rs)	Total cost of cultivation excluding WM	Total income		Net returns		Additional returns due to WM	
			1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 – Oxyfluorfen	3242/-	72,000/-	Rs. 1,18,334	Rs. 1,15,359	Rs. 43,092	Rs. 40,117	Rs. 62,442	Rs. 82,188
T_2 –Pretilachlor	2205/-	72,000/-	Rs. 1,01,754	Rs. 76,864	Rs. 27,549	Rs. 2,659	Rs. 46,899	Rs. 44,730
T_3 – Pendimethalin	3825/-	72,000/-	Rs. 67,991	Rs. 75,701	-Rs. 7,835	-Rs. 125	Rs. 11,516	Rs. 41,947
T_4 – Oxadiargyl	2529/-	72,000/-	Rs. 1,12,936	Rs. 1,14,607	Rs. 38,407	Rs. 40,078	Rs. 57,757	Rs. 82,149
T_5 - Stale seedbed	4500/-	72,000/-	Rs. 1,44,081	Rs. 1,49,855	Rs. 67,581	Rs. 73,355	Rs. 86,931	Rs. 1,15,426
T_6 - Hand weeding	30,000/-	72,000/-	Rs. 1,57,737	Rs. 1,78,560	Rs. 55,737	Rs. 76,560	Rs. 75,087	Rs. 1,18,631
T_7 - Unweeded control	-	72,000/-	Rs. 52,650	Rs. 29,929	-Rs. 19,350	-Rs. 42,071	-	-

* WM- Weed management

4.3.2. Management through post-emergence herbicides

General view of the post-emergence experimental plot is given in Plate 23.

1.1 Weeds

Observations on the weed spectrum, species-wise weed count (no.), weed dry weight (kg/ha), and nutrient removal by weeds (kg/ha), for 2017 and 2019 are given below.

C. Weed spectrum

The experiment was laid out in a site where high infestation of *S. interrupta* was observed every year. The details of the major weeds present in the field during 2017 and 2019 are given in Table 45.

The grass weeds comprised of mainly *S. interrupta*, *Oryza sativa* f. *spontanea* and *Echinochloa crus-galli*. The sedges present were *Fimbristylis miliacea* and *Cyperus iria*. The main broad leaved weeds (BLWs) were *Cyanotis axillaris, Commelina diffusa* and *Ludwigia perennis*.

B. Phytotoxicity rating

Phytotoxicity scoring of both weeds as well as crop was done at third and seven days after spraying (Table 46). Injury symptoms were graded from 0-5 using toxicity scale as per Abraham and Thomas (2007). Among various herbicides applied none of the herbicides showed phytotoxicity on rice at three and seven days after spraying.

As expected, all herbicides showed phytotoxic effect on weeds with scoring of 2-4 indicating moderate to very good control and drying of leaves after spraying.

FIRST YEAR

SECOND YEAR

Plate 23. General view of the post-emergence experimental plot

Table 45. Major weeds in post-emergence experimental field in 2017 and 2019

Sl no.	Common name	Scientific name	Family
1	Cup scale grass	*Sacciolepis interrupta*	Poaceae
2	Weedy rice	*Oryza sativa* f. *spontanea*	Poaceae
3	Barnyard grass	*Echinochloa crus-galli*	Poaceae
4	Jungle rice	*Echinochloa colona*	Poaceae
5	Hilo grass	*Paspalum conjugatum*	Poaceae
6	Hoorah grass	*Fimbristylis miliacea*	Cyperaceae
7	Yellow nut sedge	*Cyperus iria*	Cyperaceae
8	Water primrose	*Ludwigia perennis*	Onagraceae
9	Creeping Cradle Plant	*Cyanotis axillaris*	Commelinaceae
10	Spreading dayflower	*Commelina diffusa*	Commelinaceae

Table 46. Phytotoxicity rating at three and seven days after spraying post-emergence herbicides

Treatments	Score on crop		Score on weeds	
	3rd day	7th day	3rd day	7th day
T_1 - Cyhalofop-butyl	0	0	3	4
T_2 - Bispyribac sodium	0	1	2	4
T_3 – Penoxsulam	0	0	2	3
T_4 - Fenoxaprop–p–ethyl	0	0	3	4
T_5 - Triafamone + Ethoxysulfuron^	0	0	2	2
T_6 - Cyhalofop-butyl+ Penoxsulam^	0	0	3	3

^commercial formulation

D. Weed density

Data on effect of post-emergence herbicide treatments on species-wise weed count at 30 DAS, 60 DAS and at harvest for the year 2017 and 2019 are given in Table 47 and 48 respectively.

In 2017, *S. interrupta*, *Oryza sativa* f. *spontanea, Echinochloa* spp, and *Cyperus* spp were the main weed species, and among them, *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest. The treatment unweeded control (T_8) recorded the highest weed density for all the species. The population of *S. interrupta* in 2017 was lowest in hand weeded plot (T_7) *i.e.,* 6, 6 and 30 no./m^2 at 30 DAS, 60 DAS and at harvest respectively followed by fenoxaprop–p–ethyl (T_4). Unweeded control (T_8) recorded the highest weed density of *S. interrupta* 51, 99 and 204 no./m^2 at 30 DAS, 60 DAS and at harvest, respectively.

In 2019 the main weed species were *S. interrupta*, *Oryza sativa* f. *spontanea, Cyperus* spp, and *Cyanotis axillaris,* and among them *Saaciolepis interrupta* was found to be the most dominating at 30, 60 DAS and at harvest. Comparing with 2017, the type of grass species remained the same except for very few plants of *Echinochloa* spp, and the dominant sedge was *Cyperus* spp in both the years and its population remained same but population of *Cyanotis axillaris* increased in 2019 and was seen dominating among the BLWs. The treatment unweeded control (T_8) recorded the highest density of all the species except *Cyanotis*, which was found to be highest in cyhalofop-butyl + penoxsulam (T_5) applied plot at 30 and 60 DAS. The population of *S. interrupta* in 2019 was lowest in the hand weeded plot (T_7) *i.e.,* 3, 14 and 27 no./m^2, followed by fenoxaprop–p–ethyl (T_4) at 30 DAS, 60 DAS and at harvest respectively. Unweeded control (T_8) recorded the highest weed density of 28, 93 and 243 no./m^2 at 30 DAS, 60 DAS and at harvest respectively in 2019.

Table 47. Effect of post-emergence herbicides on weed species density (no./ m^2) in 2017

Treatments	*S. interrupta*			*Oryza sativa* f. *spontanea*			*Echinochloa* spp			*Cyperus* spp		
	30 DAS	60 DAS	H	30 DAS	60 DAS	H	30 DAS	60 DAS	H	30 DAS	60 DAS	H
T_1 - Cyhalofop-butyl	3.05^{d} (9)	4.60^{d} (21)	8.08^{d} (65)	2.38^{bc} (6)	3.65^{b} (13)	4.08^{b} (17)	1.38^{cd} (2)	1.38^{cd} (2)	1.69^{c} (3)	1.94^{a} (3)	1.94^{a} (3)	1.17 (1)
T_2 – Bispyribac sodium	4.08^{c} (17)	6.32^{bc} (40)	9.57^{c} (92)	2.56^{ab} (7)	3.60^{b} (13)	4.08^{b} (17)	2.02^{bc} (4)	2.02^{bc} (4)	2.43^{b} (6)	1.00^{bc} (1)	1.00^{bc} (1)	1.65 (3)
T_3 – Penoxsulam	5.09^{b} (26)	6.78^{b} (46)	9.66^{c} (93)	2.45^{ab} (6)	3.70^{b} (14)	3.54^{cd} (13)	2.52^{ab} (6)	2.52^{ab} (6)	2.77^{b} (8)	0.71^{c} (0)	0.71^{c} (0)	1.64 (2)
T_4 - Fenoxaprop–p–ethyl	2.76^{d} (8)	4.00^{d} (16)	6.90^{e} (48)	2.30^{bc} (5)	3.51^{b} (12)	3.96^{bc} (16)	1.48^{cd} (3)	1.48^{cd} (3)	1.82^{c} (4)	0.71^{c} (0)	0.71^{c} (0)	1.29 (1)
T_5 - Triafamone + Ethoxysulfuron^	3.73^{c} (14)	5.80^{c} (34)	9.27^{c} (86)	2.07^{c} (4)	3.74^{ab} (14)	3.78^{bc} (14)	1.47^{cd} (2)	1.47^{cd} (2)	1.47^{cd} (2)	1.47^{ab} (2)	1.47^{ab} (2)	1.17 (1)
T_6 - Cyhalofop-butyl+ Penoxsulam^	4.16^{c} (17)	6.39^{bc} (41)	10.62^{b} (113)	2.30^{bc} (5)	3.70^{b} (14)	4.12^{b} (17)	1.91^{bc} (4)	1.91^{bc} (4)	1.72^{c} (3)	0.71^{c} (0)	0.71^{c} (0)	1.00 (1)
T_7 - Hand weeding	2.49^{d} (6)	2.49^{e} (6)	5.48^{f} (30)	1.63^{d} (3)	2.70^{c} (7)	3.11^{c} (10)	1.14^{d} (1)	1.14^{d} (1)	1.14^{d} (1)	0.88^{bc} (0)	0.88^{bc} (0)	1.05 (1)
T_8 - Unweeded control	7.11^{a} (51)	9.95^{a} (99)	14.27^{a} (204)	2.82^{a} (8)	4.00^{a} (16)	4.76^{a} (23)	2.99^{a} (9)	2.99^{a} (9)	3.59^{a} (13)	0.71^{c} (0)	0.71^{c} (0)	1.34 (1)
SEm	0.53	0.78	0.93	0.12	0.13	0.17	0.93	0.93	0.28	0.16	0.16	0.08
CD(0.05)	0.63	0.82	0.71	0.38	0.26	0.46	0.70	0.70	0.54	0.64	0.64	NS

*√x+0.5 transformed values, original values in parentheses.

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

^ Commercial formulation, H- Harvest

Table 48. Effect of post-emergence herbicides on weed species density (no./ m^2) in 2019

Treatments	*S. interrupta*			*Oryza sativa* f. *spontanea*			*Cyperus* spp			*Cyanotis axillaris*		
	30 DAS	60 DAS	H	30 DAS	60 DAS	H	30 DAS	60 DAS	H	30 DAS	60 DAS	H
T_1 - Cyhalofop-butyl	2.93^{de} (9)	6.19^{d} (38)	7.85^{d} (62)	1.46^{ab} (2)	1.52^{b} (2)	3.46^{d} (12)	1.46^{bc} (2)	1.46^{bc} (2)	1.17 (1)	1.76^{ab} (3)	1.76^{ab} (3)	3.81^{b} (15)
T_2 – Bispyribac sodium	4.34^{b} (19)	8.02^{b} (64)	9.86^{b} (97)	1.86^{a} (3)	1.72^{b} (3)	3.41^{b} (12)	1.56^{b} (2)	1.56^{b} (2)	1.35 (2)	1.23^{bc} (1)	1.23^{bc} (1)	2.82^{c} (8)
T_3 – Penoxsulam	3.40^{cd} (12)	6.61^{cd} (44)	8.79^{c} (77)	1.76^{a} (3)	1.72^{b} (3)	3.46^{c} (12)	1.29^{bc} (1)	1.29^{bc} (1)	1.35 (2)	1.27^{bc} (1)	1.27^{bc} (1)	2.08^{d} (4)
T_4 - Fenoxaprop–p–ethyl	2.28^{ef} (5)	5.16^{e} (27)	6.65^{e} (44)	1.46^{ab} (2)	1.52^{ab} (2)	3.69^{d} (14)	1.17^{bc} (1)	1.17^{bc} (1)	1.39 (2)	1.23^{bc} (1)	1.23^{bc} (1)	2.39^{cd} (6)
T_5 - Triafamone + Ethoxysulfuron^	3.65^{c} (13)	8.22^{b} (68)	10.06^{b} (101)	1.68^{a} (2)	1.63^{b} (3)	3.51^{c} (12)	1.05^{bc} (1)	1.05^{bc} (1)	1.64 (2)	2.26^{a} (5)	2.26^{a} (5)	2.49^{cd} (6)
T_6 - Cyhalofop-butyl+ Penoxsulam^	3.78^{bc} (14)	6.73^{c} (45)	8.52^{cd} (73)	1.76^{a} (3)	1.72^{a} (3)	3.87^{c} (15)	0.88^{c} (0)	0.88^{c} (0)	1.00 (1)	2.26^{a} (5)	2.26^{a} (6)	1.14^{e} (1)
T_7 - Hand weeding	1.79^{f} (3)	3.78^{f} (14)	5.20^{f} (27)	1.05^{b} (1)	1.00^{c} (1)	2.99^{e} (9)	1.05^{bc} (1)	1.05^{bc} (1)	0.88 (0)	1.05^{c} (1)	1.05^{c} (1)	1.02^{e} (3)
T_8 - Unweeded control	5.26^{a} (28)	9.66^{a} (93)	15.58^{a} (243)	1.76^{a} (3)	1.61^{ab} (3)	3.74^{a} (14)	2.41^{a} (5)	2.41^{a} (5)	1.64 (2)	1.47^{bc} (2)	1.47^{bc} (2)	5.08^{a} (26)
SEm	0.39	0.52	1.10	0.09	0.08	0.09	0.17	0.17	0.27	1.70	1.70	0.43
CD(0.05)	0.67	0.46	0.87	0.47	NS	0.34	0.62	0.62	NS	0.67	0.67	0.70

*$\sqrt{x+0.5}$ transformed values, original values in parentheses.

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

^ Commercial formulation

Weeds were grouped into grasses, sedges and BLWs at 30 DAS, 60 DAS and at harvest and the effect of the post-emergence herbicide treatments on total weed count (no./ m^2) at 30 DAS is represented in Table 49. At 30 DAS, lowest number of total weeds per m^2 was observed in hand weeding (T_7) (12 no./m^2) and fenoxaprop-ethyl (T_4) (15 no./m^2) which were on par in 2017. In 2019 hand weeding (T_7) recorded lowest weed density of 8 no./m^2 followed by fenoxaprop-ethyl (T_4) (11 no./m^2) and the next best treatment was cyhalofop-butyl (T_1) (18 no./m^2).

Grasses, particularly *S. interrupta*, was the main and dominating weed species present in the field in both the years. Population of sedges was low while BLWs count was higher in second year compared to first year. Highest weed count was recorded in unweeded control and lowest weed count was in hand weeded treatment. During both years considering the population of grasses, hand weeding (T_7), fenoxaprop-ethyl (T_4) and cyhalofop-butyl (T_1) treatments recorded lowest densities of 8, 11 and 13 no./m^2 respectively. Highest value was in unweeded control (T_8) plots (52 no./m^2).

The pooled data revealed that unweeded control (T_8) and cyhalofop-butyl (T_1) had significantly higher density of sedges, while all other treatments were on par except hand weeded plot. There was no significant difference between the treatments with respect to density of BLWs.

Data on effect of post-emergence herbicide treatments on total weed count at 60 DAS are presented in Table 50. By 60 DAS, weed population increased in all treatments. However, the lowest total weed count was noticed in hand weeded plots, which recorded significantly lower weed population (12 no./m^2) followed by fenoxaprop-ethyl (T_4) (23 no./m^2) and cyhalofop-butyl (T_1) (32 no./m^2) during first year. In second year, hand weeded plot followed by fenoxaprop-ethyl treatment recorded lower weed densities of 20 and 34 no./m^2 respectively. The highest total weed density (119 no./m^2) was registered in unweeded control plot, followed by bispyribac sodium (T_2) (65 no./m^2) and triafamone + ethoxysulfuron (T_5) (63 no./m^2) and penoxsulam (T_3) (59 no./m^2) applied treatments. In hand weeded plot, the count of grasses was higher compared to sedges and BLWs. Hand weeding resulted in significantly lower density of grasses (14 no./m^2), while the effect was not so prominent with respect to sedges and BLWs. Fenoxaprop–p–ethyl applied treatment continued to be the next best treatment (26 no./m^2), followed by cyhalofop-butyl (35 no./m^2) with regard to control of grasses. Other treatments were not so effective in controlling grasses but were found to be better than unweeded control at 60 DAS.

At harvest stage, hand weeded plot (T_8) and fenoxaprop–p–ethyl (T_4) had lowest density of grasses (33 and 54 no./m^2 respectively) and the treatments bispyribac sodium, penoxsulam, triafamone + ethoxysulfuron, and cyhalofop-butyl + penoxsulam were at par with weed density ranging between 73-107 no./m^2 (Table 51). Hand weeding, cyhalofop-butyl +penoxsulam and penoxsulam registered superior weed control with respect to BLWs, while for sedges the effect was non-significant.

The total population of grasses, sedges as well as BLWs were significantly higher in unweeded control plot. Treatment effects were conspicuous and the total weed population was very low in treated plots compared to unweeded control. Hand weeding (T_7) resulted in lowest total weed count (37 no./m^2) followed by fenoxaprop-p-ethyl (60 no./m^2) and next best treatment was cyhalofop-butyl (84 no./m^2), while other treatments were on par.

C. Weed dry matter production

The data on weed dry matter production at 30 DAS, 60 DAS and at harvest in are shown in Table 52. As observed from pooled data, at 30 DAS dry weight of weeds was the highest in unweeded control (T_8) (46.60 g/m^2) which differed significantly from all other treatments.

Table 49. Effect of the post-emergence herbicides on total weed count (no./ m^2) at 30 DAS

Treatments	Grasses			Sedges			BLWs			TOTAL		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	3.87^{de} (15)	3.35^{d} (11)	3.65^{e} (13)	2.20 (4)	2.04^{b} (4)	2.20^{ab} (4)	1.17 (1)	1.69^{ab} (3)	1.47 (2)	4.51^{de} (20)	4.23^{d} (18)	4.39^{d} (19)
T_2 – Bispyribac sodium	5.13^{c} (27)	4.86^{b} (24)	5.06^{bc} (25)	1.94 (3)	1.76^{bc} (3)	1.86^{abc} (3)	1.00 (1)	1.28^{b} (2)	1.14 (1)	5.51^{bc} (31)	5.28^{b} (28)	5.45^{bc} (29)
T_3 – Penoxsulam	6.13^{b} (38)	3.96^{c} (16)	5.20^{b} (27)	1.64 (2)	1.74^{bc} (3)	1.74^{bcd} (3)	0.88 (0)	1.58^{ab} (3)	1.28 (2)	6.35^{b} (40)	4.58^{cd} (21)	5.54^{b} (31)
T_4 - Fenoxaprop–p–ethyl	3.65^{e} (14)	2.87^{d} (8)	3.34^{e} (11)	1.29 (1)	1.58^{bc} (2)	1.46^{cd} (2)	0.71 (0)	1.00^{b} (1)	1.00 (1)	3.85^{ef} (15)	3.36^{e} (11)	3.64^{e} (13)
T_5 - Triafamone + Ethoxysulfuron^	4.49^{cd} (20)	4.03^{c} (16)	4.28^{d} (18)	1.82 (3)	1.66^{bc} (2)	1.86^{abc} (3)	1.71 (3)	2.22^{a} (5)	1.96 (4)	5.08^{cd} (26)	4.86^{bc} (24)	5.02^{c} (25)
T_6 - Cyhalofop-butyl+ Penoxsulam^	4.96^{c} (25)	4.24^{c} (18)	4.65^{cd} (21)	1.00 (1)	1.27^{c} (1)	1.27^{cd} (1)	1.18 (1)	2.15^{a} (5)	1.72 (3)	5.15^{cd} (27)	4.90^{bc} (24)	5.07^{c} (25)
T_7 - Hand weeding	3.14^{e} (10)	2.23^{e} (5)	2.82^{f} (8)	1.17 (1)	1.17^{c} (1)	1.17^{d} (1)	1.27 (1)	1.24^{b} (2)	1.24 (2)	3.50^{f} (12)	2.76^{f} (8)	3.21^{f} (10)
T_8 - Unweeded control	8.39^{a} (70)	5.77^{a} (33)	7.21^{a} (52)	1.57 (2)	2.96^{a} (8)	2.41^{a} (5)	0.71 (0)	1.73^{ab} (3)	1.38 (2)	8.52^{a} (73)	6.71^{a} (45)	7.68^{a} (59)
SEm	0.55	0.39	0.46	-	0.19	0.15	-	0.15	-	0.53	0.42	0.47
CD(0.05)	0.67	0.56	0.44	NS	0.69	0.64	NS	0.75	NS	0.80	0.50	0.42

*√x+0.5 transformed values, original values in parentheses.

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

^ Commercial formulation

Table 50. Effect of the post-emergence herbicides on total weed count (no./ m^2) at 60 DAS

Treatments	Grasses 1st year	Grasses 2nd year	Grasses Pooled	Sedges 1st year	Sedges 2nd year	Sedges Pooled	BLWs 1st year	BLWs 2nd year	BLWs Pooled	TOTAL 1st year	TOTAL 2nd year	TOTAL Pooled
T_1 - Cyhalofop-butyl	5.17^{d} (27)	6.53^{d} (43)	5.91^{d} (35)	2.20 (4)	2.27^{abc} (5)	2.16^{ab} (5)	1.00 (1)	1.69^{ab} (3)	1.33 (2)	5.63^{d} (32)	7.02^{d} (49)	6.39^{d} (41)
T_2 – Bispyribac sodium	7.06^{bc} (50)	8.45^{b} (71)	7.79^{b} (61)	1.94 (3)	1.46^{d} (2)	1.63^{bcd} (3)	1.00 (1)	1.28^{b} (2)	1.14 (1)	7.34^{bc} (54)	8.70^{b} (76)	8.06^{b} (65)
T_3 – Penoxsulam	7.59^{b} (58)	7.16^{c} (51)	7.39^{bc} (55)	1.64 (2)	1.74^{bcd} (3)	1.58^{cd} (3)	0.88 (0)	1.58^{ab} (3)	1.28 (2)	7.77^{b} (60)	7.53^{c} (57)	7.66^{bc} (59)
T_4 - Fenoxaprop–p–ethyl	4.65^{d} (22)	5.53^{e} (31)	5.13^{e} (26)	1.29 (1)	1.56^{cd} (2)	1.38^{cd} (2)	0.71 (0)	1.00^{b} (1)	1.00 (1)	4.80^{d} (23)	5.80^{e} (34)	5.38^{e} (29)
T_5 - Triafamone + Ethoxysulfuron^	6.32^{c} (40)	8.52^{b} (73)	7.50^{bc} (56)	1.82 (3)	2.60^{a} (6)	2.23^{a} (5)	1.71 (3)	2.22^{a} (5)	1.96 (4)	6.77^{c} (46)	8.94^{b} (80)	7.96^{b} (63)
T_6 - Cyhalofop-butyl+ Penoxsulam^	6.95^{bc} (48)	7.23^{c} (52)	7.12^{c} (50)	1.00 (1)	2.46^{ab} (6)	1.79^{abc} (3)	1.18 (1)	2.15^{a} (5)	1.72 (3)	7.08^{bc} (50)	7.64^{c} (58)	7.37^{c} (54)
T_7 - Hand weeding	3.14^{e} (10)	4.12^{f} (17)	3.70^{f} (14)	1.17 (1)	1.17^{d} (1)	1.14^{d} (1)	1.27 (1)	1.24^{b} (2)	1.24 (2)	3.50^{e} (12)	4.43^{f} (20)	4.00^{f} (16)
T_8 - Unweeded control	11.09^{a} (123)	10.00^{a} (100)	10.57^{a} (112)	1.57 (2)	2.28^{abc} (5)	1.91^{abc} (4)	0.71 (0)	1.73^{ab} (3)	1.38 (2)	11.20^{a} (126)	10.57^{a} (112)	10.91^{a} (119)
SEm	0.75	0.65	0.68	-	0.18	0.12	0.13	0.15	-	0.73	0.38	0.69
CD(0.05)	0.74	0.36	0.36	NS	0.74	0.57	0.57	0.75	NS	0.77	0.67	0.37

*$\sqrt{x+0.5}$ transformed values, original values in parentheses.

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

^ Commercial formulation

Table 51. Effect of the post-emergence herbicides on total weed count (no./ m^2) at harvest

Treatments	Grasses			Sedges			BLWs			TOTAL		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	8.94^c (80)	8.08^c (65)	8.54^c (73)	2.20 (4)	1.56 (2)	1.91 (3)	1.00 (1)	3.81^b (15)	2.82^b (8)	9.21^d (85)	9.05^c (82)	9.14^c (84)
T_2 – Bispyribac sodium	10.60^b (112)	10.08^b (102)	10.36^b (107)	1.94 (3)	1.74 (3)	1.73 (3)	1.00 (1)	2.92^c (9)	2.23^{bcd} (5)	10.78^{bc} (116)	10.65^b (114)	10.74^b (115)
T_3 – Penoxsulam	10.55^b (111)	8.98^c (81)	9.81^b (96)	1.79 (3)	1.73 (3)	1.75 (3)	0.88 (0)	2.15^d (5)	1.61^{de} (3)	10.70^{bc} (115)	9.40^c (88)	10.08^b (102)
T_4 - Fenoxaprop–p–ethyl	7.55^d (57)	7.16^d (51)	7.37^d (54)	1.54 (2)	2.08 (4)	1.76 (3)	0.71 (0)	2.39^{cd} (6)	1.79^{cde} (3)	7.70^e (59)	7.83^d (61)	7.79^d (60)
T_5 - Triafamone + Ethoxysulfuron^	9.62^c (93)	10.36^b (107)	10.01^b (100)	1.82 (3)	2.24 (5)	2.06 (4)	1.71 (3)	2.92^c (9)	2.40^{bc} (6)	9.92^{cd} (99)	10.98^b (121)	10.48^b (110)
T_6 - Cyhalofop-butyl+ Penoxsulam^	10.90^b (119)	8.96^c (80)	9.98^b (100)	1.10 (1)	1.46 (2)	1.24 (1)	1.18 (1)	1.38^e (2)	1.33^e (2)	11.01^b (121)	9.17^c (84)	10.15^b (103)
T_7 - Hand weeding	5.81^e (34)	5.60^e (32)	5.73^e (33)	1.17 (1)	1.35 (2)	1.14 (1)	1.27 (1)	1.21^e (5)	1.24^e (3)	6.00^f (36)	6.19^e (38)	6.13^e (37)
T_8 - Unweeded control	15.57^a (243)	16.22^a (264)	15.90^a (253)	1.34 (1)	2.79 (7)	2.16 (4)	2.38 (5)	5.25^a (28)	4.08^a (17)	15.78^a (249)	17.26^a (299)	16.55^a (274)
SEm	0.94	1.05	0.98	-	-	-	-	0.42	0.30	0.94	0.79	1.01
CD(0.05)	0.69	0.82	0.66	NS	NS	NS	NS	0.76	0.74	0.78	1.11	0.68

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

This was followed by penoxsulam, bispyribac sodium, triafamone + ethoxysulfuron, cyhalofop-butyl+ penoxsulam and cyhalofop-butyl treated plots which were on par. The lowest weed dry weight at 30 DAS was observed in hand weeding (T_7) (3.48 g/m^2) which was followed by fenoxaprop–p–ethyl (T_4) (9.25 g/m^2) treated plots.

At 60 DAS, lowest weed dry weight was recorded in hand weeded plot (T_7) (13.01 g/m^2) followed by fenoxaprop–p–ethyl (T_4) (21.94 g/m^2) as seen from the pooled means. The highest weed dry matter production was observed in unweeded control (102.19 g/m^2) which was significantly higher than all other treatments, and was followed by bispyribac sodium (T_2), triafamone + ethoxysulfuron (T_5) and penoxsulam (T_3) treated plots. The treatments cyhalofop-butyl (T_1) and cyhalofop-butyl+ penoxsulam (T_6) were on par with respect to weed dry matter production at 60 DAS.

At the time of harvest, weed dry weight was lowest in hand weeding (34.23 g/m^2) followed by fenoxaprop–p–ethyl (65.64 g/m^2) and cyahalofop-butyl (71.27 g/m^2) and penoxsulam (T_3) the next best was bispyribac sodium (T_2) followed by cyhalofop-butyl+ penoxsulam (T_6). However, there was an increase in weed dry weight from 102.19 g/m^2 at 60 DAS to 170.54 g/m^2 at harvest in unweeded plot, and this treatment produced significantly higher weed dry matter.

D. Nutrient removal by weeds

Data on the effects of post-emergence herbicides on weed removal of nutrients viz., nitrogen, phosphorus and potassium by weeds at 30 and 60 DAS are presented in Tables 53 and 54. Both at 30 and 60 DAS, the highest removal of N, P and K was recorded in unweeded control plot (T_8) which was significantly superior to all other treatments and lowest removal was in hand weeded plot followed by fenoxaprop-p-ethyl treatment.

As observed from pooled data, at 30 DAS, highest N removal of 7.09 kg/ha was observed in unweeded control followed by cyhalofop-butyl+ penoxsulam and penoxsulam applied plots which had a removal of 3.56 kg/ha and 3.37 kg/ha respectively and they were on par with triafamone + ethoxysulfuron (3.01 kg/ha). The treatments cyhalofop-butyl and bispyribac sodium were at par and registered lower values of removal ranging between 2.45 -2.59 kg/ha. By 60 DAS, N removal increased to 14.40 kg/ha in unweeded control and the lowest removal of 2.18 kg/ha was recorded in hand weeded plot and was comparable with fenoxaprop-p-ethyl (3.57 kg/ha). A removal of 9.06 kg/ha of N was noticed in the treatment penoxsulam which was in tune with the high dry matter production registered in this treatment.

At 30 DAS, highest P uptake by weeds was noticed in unweeded control with 0.99 kg/ha followed by cyhalofop-butyl + penoxsulam applied plot (0.49 kg/ha) which was on par with penoxsulam and cyhalofop-butyl treatments whereas there was very low removal of phosphorus by weeds in fenoxaprop–p–ethyl applied plot as seen from pooled data. By 60 DAS, P removal by weeds in unweeded control was 1.51 kg/ha while the treatments triafamone + ethoxysulfuron and penoxsulam were on par with removal of 0.91 kg/ha, and lowest removal was registered in hand weeding followed by fenoxaprop–p–ethyl plots with a removal of 0.17 to 0.47 kg/ha. The bispyribac sodium treated plot however, registered a comparatively higher P removal of 1.09 kg/ha.

As evident in the pooled data, at 30 DAS, highest K removal of 10.12 kg/ha was observed in unweeded control and it increased to 11.24 kg/ha by 60 DAS which was statistically superior to other treatments, and the lowest removal was in hand weeded plot (0.65 and 1.87 kg/ha at 30 and 60 DAS respectively). All other treatments were on par with respect to K removal by weeds at both 30 and 60 DAS.

Table 52. Effect of post-emergence herbicides on weed dry weight (g/m^2) at 30 DAS, 60 DAS and at harvest

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd year	Pooled	1st Year	2nd year	Pooled	1st year	2nd Year	Pooled
T_1 - Cyhalofop-butyl	4.48^{bc} (20.13)	3.48^{c} (12.11)	4.01^{b} (16.12)	6.95^{c} (48.50)	6.54^{d} (42.77)	6.75^{c} (45.63)	8.31^{e} (69.10)	8.56^{d} (73.43)	8.44^{de} (71.27)
T_2 – Bispyribac sodium	4.03^{d} (16.23)	4.04^{b} (16.37)	4.04^{b} (16.30)	7.06^{c} (50.03)	8.18^{b} (66.97)	7.64^{b} (58.50)	9.55^{cd} (91.33)	9.68^{c} (93.81)	9.62^{c} (92.57)
T_3 – Penoxsulam	4.75^{b} (22.57)	3.45^{c} (11.93)	4.15^{b} (17.25)	7.93^{b} (62.87)	6.73^{d} (45.36)	7.36^{b} (54.11)	8.77^{e} (77.10)	9.02^{d} (81.41)	8.90^{d} (79.23)
T_4 - Fenoxaprop–p–ethyl	3.32^{e} (11.10)	2.72^{d} (7.40)	3.04^{c} (9.25)	4.87^{d} (23.70)	4.49^{e} (20.18)	4.69^{d} (21.94)	8.85^{de} (78.43)	7.27^{e} (52.84)	8.10^{e} (65.64)
T_5 - Triafamone + Ethoxysulfuron^	4.14^{cd} (17.20)	3.92^{b} (15.40)	4.04^{b} (16.30)	6.44^{c} (41.63)	8.44^{b} (71.24)	7.51^{b} (56.44)	10.16^{c} (103.40)	10.46^{b} (109.57)	10.31^{b} (106.48)
T_6 - Cyhalofop-butyl+ Penoxsulam^	4.14^{cd} (17.20)	3.92^{b} (15.38)	4.03^{b} (16.29)	6.59^{c} (43.53)	7.36^{c} (54.23)	6.99^{c} (48.88)	10.87^{b} (118.27)	8.60^{d} (74.00)	9.80^{bc} (96.13)
T_7 - Hand weeding	1.90^{f} (3.67)	1.81^{e} (3.30)	1.86^{d} (3.48)	3.82^{d} (14.83)	3.34^{f} (11.18)	3.60^{e} (13.01)	6.78^{f} (46.00)	4.73^{f} (22.47)	5.85^{f} (34.23)
T_8 - Unweeded control	7.06^{a} (50.00)	6.57^{a} (43.20)	6.82^{a} (46.60)	10.26^{a} (105.30)	9.95^{a} (99.08)	10.11^{a} (102.19)	13.32^{a} (177.57)	12.79^{a} (163.52)	13.05^{a} (170.54)
SEm	0.51	0.48	0.49	0.65	0.75	0.62	0.68	0.83	0.73
CD(0.05)	0.43	0.34	0.32	0.67	0.32	0.36	0.69	0.54	0.55

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

Table 53. Effect of post-emergence herbicides on nutrient removal by weeds at 30 DAS

Treatments	N removal (kg/ha)			P removal (kg/ha)			K removal (kg/ha)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	2.48^{b}	2.42^{cd}	2.45^{c}	0.56^{b}	0.29^{d}	0.43^{bc}	3.31^{c}	3.13^{de}	3.22^{bc}
T_2 – Bispyribac sodium	1.81^{c}	3.37^{bc}	2.59^{c}	0.43^{c}	0.32^{d}	0.38^{cd}	3.06^{cd}	4.29^{bc}	3.68^{b}
T_3 – Penoxsulam	2.77^{b}	3.97^{b}	3.37^{b}	0.47^{bc}	0.44^{c}	0.45^{bc}	4.75^{b}	3.29^{cde}	4.02^{b}
T_4 - Fenoxaprop–p–ethyl	1.15^{d}	1.52^{de}	1.33^{d}	0.23^{d}	0.16^{e}	0.19^{e}	2.01^{d}	2.51^{e}	2.26^{c}
T_5 - Triafamone + Ethoxysulfuron^	1.90^{c}	4.12^{b}	3.01^{bc}	0.29^{d}	0.30^{d}	0.29^{de}	2.95^{cd}	4.56^{b}	3.76^{b}
T_6 - Cyhalofop-butyl+ Penoxsulam^	2.70^{b}	4.41^{b}	3.56^{b}	0.44^{bc}	0.55^{b}	0.49^{b}	3.54^{c}	3.95^{bcd}	3.75^{b}
T_7 - Hand weeding	0.53^{e}	0.75^{e}	0.64^{d}	0.06^{e}	0.05^{f}	0.06^{f}	0.57^{e}	0.73^{f}	0.65^{d}
T_8 - Unweeded control	3.76^{a}	10.42^{a}	7.09^{a}	1.16^{a}	0.82^{a}	0.99^{a}	10.73^{a}	9.51^{a}	10.12^{a}
SEm	0.36	1.04	0.68	0.12	0.08	0.11	1.07	0.89	0.96
CD(0.05)	0.47	1.10	0.78	0.13	0.09	0.09	1.12	1.07	1.09

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

^ commercial formulation

Table 54. Effect of post-emergence herbicides on nutrient removal by weeds at 60 DAS (kg/ha)

Treatments	N			P			K		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	7.53^{c}	3.42^{d}	5.47^{c}	1.10^{bc}	0.60^{c}	0.85^{c}	5.84^{b}	7.26^{c}	6.55^{b}
T_2 – Bispyribac sodium	6.55^{c}	10.77^{b}	8.66^{b}	0.98^{c}	1.21^{a}	1.09^{b}	4.64^{b}	10.77^{a}	7.70^{b}
T_3 – Penoxsulam	9.42^{b}	8.70^{c}	9.06^{b}	1.29^{b}	0.53^{cd}	0.91^{bc}	5.48^{b}	8.70^{bc}	7.09^{b}
T_4 - Fenoxaprop–p–ethyl	3.43^{d}	3.72^{d}	3.57^{d}	0.55^{d}	0.39^{d}	0.47^{d}	2.81^{c}	2.89^{d}	2.85^{c}
T_5 - Triafamone + Ethoxysulfuron^	6.24^{c}	9.88^{bc}	8.06^{b}	0.69^{d}	1.13^{a}	0.91^{bc}	4.79^{b}	9.17^{ab}	6.98^{b}
T_6 - Cyhalofop-butyl+ Penoxsulam^	6.57^{c}	8.72^{c}	7.65^{b}	0.74^{d}	0.82^{b}	0.78^{c}	5.30^{b}	8.21^{bc}	6.76^{b}
T_7 - Hand weeding	2.17^{d}	2.20^{d}	2.18^{d}	0.19^{e}	0.16^{e}	0.17^{e}	1.55^{c}	2.20^{d}	1.87^{c}
T_8 - Unweeded control	14.21^{a}	14.60^{a}	14.40^{a}	1.75^{a}	1.27^{a}	1.51^{a}	11.77^{a}	10.71^{a}	11.24^{a}
SEm	1.26	1.51	1.22	0.19	0.14	0.13	1.08	1.15	0.90
CD(0.05)	1.86	1.93	1.85	0.26	0.18	0.22	1.48	1.71	1.53

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

^ Commercial formulation

1.2 Crop growth and yield parameters

The major observations recorded in rice are given below

A. Plant height

Data regarding the effect of various post-emergence herbicides on plant height of rice at 30 DAS, 60 DAS and at harvest are given in Table 55. At 30 DAS, the greatest height was recorded in hand weeded plot (T_7) (42.63 cm) and lowest height of 15.28 cm was in unweeded control (T_8). All other treatments were on par with respect to plant height at 30 DAS.

Hand weeded plot (T_7) recorded greatest plant height of 62.65 cm at 60 DAS, followed by the treatments cyhalofop-butyl+ penoxsulam (T_5) and triafamone + ethoxysulfuron (T_6) which were on par with each other. Unweeded control recorded lowest plant height of 34.83 cm. At harvest stage also, plant height followed the same trend and hand weeded plot (T_7) recorded the greatest plant height of 108.30 cm, which was followed by fenoxaprop–p–ethyl (84.30 cm), cyhalofop-butyl (83.85 cm), triafamone + ethoxysulfuron, penoxsulam and cyhalofop-butyl + penoxsulam. Unweeded control (T_8) had lowest plant height of 54.85 cm.

B. Number of tillers per sq.m.

The data on tiller count/m^2 are presented in Table 56. It was observed that hand weeded plot recorded significantly higher number of tillers/m^2 at all stages of observation and was significantly superior to all other treatments. At 30 DAS, significantly higher number of tillers/m^2 (153.33) was recorded by the hand weeded plot (T_7), and the second highest number of tillers/m^2 was recorded by fenoxaprop-p-ethyl (T_4) (109.67 no./m^2), while lowest tiller number per m^2 was seen in unweeded plot (T_8) (36 no./m^2).

Table 55. Effect of post-emergence herbicides on plant height (cm) of rice at different growth stages

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd Year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	36.73[a]	30.30[bc]	*11.53[b] (33.52)	56.40[ab]	41.27[e]	13.09[d] (48.83)	76.85[b]	90.87[bc]	83.85[b]
T_2 – Bispyribac sodium	37.93[a]	28.47[c]	11.24[b] (33.20)	50.80[bc]	40.67[e]	12.49[d] (45.73)	69.81[bc]	84.10[c]	76.97[c]
T_3 – Penoxsulam	37.20[a]	33.10[b]	12.24[b] (35.15)	54.13[abc]	43.83[de]	13.41[cd] (48.98)	71.51[b]	86.73[b]	79.12[bc]
T_4 - Fenoxaprop–p–ethyl	39.47[a]	32.30[b]	12.33[b] (35.88)	57.87[ab]	47.57[cd]	14.48[bc] (52.72)	71.99[b]	96.63[b]	84.30[b]
T_5 - Triafamone + Ethoxysulfuron^	38.47[a]	31.44[bc]	12.01[b] (34.96)	49.13[bc]	51.63[bc]	14.55[bc] (50.38)	60.97[d]	96.00[b]	78.47[bc]
T_6 - Cyhalofop-butyl+ Penoxsulam^	38.27[a]	31.83[bc]	12.07[b] (35.05)	50.87[bc]	51.97[b]	14.77[b] (51.42)	62.33[cd]	96.13[b]	79.22[bc]
T_7 - Hand weeding	42.80[a]	42.47[a]	15.11[a] (42.63)	61.40[a]	63.90[a]	18.06[a] (62.65)	101.38[a]	115.23[a]	108.30[a]
T_8 - Unweeded control	15.33[b]	15.23[d]	5.42[c] (15.28)	44.40[c]	25.27[f]	8.85[e] (34.83)	58.71[d]	51.00[d]	54.85[d]
SEm	2.99	2.64	0.96	1.91	3.95	0.92	4.78	6.43	5.13
CD(0.05)	7.11	3.68	1.24	9.81	4.35	1.25	7.63	8.48	5.89

* R (weighted MSE) transformed values, original values in parentheses

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

^ Commercial formulation

At 60 DAS also the hand weeding treatment recorded significantly higher number of tillers/m^2 (267 no./m^2) followed by fenoxaprop–p–ethyl (T_4) (178 no./m^2) and cyhalofop-butyl (174 no./m^2) (T_1) treated plots.

The same trend as in the case of tiller count at 60 DAS was observed at harvest, which is also evident in the pooled data. Significantly higher tiller count (141.83 no./m^2) was recorded in hand weeded plot (T_7) followed by fenoxaprop–p–ethyl (T_4) and cyhalofop-butyl (T_1) with 97 tiller no./m^2 and lowest was in unweeded control (53 no./m^2) followed by the treatments triafamone + ethoxysulfuron (63.67 no./m^2), cyhalofop-butyl+ penoxsulam (69.33 no./m^2) and bispyribac sodium (69.67 no./m^2).

C. Yield attributes

Data on the effect of post-emergence herbicides on yield attributes are presented in Table 57. Comparing the years (2017 and 2019), all the yield attributes were improved in second year, compared to first year and hand weeded plot (T_7) was best in both the years with higher values, while unweeded control (T_8) had lowest values.

1. Number of panicles

It is clear from the pooled data in Table 57 that number of panicles per square metre was significantly higher in hand weeded treatment (126.33/m^2) (T_7) followed by triafamone + ethoxysulfuron and cyhalofop-butyl+ penoxsulam which were on par and significantly inferior to other treatments. The values were significantly higher in fenoxaprop–p–ethyl (T_4) (74/m^2) and cyhalofop-butyl (T_1) (68/m^2) with respect to panicles/m^2 and were statistically superior compared to other herbicide treatments. Lowest number was noticed in unweeded control (31.00/m^2) (T_8).

Table 56. Effect of post-emergence herbicides on tiller production (no./m^2) of rice at different growth stages

Treatments	30 DAS			60 DAS			Harvest		
	1st year	2nd year	Pooled	1st year	2nd Year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	90.67^{b}	102.67^{c}	97.00^{c}	152.33^{b}	194.67^{b}	174.00^{b}	85.33^{b}	108.67^{b}	97.00^{b}
T_2 – Bispyribac sodium	77.67^{c}	79.33^{d}	78.67^{de}	130.33^{cd}	154.00^{c}	142.33^{cd}	55.67^{d}	83.00^{de}	69.67^{d}
T_3 – Penoxsulam	81.33^{c}	80.00^{d}	81.00^{d}	142.00^{bc}	151.33^{c}	146.67^{c}	71.67^{c}	91.00^{cd}	81.67^{c}
T_4 - Fenoxaprop–p–ethyl	94.67^{b}	123.67^{b}	109.67^{b}	155.33^{b}	200.33^{b}	178.00^{b}	85.67^{b}	107.67^{b}	97.00^{b}
T_5 - Triafamone + Ethoxysulfuron^	68.00^{d}	89.00^{d}	79.00^{de}	124.67^{d}	142.67^{c}	134.00^{de}	47.67^{e}	79.67^{e}	63.67^{d}
T_6 - Cyhalofop-butyl+ Penoxsulam^	54.33^{e}	89.00^{d}	72.00^{e}	95.00^{e}	151.00^{c}	123.33^{e}	43.67^{ef}	94.67^{c}	69.33^{d}
T_7 - Hand weeding	128.00^{a}	178.67^{a}	153.33^{a}	205.67^{a}	328.00^{a}	267.00^{a}	128.00^{a}	155.67^{a}	141.83^{a}
T_8 - Unweeded control	42.00^{f}	29.33^{e}	36.00^{f}	67.67^{f}	79.00^{d}	73.67^{f}	36.67^{f}	69.00^{f}	53.00^{e}
SEm	9.34	15.07	11.94	14.64	13.07	19.69	8.25	10.43	10.33
CD(0.05)	7.59	10.75	7.14	14.80	25.45	11.89	7.49	13.39	7.55

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

Table 57. Effect of post-emergence herbicides on yield attributes of rice

Treatments	Panicles (No./m^2)			Filled grains/panicle			1000 grain weight (g)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	58.00^{bc}	77.67^{bc}	68.00^{b}	56.33^{bc}	58.67^{cd}	58.00^{cd}	24.37^{b}	25.57^{a}	24.97^{bc}
T_2 – Bispyribac sodium	36.67^{d}	60.00^{d}	48.67^{d}	51.00^{cd}	58.67^{cd}	55.00^{d}	23.77^{bc}	25.47^{a}	24.62^{cd}
T_3 – Penoxsulam	50.33^{c}	63.33^{d}	57.00^{c}	55.00^{bcd}	67.00^{c}	61.33^{c}	24.03^{bc}	25.67^{a}	24.85^{bcd}
T_4 - Fenoxaprop–p–ethyl	65.33^{b}	82.00^{b}	74.00^{b}	60.00^{b}	79.00^{b}	69.67^{b}	25.47^{a}	25.37^{a}	25.33^{b}
T_5 - Triafamone + Ethoxysulfuron^	26.67^{e}	56.33^{d}	41.67^{e}	41.00^{e}	54.00^{d}	47.67^{e}	23.30^{c}	25.30^{a}	24.29^{d}
T_6 - Cyhalofop-butyl+ Penoxsulam^	21.33^{ef}	71.00^{c}	46.33^{de}	47.67^{de}	58.00^{cd}	53.00^{de}	23.60^{bc}	26.10^{a}	24.85^{bcd}
T_7 - Hand weeding	78.00^{a}	173.67^{a}	126.33^{a}	77.00^{a}	151.33^{a}	114.33^{a}	26.23^{a}	26.23^{a}	26.24^{a}
T_8 - Unweeded control	13.67^{f}	47.33^{e}	31.00^{f}	16.00^{f}	33.00^{e}	24.67^{f}	23.17^{c}	24.10^{b}	23.63^{e}
SEm	8.05	14.11	10.47	6.17	12.48	8.98	0.38	0.23	0.27
CD(0.05)	7.77	7.40	6.26	7.47	10.60	6.11	1.01	1.08	0.64

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

2. Filled grains per panicle and test weight of rice

The number of filled grains per panicle ranged from 24.67 to 114.33. It was observed from the pooled data that highest number of 114.33 filled grains/panicle was recorded in hand weeded control (T_7) followed by fenoxaprop–p–ethyl (T_4) (69.67 no.). In unweeded control plot there were only 24.67 grains/panicle. The test weight (1000 grain weight) was in the range of 23.63 to 26.24 g, with unweeded treatment recording the lowest value and hand weeding with highest value.

3. Grain yield, straw yield and harvest index

Details of grain yield, straw yield and harvest index as influenced by post-emergence herbicide application are given in Table 58.

In the 1st year, significantly higher grain yield (2260 kg/ha) was recorded in the treatments hand weeding (T_7) followed by cyhalofop-butyl (T_1) (1302 kg/ha) and fenoxaprop–p–ethyl (T_4) (1247 kg/ha) which were on par, whereas in the 2nd year it was significantly higher under hand weeding treatment (3649 kg/ha) followed by fenoxaprop–p–ethyl (2299 kg/ha) and the next best was cyhalofop-butyl with 1983 kg/ha. The pooled data showed that grain yield of 1280 kg/ha was recorded by penoxsulam which was statistically superior to bispyribac sodium, cyhalofop-butyl+ penoxsulam and triafamone + ethoxysulfuron which had grain yields of 1061, 1010 and 942 kg/ha respectively and were on par with each other. The treatment unweeded control (T_8) produced significantly lower grain yield of 517 kg/ha. Highest grain yield of 2955 kg/ha was obtained in the treatment hand weeding (T_7) followed by fenoxaprop-p-ethyl (T_4) with 1733 kg/ha.

In the 1st year, the yield of rice straw was highest in hand weeded plot (T_7) with 3384 kg/ha followed by cyhalofop-butyl (2519 kg/ha) and fenoxaprop–p–ethyl (2453 kg/ha), while in the 2nd year significantly higher value was observed in hand weeded (4993 kg/ha) followed by fenoxaprop–p–ethyl plot (3656 kg/ha). Pooled da mta also showed the same trend as in 1st year. Among the other treatments penoxsulam recorded higher straw yield followed by triafamone + ethoxysulfuron and cyhalofop-butyl+ penoxsulam which were on par with each other. The lowest yield of 1008 kg/ha was obtained in unweeded control.

Significantly higher values of harvest index were observed in the treatments hand weeding (0.41) followed by cyhalofop-butyl and fenoxaprop–p–ethyl with HI of 0.36 and lowest HI values were recorded in triafamone + ethoxysulfuron (0.29)

D. Nutrient uptake by rice

The data on nutrient uptake by rice (Table 59) at 60 DAS revealed that highest N, P and K uptake was in hand weeded treatment with 23.03 kg/ha, 3.34 kg/ha and 35.04 kg/ha, respectively. Cyhalofop-butyl followed by fenoxaprop-p-ethyl treatments resulted in second highest N and K uptake, and cyhalofop-butyl applied plot recorded the second highest P uptake. The treatments that showed lowest N, P, K uptake values were unweeded control which had values of 2.46, 0.23 and 3.05 kg/ha of N, P and K, respectively followed by cyhalofop-butyl+ penoxsulam (T_6) and triafamone + ethoxysulfuron (T_5).

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

As observed from the pooled data weed control efficiency at 30 and 60 DAS is represented in table 60. At harvest, highest weed control efficiency of 80.10 % was obtained in hand weeded plots followed by fenoxaprop–p–ethyl (61.50 %) and cyhalofop-butyl (57.90 %) herbicide treatments. Treatment unweeded control showed highest weed index of 82.16 % compared to other treatments, followed by triafamone + ethoxysulfuron (67.89 %) and cyhalofop-butyl+ penoxsulam (66.66 %). (Table 61).

Table 58. Effect of post-emergence herbicides on grain and straw yield (kg/ha) of rice

Treatments	Grain yield			Straw yield			HI		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	1302^{b}	1983^{c}	1643^{c}	2519^{b}	3239^{c}	2879^{b}	0.34^{b}	0.38^{bc}	0.36^{b}
T_2 – Bispyribac sodium	950^{d}	1171^{e}	1061^{e}	1889^{cd}	2544^{e}	2217^{d}	0.34^{b}	0.32^{d}	0.32^{cd}
T_3 – Penoxsulam	1131^{c}	1428^{d}	1280^{d}	2134^{c}	2896^{d}	2515^{c}	0.35^{b}	0.33^{d}	0.34^{c}
T_4 - Fenoxaprop–p–ethyl	1247^{bc}	2299^{b}	1773^{b}	2453^{b}	3656^{b}	3055^{b}	0.34^{b}	0.39^{b}	0.36^{b}
T_5 - Triafamone + Ethoxysulfuron^	736^{e}	1147^{e}	942^{e}	1751de	2917^{d}	2334^{cd}	0.30^{c}	0.28^{e}	0.29^{e}
T_6 - Cyhalofop-butyl+ Penoxsulam^	657^{e}	1361de	1010^{e}	1505^{e}	2761de	2133^{d}	0.30^{c}	0.33^{d}	0.32^{d}
T_7 - Hand weeding	2260^{a}	3649^{a}	2955^{a}	3384^{a}	4993^{a}	4189^{a}	0.40^{a}	0.42^{a}	0.41^{a}
T_8 - Unweeded control	435^{f}	597^{f}	517^{f}	948^{f}	1067^{f}	1008^{e}	0.31^{c}	0.36^{c}	0.34^{c}
SEm	198.28	333.51	263.55	260.22	269.60	320.68	0.01	0.01	0.01
CD(0.05)	149.25	222.07	121.06	275.18	389.14	218.86	0.02	0.02	0.02

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

Table 59. Effect of post-emergence herbicides on uptake of nutrients by rice at 60 DAS (kg/ha)

Treatments	N			P			K		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	7.66^{b}	23.03^{b}	15.34^{b}	1.42^{b}	3.46^{a}	2.44^{b}	13.21^{b}	29.36^{b}	21.29^{b}
T_2 – Bispyribac sodium	4.59^{c}	7.55^{de}	6.07^{de}	0.63^{cd}	0.89^{cd}	0.76^{cde}	6.65^{d}	11.16^{cde}	8.91^{de}
T_3 – Penoxsulam	5.38^{bc}	11.70^{cd}	8.54^{cd}	0.85^{c}	1.17^{bc}	1.01^{cd}	8.07^{cd}	12.72^{cd}	10.40^{cd}
T_4 - Fenoxaprop–p–ethyl	7.64^{b}	15.26^{c}	11.45^{bc}	0.88^{c}	1.85^{b}	1.37^{c}	11.56^{bc}	19.70^{c}	15.63^{bc}
T_5 - Triafamone + Ethoxysulfuron^	3.18^{cd}	7.97^{de}	5.58^{de}	0.60^{cd}	0.63^{cd}	0.62^{de}	4.71^{de}	9.00^{de}	6.85^{de}
T_6 - Cyhalofop-butyl+ Penoxsulam^	3.15^{cd}	10.00^{cd}	6.57^{de}	0.59^{cd}	1.36^{bc}	0.97^{cd}	4.10^{de}	11.92^{cde}	8.01^{de}
T_7 - Hand weeding	14.83^{a}	31.23^{a}	23.03^{a}	2.91^{a}	3.77^{a}	3.34^{a}	21.88^{a}	48.21^{a}	35.04^{a}
T_8 - Unweeded control	1.61^{d}	3.31^{e}	2.46^{e}	0.26^{d}	0.20^{d}	0.23^{e}	2.17^{e}	3.95^{e}	3.05^{e}
SEm	1.47	3.25	2.33	0.29	0.46	0.36	2.25	5.06	3.64
CD(0.05)	2.71	6.07	4.38	0.49	0.80	0.64	4.15	27.37	6.43

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

Table 60. Effect of post-emergence herbicides on weed control efficiency (WCE) at 30 DAS and 60 DAS

Treatments	30 DAS			60 DAS		
	1st year	**2nd year**	**Pooled**	**1st year**	**2nd year**	**Pooled**
T_1 - Cyhalofop-butyl	59.90	71.87	65.89	53.77	56.80	55.29
T_2 – Bispyribac sodium	67.18	61.90	64.54	52.53	32.43	42.48
T_3 – Penoxsulam	54.47	72.39	63.43	40.11	54.16	47.14
T_4 - Fenoxaprop–p–ethyl	77.94	82.90	80.42	77.34	79.62	78.48
T_5 - Triafamone + Ethoxysulfuron^	65.69	64.17	64.93	44.45	28.10	36.28
T_6 - Cyhalofop-butyl+ Penoxsulam^	65.29	64.24	64.76	58.32	45.29	51.81
T_7 - Hand weeding	92.76	92.30	92.53	86.04	88.73	87.39
T_8 - Unweeded control	0.0	0.0	0.0	0.0	0.0	0.0

^ Commercial formulation

Table 61. Effect of post-emergence herbicides on weed control efficiency (WCE) and weed index (WI)

Treatments	WCE			WI		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T_1 - Cyhalofop-butyl	60.82	54.87	57.90	42.10	45.60	43.85
T_2 – Bispyribac sodium	48.38	42.61	45.50	57.74	67.90	62.83
T_3 – Penoxsulam	56.08	50.14	53.10	49.54	60.90	55.21
T_4 - Fenoxaprop–p–ethyl	55.43	67.58	61.50	44.60	37.00	40.78
T_5 - Triafamone + Ethoxysulfuron^	41.78	33.03	37.40	67.29	68.50	67.89
T_6 - Cyhalofop-butyl+ Penoxsulam^	33.24	54.74	44.00	70.70	62.60	66.66
T_7 - Hand weeding	74.01	86.20	80.10	0.0	0.0	0.0
T_8 - Unweeded control	0.0	0.0	0.0	80.72	83.60	82.16

^ Commercial formulation

G. Economics of cultivation

Among different treatments maximum B:C ratio of 0.7, 0.7 and 0.8 was registered in fenoxaprop-p-ethyl (T_4), cyhalofop-butyl (T_1) and hand weeding treatments (T_7) during first year but there was no net profit in any of the treatments during this year whereas in second year maximum B:C ratio of 1.1, 1.3 and 1.4 was registered in fenoxaprop-p-ethyl (T_4), cyhalofop-butyl (T_1) and hand weeding treatments (T_7) with a net profit of Rs. 5,173, Rs. 19,624 and Rs. 38,964 in the respective treatments. Least B:C ratio of 0.3 was noted in unweeded control (Table 62).

Partial budgeting reveals that the additional returns due to weed management was highest for hand weeding. Fenoxaprop-p-ethyl and cyhalofop-butyl also recorded additional returns of Rs. 33,192 and Rs. 32,863 in first year whereas in second year Rs. 66,436 and Rs. 51,984 respectively was registered. In terms of additional returns due to weed management, many herbicidal treatments were inferior to hand weeding, as the net returns was lower (Table 63).

Table 62. Effect of post-emergence herbicides on economics of cultivation (Rs./ha)

Treatments	Total cost	Total income		Net profit		B:C ratio	
		1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 - Cyhalofop-butyl	75,900/-	56,566/-	81,073/-	-19,335/-	5,173/-	0.7	1.1
T_2 – Bispyribac sodium	74,771/-	41,707/-	53,241/-	-33,065/-	-21,530/-	0.6	0.7
T_3 – Penoxsulam	75,233/-	48,676/-	63,172/-	-26,557/-	-12,061/-	0.6	0.8
T_4 - Fenoxaprop–p–ethyl	73,525/-	54,520/-	93,149/-	-19,006/-	19,624/-	0.7	1.3
T_5 - Triafamone + Ethoxysulfuron^	76,000/-	34,756/-	55,764/-	-41,245/-	-20,237/-	0.5	0.7
T_6 - Cyhalofop-butyl+ Penoxsulam^	77,670/-	30,532/-	60,216/-	-47,139/-	-17,455/-	0.4	0.8
T_7 - Hand weeding	1,02,000/-	89,784/-	1,40,964/-	-12,216/-	38,964/-	0.8	1.4
T_8 - Unweeded control	72,000/-	19,803/-	25,189/-	-52,197/-	-46,812/-	0.3	0.3

Table 63. Economics of weed control by partial budgeting (Rs./ha)

Treatments	Additional cost for WM (Rs)	Total cost of cultivation excluding WM(Rs)	Total income (Rs)		Net returns (Rs)		Additional returns due to WM (Rs)	
			1st year	2nd year	1st year	2nd year	1st year	2nd year
T_1 - Cyhalofop-butyl	3900/-	72,000/-	56,566/-	81,073/-	- 19,335/-	5,173/-	32,863/-	51,985/-
T_2 – Bispyribac sodium	2771/-	72,000/-	41,707/-	53,241/-	- 33,065/-	- 21,530/-	19,133/-	25,282/-
T_3 – Penoxsulam	3233/-	72,000/-	48,676/-	63,172/-	- 26,557/-	- 12,061/-	25,640/-	34,751/-
T_4 - Fenoxaprop–p–ethyl	1525/-	72,000/-	54,520/-	93,149/-	- 19,006/-	19,624/-	33,192/-	66,436/-
T_5 - Triafamone + Ethoxysulfuron^	4000/-	72,000/-	34,756/-	55,764/-	- 41,245/-	- 20,237/-	10,953/-	26,575/-
T_6 - Cyhalofop-butyl+ Penoxsulam^	5670/-	72,000/-	30,532/-	60,21t6/-	- 47,139/-	- 17,455/-	5,059/-	29,357/-
T_7 - Hand weeding	30,000/-	72,000/-	89,784/-	1,40,964/-	- 12,216/-	38,964/-	64,413/-	85,776/-
T_8 - Unweeded control	-	72,000/-	19,803/-	25,189/-	- 52,197/-	- 46,812/-	-	-

WM- Weed management

4.3.3. Integrated weed management

General view of the integrated weed management experimental plot is given in Plate 24.

1.1 Weeds

Observations on the weed spectrum, species-wise weed count (no./m^2), weed dry weight (kg/ha), and nutrient removal by weeds (kg/ha) are given below.

A. Weed spectrum

The experiment was laid out in a site where high infestation of *Sacciolepis interrupta* was observed every year. The details of the major weeds present in the field during 2019 are given in Table 64.

Grass weeds comprised of mainly *Sacciolepis interrupta*, *Oryza sativa* f. *spontanea, Echinochloa crus-galli* and *Paspalum conjugatum.* Sedges present were *Fimbristylis miliacea* and *Cyperus iria*. Main broad leaved weeds (BLWs) were *Cyanotis axillaris*, *Commelina diffusa* and *Ludwigia perennis*.

B. Weed density

Data on effect of integrated management treatments on species-wise weed count at 30 DAS, 60 DAS and at harvest for the year 2019 are given in Table 65.

In 2019 the main weed species were *Sacciolepis interrupta*, *Oryza sativa* f. *spontanea, Fimbristylis miliacea* and *Cyanotis axillaris.* Among them, *Saaciolepis interrupta* was found to be the most dominating at 30, 60 DAS and at harvest. Unweeded control (T_8) recorded the highest density of all the species. Populations of *Sacciolepis interrupta* were lowest in the hand weeded plot (T_7) *i.e.*, 0, 2 and 4 no./m^2 at 30 DAS, 60 DAS and at harvest respectively, followed by the treatment oxyfluorfen + hand weeding at 45 DAS (T_6). Unweeded control (T_8) recorded the highest density of 28, 54 and 194 no./m^2 at 30 DAS, 60 DAS and at harvest respectively. Densities of *Fimbristylis miliacea* was highest in unweeded control and at 30 DAS. Variations among the other treatments was not very conspicuous at 60 DAS and at harvest. BLWs mainly *Cyanotis axillaris* was present at 7, 30 and 25 no./m^2 in unweeded control at 30 DAS, 60 DAS and at harvest respectively.

Table 64. Major weeds in integrated management experimental field in 2019

Sl no.	Common name	Scientific name	Family
1	Cup scale grass	*Sacciolepis interrupta*	Poaceae
2	Weedy rice	*Oryza sativa* f. *spontanea*	Poaceae
3	Barnyard grass	*Echinochloa crus-galli*	Poaceae
4	Jungle rice	*Echinochloa colona*	Poaceae
5	Hilo grass	*Paspalum conjugatum*	Poaceae
6	Hoorah grass	*Fimbristylis miliacea*	Cyperaceae
7	Rice flat sedge	*Cyperus iria*	Cyperaceae
8	Water primrose	*Ludwigia perennis*	Onagraceae
9	Creeping Cradle Plant	*Cyanotis axillaris*	Commelinaceae
10	Spreading dayflower	*Commelina diffusa*	Commelinaceae

Weeds were grouped into grasses, sedges and BLWs at 30 DAS, 60 DAS and at harvest and the effect of integrated weed management treatments on total weed density (no./ m^2) at these stages is represented in Table 66. At 30 DAS, lowest grass density was observed in hand weeded plot (T_7) followed by oxyfluorfen + hand weeding at 45 DAS (T_6) with 3 no./m^2 in both the plots. Sedges and BLWs were also present but the count was much less than grasses mainly due to very high density of *Sacciolepis interrupta*. Highest BLW population was recorded in unweeded control (11 no./m^2) whereas it was nil in hand weeded plot.

Plate 24. General view of the integrated management experimental plot

Table 65. Effect of integrated weed management treatments on weed species density (no./m^2) in 2019

Treatments	*Sacciolepis interrupta*			*Oryza sativa* f. *spontanea*			*Fimbristylis miliacea*			*Cyanotis axillaris*		
	30 DAS	**60 DAS**	**Harvest**	**30 DAS**	**60 DAS**	**Harvest**	**30 DAS**	**60 DAS**	**Harvest**	**30 DAS**	**60 DAS**	**Harvest**
T_1 – SSB + fenoxaprop– p–ethyl	*1.56^{bc} (2)	4.32^{c} (19)	6.54^{c} (43)	1.72 (3)	2.77^{a} (8)	3.10^{c} (10)	0.88^{b} (0)	1.46^{b} (2)	1.17 (1)	0.88^{b} (0)	1.86^{b} (3)	3.81^{b} (15)
T_2 - SSB + cyhalofop-butyl	1.86^{b} (3)	5.16^{b} (27)	6.81^{bc} (46)	1.52 (2)	2.83^{b} (8)	2.99^{cd} (9)	0.88^{b} (0)	1.34^{b} (1)	1.35 (2)	1.27^{b} (1)	1.86^{b} (3)	2.82^{c} (8)
T_3 - SSB + hand weeding at 45 DAS	1.46^{bc} (2)	3.51^{d} (12)	3.89^{e} (15)	1.41 (2)	2.16^{c} (5)	2.71^{d} (7)	1.34^{b} (1)	1.34^{b} (1)	1.27 (1)	1.29^{b} (1)	1.17^{cd} (1)	2.08^{cd} (4)
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	1.68^{b} (2)	4.04^{c} (16)	5.24^{d} (28)	1.72 (3)	2.76^{b} (8)	3.51^{b} (12)	1.17^{b} (1)	1.64^{b} (2)	1.64 (2)	1.17^{b} (1)	1.52^{bc} (2)	2.39^{c} (6)
T_5 - Oxyfluorfen + cyhalofop-butyl	1.56^{bc} (2)	4.96^{b} (25)	7.35^{b} (54)	1.63 (3)	2.83^{b} (8)	3.74^{ab} (14)	1.46^{ab} (2)	1.27^{b} (1)	1.68 (2)	1.05^{b} (0)	1.44^{bc} (2)	2.49^{c} (6)
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	1.05^{cd} (1)	1.88^{e} (4)	2.37^{f} (6)	1.41 (2)	2.16^{c} (5)	2.65^{d} (7)	1.17^{b} (1)	1.17^{b} (1)	1.17 (1)	1.05^{b} (1)	1.34^{d} (1)	1.63^{e} (3)
T_7 - Hand weeding at 20 & 45 DAS	0.88^{d} (0)	1.28^{f} (2)	2.08^{f} (4)	1.41 (2)	2.00^{c} (4)	2.24^{e} (5)	0.88^{b} (0)	1.17^{b} (1)	1.17 (1)	0.71^{c} (0)	0.71^{bc} (0)	1.14^{de} (1)
T_8 - Unweeded control	5.33^{a} (28)	7.35^{a} (54)	13.92^{a} (194)	1.61 (3)	3.31^{a} (11)	4.00^{a} (16)	2.02^{a} (4)	2.73^{a} (7)	2.30 (5)	2.73^{a} (7)	5.52^{a} (30)	5.01^{a} (25)
SEm	0.49	0.67	1.33	0.04	0.15	0.21	0.13	0.18	0.13	0.21	0.52	0.43
CD(0.05)	0.54	0.46	0.76	NS	0.26	0.34	0.61	0.68	NS	0.71	0.57	0.74

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

Table 66. Effect of integrated weed management treatments on total weed count (no./ m^2) at different growth stages of rice

Treatments	Grasses			Sedges			BLWs			Total		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T_1 – SSB + fenoxaprop– p–ethyl	2.38^{b} (6)	5.26^{cd} (28)	7.32^{c} (54)	0.88^{b} (0)	1.76^{bc} (3)	1.56^{bc} (2)	1.00^{cd} (1)	2.04^{b} (4)	3.81^{b} (15)	2.57^{c} (7)	5.83^{c} (34)	8.37^{c} (70)
T_2 - SSB+ cyhalofop-butyl	2.58^{b} (7)	6.02^{b} (36)	7.55^{c} (57)	0.88^{b} (0)	1.72^{bcd} (3)	1.74^{bc} (3)	1.57^{bcd} (2)	2.02^{b} (4)	2.92^{c} (29)	3.04^{bc} (9)	6.52^{b} (43)	8.30^{c} (69)
T_3 - SSB+ hand weeding at 45 DAS	2.08^{c} (4)	4.24^{e} (18)	4.79^{e} (23)	1.34^{b} (1)	1.68^{bcd} (2)	1.44^{bc} (2)	2.04^{b} (4)	1.68^{bc} (2)	2.15^{de} (5)	3.09^{b} (10)	4.76^{d} (23)	5.41^{e} (29)
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	2.51^{b} (6)	5.03^{d} (25)	6.42^{d} (41)	1.17^{b} (1)	2.26^{b} (5)	1.79^{bc} (3)	1.56^{bcd} (2)	1.52^{c} (2)	2.39^{cd} (6)	3.05^{bc} (9)	5.66^{c} (32)	7.09^{d} (50)
T_5 - Oxyfluorfen + cyhalofop-butyl	2.37^{b} (6)	5.74^{bc} (33)	8.28^{b} (69)	1.46^{ab} (2)	1.44^{cd} (2)	2.24^{ab} (5)	1.29^{bcd} (1)	1.56^{bc} (2)	2.92^{c} (9)	2.94^{bc} (9)	6.05^{c} (37)	9.05^{b} (82)
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	1.82^{cd} (3)	2.94^{f} (9)	3.60^{f} (13)	1.17^{b} (1)	1.44^{cd} (2)	1.17^{c} (1)	1.72^{bc} (3)	1.68^{bc} (2)	1.63^{ef} (3)	2.64^{bc} (7)	3.65^{e} (13)	4.12^{f} (17)
T_7 - Hand weeding at 20 & 45 DAS	1.73^{d} (3)	2.52^{f} (6)	3.11^{f} (10)	0.88^{b} (0)	1.17^{d} (1)	1.17^{c} (1)	0.71^{d} (0)	0.71^{d} (0)	1.14^{f} (1)	1.82^{d} (3)	2.64^{f} (7)	3.31^{g} (11)
T_8 - Unweeded control	5.80^{a} (34)	8.19^{a} (67)	14.66^{a} (215)	2.02^{a} (4)	3.18^{a} (10)	2.79^{a} (7)	3.39^{a} (11)	5.70^{a} (32)	5.19^{a} (27)	6.95^{a} (48)	10.43^{a} (109)	15.79^{a} (249)
SEm	0.46	0.63	1.28	0.13	0.22	0.19	0.28	0.53	0.45	0.54	0.81	1.36
CD(0.05)	0.28	0.48	0.59	0.61	0.58	0.83	0.86	0.49	0.71	0.48	0.46	0.58

*$\sqrt{x+0.5}$ transformed values, original values in parentheses.

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

SSB- Stale seed bed

By 60 DAS, weed population increased in all treatments. However, the lowest grass count was noticed in hand weeding plot (T_7) and oxyfluorfen + hand weeding at 45 DAS (T_6) (6 and 9 no./m^2) and these plots had very few sedges. The highest population of grasses, sedges and BLWs was registered in unweeded control plot (67, 10, 32 no./m^2) respectively.

At harvest stage, hand weeded plot as well as oxyfluorfen + hand weeding at 45 DAS recorded low number of sedges and BLWs although a few grasses were present (10 and 13 no./m^2 respectively). In general grasses were the dominant group as compared to sedges and BLWs and the weed population was low in herbicide applied plots compared to unweeded control (249 no./m^2).

C. Weed dry matter production

The data on weed dry matter production at 30 DAS, 60 DAS and at harvest are shown in Table 67. At 30 DAS, dry weight of weeds was the highest (40.81 g/m^2) in unweeded control (T_8) which differed significantly from all other treatments and was followed by SSB + hand weeding at 45 DAS (T_3) (3.70 g/m^2), oxyfluorfen + fenoxaprop–p–ethyl and oxyfluorfen + cyhalofop-butyl treated plots which were on par. The lowest weed dry weight at 30 DAS was observed in hand weeding (T_7) which was followed by SSB + fenoxaprop–p–ethyl (T_1) (2.07 g/m^2) and oxyfluorfen + hand weeding at 45 DAS (T_6) (0.47 g/m^2) treated plots.

At 60 DAS, lowest weed dry weight was recorded in hand weeded plot (T_7) and oxyfluorfen + hand weeding at 45 DAS (T_6) plots (3.73 and 3.83 g/m^2 respectively) followed by SSB+ hand weeding at 45 DAS (T_4) (12.90 g/m^2). The highest weed dry matter production was observed in unweeded control (101.59 g/m^2) which was significantly lower than all other treatments, and was followed by oxyfluorfen + cyhalofop-butyl treated plot (21.96 g/m^2).

Table 67. Effect of integrated weed management treatments on weed dry weight (g/m^2)

Treatments	30 DAS	60 DAS	Harvest
T_1 – SSB + fenoxaprop– p–ethyl	1.60[c] (2.07)	4.03[d] (16.25)	8.16[b] (66.68)
T_2 - SSB+ cyhalofop-butyl	1.70[c] (2.40)	4.47[bc] (20.00)	7.83[bc] (61.33)
T_3 - SSB+ hand weeding at 45 DAS	2.05[b] (3.70)	3.59[e] (12.90)	3.70[e] (13.67)
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	1.80[bc] (2.73)	4.30[cd] (18.48)	6.53[d] (42.65)
T_5 - Oxyfluorfen + cyhalofop-butyl	1.82[bc] (2.83)	4.68[b] (21.96)	7.73[c] (59.83)
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	1.72[c] (2.47)	1.96[f] (3.83)	2.91[f] (8.47)
T_7 - Hand weeding at 20 & 45 DAS	0.71[d] (0)	1.93[f] (3.73)	2.52[g] (6.37)
T_8 - Unweeded control	6.42[a] (40.81)	10.08[a] (101.59)	13.17[a] (173.61)
SEm	1.36	0.89	1.24
CD(0.05)	0.29	0.33	0.34

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

At the time of harvest also, weed dry weight was lowest (6.37 g/m^2) in hand weeded plot followed by oxyfluorfen + hand weeding at 45 DAS (8.47 g/m^2). The treatment SSB + hand weeding at 45 DAS (T_3) was the next best followed by oxyfluorfen + fenoxaprop–p–ethyl (T_4). However, there was an increase in weed dry weight from 101.59 g/m^2 at 60 DAS to 173.61 g/m^2 at harvest in unweeded plot, and this treatment produced significantly higher weed dry matter.

D. Nutrient removal by weeds

Data on the effect of integrated management treatments on nutrient removal of nutrients *viz.*, nitrogen, phosphorus and potassium, by weeds at 30 and 60 DAS are presented in Table 68. The highest removal of N, P and K was recorded in unweeded control plot (T_8) which was significantly superior to all other treatments.

At 30 DAS, highest N removal of 8.83 kg/ha was observed in unweeded control followed by SSB + hand weeding at 45 DAS (T_3) applied plots which had a removal of 1.19 kg/ha and was on par with all other treatments except hand weeded plot (T_7) and the values ranged from 0.67 to 0.48 kg/ha and hand weeded plot registered zero removal. By 60 DAS, N removal increased to 10.40 kg/ha in unweeded control and the lowest removal of 0.38 kg/ha was recorded in hand weeded plot and the next best treatment was SSB+ hand weeding at 45 DAS (0.46 kg/ha).

At 30 DAS, highest P uptake by weeds was noticed in unweeded control with 0.69 kg/ha followed by SSB+ hand weeding at 45 DAS (T_3) plot (0.13 kg/ha). All other treatments were on par. By 60 DAS, P removal by weeds in unweeded plot was 0.85 kg/ha. Hand weeded plot and oxyfluorfen + hand weeding at 45 DAS registered lowest removal of 0.04 and 0.05 kg/ha respectively.

As seen from the data, at 30 DAS, highest K removal of 8.06 kg/ha was observed in unweeded control and it increased to 11.34 kg/ha by 60 DAS which was statistically superior to other treatments, and the lowest removal was in hand weeded plot (0.0 and 0.38 kg/ha at 30 DAS and 60 DAS). Next best treatment in terms of lower K removal at 60 DAS after hand weeded plot was in the SSB+ hand weeding at 45 DAS plot (T_3). Remaining treatments were on par with respect to K removal by weeds at both 30 and 60 DAS.

Table 68. Effect of integrated weed management treatments on nutrients removal by weeds at 30 and 60 DAS

Treatments	N removal (kg/ha)		P removal (kg/ha)		K removal (kg/ha)	
	30 DAS	**60 DAS**	**30 DAS**	**60 DAS**	**30 DAS**	**60 DAS**
T_1 – SSB + fenoxaprop– p–ethyl	0.53^{bc}	1.85^{bc}	0.04^{c}	0.17^{c}	0.68^{bc}	2.78^{bc}
T_2 - SSB+ cyhalofop-butyl	0.53^{bc}	2.61^{bc}	0.05^{c}	0.37^{b}	0.67^{bc}	3.04^{b}
T_3 - SSB+ hand weeding at 45 DAS	1.19^{b}	1.72^{c}	0.13^{b}	0.15^{c}	0.98^{b}	1.72^{c}
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	0.54^{bc}	2.24^{bc}	0.06^{c}	0.34^{b}	0.89^{b}	3.00^{b}
T_5 - Oxyfluorfen + cyhalofop-butyl	0.67^{bc}	2.88^{b}	0.05^{c}	0.29^{b}	0.74^{bc}	2.88^{bc}
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	0.48^{bc}	0.46^{d}	0.04^{c}	0.05^{d}	0.53^{bc}	0.46^{d}
T_7 - Hand weeding at 20 & 45 DAS	0.00^{c}	0.38^{d}	0.00^{c}	0.04^{d}	0.00^{c}	0.38^{d}
T_8 - Unweeded control	8.83^{a}	10.40^{a}	0.69^{a}	0.85^{a}	8.06^{a}	11.34^{a}
SEm	1.04	1.13	0.08	0.09	0.09	1.22
CD(0.05)	0.82	1.04	0.06	0.09	0.76	1.16

In a column, means followed by common letters do not differ significantly at 5% level by DMRT
SSB- Stale seed bed

1.2 Crop growth and yield parameters

A. Plant height

Data regarding the effect of various integrated weed management treatments on plant height (cm) and tiller production (no.) of rice at 30 DAS, 60 DAS and at harvest are given in Table 69. At 30 DAS, the tallest plants was recorded in SSB + hand weeding at 45 DAS (T_3) (32.73 cm) and smallest plants of 17.03 cm was registered in unweeded control (T_8). All other treatments were on par with respect to plant height at 30 DAS.

Hand weeded plot (T_7), SSB + fenoxaprop–p–ethyl (T_1), oxyfluorfen + hand weeding at 45 DAS (T_6), SSB+ cyhalofop-butyl (T_2), and SSB+ hand weeding at 45 DAS (T_3) treatments recorded greatest plant height and were on par with each other. Unweeded control recorded lowest plant height of 27.80 cm. At harvest stage also, plant height followed the same trend and hand weeded plot (T_7) recorded the greatest plant height of 112.73 cm, other treatments were on par and unweeded control (T_8) had lowest plant height of 65.67 cm.

B. Number of tillers

The data on tiller count/m^2 at different growth stages of rice are presented in Table 69. It was observed that hand weeded plot recorded significantly higher number of tillers/m^2 at all stages of observation and was significantly superior to all other treatments. At 30 DAS, significantly higher number of tillers/m^2 (259.00) was recorded in the hand weeded plot (T_7), and the second highest number of tillers/m^2 was recorded in the treatment oxyfluorfen + hand weeding at 45 DAS (T_6) (244.66 no./m^2), while lowest tiller number per m^2 was seen in unweeded plot (T_8) (43.33).

At 60 DAS also the hand weeding treatment recorded significantly higher number of tillers/m^2 (472.67 no./m^2) followed by oxyfluorfen + hand weeding at 45

DAS (T_6) (455.62 no./m^2). At harvest significantly higher tiller count (268.33, 247.00 and 229.67 no./m^2 respectively) was recorded in hand weeded plot (T_7), SSB+ hand weeding at 45 DAS (T_3) and oxyfluorfen + hand weeding at 45 DAS (T_6). Lowest was in unweeded control (46.00 no./m^2) followed by the treatments oxyfluorfen + cyhalofop-butyl (92.33 no./m^2)

C. Yield attributes

Data on the effect of integrated weed management treatments on yield attributes are given in Table 70.

1. Number of panicles

It is clear from the data in Table 70 that number of panicles per square metre was significantly higher in hand weeded treatment (246.00/m^2) (T_7), SSB+ hand weeding at 45 DAS (225.00/m^2) (T_3) and oxyfluorfen + hand weeding at 45 DAS (214.67/m^2) (T_6), which were on par and lowest value was noticed in unweeded control (48.33/m^2) (T_8) followed by SSB + fenoxaprop–p–ethyl (T_1), SSB+ cyhalofop-butyl (T_2), oxyfluorfen + cyhalofop-butyl (T_5) treatments which were on par and the values were significantly inferior to other treatments.

2. Filled grains per panicle and test weight of rice

The number of filled grains per panicle ranged from 19 to 89. It was observed that highest number of 89, 87 and 83 grains/panicle was recorded in hand weeding (T_7), oxyfluorfen + hand weeding at 45 DAS (T_6) and SSB + hand weeding at 45 DAS (T_3) respectively, and oxyfluorfen + fenoxaprop–p–ethyl (T_4) (81.67 no.). In unweeded control plot there were only 19 grains/panicle.

Table 69. Effect of integrated weed management treatments on plant height (cm) and tiller production (no.) of rice

Treatments	Plant height (cm)			Tiller production (no./m^2)		
	30 DAS	**60 DAS**	**Harvest**	**30 DAS**	**60 DAS**	**Harvest**
T_1 – SSB + fenoxaprop– p–ethyl	23.60^{bc}	51.80^{a}	88.49^{b}	116.00^{f}	199.00^{f}	118.00^{c}
T_2 - SSB+ cyhalofop-butyl	26.83^{ab}	50.80^{ab}	88.73^{b}	128.33^{ef}	215.67^{e}	107.67^{c}
T_3 - SSB+ hand weeding at 45 DAS	32.73^{a}	48.10^{abc}	90.29^{b}	224.33^{c}	417.33^{c}	247.00^{a}
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	23.20^{bc}	43.67^{c}	88.03^{b}	176.67^{d}	335.00^{d}	187.67^{b}
T_5 - Oxyfluorfen + cyhalofop-butyl	28.20^{ab}	44.45^{bc}	86.00^{b}	129.67^{e}	207.67^{ef}	92.33^{cd}
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	28.93^{ab}	50.47^{abc}	90.00^{b}	244.67^{b}	455.67^{b}	229.67^{ab}
T_7 - Hand weeding at 20 & 45 DAS	28.50^{ab}	52.46^{a}	112.73^{a}	259.00^{a}	472.67^{a}	268.33^{a}
T_8 - Unweeded control	17.03^{c}	27.80^{d}	65.67^{c}	43.33^{g}	61.00^{g}	46.00^{d}
SEm	1.68	2.87	4.47	26.26	52.07	28.96
CD(0.05)	7.42	7.11	9.41	12.49	12.99	52.24

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

SSB- Stale seed bed

Test weight (1000 grain weight) of the grain was in the range of 24.13 g to 26.80 g, with unweeded treatment recording the lowest value and hand weeding as well as oxyfluorfen + hand weeding at 45 DAS and SSB + hand weeding at 45 DAS resulting in the highest value. The treatment oxyfluorfen + fenoxaprop-p-ethyl (T_4) resulted in low test weight of 25.27g.

3. Grain yield, straw yield and harvest index

Details of grain yield, straw yield and harvest index as influenced integrated weed management treatments are given in Table 71.

Highest grain yield of 4560 kg/ha was recorded in the treatment hand weeding (T_7) followed by SSB+ hand weeding at 45 DAS (T_3) (4239 kg/ha) and oxyfluorfen + hand weeding at 45 DAS (T_6) (4079 kg/ha) which were on par. Oxyfluorfen + fenoxaprop–p–ethyl (T_4) (3639 kg/ha) was found to be statistically superior to remaining herbicidal treatments. The treatment unweeded control (T_8) produced significantly lower grain yield of 497 kg/ha

The straw yield was higher and comparable in the treatments SSB+ hand weeding at 45 DAS (T_3), hand weeded plot (T_7), and oxyfluorfen + hand weeding at 45 DAS (T_6) with 6100, 6019 and 5735 kg/ha respectively followed by oxyfluorfen + fenoxaprop–p–ethyl (T_4) (5199 kg/ha). All other treatments were on par with each other with respect to straw yield except for unweeded control. The lowest straw yield of 1200 kg/ha was obtained in unweeded control.

Significantly higher values of harvest index were observed in the treatments hand weeding (0.43) followed by oxyfluorfen + hand weeding at 45 DAS (0.42) and lowest HI value was recorded in unweeded control (0.29).

D. Nutrient uptake by rice

The data on nutrient uptake by rice (Table 72) at 60 DAS revealed that highest N, P and K uptake was in the treatments hand weeding (40.07, 4.84 and 75.30 kg ha), oxyfluorfen + hand weeding at 45 DAS (35.39, 4.81 and 64.01 kg ha) and SSB+ hand weeding at 45 DAS treatments with (39.49, 3.95 and 67.64 kg ha) which were on par. P uptake was also significantly high in SSB+ hand weeding at 45 DAS (4.96 kg/ha). All other treatments were on par with respect N, P and K uptake except for the treatments oxyfluorfen+ cyhalofop-butyl. The lowest N, P and K uptake was in unweeded control which had values of 2.59, 0.15 and 3.25 kg/ha of N, P and K respectively.

E. Weed Index (WI) and Weed Control Efficiency (WCE)

WCE at 30 and 60 DAS is represented in table 73. Highest WCE at both 30 and 60 DAS was recorded in hand weeded plot (100.00 % and 96.23 % respectively). At harvest, the treatment SSB+ hand weeding at 45 DAS resulted in significantly better weed control as indicated by the lowest weed index of 7.09, and was on par with the treatment oxyfluorfen+ hand weeding at 45 DAS, which had a value of 10.41 Highest weed control efficiency of 96.33% and 95.13% was obtained in hand weeded plots and oxyfluorfen + hand weeding at 45 DAS treated plots respectively. As observed from the data unweeded control showed highest weed index of 89.08 % compared to other treatments, followed by oxyfluorfen + cyhalofop-butyl (43.42 %) and SSB+ cyhalofop-butyl (40.08%). (Table 74).

F. Economics of cultivation

Among different treatments higher B:C ratio of 1.9 was obtained in SSB+ hand weeding at 45 DAS (T_3). The treatments oxyfluorfen + hand weeding at 45 DAS (T_6) and hand weeding at 20 and 45 DAS (T_7) registered a B:C ratio of 1.8 and 1.7 respectively and least B:C ratio of 0.3 was noted in unweeded control (Table 75).

Table 70. Effect of integrated weed management treatments on yield attributes of rice

Treatments	Panicles (No./m^2)	Filled grains/panicle (No.)	1000 grain weight (g)
T_1 – SSB + fenoxaprop– p–ethyl	94.67^c	73.00^{bc}	26.30^{ab}
T_2 - SSB+ cyhalofop-butyl	87.33^c	69.00^c	25.87^b
T_3 - SSB+ hand weeding at 45 DAS	225.00^a	83.00^a	26.63^a
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	166.00^b	81.67^{ab}	25.27^c
T_5 - Oxyfluorfen + cyhalofop-butyl	72.00^c	50.67^d	26.40^{ab}
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	214.67^a	87.00^a	26.50^a
T_7 - Hand weeding at 20 & 45 DAS	246.00^a	89.00^a	26.80^a
T_8 - Unweeded control	48.33^c	19.00^e	24.13^d
SEm	27.52	8.37	0.31
CD(0.05)	48.10	8.76	0.54

In a column, means followed by common letters do not differ significantly at 5% level in DMRT, SSB- Stale seed bed

Table 71. Effect of integrated weed management treatments on yield and harvest index of rice

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	HI
T_1 – SSB + fenoxaprop– p–ethyl	2965^d	4172^c	0.41^{abc}
T_2 - SSB$^{\$}$+ cyhalofop-butyl	2733de	3945^c	0.41^{bc}
T_3 - SSB$^{\$}$+ hand weeding at 45 DAS	4239^b	6100^a	0.41^{bc}
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	3639^c	5199^b	0.41^{abc}
T_5 - Oxyfluorfen + cyhalofop-butyl	2580^e	3984^c	0.39^c
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	4079^b	5735^a	0.42^{ab}
T_7 - Hand weeding at 20 & 45 DAS	4560^a	6019^a	0.43^a
T_8 - Unweeded control	497^f	1200^d	0.29^d
SEm	459.94	573.79	0.15
CD(0.05)	304.51	401.98	0.02

In a column, means followed by common letters do not differ significantly at 5% level in DMRT, SSB- Stale seed bed

Table 72. Effect of integrated weed management treatments on nutrient uptake of rice at 60 DAS

Treatments	N (kg/ha)	P (kg/ha)	K (kg/ha)
T_1 – SSB+ fenoxaprop– p–ethyl	32.86^{ab}	4.96^{a}	42.11^{b}
T_2 - SSB+ cyhalofop-butyl	23.43^{bc}	2.76^{bc}	34.64^{bc}
T_3 - SSB+ hand weeding at 45 DAS	39.49^{a}	3.95^{ab}	67.64^{a}
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	31.70^{ab}	3.85^{ab}	40.91^{b}
T_5 - Oxyfluorfen + cyhalofop-butyl	19.84^{c}	1.58^{c}	22.39^{c}
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	35.39^{a}	4.81^{a}	64.01^{a}
T_7 - Hand weeding at 20 & 45 DAS	40.07^{a}	4.84^{a}	75.30^{a}
T_8 - Unweeded control	2.59^{d}	0.15^{d}	3.25^{d}
SEm	4.43	0.61	8.62
CD(0.05)	9.82	1.26	15.54

In a column, means followed by common letters do not differ significantly at 5% level in DMRT, SSB- Stale seed bed

Table 73. Effect of integrated weed management treatments on weed control efficiency (WCE) at 30 and 60 DAS

Treatments	30 DAS (%)	60 DAS (%)
T_1 -SSB + fenoxaprop– p–ethyl	94.86	83.99
T_2 - SSB + cyhalofop-butyl	94.09	80.21
T_3 - SSB + hand weeding at 45 DAS	90.76	87.26
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	93.21	81.73
T_5 - Oxyfluorfen + cyhalofop-butyl	92.95	78.28
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	100.00	96.23
T_7 - Hand weeding at 20 & 45 DAS	93.89	96.34
T_8 - Unweeded control	-	-

SSB- Stale seed bed

Table 74. Effect of integrated weed management treatments on weed control efficiency (WCE) and weed index (WI)

Treatments	WCE (%)	WI (%)
T_1 - SSB + fenoxaprop– p–ethyl	61.60	31.68
T_2 - SSB+ cyhalofop-butyl	64.57	40.08
T_3 - SSB+ hand weeding at 45 DAS	92.07	7.09
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	75.37	20.05
T_5 - Oxyfluorfen + cyhalofop-butyl	65.50	43.42
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	95.13	10.41
T_7 - Hand weeding at 20 & 45 DAS	96.33	-
T_8 - Unweeded control	-	89.08

SSB- Stale seed bed

Table 75. Effect of integrated weed management treatments on economics of cultivation (Rs./ha)

Treatments	Total cost (Rs./ha)	Total income (Rs./ha)	Net profit (Rs./ha)	B:C ratio
T_1 – SSB + fenoxaprop– p–ethyl	79,271/-	1,15,517/-	36,246/-	1.5
T_2 - SSB + cyhalofop-butyl	80,400/-	1,07,324/-	26,924/-	1.3
T_3 - SSB + hand weeding at 45 DAS	88,500/-	1,66,303/-	77,803/-	1.9
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	78,013/-	1,42,445/-	64,432/-	1.8
T_5 - Oxyfluorfen + cyhalofop-butyl	79,142/-	1,03,524/-	24,382/-	1.3
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	87,242/-	1,58,881/-	71,639/-	1.8
T_7 - Hand weeding at 20 & 45 DAS	1,02,000/-	1,74,282/-	72,282/-	1.7
T_8 - Unweeded control	72,000/-	23,619/-	-48,381/-	0.3

SSB- Stale seed bed

Partial budgeting reveals that the additional returns due to herbicide application was the highest for SSB+ hand weeding at 45 DAS. Among the herbicide combinations oxyfluorfen + hand weeding at 45 DAS and oxyfluorfen + fenoxaprop–p–ethyl performed better with additional returns of Rs. 1,20,020 and Rs. 1,12,813, both were superior to other combinations. In terms of additional returns due to weed management, many other herbicidal treatments were inferior to SSB+ hand weeding, as the net returns was lower (Table 76).

Table 76. Economics of weed control by partial budgeting (Rs./ha)

Treatments	Cost of cultivation excluding WM (Rs./ha)	Additional cost for WM (Rs./ha)	Total income (Rs./ha)	Net returns (Rs./ha)	Additional returns due to WM (Rs./ha)
T_1 - SSB + fenoxaprop– p–ethyl	72,000/-	7271/-	1,15,517/-	36,246/-	84,627/-
T_2 - SSB + cyhalofop-butyl	72,000/-	8400/-	1,07,324/-	26,924/-	75,305/-
T_3 - SSB + hand weeding at 45 DAS	72,000/-	16500/-	1,66,303/-	77,803/-	1,26,184/-
T_4- Oxyfluorfen + fenoxaprop–p–ethyl	72,000/-	6013/-	1,42,445/-	64,432/-	1,12,813/-
T_5 - Oxyfluorfen + cyhalofop-butyl	72,000/-	7142/-	1,03,524/-	24,382/-	72,763/-
T_6 - Oxyfluorfen + Hand weeding at 45 DAS	72,000/-	15,242/-	1,58,881/-	71,639/-	1,20,020/-
T_7 - Hand weeding at 20 & 45 DAS	72,000/-	30,000/-	1,74,282/-	72,282/-	1,20,663/-
T_8 - Unweeded control	72,000/-	-	23,619/-	-48,381/-	-

SSB- Stale seed bed, WM- Weed management

Discussion

5. DISCUSSION

Sacciolepis interrupta is a serious weed in the semi dry rice growing areas and is seen in all the major rice ecosystems of Kerala. Knowledge on the habit, habitat, biology and influence of environmental factors on germination and growth could help in formulating better management practices for the weed. The results obtained from survey, laboratory and pot culture studies, and field experiments conducted as part of the thesis programme entitled 'Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice' presented in chapter IV is discussed hereunder based on available literature. Intensity of dominance caused by S. interrupta in farmer's rice fields is depicted in Plate 25.

5.1. Distribution and morphological study of *S. interrupta*

A. Weed phytosociology

Serious problem of *S. interrupta* in different rice tracts is aggravated by the appearance of a number of morphotypes or biotypes. Biotypes are plants showing a random genetic variant within an ecotype (Klingman and Oliver, 1994). For monitoring and comparing plant community changes over time, density, frequency and abundance act as useful indices (Bonham, 2013).

1. ***Kole*** **rice tract**

In *Kole* tract, a total of 11 weed species were observed in surveyed areas, and out of these *S. interrupta* and weedy rice registered highest density, frequency, and abundance (Figure 5, Table 6). This was in line with the report by Latha and Jaikumaran (2015), out of a quantitative weed survey in the rice fields of *Kole* lands which revealed a relative density of 2.46 per cent of *S. interrupta.* Among different blocks surveyed, *S. interrupta* dominated in Pullazhi, Manakkody, and Alappad blocks of *Kole* lands.

2. ***Kuttanad*** **rice tract**

In *Kuttanad* tract, *S. interrupta* was observed in the rice field bunds, marshy areas and stream banks apart from the rice fields. *Echinochloa crus-galli* was seen to be the dominant weed in the surveyed areas of *Kuttanad*, with highest relative density, frequency, out of 12 species, followed by *S. interrupta* and *Salvinia molesta* (Figure 6; Table 7).

3. **Palakkad rice tract**

In surveyed areas of Palakkad, a total of 15 species dominated and out of them, *S. interrupta* recorded highest relative density, frequency, and abundance, followed by *Leptochloa* sp. (Figure 7; Table 8) and this is because of the system of rice cultivation followed as well as the pattern of rainfall in the Palakkad rice tract as confirmed by AICRP-WC (1997). Chithali block had severe infestation of *S. interrupta* and wide variation was exhibited in the morphological characters of *S. interrupta*, indicating the existence of morphotypes and higher seed bank in that area.

B. Cluster analysis of *S. interrupta* morphotypes

Growth stage, age, biotype or environment play a vital role in affecting the morphological appearance of a particular morphological trait of the same weed species (Booth *et al*., 2010). Summed dominance ratio (SDR) of *S. interrupta* morphotypes in different surveyed rice tracts is represented in figure 8. From the survey conducted in the major rice producing tracts of Kerala, fifteen morphotypes of *S. interrupta* were grouped into three groups. Group A (green variegated) referred to the morphotypes from Palakkad with medium stature and narrow light green leaves having green coloured panicles (4-6 no./plant), oblong spikelets (311-348 spikelets/panicle), spikelet length and width varying between 4.6-4.8 mm and 0.9-1.3 mm respectively. Severe infestation of *S. interrupta* group A in the surveyed locations of Palakkad rice tract was observed where semi-dry system of rice cultivation was followed throughout, with saturated soil conditions, near neutral pH, low organic carbon and low nutrient status.

Plate 25. Dominance of *Sacciolepis interrupta* in farmer's rice field

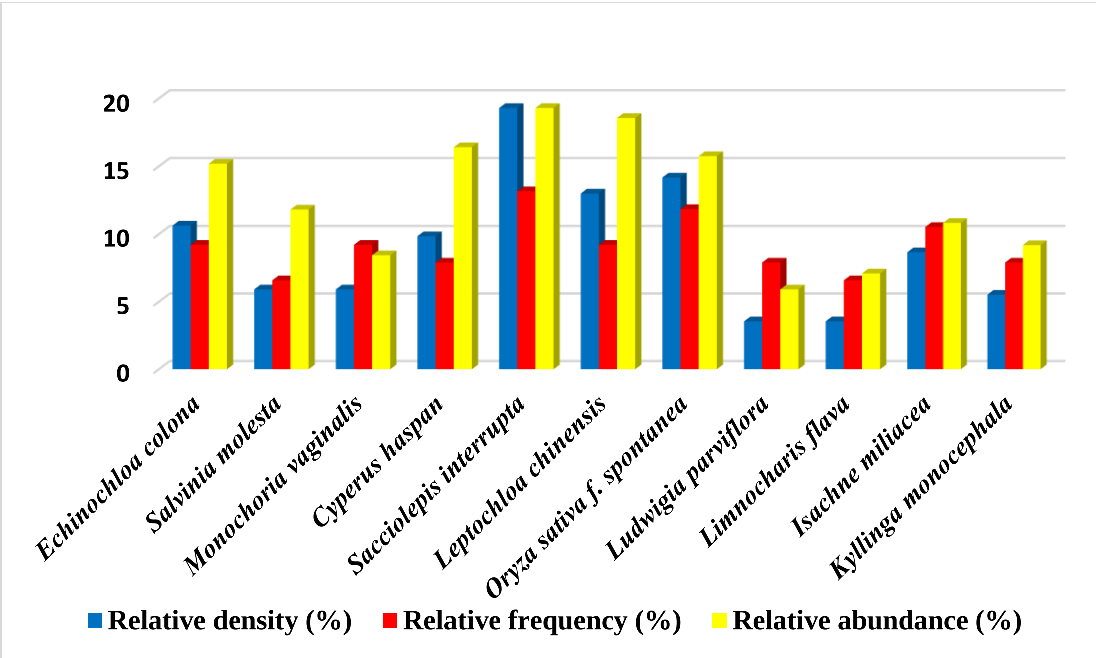


Figure 5. Distribution and dominance of weed species in surveyed areas of *Kole* tract

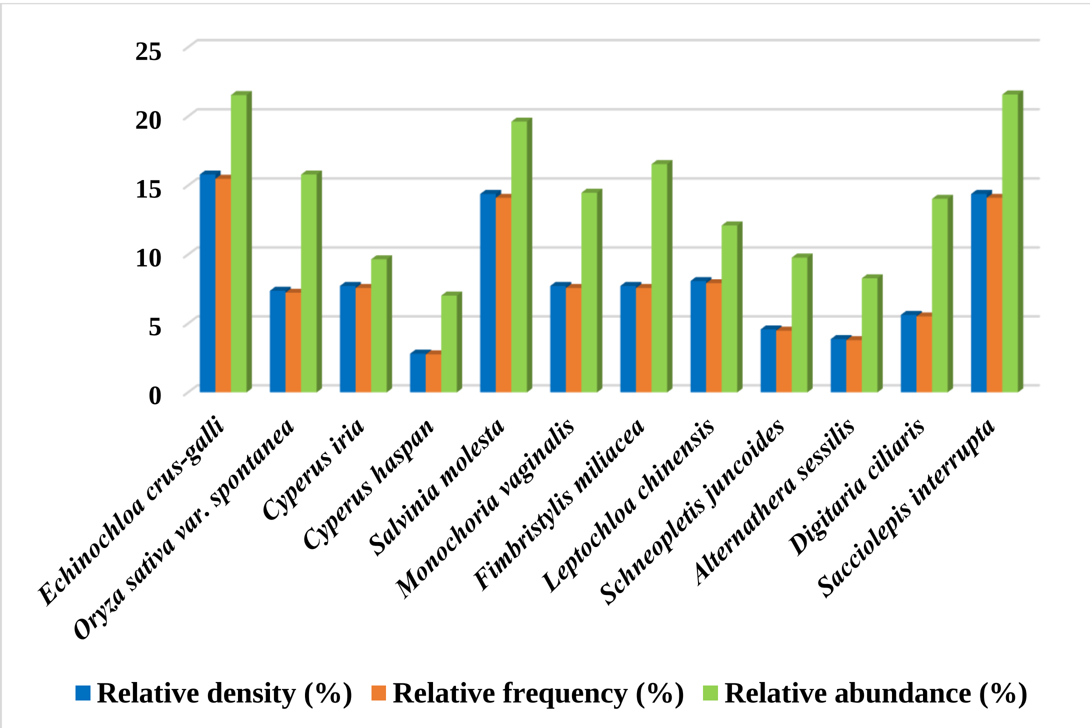


Figure 6. Distribution and dominance of weed species in surveyed areas of *Kuttanad* tract

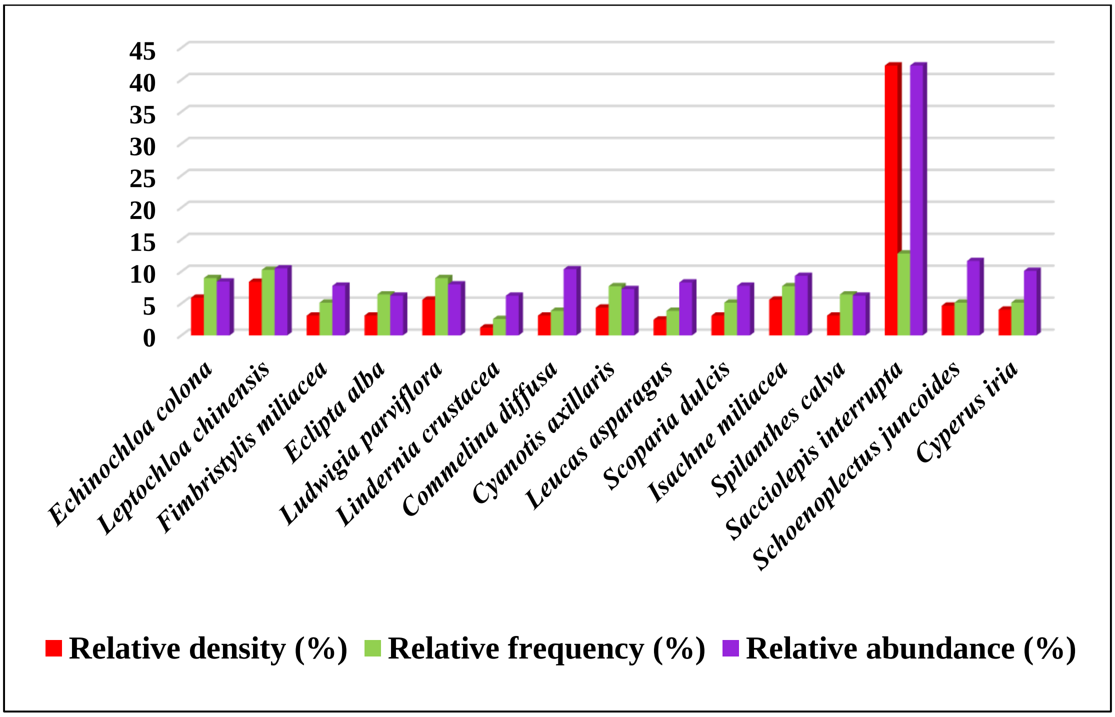


Figure 7. Distribution and dominance of weed species in surveyed areas of Palakkad tract

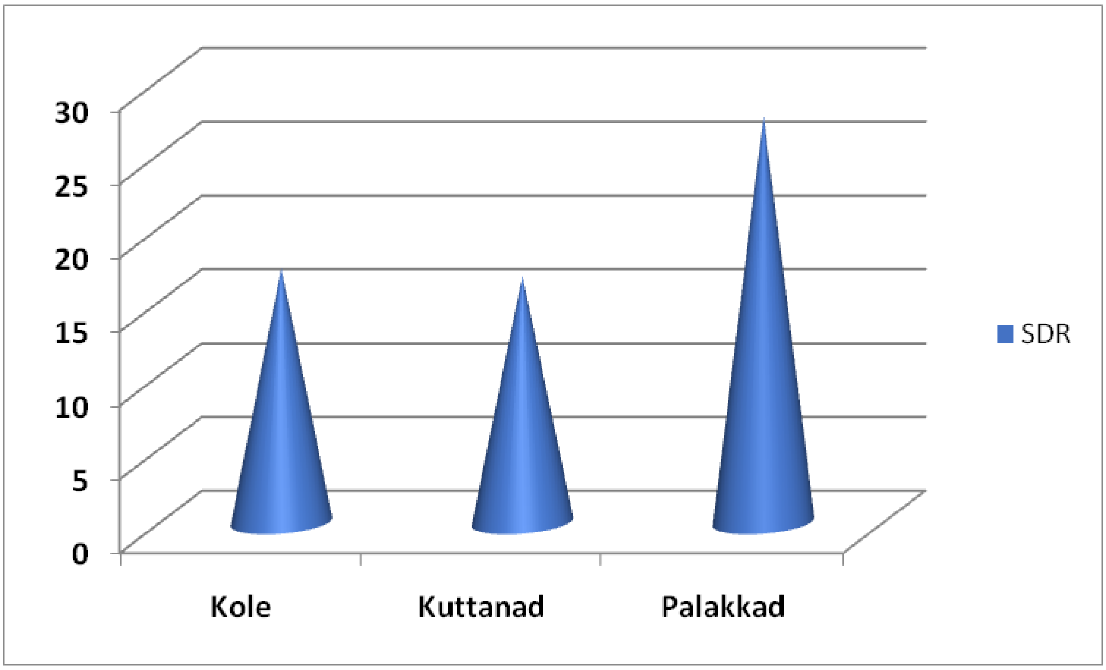


Figure 8. Summed dominance ratio (SDR) of *S. interrupta* morphotypes in surveyed tracts

Group B (purple variegated) comprised the morphotypes from *Kole* tract with tall statured plants and narrow dark green leaves having purple coloured panicles (4-6 no./plant), enlongated spikelets (311-348 spikelets/panicle), spikelet length of 4.6-4.8 mm and width of about 0.9-1.3 mm. These morphotypes of *S. interrupta* was dominant in acidic pH, medium organic carbon and submerged soils of Kole lands.

Kuttanad tract types, categorized into Group C (green-purple variegated) were short statured, profuse tillering plants with broad dark green leaves having bicoloured green and purple panicles (6-8 no./plant), oblong to bulged spikelets (378-391 spikelets/panicle), short spikelets with length of 4.1-4.5 mm and width of 1.6-1.8 mm. Their density was prominently high in highly acidic and nutrient rich submerged soils of Kuttanad.

C) Habitat analysis

Higher values of diversity and evenness indices (>1), indicate that weed species within the habitat were diverse and more equally distributed, but increase in dominance of one weed species would decrease the diversity of the habitat and also lower the values (Wilson *et al*., 2009). Data on weed vegetation analysis in different rice tracts are given in figure 9.

Simpson diversity (D), Shannon-Wiener diversity (H) and Evenness (J) indices were highest in *Kuttanad* and *Kole, i.e*., 0.9, 2.3 and 0.95, and 0.8, 2.2 and 0.94, respectively, whereas in Palakkad tract they were 0.7, 1.5 and 0.57, respectively, showing a high degree of domination of one species in Palakkad tract and a larger diversity of weed species in the other two tracts.

5.2. Biology of *S. interrupta*

1. Biology

Information on weed biology plays an important role in effectively managing weeds. It helps to understand weeds better with regard to their dormancy, competitiveness and resistance to edaphic factors.

In the present programme, biology of *S. interrupta* was studied with respect to weed morphological characters, time taken for seed germination, time taken to complete different growth stages, number of tillers/plant, number of panicles/plant, seed production capacity and content of major nutrients at flowering. Apart from this, attempts were also made to study methods of propagation, factors affecting germination by adopting different scarifying techniques and effect of environmental factors such as light and temperature on germination and propogation.

A. Morphological characters

S. interrupta is an annual or perennial plant, with erect or creeping or geniculate habit with rooting at lower nodes, and glabrous nodes and a plant height of 70-112 cm. Its habitat is semi dry rice growing areas, but also seen in wet seeded rice too, owing to mimicry with rice seedlings at young stages. Apart from that it is seen on field bunds, marshy areas and stream banks which was in line with the findings of Clayton *et al*. (2006).

Tiller number ranged from 3 to 6 and the number of panicles were 3 to 4 per plant. Inflorescence is an erect, compact, terminal raceme like panicle about 8 to 30 cm long and is of either interrupted or spiciform type and length ranging from 8- 30 cm. The spikelets are ovate or lanceolate, either green coloured or green coloured with violet variegations and about 2.1 to 4.8 mm long. July to September is the peak period of flowering in *S. interrupta*. Seeds are 2 to 2.5 mm long and ovoid in shape, with light brown colouration (Table 18). *S. interrupta* is propagated sexually by seeds and vegetatively by root clumps or by culm cuttings. Seeds are shed and dispersed by wind and water. Seeds undergo dormancy for a period of six to nine months (September to April), and germinate under favourable high temperature conditions (May to August). *S. interrupta* can also be vegetatively propagated throughout the year either by rooted clumps or by culm pieces. The culms produce new roots from the nodes placed below the soil which continue to grow as new plants. The ability of *S. interrupta* to propagate by diverse means is directly related to its persistence in rice fields and the difficulty to reduce its population below the threshold level.

B. Ontogeny

In field conditions, the weed seedlings emerged 7-9 DAS. Tillering was completed between 14-17 days, with panicle initiation started soon after, and completed within 15-18 days, with a total period of 58-59 days. The weed started flowering after the booting and heading period of 9-14 days, and flowering continued for 6 days. Ripening phase took 17-24 days and the total duration of weed was 81 to 86 days.

C. Propagation methods

S. interrupta has the ability to propagate by different methods. Seeds, culm cuttings and root clumps were observed to be on par in germination and regeneration capacity. Morphological characters like branching, tillering, leaf length, and leaf width were found to be improved in vegetatively propagated plants compared to seed propagated ones, whereas plant height was greater in seedlings.

2. Germination studies

Seed germination is a complex physiological process affected by factors like temperature, moisture, light, seeding depth and others (Bewley and Black, 1994; Baskin and Baskin, 1998). Effective weed management in a cropped field is often difficult due to the common occurrence of dormancy in weed seed populations, which results in unpredictable weed emergence time span.

In the present study, *S. interrupta* exhibited varying degrees of dormancy. Seeds of *S. interrupta* are characterized by small, dormant seeds which are able to germinate only under favorable environmental conditions. Dormancy in grasses can be attributed to either innate dormancy (primary dormancy), which occurs in the embryo covering structures, or inside the embryo, and induced dormancy (secondary dormancy) which are due to environmental conditions (Simpson, 1990; Adkins *et al*., 2002).

A) Laboratory studies for breaking dormancy

Embryos of *S. interrupta* seeds were found to be viable, but failed to germinate even after scarification treatments in off season, but almost all of them were able to germinate during the period from May to August, indicating a high level of innate dormancy which required a biochemical trigger, which in *S. interrupta* could be related to the season.

During May to August, among the different treatments, concentrated sulphuric acid treatment for 5 to 30 min resulted in 80% germination in fresh seeds, and perchloric acid (1%) recorded highest germination percentage of 64% in old seeds compared to untreated seeds, which had lowest rate of germination in both the cases (Figure 10 and Table 20). Tigabu and Oden (2001) reported that concentrated H_2SO_4 caused modification or scarification of the hull or seed coat membranes, and also supplied additional oxygen to the seed and thereby caused breaking of seed dormancy of many species with impermeable seed coat.

The response of old seeds (one year old) to scarification treatments was higher compared to fresh seeds (freshly harvested). Dhawan (2009) reported that both mechanical scarification and chemical scarification resulted in 100% germination in 1, 2 and 3 year old seeds of *Melilotus* species and old seeds had higher germination rate than fresh seeds.

Temperature and light are considered as important factors influencing seed germination of several weed species (Benvenuti *et al*., 2004; Burke *et al*., 2003). Germination of *S. interrupta* seeds was influenced by the interaction between temperature and light. *S. interrupta* seeds germinated at higher temperatures both under continuous light as well as alternate light and dark conditions, showing that the weed was positively photoblastic under high temperature regimes. Light strongly stimulated germination, while darkness completely inhibited germination of *S. interrupta*. Maximum germination (68 %) occurred when seeds were exposed to higher temperature of 38^0C under continuous light for a period of 14 days. With the same temperature under alternate light and dark conditions, a germination of 54.7 %

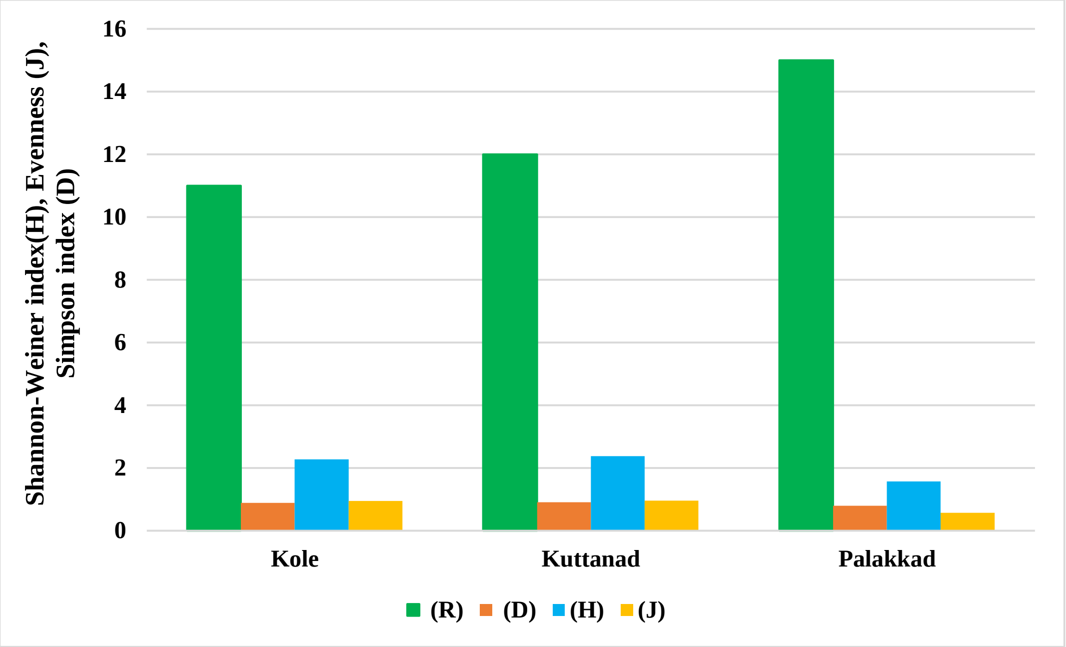


Figure 9. Weed vegetation analysis indices in different rice tracts of Kerala

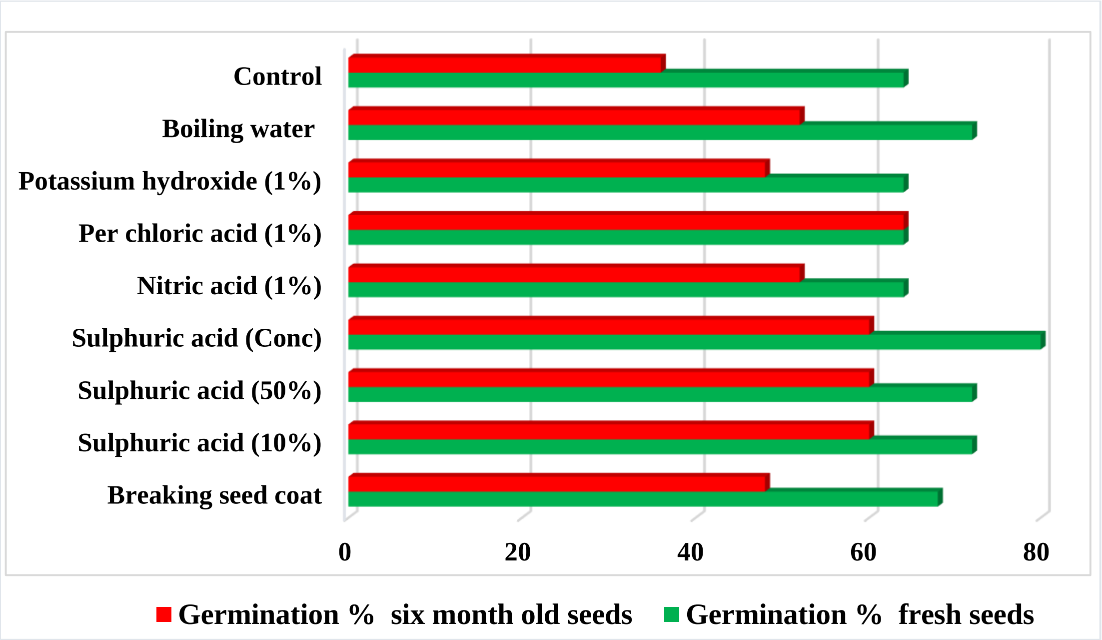


Figure 10. Effect of seed scarification treatments on germination of *S. interrupta*

was recorded. At lower temperatures there was no influence of light on germination, and germination was 0% (Table 21). Seeds of some weed species like tropical signal grass (*Urochloa subquadripara*) germinate equally in light and dark conditions (Teuton *et al*., 2004) and seeds of other species like Chinese sprangletop (*Leptochloa chinensis* (L.) Nees) and barnyard grass (*Echinochloa crus-galli* (L.) Beauv.) require light to stimulate germination (Chauhan and Johnson, 2008; Boyd and vanAcker, 2004).

B) Pot culture studies

S. interrupta seed, under continuous submergence showed higher germination and emergence compared to upland condition. Lowland with continuous flooding treatment had highest germination percentage at 7, 14 and 30 days after sowing, followed by lowland conditions with alternate flooding and drying. Emergence was lowest under upland conditions.

Kaur *et al.* (2008) have reported that under high moisture conditions emergence and growth of rice weeds, especially grassy weeds, was more compared to dry conditions. *S. interrupta* responded well to flooding, which was the ideal condition for its germination, indicating that flooding in rice may not help in decreasing the emergence of this weed.

Burial along with rice was found to significantly reduce the germination of *S. interrupta* at all dates of observation and this may be due to the competition exerted by rice seeds on *S. interrupta*, inhibiting its germination. Jose *et al*. (2013) also found that the germination percentage of weedy rice was 56% in presence of rice and it was 67% in absence of rice. Interaction effect was significant and highest germination of 27%, 37% and 35% was observed at 7, 14 and 30 DAS respectively in lowland condition with continuous flooding, in the absence of rice seeds. The rate of germination and seedling vigour index was low when *S. interrupta* was sown along with rice seeds and it was higher in absence of rice seeds (Figure 11 and 12; Table 22).

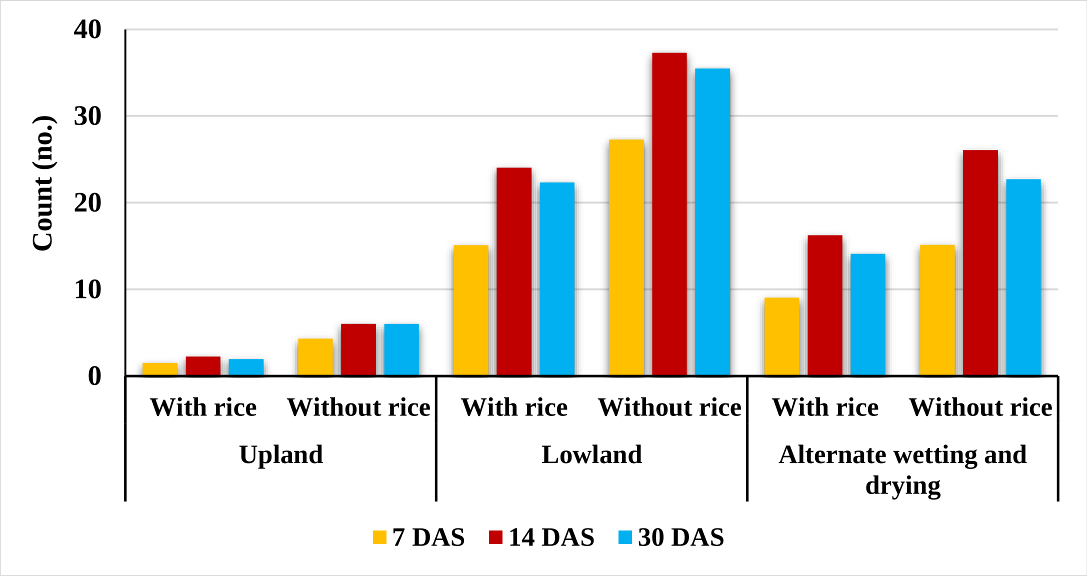


Figure 11. Effect of soil moisture status on germination of *S. interrupta*

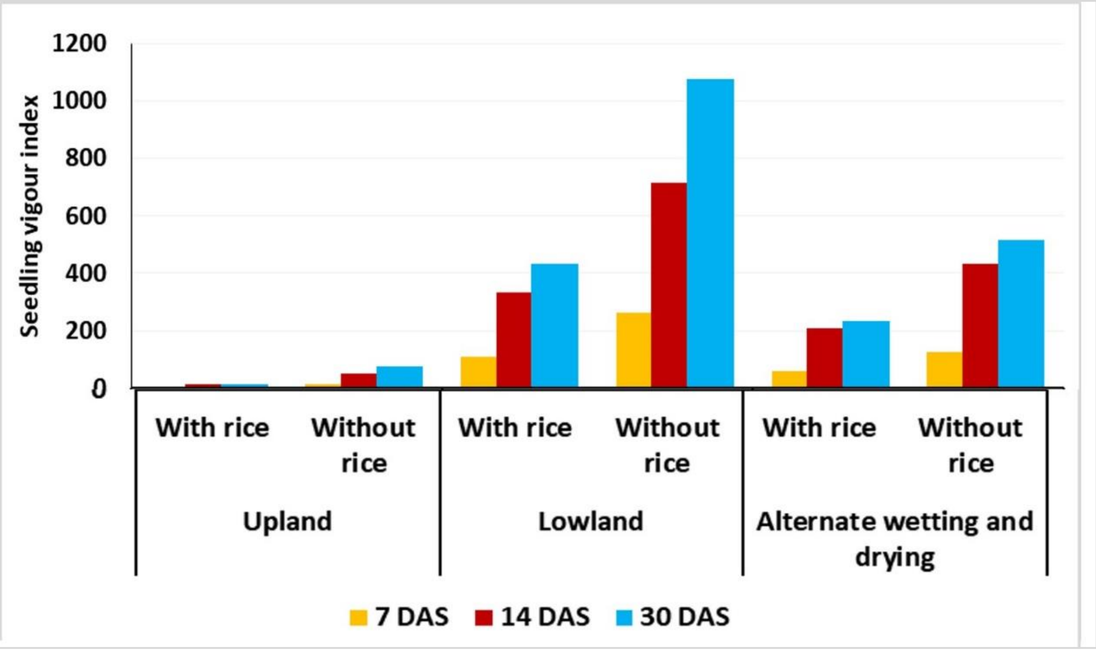


Figure 12. Effect of soil moisture status on seedling vigour index of *S. interrupta*

Non-scarified fresh and old seeds of *S. interrupta* failed to germinate in initial three months *i.e.*, from January to March, as well as in the last four months *i.e.*, September to December. Germination improved from the 3rd week of April onwards in fresh seeds and from 1st week of May in case of old seeds. Germination percentage and seedling vigour index was highest in the 3rd and 4th weeks of June for both fresh and old seeds (92% and 80% respectively) (Figure 13 and 14; Table 20).

Fresh seeds showed a higher rate of germination compared to old seeds, in the months when germination occurred, probably due to the non-dormancy of freshly harvested seeds compared to old seeds. Similar results were confined in nine different *Rumex* species by vanAssche *et al*. (2002). Abraham and Abraham (2005) studied the seasonal variations in *Mikania* species and found that peak period of germination was during May to June *i.e.*, on first receipt of rains. Fresh seeds had higher germination rate.

Emergence of *S. interrupta* decreased as the depth of seed placement in soil increased which is quite remarkable as the seed of many species when placed on surface had little or no emergence (Singh *et al*., 2007b). Per cent of seedling emergence decreased drastically beyond the placement depth of 5 cm and it was only 12% at placement depth of 5 cm. About 72% of seeds germinated when seeds were placed at the surface (0 cm) and it was 44% at 2 cm depth by end of 4 weeks after sowing (Figure 15 and 16; Table 24). It was thus clear that *S. interrupta* emerged mostly from shallow depths of the soil and seeds located deep in the soil beyond 5cm, had less chance of emergence.

These findings were confirmed by Benvenuti *et al*. (2004) who reported a progressive decline in seedling emergence of grass weeds like *Leptochloa chinensis* with increasing depth of seeding. Tillage, has a profound influence on the emergence of *S. interrupta*, when new lots of buried seed are brought to the surface, coinciding with the receipt of rains and development of submerged conditions which favours germination.

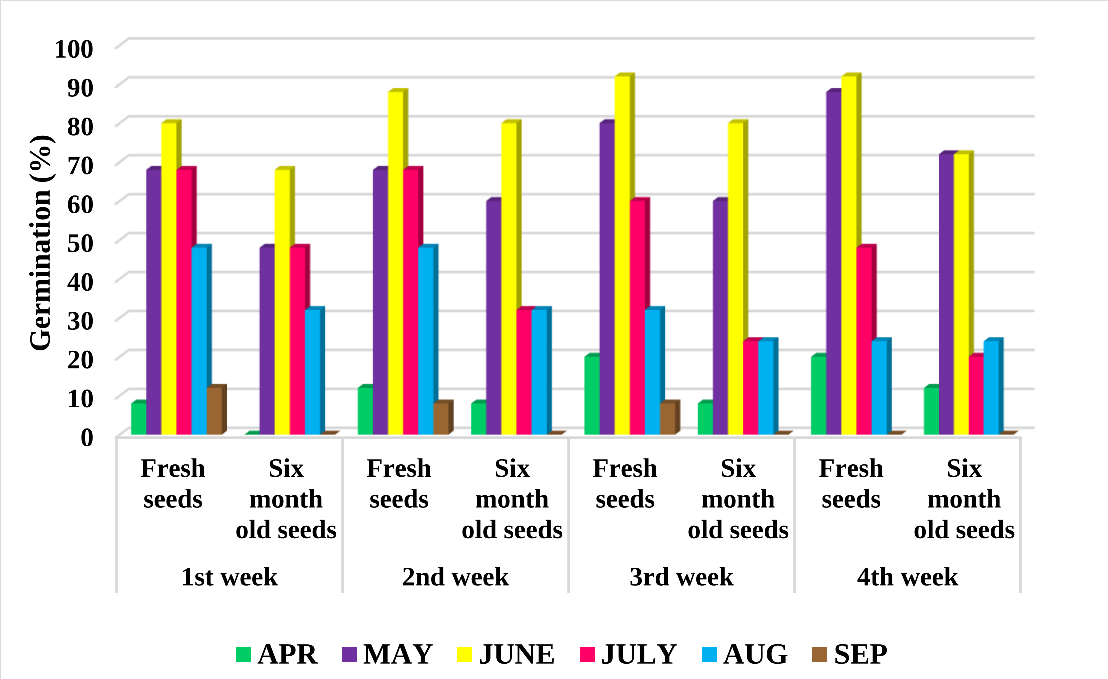


Figure 13. Seasonal variations in germination (%) of *S. interrupta*

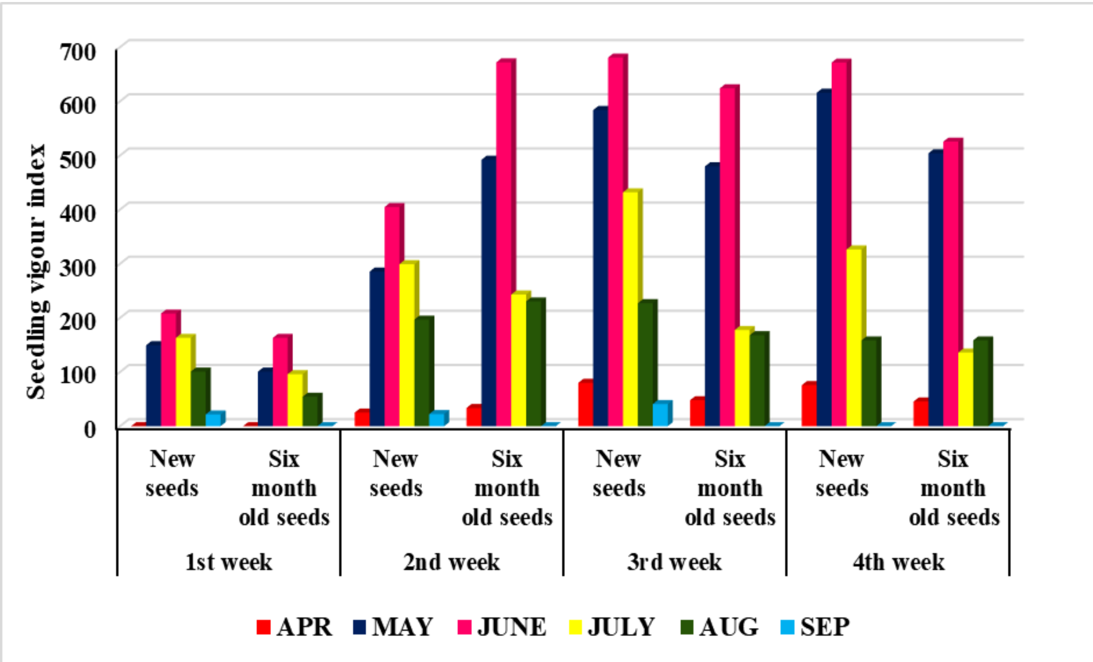


Figure 14. Seasonal variations on seedling vigour index of *S. interrupta*

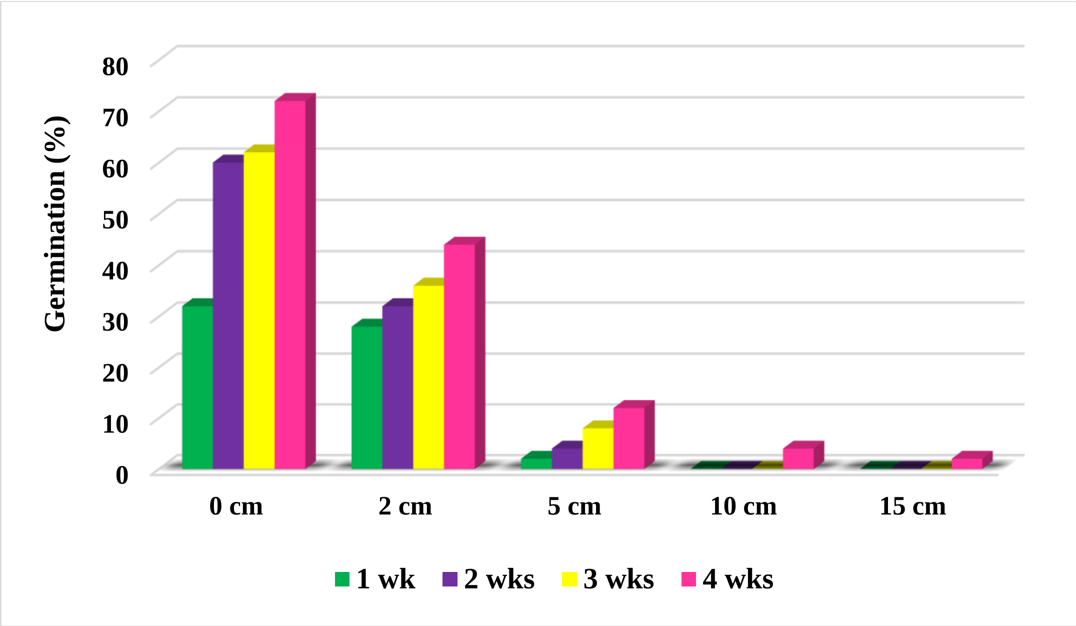


Figure 15. Effect of depth of burial on germination (%) of *S. interrupta*

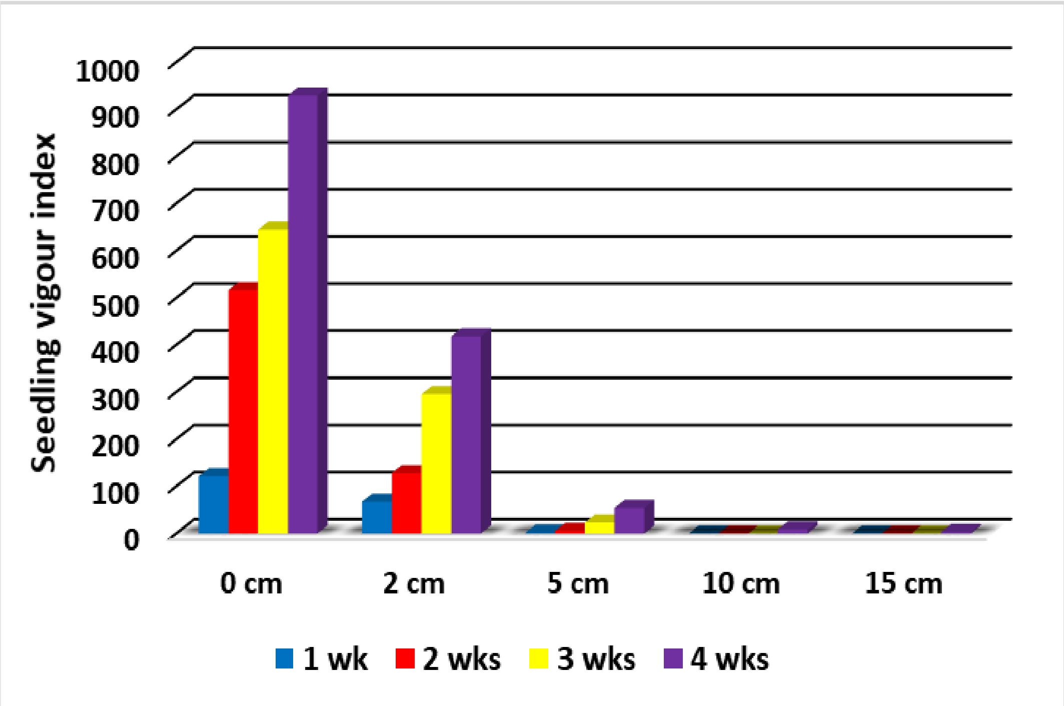


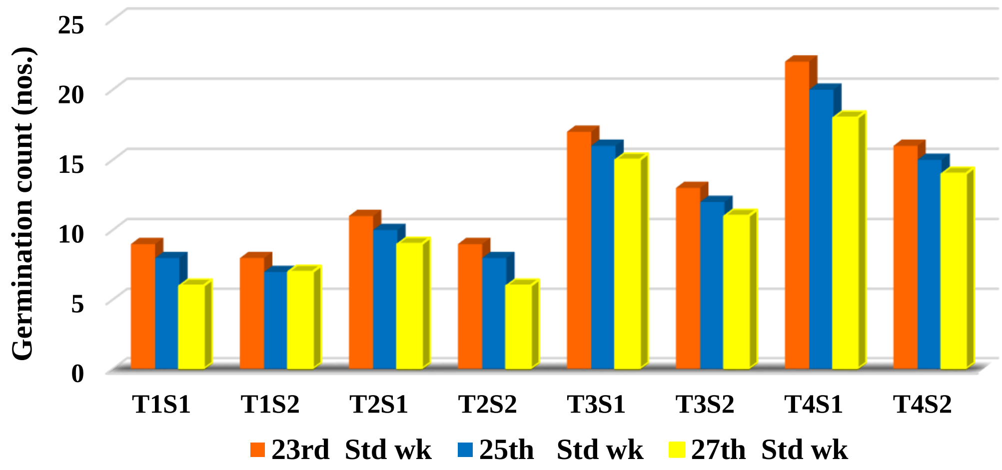
Figure 16. Effect of depth of burial on seedling vigour index of *S. interrupta*

Weed seed persistence in the soil is a common trait. Seeds of many weed species can remain viable in the soil for longer than 10 years (Burnside, 1996). Seed longevity is the prime contributor for weed seed persistence. Germination percentage of *S. interrupta* seeds was highest in the month of June (23^{rd} to 25^{th} standard week) compared to other months, when tested for seed longevity.

Davis *et al.* (2005) reported that environmental factors like seed depth placement, tillage and abiotic environmental factors affect seed persistence. Tillage systems influence vertical weed seed distribution in the soil profile, and this differential distribution could affect weed seedling emergence (Chauhan *et al*., 2006). Seed longevity studies showed that shallow burial depth had a higher rate of viability loss than burial at deeper depth. *S. interrupta* had highest germination in the month of June irrespective of the depth of burial.

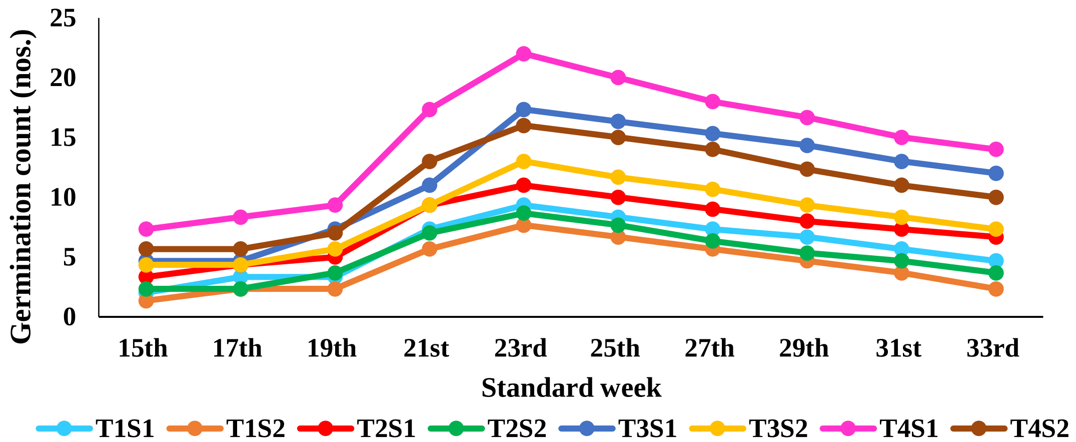
Rate of germination of *S. interrupta* increased when placed along with rice seeds into the soil and this could be correlated with the findings of Takeuchi *et al*. (2001) who reported that germination of submerged *Monochoria* seeds was accelerated by the presence of rice seeds, and rice seeds play a critical role in promoting germination of *Monochoria* species (Xuan *et al*., 2016). Burial of *S. interrupta* at 8cm depth along with rice seeds had highest germination rate in 23^{rd} standard week (Figure 17 and Table 25) and this was in line with findings of Harrison *et al*. (2003) who reported that weed seed persistence in the soil seed bank was proportional to its burial depth.

The germination in *S. interrupta* increased from 15^{th} standard week *i.e*., 1^{st} week of May, and was highest during 23^{rd} standard week *i.e*., June, and started to decline from there and reached zero by end of 33^{rd} standard week *i.e*., 4th week of August (Figure 18). Abeyesekara *et al*. (2010), from seed burial studies conducted at Sri Lanka, found that germination of seeds buried at 20 cm depth was 68% four weeks after burial and decreased to 33% at 80 weeks after burial.



T_1S_1- *Sacciolepis* with rice seeds at 0 cm depth, T_1S_2- *Sacciolepis* alone at 0 cm depth, T_2S_1- *Sacciolepis* with rice seeds at 2 cm depth, T_2S_2- *Sacciolepis* alone at 2 cm depth, T_3S_1- *Sacciolepis* with rice seeds at 4 cm depth, T_3S_2- *Sacciolepis* alone at 4 cm depth, T_4S_1- *Sacciolepis* with rice seeds at 8 cm depth, T_4S_2- *Sacciolepis* alone at 8 cm depth

Figure 17. Effect of seed longevity with and without rice seeds on germination of *S. interrupta*



T_1S_1- *Sacciolepis* with rice seeds at 0 cm depth, T_1S_2- *Sacciolepis* alone at 0 cm depth, T_2S_1- *Sacciolepis* with rice seeds at 2 cm depth, T_2S_2- *Sacciolepis* alone at 2 cm depth, T_3S_1- *Sacciolepis* with rice seeds at 4 cm depth, T_3S_2- *Sacciolepis* alone at 4 cm depth, T_4S_1- *Sacciolepis* with rice seeds at 8 cm depth, T_4S_2- *Sacciolepis* alone at 8 cm depth

Figure 18. Effect of depth of seed burial in soil with and without rice seeds on germination of *S. interrupta*

5.3. Management of *S. interrupta* in rice

Field experiments were conducted at a farmers' field in Chithali, in Palakkad district to study the efficacy of different pre-emergence, post-emergence herbicides in separate experiments for two years (2017 and 2019), and a third experiment was conducted in 2019, integrating the best of pre and post-emergence treatments. The results obtained from the experiments, reported in the previous chapter, are discussed below based on available literature.

5.3.1. Management through pre-emergence herbicides

1.1 **Studies on weeds**

A) Weed flora and density

Weed flora in the experimental area during 2017 and 2019 comprised of mainly *S. interrupta*, *Oryza sativa* f. *spontanea*, *Leptochloa chinensis* and *Echinochloa crus-galli* among grasses. The sedge present in 2017 was *Fimbristylis miliacea* and *Cyperus iria* in 2019. The main broad leaved weeds (BLWs) were *Cyanotis axillaris* and *Commelina diffusa* in both the years.

Among them, *S. interrupta* was found to be dominant one at 30 DAS, 60 DAS and at harvest in both the years. Hand weeded (T_6) followed by stale seed bed (T_5) plots had lowest population of *S. interrupta*, and unweeded control (T_7) recorded the highest population (Figure 19 and 20). The density of *S. interrupta* in unweeded control in both years is represented in Figures 21 and 22 (Tables 28 and 29). Verma *et al*. (2004) also reported that in direct seeded rice *Echinochloa crus-galli*, *Echinochloa colona*, *Eleusine indica*, *S. interrupta*, *Eclipta alba*, *Ludwigia parviflora*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliace*a are the major weed species.

A critical analysis of relative proportion of grasses, sedges and BLWs to total weed population in unweeded control revealed that during all the stages of rice crop, the population of grasses was higher than that of sedges and BLWs in both the years. The higher proportion of grasses compared to sedges and BLWs in rice in dry seeded

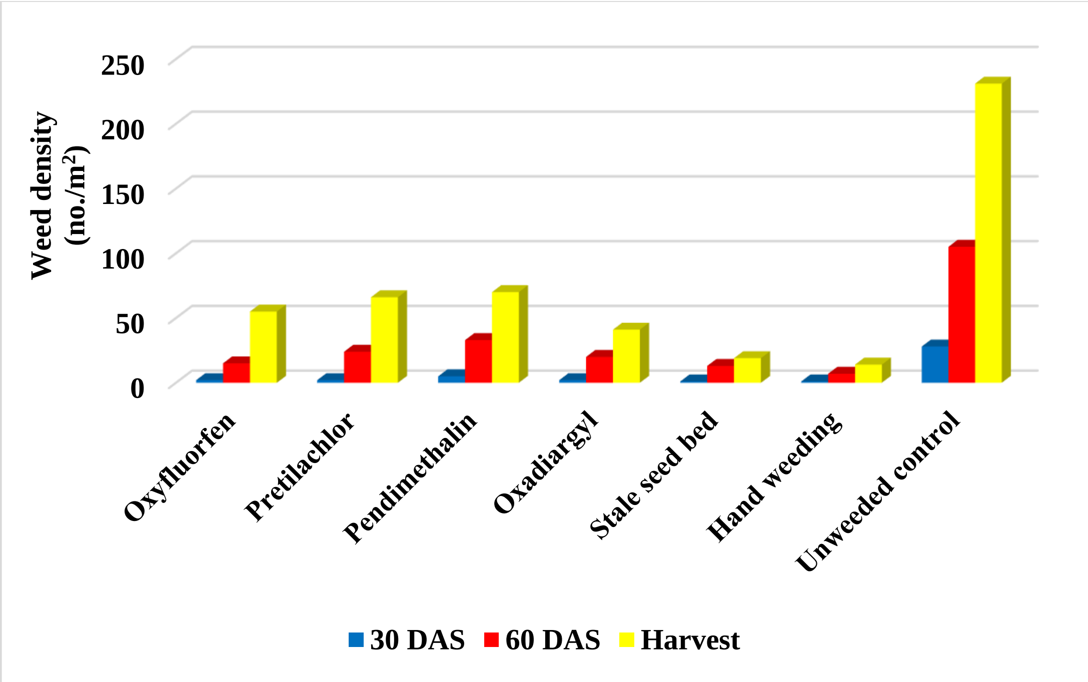


Figure 19. Effect of pre-emergence herbicides on *Sacciolepis* density (no./ m^2) in 2017

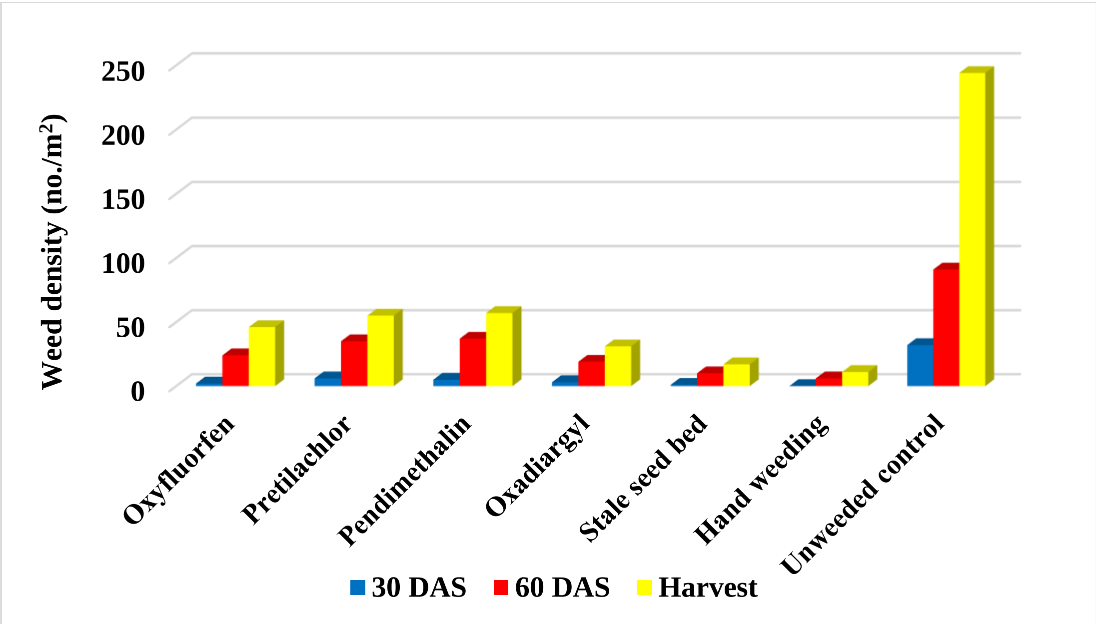


Figure 20. Effect of pre-emergence herbicides on *Sacciolepis* density (no./ m^2) in 2019

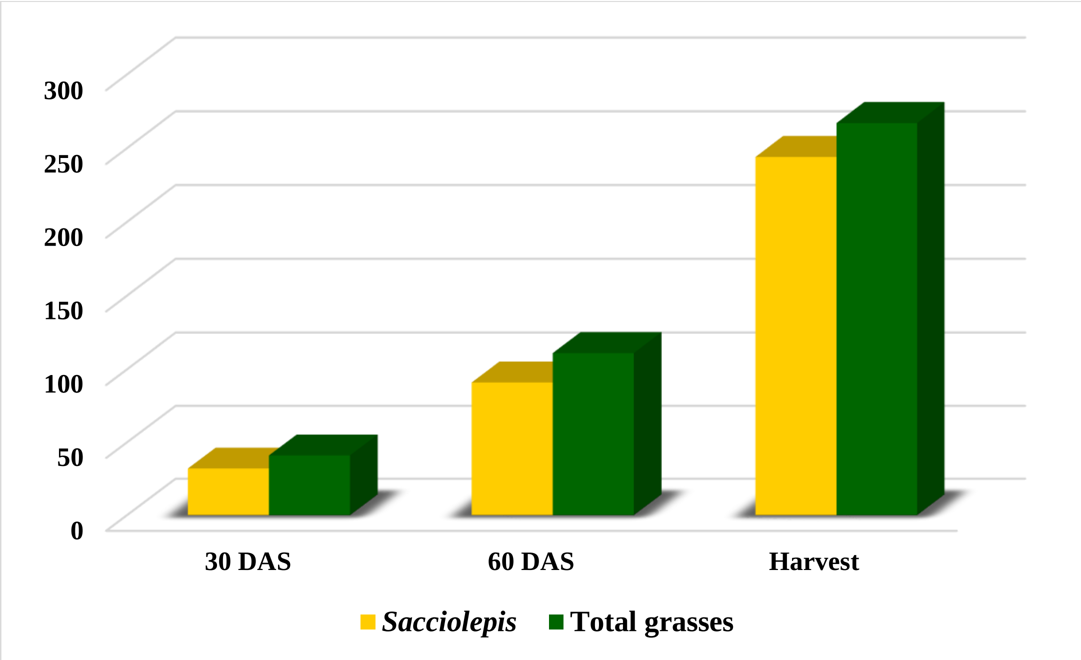


Figure 21. Density of *S. interrupta* (no./m^2) at various stages of crop in unweeded control in 2017

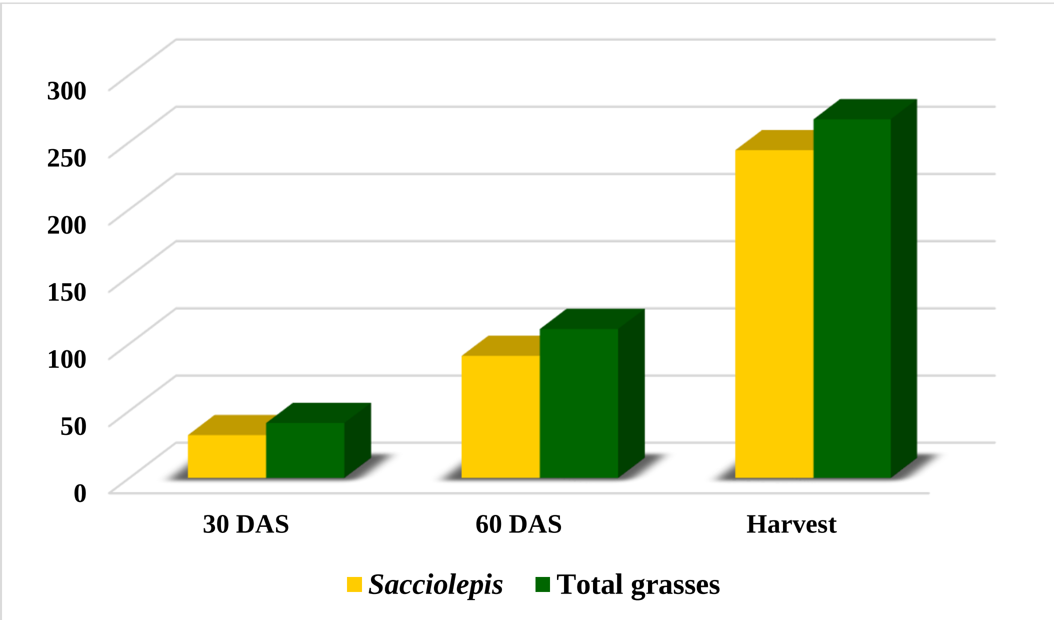


Figure 22. Density of *S. interrupta* (no./ m^2) at various stages of crop in unweeded control in 2019

rice was also reported by Rao *et al*. (2008) and Singh *et al*. (2013). Among grasses, *S. interrupta* was predominant**.** The population of sedges was low, while population of BLWs was higher in second year than first year, with *Cyanotis axillaris* as the dominant BLW. Similar results were also reported by Mishra and Singh (2008). Unweeded control had highest density of grasses, sedges and BLWs at all three stages of crop.

B) Effect of various treatments on weed parameters

Effect of pre-emergence herbicides lasted only for 15-20 DAS and weed density was lower initially but due to deficit rainfall and increased temperatures during the initial phase of crop period, a favorable microclimate for germination of weeds, especially *S. interrupta*, was created due to higher seed bank in the experimental field. Matloob *et al.* (2015) also reported that changing climatic scenario *i.e.*, increasing temperatures and variations in rainfall pattern, led to change the weed population dynamics.

Among different treatments, the highest total weed densities, weed density of grasses, sedges and BLWs and weed dry weights at 30 DAS, 60 DAS and at harvest were in unweeded control (T_7). The weed density and weed dry weight increased linearly from 30 DAS to harvest due to the progressive growth of weeds, as well as continued germination and growth of weeds, particularly of *S. interrupta*, which recorded highest population at all stages (Figures 23 and 24; Tables 30, 31 and 32).

The lowest values for weed densities and dry weights were recorded in hand weeded plot (T_6), which corroborates the findings of Maity and Mukherjee (2011) observed that hand weeding at critical growth stages of crop resulted in lower weed index and weed dry weight. Hand weeding decreased the density of weeds by 90 % especially that of grasses was reported by Mubeen *et al*. (2014), whereas the effect on hand weeding treatment was not so prominent with respect to sedges and BLWs in the experiment field and all treatments were on par.

Stale seedbed (T_6) continued to be the next best treatment with respect to weed density and weed dry weight among the different pre-emergence treatments,

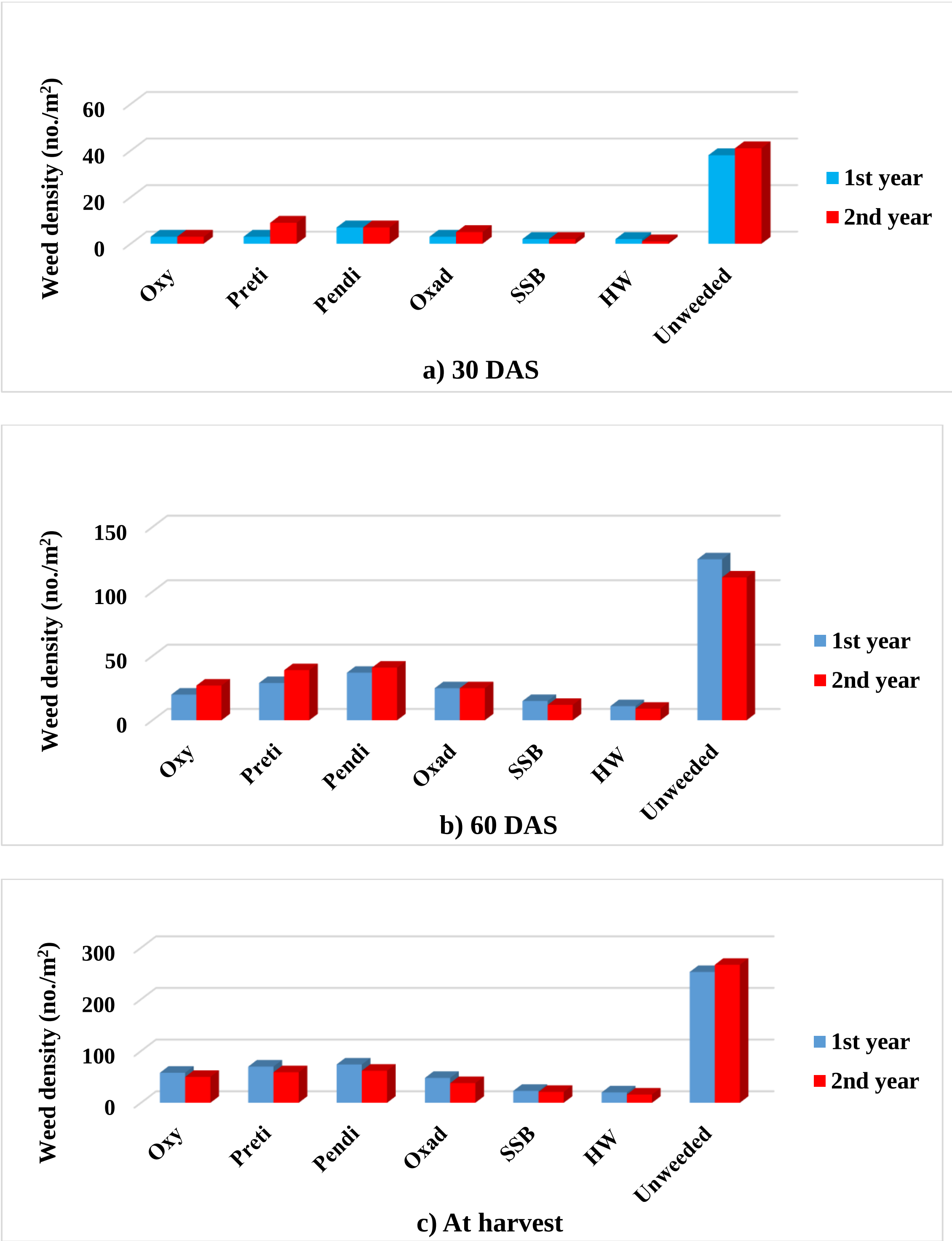


Figure 23. Effect of pre-emergence herbicides on grasses density (no./m^2) at various stages of the crop

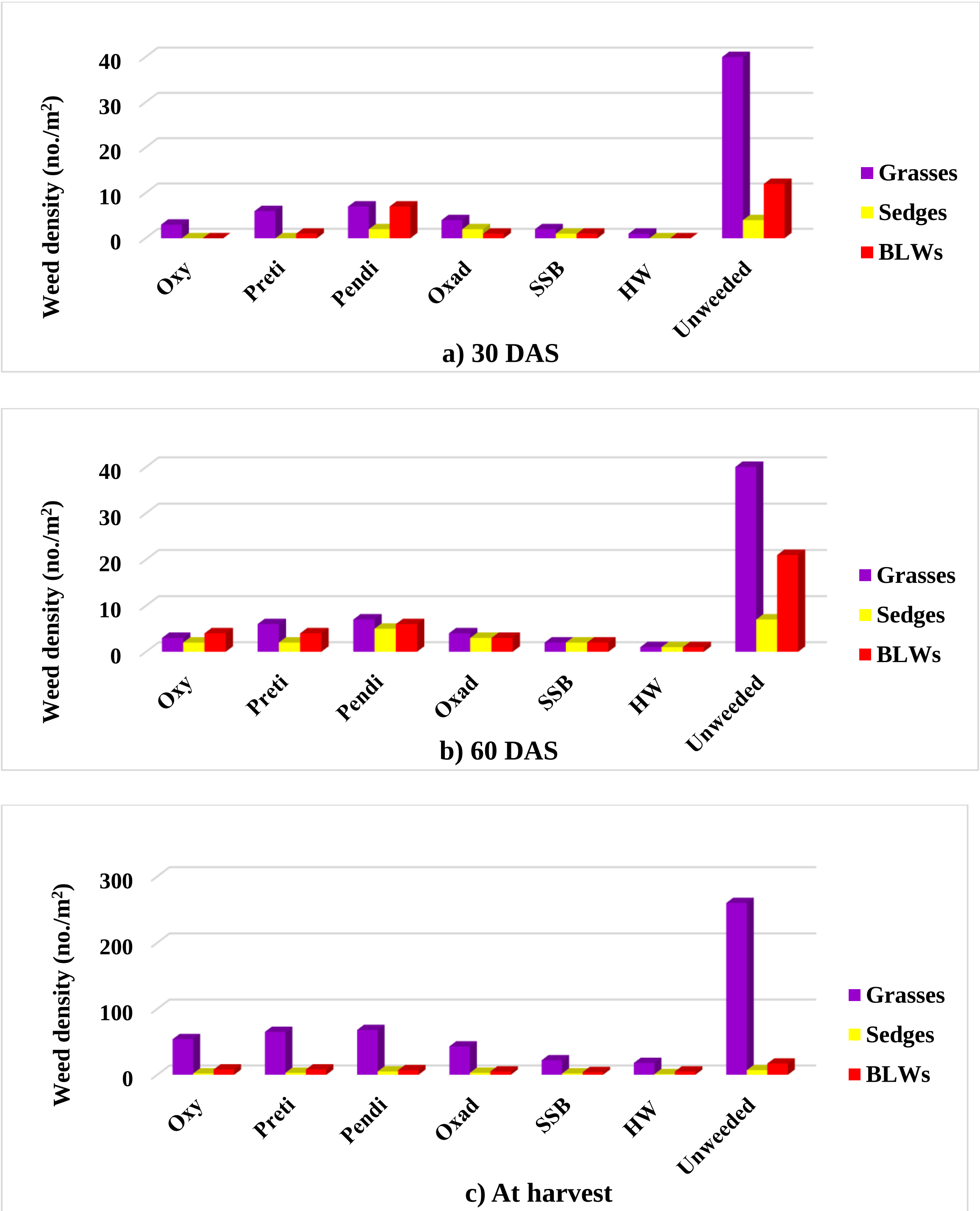


Figure 24. Effect of pre-emergence herbicides on weed density (no./m^2) at various stages of the crop

probably due to flushing out of germinated weed seeds before sowing of the crop, and thereby leading to reduction in subsequent weed seedling emergence and efficient control of *S. interrupta*. This was in line with the findings of Renu *et al*. (2006) who reported that stale seed bed was a cultural- preventive technique for control of *S. interrupta* in dry seeded rice. Jordon and Bollich (2002) also reported that stale seedbed efficiently depleted the soil seed bank.

Among the herbicide treatments, at 30 DAS, oxyfluorfen recorded lowest total weed density, density of grasses and weed dry weight, whereas at 60 DAS and at harvest oxadiargyl and oxyfluorfen were on par. Oxyfluorfen and oxadiargyl had the same mode of action, *i.e.*, inhibition of protoporphyrinogen oxidase (Photosynthesis II inhibitors) leading to necrosis which might have been the reason for efficient control of *S. interrupta* in these treatments. Rao *et al*. (2007) and Abraham *et al*. (2010) observed that oxyfluorfen efficiently controlled grasses, sedges and BLWs up to 45 DAS, resulting in lower weed density. Sharma *et al*. (2004) indicated that oxadiargyl was very efficient in controlling weed population especially of grasses. Pre-emergence application of oxadiargyl reduced density and dry weight of weeds as reported by Jadhav *et al*. (2009) and Yadav *et al*. (2009).

Pretilachlor and pendimethalin were not so effective in controlling grasses which is evident from the higher weed density and weed dry weight at all stages of crop. Reduction in cell division and cell elongation caused by these two herbicides was not sufficient in reducing the weed density especially that of *S. interrupta.* This was in line with findings of Chauhan *et al*. (2015) who reported that pretilachlor at lower doses was inefficient in controlling the weed population, especially of a few grasses and BLWs.

Ahmed and Chauhan (2014) observed that pendimethalin alone could not reduce the weed density in boro-summer rice. Pre-emergence application of pendimethalin reduced the weed density especially of grasses only up to 20 DAS, and further it was ineffective (Nayak *et al*., 2014). This might be reason for these treatments recording highest number of weeds and dry weights after unweeded control (Figure 25; Table 33).

Highest N, P and K removal was noticed in unweeded control irrespective of stage of crop growth due to high weed dry matter production. The uptake was 14.26 kg N/ha, 2.40 kg P/ha and 13.86 kg K/ha in unweeded plot at 60 DAS whereas in hand weeded plots, the corresponding values were 0.38 kg N/ha, 0.05 kg P/ha and 0.49 kg K/ha. This was in line with the findings of Maity and Mukherjee (2011) who reported removal of 34.4 kg N/ha, 7.4 kg P/ha and 37.8 kg K/ha in complete weedy situation. However, actual removal of nutrients by weeds in hand weeded control plots would have been still higher than this, if the nutrient removal by the weeds pulled out from hand weeded control had been accounted (Figure 26; Table 34). Both at 30 and 60 DAS, lowest removal of major nutrients N, P and K was observed in hand weeding treatment (T_6), followed by stale seed bed (T_5). Among herbicide treatments, oxyfluorfen had lowest values for nutrient removal by weeds, except in the case of K at 60 DAS, where oxadiargyl treated plots registered lowest removal values.

1.2 **Studies on crop**

A) Plant growth parameters

Among various treatments, tallest plants with 40.68 cm height at 30 DAS was recorded in stale seedbed, which might have been due to less weed competition and more space available from early growth phase**.**

There was slight reduction in height of rice plants in pretilachlor sprayed plots compared to hand weeded plot, though no visual phytotoxicity symptoms were not expressed. It could be due to action of this herbicide on plant physiological activities, inhibiting cell elongation leading to reduction in height (Table 36). Reetu *et al*. (2014) reported that application of pretilachlor led to reduction in plant height, fresh and dry weight of rice. However, as the plant growth advanced, the tallest plants were observed in hand weeded plot followed by stale seedbed and all other treatments were on par except for unweeded control. The lowest plant height of 31.06 and 48.63 cm was registered on unweeded control at 60 DAS and harvest

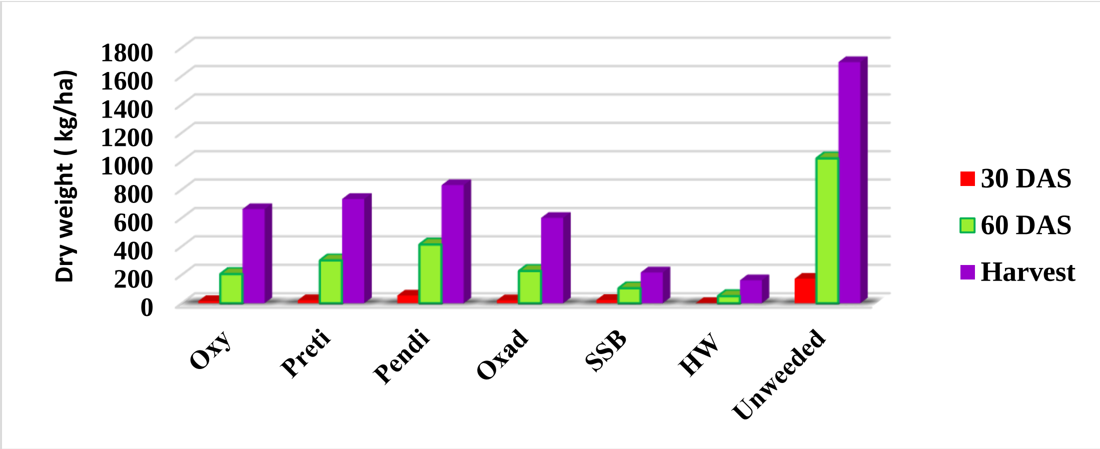


Figure 25. Effect of pre-emergence herbicides on weed dry weight (kg/ha)

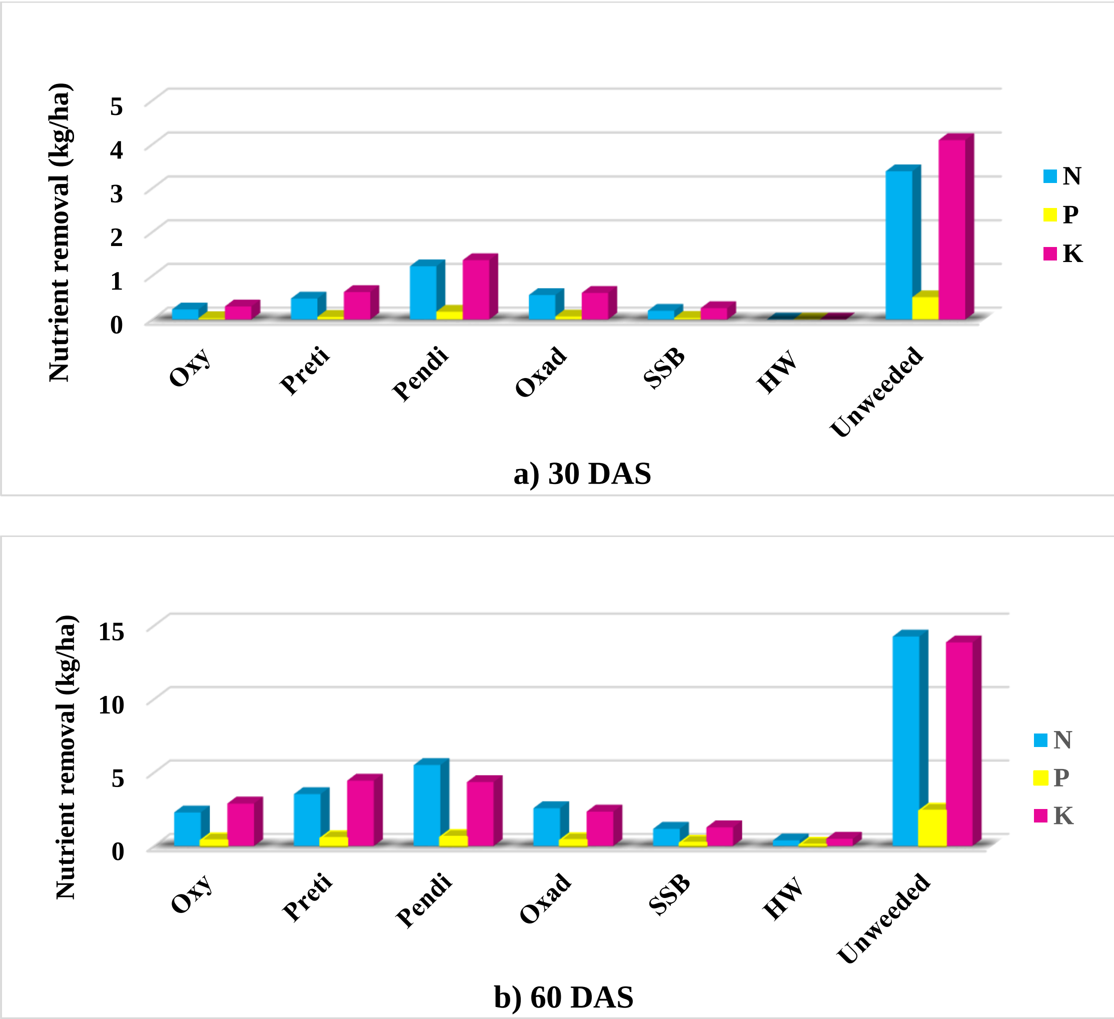


Figure 26. Effect of pre-emergence herbicides on nutrient removal by weeds (kg/ha) at 30 and 60 DAS

respectively. This could be due to effect of *S. interrupta* population on rice plants, with severe weed competition leading to reduced height of rice plants.

At 30 DAS and 60 DAS hand weeding registered greatest number of tillers/m^2 (Table 37). Similar results were also reported by Lakshmi *et al*. (2006). Tiller count decreased by 72 % in unweeded control compared to hand weeding at 60 DAS, which was due to severe competition from the weed *S. interrupta*. At this stage hand weeding twice was statistically superior to all other treatments followed by stale seedbed and oxadiargyl treatments which were on par with each other. From the tiller count, it could be inferred that though hand weeding was costly and laborious, it gave complete control of weeds, especially grassy weeds, and rice plants gained some advantage over those treated with herbicide.

B) Yield and yield attributes

Highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding (T_6) (Table 38). Except for 1000 grain weight, hand weeding was statistically superior to all other treatments in case of yield and yield attributes. Several authors like Subhalakshmi and Venkataramana (2009), Hasanuzzamam *et al*. (2009) and Maity and Mukerjee (2011) reported an increase in yield and yield attributes due to hand weeding. A reduction to the tune of 72 % was observed in tiller count/m^2 at 60 DAS in unweeded control as compared to hand weeding treatment which affected the number of productive tillers. Weed competition led to reduction in number of panicles/m^2 and filled grains/panicle to the extent of 78.00 % and 65.00 % respectively as compared to hand weeding. There was no significant difference among the treatments for filled grains/panicle except for unweeded control, which had lowest values.

The highest grain yield of 4172 kg/ha with WCE of 90.00 %, and 3744 kg/ha with WCE of 86.00 % were recorded in hand weeded control and stale seedbed plot respectively during 1st year. In 2nd year it was significantly higher in the hand weeded treatment with grain yield of 4743 kg/ha with WCE of 91 %, followed by stale seedbed with grain yield of 3893 kg/ha with WCE of 88 % (Figures 27 and 28; Table

39). Maity and Mukherjee (2011) also reported that hand weeding resulted in higher WCE (97.07 %) and hence higher grain yield. Verma *et al*. (2004) reported a WCE of 90.60 % by hand weeding in DSR and thereby, a higher grain yield of 3.6 t/ha.

Stale seedbed was the next best treatment after hand weeding. Similar results were also reported by Marahatta *et al*. (2017). Pandey *et al*. (2009) observed that stale seedbed resulted in higher WCE and thereby high grain yield.

It could be seen from the pooled data that a WCE of 60.00 % was achieved by application of oxadiargyl and oxyfluorfen. Yadav *et al*. (2009) and Kiran and Subramanyam (2010) reported that oxadiargyl application resulted in highest number of filled grains/panicle and yield of rice which were on par with hand weeding twice at 20 and 40 DAS. Reshma (2014) and Priya *et al.* (2017) also reported a WCE of 89.00 to 92.00 % by application of oxyfluorfen. However, in the present study control of *S. interrupta* was not achieved by these two herbicides probably because of high density and larger seed bank of *S. interrupta* in the experimental plots. There was complete `canopy coverage by *S. interrupta* which competed with the crop for growth factors and hence adversely affected the yield. This is evident from the weed dry matter production of 1698 kg/ha in unweeded plot at harvest.

It could be seen that yield reduction due to weed competition was 38 % and 61 % during 1st and 2nd year respectively in case of the treatment pretilachlor, in which weed dry matter production was 778 kg/ha in 1st year and 689.7 kg/ha in 2nd year. In case of pendimethalin treatment it was 60 % and 62 % during 1st and 2nd year respectively with higher weed dry matter production of 1031.7 kg/ha in 1st year and 631.3 kg/ha in 2nd year.

In unweeded control grain and straw yield reduction was to the tune 78% and 68% respectively. The WI of 70.00 % and 86.00 % during 1st and 2nd year respectively in unweeded control was statistically superior among the treatments (Table 42). The weed population, made up mostly of *S. interrupta*, produced dry matter of 1587 kg/ha and 1646 kg/ha in 1st and 2nd year respectively which imparted serve competitive effect on rice plants and affected yield parameters and rice yield (Figure 29).

From the results it could be inferred that instead of going for hand weeding twice, ploughing the land two weeks before sowing and destroying germinated weeds either by ploughing or by applying herbicide, reduced the weed seed bank and thereby reduced weed density, resulting in satisfactory yields. It was also clear that application of oxadiargyl or oxyfluorfen was more advisable than application of pretilachlor or pendimethalin for control of *S. interrupta*, as both the former registered statistically comparable yields. However, between the two, pretilachlor was more effective in controlling weed with a yield advantage of 501 kg/ha over pendimethalin. In the situation where population of grasses especially *S. interrupta* density is high, going for either cultural method *i.e.,* adopting stale seedbed or pre-emergence application of herbicides inhibiting protoporphyrinogen oxidase mode of action *i.e.* oxadiargyl or oxyfluorfen is advisable than laborious hand weeding.

Straw yield also followed the same trend like grain yield. During 1st year hand weeding and stale seedbed treatments resulted in higher straw yield followed by oxyfluorfen and oxadiargyl which were on par with each other.

In the 2nd year hand weeding was superior followed by stale seedbed treatment. Oxyfluorfen and oxadiargyl were on par with each other. The plants in hand weeded plots were superior to other treatments in terms of growth and yield parameters, which resulted in highest grain and straw yield with WCE of 90%.

Harvest index ranged from 0.35 to 0.44, the highest being in hand weeding and stale seedbed and the lowest in unweeded control. This was due to the fact that magnitude of reduction in grain yield due to weed competition was more compared to reduction in straw yield.

C) Nutrient uptake by rice at 60 DAS

The uptake of N, P and K by rice is a function of straw yield, grain yield and their nutrient content. The highest N, P and K uptake was in hand weeded treatment (37.89 kg/ha, 6.20 kg/ha and 52.80 kg/ha). The favourable growth conditions due to

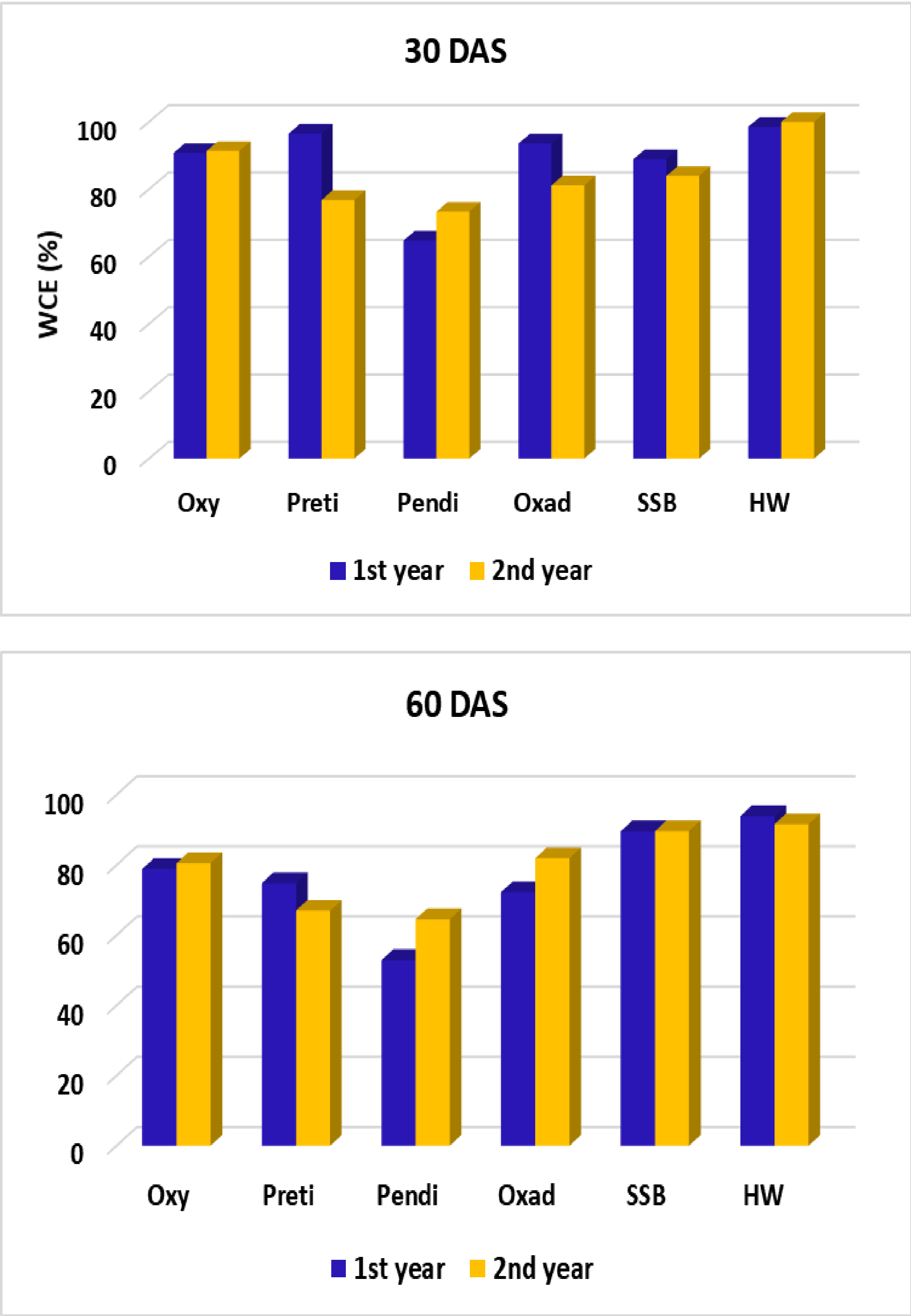


Figure 27. Effect of pre-emergence herbicides on weed control efficiency (WCE) (%) in different years at 30 and 60 DAS

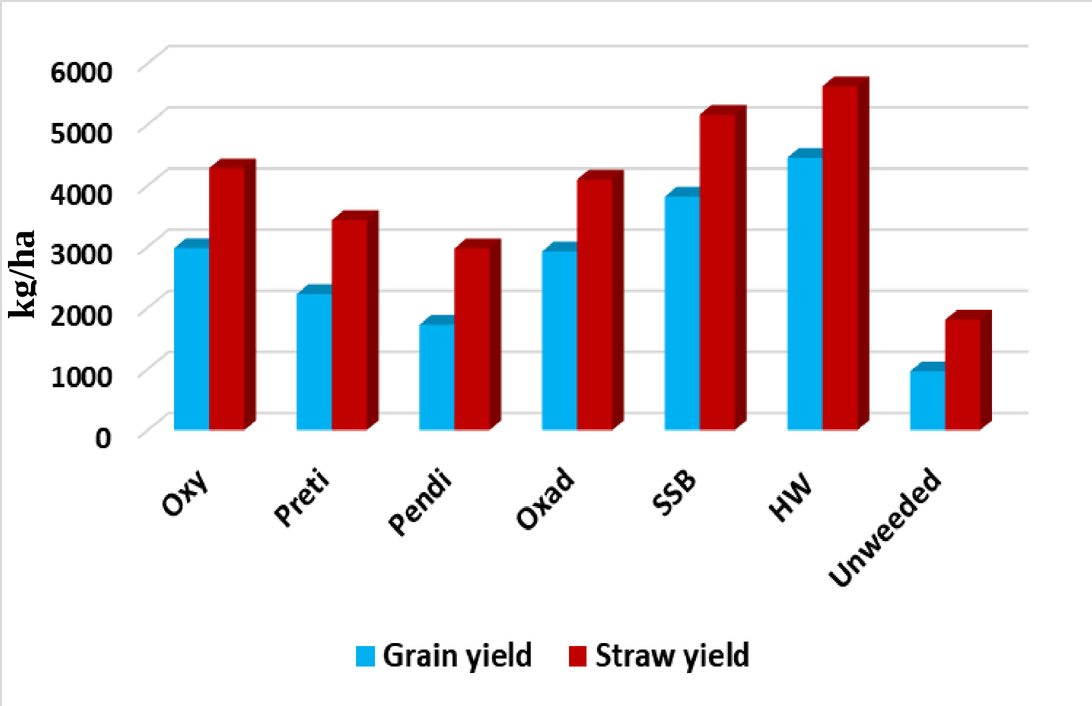


Figure 28. Effect of pre-emergence herbicides on grain and straw yield of direct seeded rice (kg/ha)

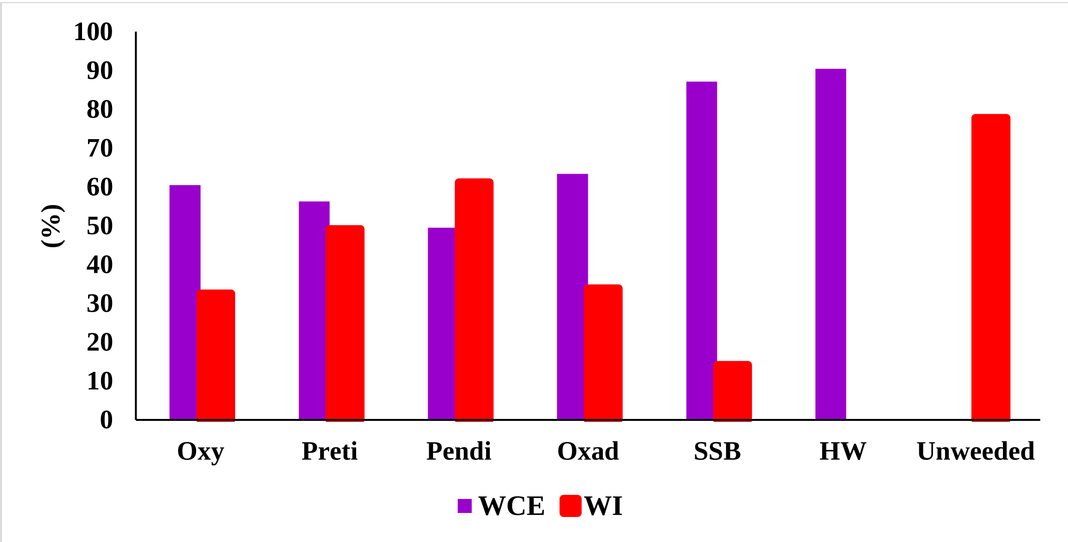


Figure 29. Effect of pre-emergence herbicides on weed control efficiency (WCE) (%) and weed index (WI) in direct seeded rice

high WCE of 90% in hand weeded treatment resulted in better uptake of nutrients similar to the findings of Subhalakshmi and Venkataramana (2009). In the 2nd year, stale seedbed treatment followed by oxadiargyl treatments resulted in highest N and K uptake, and stale seedbed treatment followed by oxyfluorfen application resulted in second highest P uptake. In unweeded control the N, P and K uptake by rice was very low (4.27 kg/ha, 0.5 kg/ha and 5.0 kg/ha N, P and K respectively) and complemented by highest nutrient removal of 14.26 kg N /ha, 2.40 kg P /ha and 13.86 kg K /ha by weeds. In hand weeded plots the removal was to the tune of 0.38 kg N /ha, 0.08 kg P /ha and 0.49 kg K /ha. This huge removal of nutrients by weeds resulted in poor growth and dry matter production of rice in unweeded control.

D) Economics of weed control

The major advantage in going for herbicidal control of weeds is the reduction in the cost of cultivation. Working out economics of cultivation while using different herbicides or herbicide combinations is important so that a final recommendation considering cost involved as well as net returns can be formulated. An analysis of the economics of rice cultivation shows that for high returns (Rs. 67,581/ha and Rs. 73,355/ha) and B:C ratio of 1.9 and 2.0 by stale seedbed during first and second year respectively (Table 44). The treatments oxadiargyl and oxyfluorfen also gave a B:C ratio of 1.5 and 1.6 respectively and the grain yield of 2924 kg/ha obtained with oxadiargyl was statistically on par with oxyfluorfen (2979 kg/ha). Hence, it can be inferred that these three can be recommended for maximum net profit as well as B:C ratio. Stale seed bed alone or pre-emergence application of oxyfluorfen can be rated as best treatments especially in a situation where the weed *S. interrupta* is dominant. However, pre-emergence herbicides alone were inefficient in control of *Sacciolpeis interrupta* and their efficiency lasted only up to 30 DAS.

5.3.2. Management through post-emergence herbicides

1.1 Studies on weeds

A) Weed flora and density

Weed flora in the experimental area during 2017 and 2019 was comprised mainly of the grasses *S. interrupta*, *Oryza sativa* f. *spontanea*, *Leptochloa chinensis* and *Echinochloa crus-galli*. The sedges present were *Cyperus* spp and the main broad leaved weed (BLW) was *Cyanotis axillaris* in both the years.

Among them *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest in both the years. Hand weeding (T_7), fenoxaprop-p-ethyl (T_4) and cyhalofop-p-butyl (T_1) treatments resulted in lowest population of *S. interrupta* whereas unweeded control (T_8) recorded the highest population of *S. interrupta* (Figures 30 and 31; Tables 47 and 48). The density of *S. interrupta* in unweeded control is represented in Figures 32 and 33. In direct seeded rice *Echinochloa crus-galli*, *Echinochloa colona*, *Eleusine indica*, *S. interrupta*, *Eclipta alba*, *Ludwigia parviflora*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliace*a were the major weed species was reported by Verma *et al*. (2004).

A critical analysis of relative proportion of grasses, sedges and BLWs to total weed population in unweeded control revealed that during all the stages of rice crop, the population of grasses was higher than that of sedges and BLWs in both the years. Rao *et al*. (2008) and Singh *et al*. (2013) reported higher proportion of grasses compared to sedges and BLWs in rice in dry seeded rice. Among grasses, *S. interrupta* was the predominant one**.** The population of sedges was low, while population of BLWs was higher in second year than first year, with *Cyanotis axillaris* as the dominant weed. Similar results were also reported by Mishra and Singh (2008). Unweeded control had highest density of grasses, sedges and BLWs at all three stages of crop.

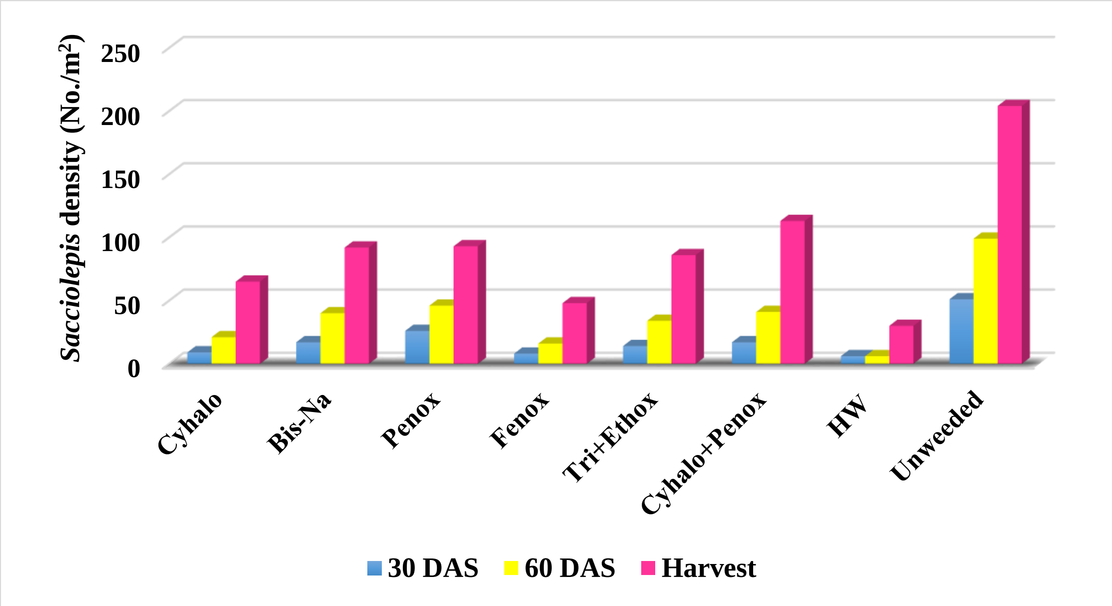


Figure 30. Effect of post-emergence herbicides on *Sacciolepis* density (no./ m^2) in direct seeded rice during 2017

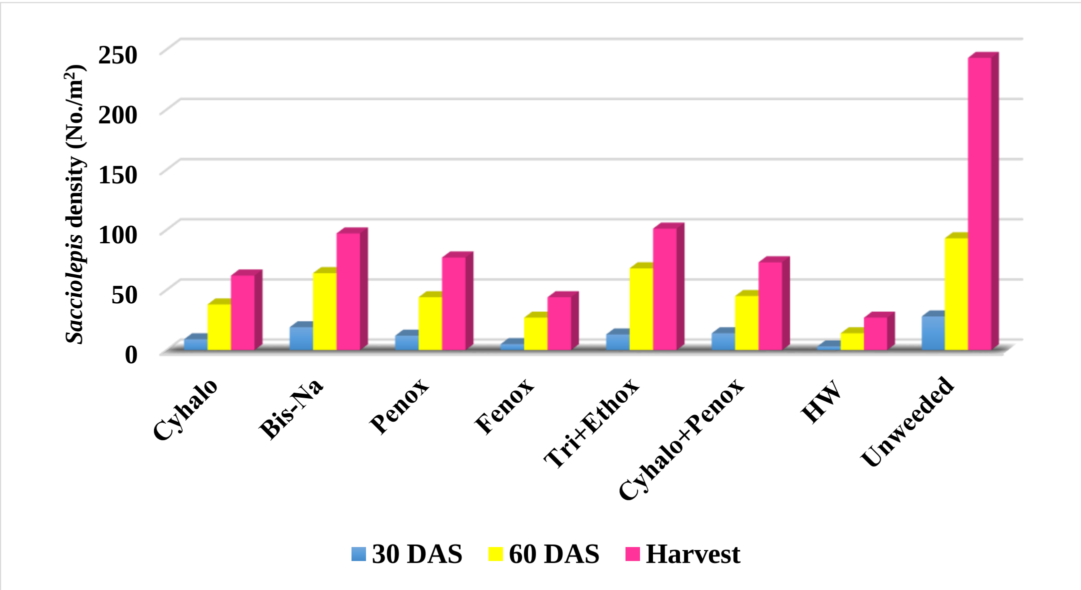


Figure 31. Effect of post-emergence herbicides on *Sacciolepis* density (no./ m^2) in direct seeded rice during 2019

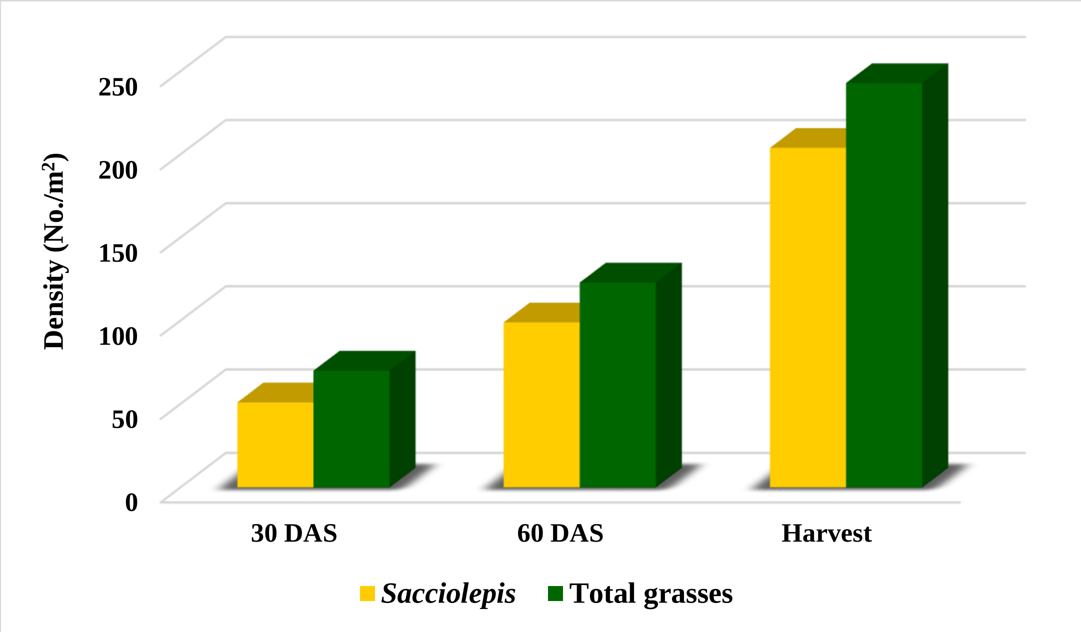


Figure 32. Density of *S. interrupta* (no./m^2) at various stages of crop in unweeded control in 2017

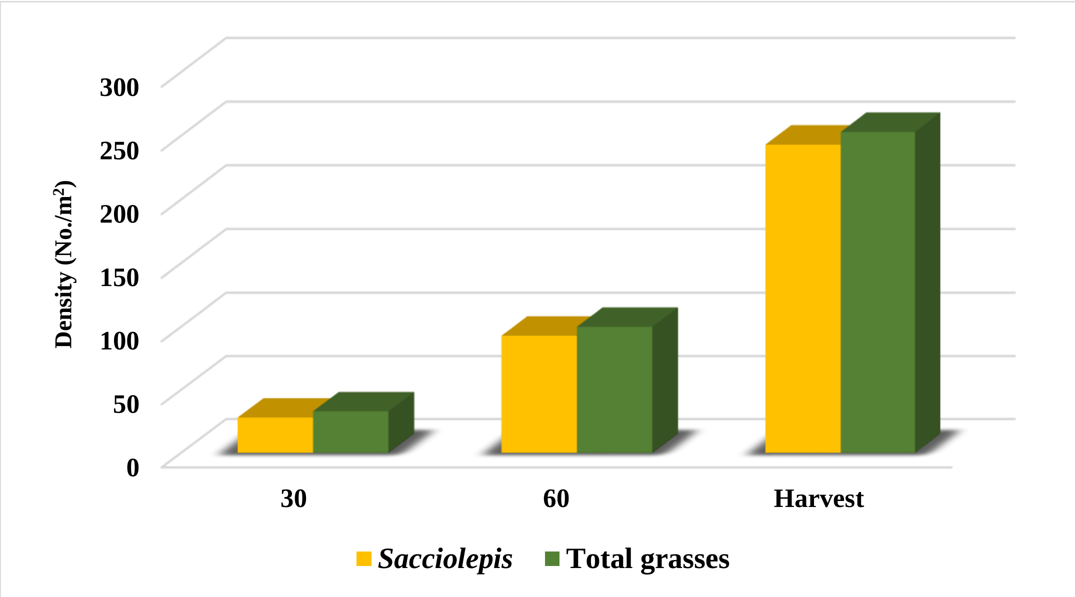


Figure 33. Density of *S. interrupta* (no./ m^2) at various stages of crop in unweeded control in 2019

B) Effect of various treatments on weed

Efficacy of post-emergence herbicides could be exploited fully if there was enough moisture in the field after herbicide application, but due to deficit rainfall and high temperature after herbicide application, regrowth of the weeds, especially of *S. interrupta*, due to higher seed bank in the experimental area, was clearly visible in weed data. Increasing temperatures and variations in rainfall pattern experienced during the past few decades could have led to change in the weed population dynamics (Matloob *et al*., 2015).

Among different treatments, the highest total weed density, weed density of grasses, sedges and BLWs and weed dry weight at 30 DAS, 60 DAS and at harvest was in unweeded control (T_8). The weed density and weed dry weight increased from 30 DAS to harvest linearly due to the progressive growth of weeds as well as continued germination and growth of weeds, mostly of *S. interrupta*, which recorded highest population at all stages (Figures 34 and 35; Tables 49, 50 and 51).

The lowest weed density was seen in hand weeded plot (T_7), which corroborated with the findings of Rekha *et al*. (2002). Maity and Mukherjee (2011) observed that hand weeding at critical growth stages of crop resulted in lower weed index and weed dry weight. The treatment effect was conspicuous and total weed population was very low in treated plots, compared to unweeded control. Hand weeding decreased the density of weeds by 90% especially that of grasses as reported by Mubeen *et al*. (2014), whereas the effect of hand weeding treatment was not so prominent with respect to sedges and BLWs and all treatments were on par except for unweeded control.

The next best treatment with respect to grass control was fenoxaprop-p-ethyl (T_4) which had lowest density and weed dry weight of grasses especially of *S. interrupta*, and thereby low total density. Fenoxaprop-p-ethyl is a new generation herbicide which inhibits acetyl co-enzyme A synthesis and is very effective against grasses. Singh *et al.* (2004) reported that fenoxaprop-p-ethyl effectively controlled grass species like *Echinochloa colona, Echinochloa crus-galli*, *Leptochloa chinensis*

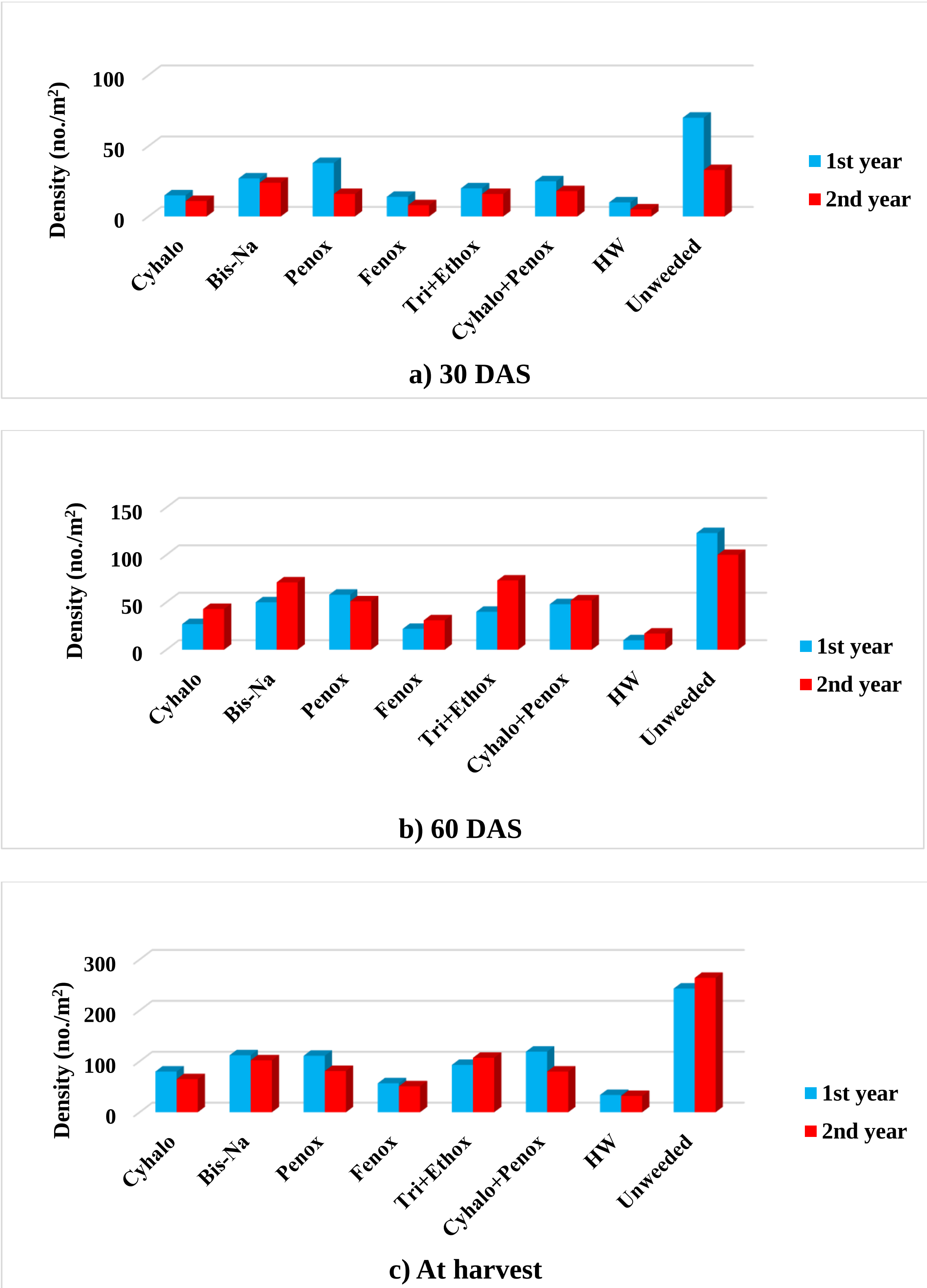


Figure 34. Effect of post-emergence herbicides on density of grasses (no./m^2) at various stages of the crop

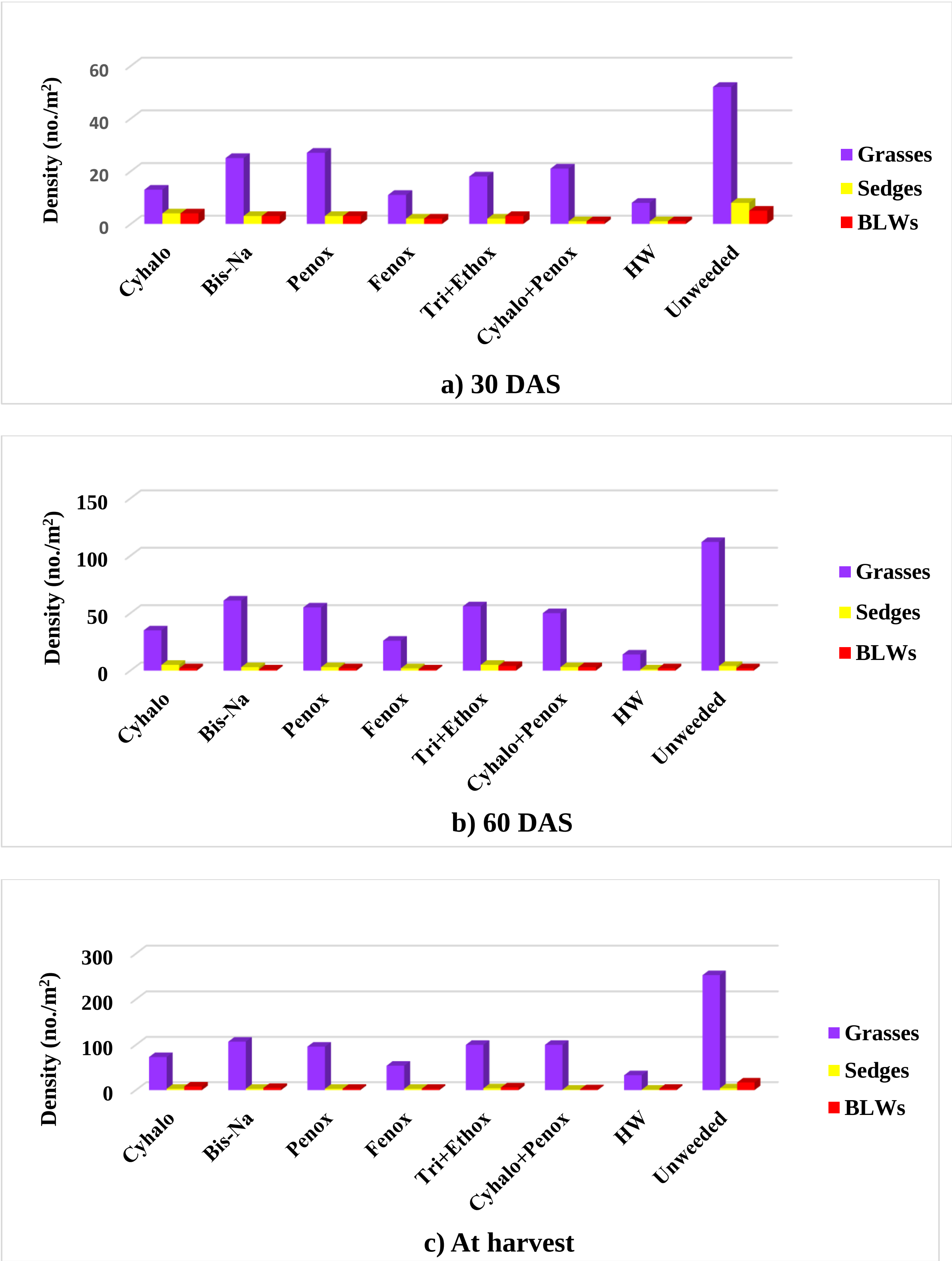


Figure 35. Effect of post-emergence herbicides on weed density (no./m^2) at various stages of the crop

and *Ischaemum rugosum.* The effectiveness of fenoxaprop-p-ethyl in decreasing the density and dry weight of grassy weeds was reported by Mallick *et al.* (2009).

Weeds, especially sedges and BLWs, were present in treatments applied with graminicides such as cyhalofop-butyl. Cyhalofop-butyl (T_1) treatment was also efficient in controlling the grassy weed population, but it effective in controlling sedges and BLWs. Hence the high weed count was contributed by BLWs and sedges. A similar effect was reported by Choubey *et al*. (2001). At 30 DAS, 60 DAS and at harvest, with respect to control of grassy weeds especially *S. interrupta*, fenoxaprop-p-ethyl was best, followed by cyhalofop-butyl. Scott (2003) observed that cyhalofop-butyl was a very effective herbicide for control of grasses like barnyard grass. Similar results were also reported by Singh *et al*. (2008).

The other treatments, bispyribac sodium (T_2), penoxsulam (T_3), triafamone + ethoxysulfuron (T_5), and cyhalofop-butyl + penoxsulam (T_6) were on par with respect to density of grasses and total weed count at 30 DAS, 60 DAS and at harvest (Table 52). Hand weeding and cyhalofop-butyl + penoxsulam (T_6) registered superior weed control with respect to BLWs at harvest, while for sedges the effect was non-significant. Peerzada *et al*. (2016) also reported that combination of penoxsulam+ cyhalofop-butyl gave a broad spectrum control of sedges and BLWs.

The herbicides bispyribac sodium, penoxsulam and the other two ready mix commericial formulations *i.e.*, triafamone + ethoxysulfuron, and cyhalofop-butyl + penoxsulam, failed to completely control the weeds, especially grasses, because of similar mode of action, *i.e.*, inhibition of the enzyme acetolactate synthase (ALS) which is essential for synthesis of essential amino acids.

S. interrupta showed resistance to these herbicides, probably due to modification of site of action of these herbicides, leading to either altered ALS gene or herbicide degradation or enhanced metabolism. Riar *et al*. (2013) reported similar type of results in *Echinochloa crus-galli,* with the barnyard grass resistant to ALS inhibiting herbicides like bispyribac sodium, penoxsulam, etc.

Highest N, P and K removal was noticed in unweeded control irrespective of stage of crop growth due to high weed dry matter production (Figure 36; Tables 53 and 54). The removal was 14.40 kg N/ha, 1.27 kg P/ha and 11.24 kg K/ha in unweeded plot at 60 DAS whereas in hand weeded plots, the corresponding values were 2.18 kg N/ha, 0.17 kg P/ha and 1.87 kg K/ha. This was in line with the findings of Maity and Mukherjee (2011) who reported removal of 34.4 kg N/ha, 7.4 kg P/ha and 37.8 kg K/ha in complete weedy situation. However, actual removal of nutrients by weeds in hand weeded control plots would have been still higher than this if the nutrient removal by the weeds pulled out from hand weeded control had also been accounted for.

Both at 30 and 60 DAS, lowest removal of major nutrients N, P and K was observed in hand weeded plot (T_6), followed by fenoxaprop-p-ethyl (T_4). A removal of 9.06 kg/ha of N was noticed in the treatment penoxsulam which was in line with the high dry matter production registered in this treatment. P removal by weeds in unweeded control was 1.51 kg/ha while the treatments triafamone + ethoxysulfuron and penoxsulam were on par with removal of 0.91 kg/ha (Figure 37).

The bispyribac sodium treated plot however, registered a comparatively higher P removal of 1.09 kg/ha. At 60 DAS, highest K removal of 11.24 kg/ha was observed in unweeded control which was statistically superior to other treatments, and the lowest removal was in hand weeded plot (0.65 and 1.87 kg/ha at 30 and 60 DAS respectively).

1.2 **Studies on crop**

A) Plant growth parameters

Among various treatments, tallest plants with 42.63 cm and 63.90 cm height at 30 DAS and 60 DAS respectively were observed in hand weeded plot, which may be due to less weed competition and more space available from early growth phase leading to increase in height. At 60 DAS, the treatments cyhalofop-butyl+ penoxsulam (T_5) and triafamone + ethoxysulfuron (T_6) recorded tallest plants with 51.42 and 50.38cm respectively which may be due to severe weed competition from

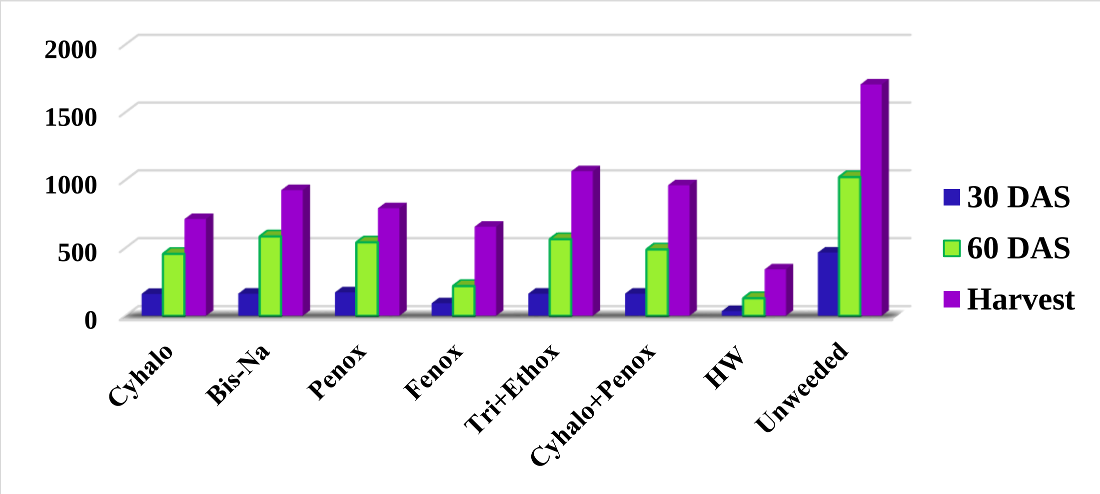
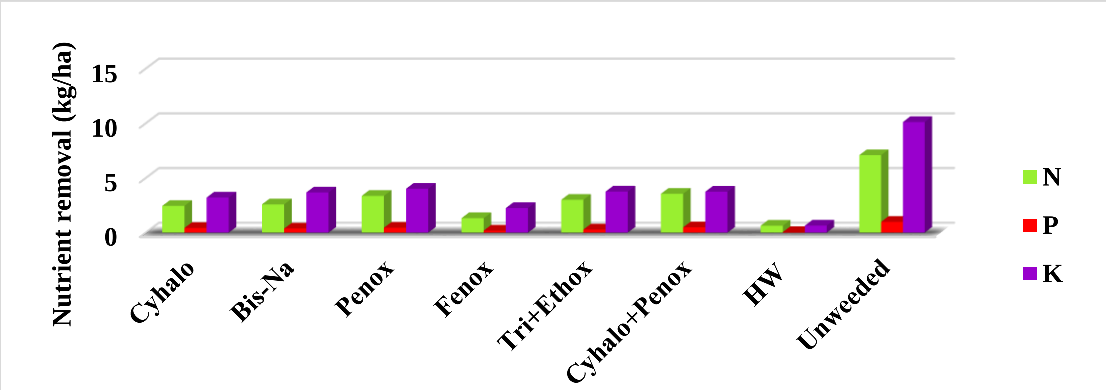
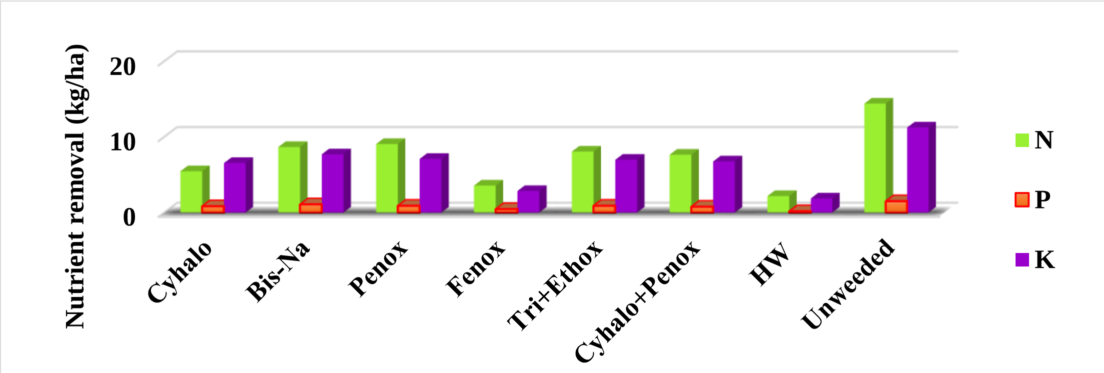


Figure 36. Effect of post-emergence herbicides on weed dry weight (kg/ha)



a) 30 DAS)



b) 60 DAS

Figure 37. Effect of post-emergence herbicides on nutrient removal by weeds (kg/ha) at 30 and 60 DAS in direct seeded rice

early growth phase leading to increase in height at the expense of tillering in these treatments. However, as growth advanced, hand weeding recorded highest plant height followed by treatments cyhalofop-butyl (T_1) and fenoxaprop-p-ethyl (T_4) and there was no significant difference between other herbicide treatments, while unweeded control recorded lowest plant height at all stages of rice (Table 55).

At 30 DAS and 60 DAS hand weeding registered maximum number of tillers/m^2 (Table 56). Similar results were also reported by Lakshmi *et al*. (2006). Tiller count decreased by 67% and 75% during 1st and 2nd year respectively in unweeded control compared to hand weeding by 60 DAS owing to severe competition from weeds. At this stage hand weeding twice was statistically superior to all other treatments as was the case in the previous experiment.

B) Yield and yield attributes

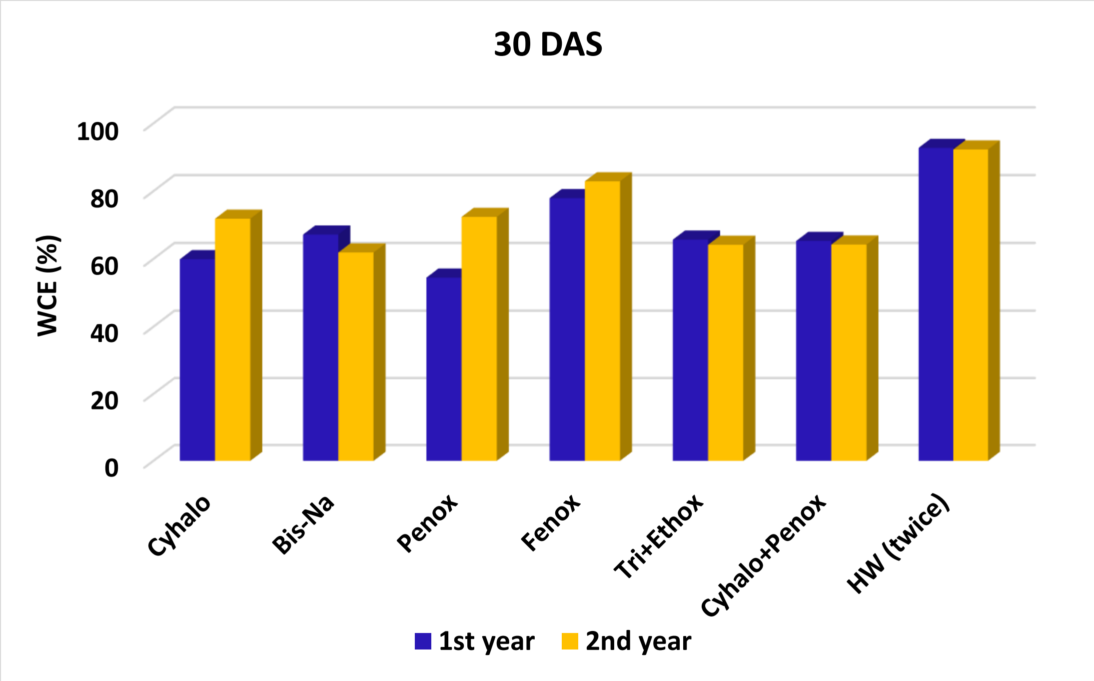
Highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding (T_7) (Table 57). Several authors like Subhalakshmi and Venkataramana (2009), Hasanuzzamam *et al.* (2009) and Maity and Mukerjee (2011) reported an increase in yield and yield attributes due to hand weeding. Unweeded control registered a reduction in number of panicles/m^2 to an extent of 82% and 73% in 1st and 2nd year respectively. A reduction observed in tiller count/m^2 adversely affected the number of productive tillers also. Weed competition also lowered filled grains/panicle by 79% and 77% in 1st and 2nd year respectively in unweeded plot compared to hand weeding twice, showing the intensity of competition and loss caused by *S. interrupta*, inhibiting the growth and development of rice leading to decreased production and productivity. The test weight of grains did not differ significantly in treatments except for hand weeding, probably because it was a varietal character decided by the genetic makeup of the plant.

The next best treatments after hand weeding with respect to yield attributes were fenoxaprop-p-ethyl (T_4) and cyhalofop-butyl (T_1). Apart from fenoxaprop-p-ethyl and cyhalofop-butyl, application of penoxsulam (T_3) also resulted in higher number of panicles/m^2 and filled grains/panicle compared to other herbicide treatments and was statistically superior. Similar results were also reported by Mishra *et al*. (2007) and Singh *et al*. (2007a).

The highest grain yield of 2260 kg/ha and 3384 kg/ha during 1st and 2nd year respectively was recorded in hand weeded plots where WCE of 74% in 1st year and 86% in 2nd year were recorded (Figures 38 and 39; Table 58). Maity and Mukherjee (2011) also reported that hand weeding resulted in higher WCE (97.07%) and hence higher grain yield. Verma *et al*. (2004) reported a WCE of 90.6% in DSR due to hand weeding, and thereby higher grain yield of 3.6 t/ha.

Fenoxaprop-p-ethyl was the next best treatment with a grain yield of 1773 kg/ha and a WCE of 62%. Dixit and Varshney (2008) reported that application of fenoxaprop-p-ethyl resulted in greater number of panicles and filled grains, and therefore higher grain yield. Similar results were also reported by Sreedevi *et al*. (2009). Cyhalofop-butyl also stood as second best treatment with grain yield of 1643 kg/ha and a WCE of 58%. Angiras and Attri (2002) and Saini (2005) also reported a WCE of 89% and higher grain yield by application of cyhalofop-butyl (Table 61). However, the full extent control of *S. interrupta* was not achieved by these herbicides because of congenial climate for growth and development of *S. interrupta* during crop growth period and large seed bank with high population density of *S. interrupta* in the experimental field. *S. interrupta* thrived in the field with complete canopy coverage and competed with the crop for growth factors and hence adversely affected the yield. This was evident from the weed dry matter production of 1705 kg/ha in unweeded plot at harvest.

It could be seen from the pooled data that yield reduction due to weeds especially *S. interrupta* was 56 %, 64 %, 65 % and 68 % in treatments penoxsulam (T_3), bispyribac sodium (T_2), cyhalofop-butyl+ penoxsulam (T_6) and triafamone + ethoxysulfuron (T_5) respectively as the weed dry matter production was higher in these treatments. Weed indices of 44 % and 41 % was recorded in treatments fenoxaprop-p-ethyl (T_4) and cyhalofop-butyl (T_1) respectively, which were statistically on par (Figure 40; Table 62).



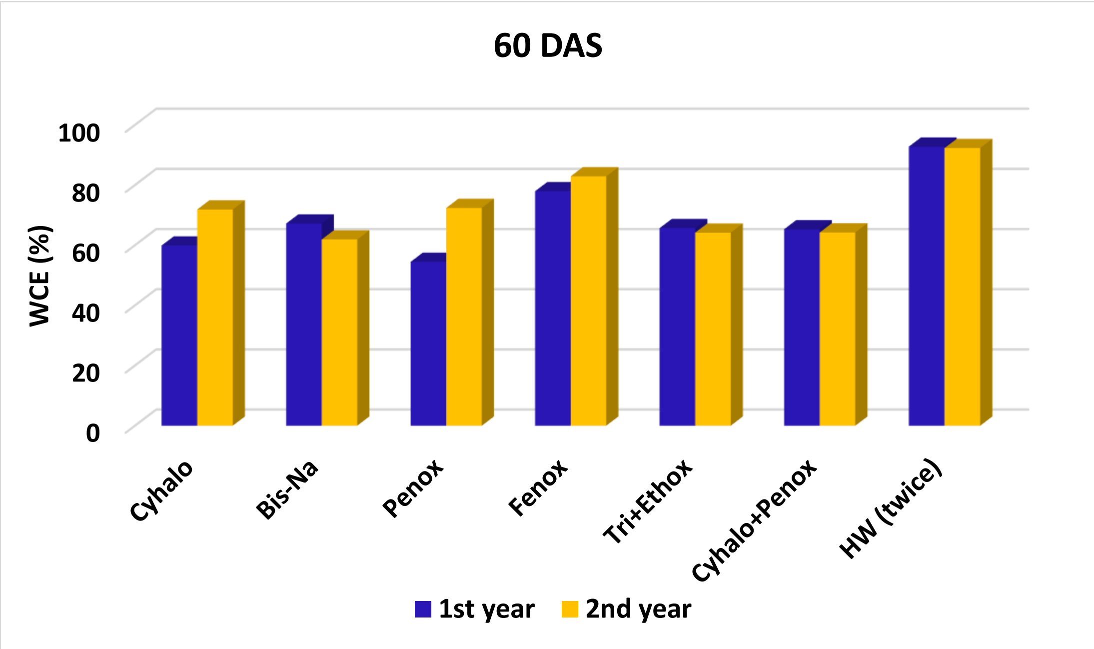


Figure 38. Effect of post-emergence herbicides on weed control efficiency (WCE) (%) in different years at 30 and 60 DAS

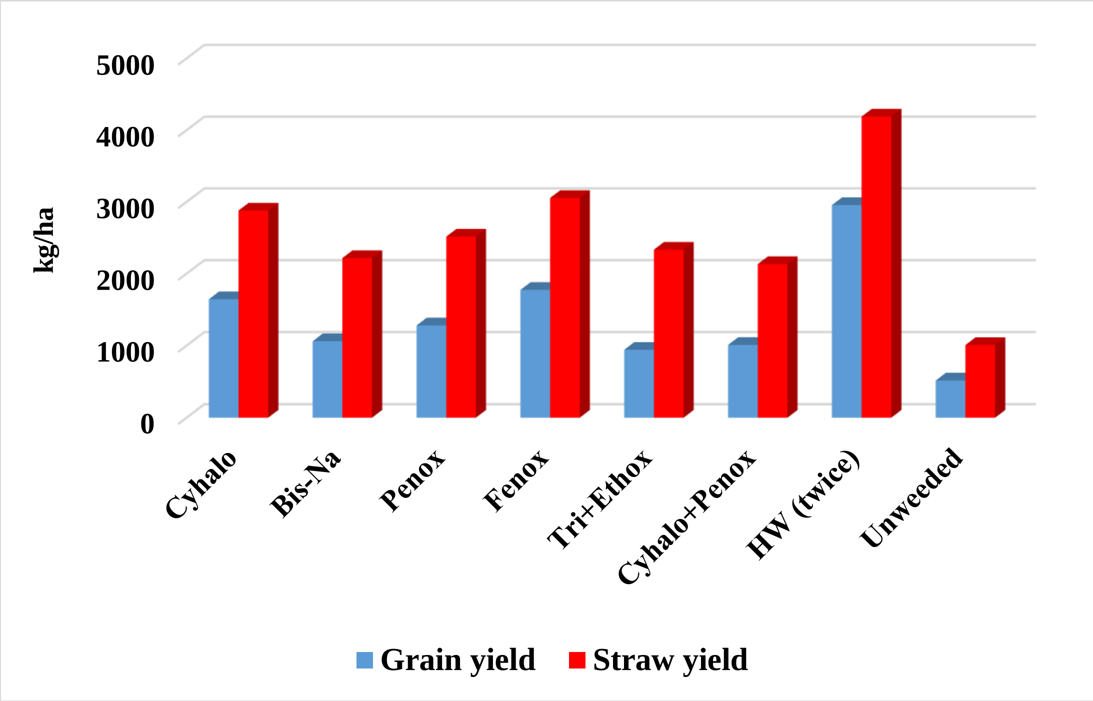


Figure 39. Effect of post-emergence herbicides on grain and straw yield of rice (kg/ha)

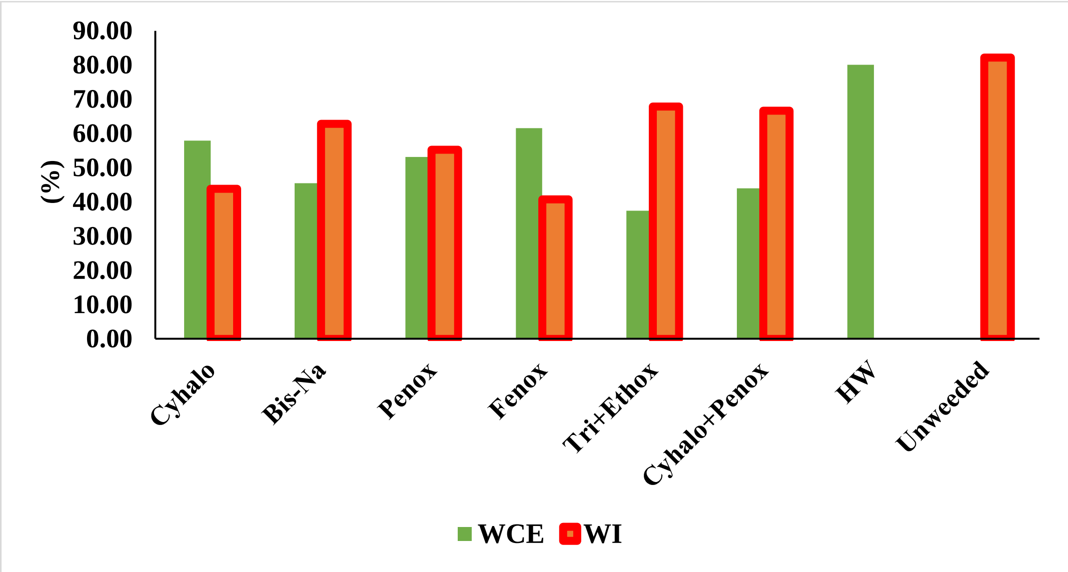


Figure 40. Effect of post-emergence herbicides on weed control efficiency (WCE) (%) and weed index (WI)

It could be inferred that *S. interrupta* population which produce dry matter production up to 340 kg/ha will not impart competitive effect on rice plants, so that yield and yield parameters are affected. In unweeded control grain and straw yield reduction was to tune of 81 % and 72% in 1st year and 84 % and 79 % during 2nd year due to severe competition from weeds.

Straw yield also followed the same trend of grain yield. Hand weeding recorded highest straw yield followed by fenoxaprop-p-ethyl and cyhalofop-butyl which were on par with each other whereas in the second year, fenoxaprop-p-ethyl was superior to cyhalofop-butyl. The plants in hand weeded plots were superior to other treatment plants in terms of plant growth, number of tillers and yield parameters which thus resulted in higher grain and straw yields and had highest WCE of 80 %.

The harvest index ranged from 0.29-0.41, with the highest being in hand weeding followed by fenoxaprop-p-ethyl and cyhalofop-butyl, and lowest in unweeded control due to severe weed competition. This was due to the fact that magnitude of reduction in grain yield due to weed competition was more compared to reduction in straw yield.

As was seen in the previous experiment, application of fenoxaprop-p-ethyl or cyhalofop-butyl seemed more advisable as both treatments were statistically on par with respect to grain yield. In areas where the grass population, especially of *S. interrupta* was quite high, application of either fenoxaprop-p-ethyl or cyhalofop-butyl herbicides would give good control of the weed. It was also clear that application of bispyribac sodium, penoxsulam and the two commercial formulations *i.e.*, combination of cyhalofop-butyl+ penoxsulam and triafamone + ethoxysulfuron whose mode of action is inhibition of the enzyme acetolactate synthase (ALS) were not advisable because of their tolerance by *S. interrupta*.

C) Nutrient uptake by rice at 60 DAS

The uptake of N, P and K by rice is a function of straw yield, grain yield and its nutrient content. The highest N, P and K uptake was in hand weeded treatment

(23.03 kg/ha, 3.34 kg/ha and 35.04 kg/ha) (Table 59). The favourable growth conditions due to high WCE of 90% in hand weeded treatment resulted in better uptake of nutrients as also reported in the findings of Subhalakshmi and Venkataramana (2009).

Cyhalofop-butyl followed by fenoxaprop-p-ethyl resulted in second highest N and K uptake, and cyhalofop-butyl applied plots recorded 2nd highest P uptake. In unweeded control the N, P and K uptake by rice was very low (2.46 kg/ha, 0.23 kg/ha and 3.05 kg/ha respectively) which resulted in highest nutrient removal of 7.09 kg/ha N, 0.99 kg/ha P and 10.12 kg/ha K by weeds compared to 0.64 kg/ha N, 0.06 kg/ha P and 0.65 kg/ha K in hand weeded plot.

This huge removal of nutrient by weeds resulted in poor growth and dry matter production of rice in unweeded control.

D) Economics of weed control

An analysis of the economics of rice cultivation showed that during the first year, because of less rainfall, favoured the weed growth especially growth of *S. interuupta* due to higher seed bank in experimental area, which resulted in lower grain yield of rice and thereby net loss in all the treatments. However, during the second year, highest returns (Rs. 38,964/-) and B:C ratio (1.4) were achieved by hand weeding which was the best treatment. Among the post-emergence herbicides, fenoxaprop-p-ethyl was best with highest returns of Rs. 19,624 and B:C ratio of 1.3, followed by the treatment cyhalofop-butyl with net returns of Rs. 5,173/-. Hence, although hand weeding was the best method for control of graminaceous weeds, especially *S. interrupta*, fenoxaprop-p-ethyl and cyhalofop-butyl could be recommended as best post-emergence herbicides for control of *S. interrupta* compared to other treatments especially in a situation where the weed *S. interrupta* was dominant.

5.3.3. Integrated weed management

1.1 **Studies on weeds**

A) Weed flora and density

Grass weed flora in the experimental area during 2019 comprised of mainly *S. interrupta, Oryza sativa* f. *spontanea, Echinochloa crus-galli* and *Paspalum conjugatum*. The sedges present were *Fimbristylis miliacea* and *Cyperus* spp and the main broad leaved weeds (BLW) were *Cyanotis axillaris, Commelina diffusa* and *Ludwigia perennis*.

Among them *S. interrupta* was found to be the most dominant at 30 and 60 DAS and at harvest in both the years. Hand weeding (T_7) and oxyfluorfen+ hand weeding at 45 DAS (T_4) recorded lowest population of *S. interrupta* whereas unweeded control (T_8) recorded the highest population of *S. interrupta* (Figure 41; Table 65) and the percentage of density of *S. interrupta* in unweeded control is represented in Figure 42. In direct seeded rice *Echinochloa crus-galli*, *Echinochloa colona*, *Eleusine indica*, *S. interrupta*, *Eclipta alba*, *Ludwigia parviflora*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliace*a were the major weed species reported by Verma *et al*. (2004).

A critical analysis of relative proportion of grasses, sedges and BLWs to total weed population in unweeded control revealed that during all the stages of rice crop, the population of grasses was higher than that of sedges and BLWs. Rao *et al*. (2008) and Singh *et al*. (2013) reported that higher proportion of grasses compared to sedges and BLWs in rice in dry seeded rice. Among grasses, *S. interrupta* was the predominant one**.** The population of sedges was low, while population of BLWs was higher and *Cyanotis axillaris* was the dominant BLW. Similar results were also reported by Mishra and Singh, 2008.

B) Effect of various treatments on weed parameters

Efficacy of herbicides will be more, if there is enough soil moisture after herbicide application, but deficit rainfall and high temperature after herbicide

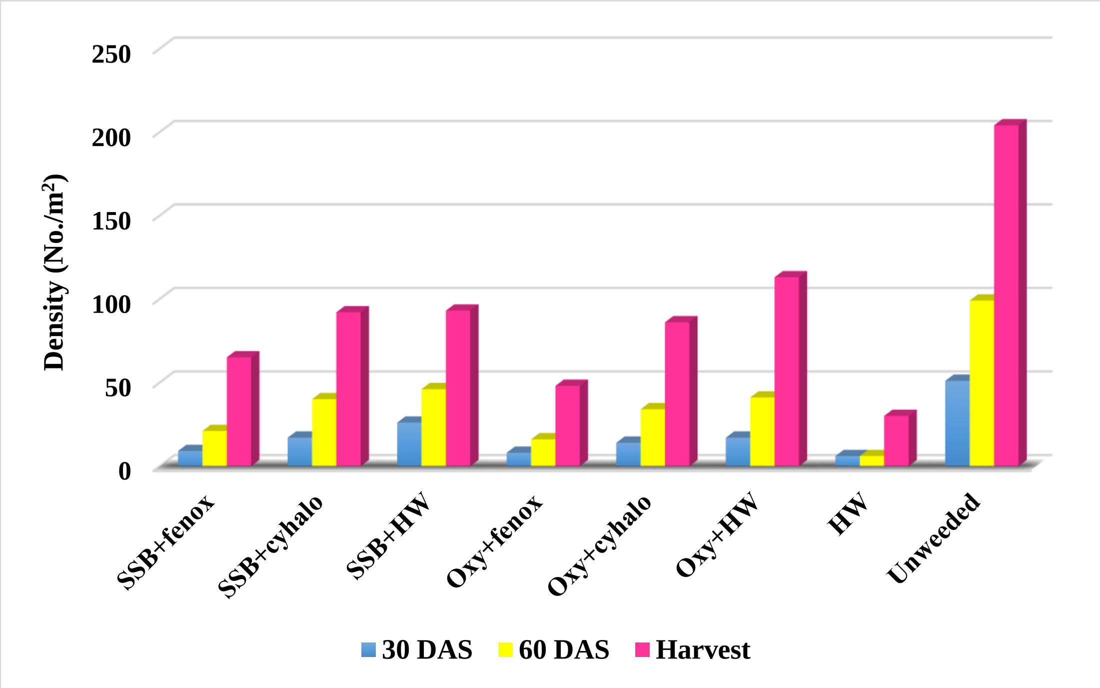


Figure 41. Effect of IWM treatments on *Sacciolepis* density (no./ m^2)

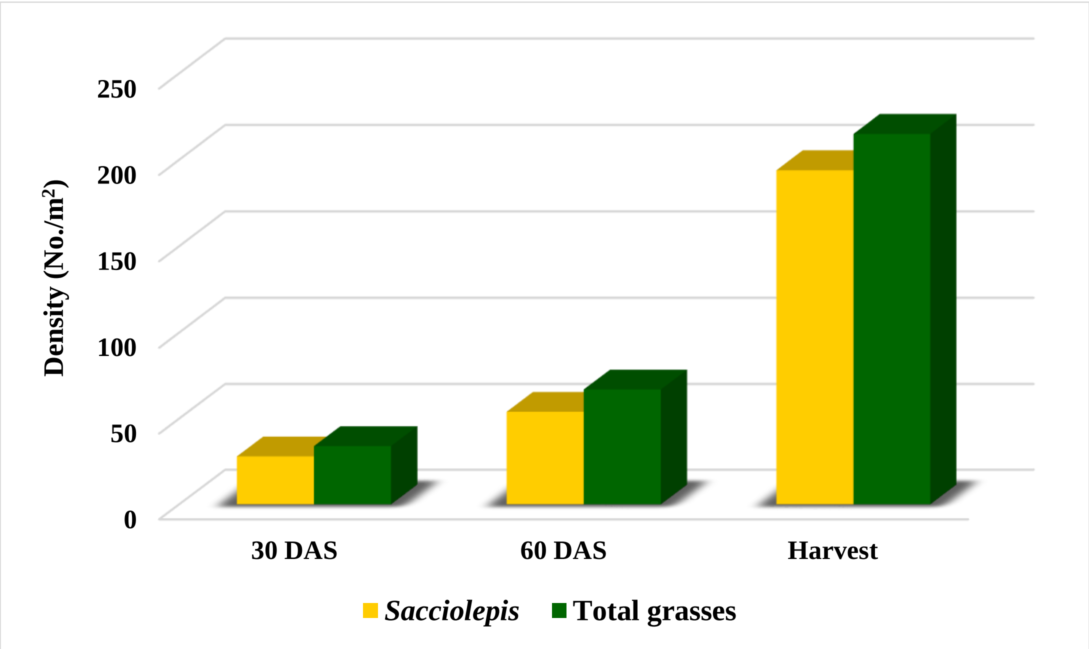


Figure 42. Density of *S. interrupta* (no./m^2) at various stages of crop in unweeded control

application in experimental field led to regrowth of the weeds. Matloob *et al*. (2015) also reported that increasing temperatures and variations in rainfall pattern could lead to changes in the weed population dynamics.

The weed density and weed dry weight increased linearly from 30 DAS to harvest due to the progressive growth of weeds in the period as well as further germination and growth of weeds, mostly of *S. interrupta*, which recorded highest population at all stages (Figure 43; Tables 66 and 67).

The lowest weed density and dry weight were seen in hand weeded plot (T_7) *i.e*., (3, 6 and 10 no./m^2) and (0, 3.73 and 6.37 g/m^2) at 30 DAS, 60 DAS and harvest respectively. This corroborates with the findings of Rekha *et al*. (2002) who reported a lower weed dry matter production in hand weeded control. Maity and Mukherjee (2011) observed that hand weeding at critical growth stages of crop resulted in lower weed index and weed dry weight. The treatment effect was conspicuous and total weed population was very low in treated plots, compared to unweeded control.

Hand weeding decreased the density of weeds by 90% especially population of grasses was reported by Mubeen *et al*. (2014), whereas the effect hand weeding treatment was not so prominent with respect to sedges and BLWs and all treatments were on par except unweeded control.

The next best treatment with respect to grass control was oxyfluorfen + hand weeding at 45 DAS (T_6) which had lowest density and weed dry weight of grasses especially *S. interrupta*, and thereby low total density. Kathiresan and Manoharan (2002) also reported that application of oxyfluorfen followed by hand weeding at 45 DAS recorded lower weed population and weed dry weight in semi-dry rice. Similar results were also reported by Abraham and Menon (2015) in wet seeded rice.

Stale seedbed+ hand weeding at 45 DAS also recorded lower number of grasses especially *S. interrupta i.e*., 4, 18 and 23 no./m^2 at 30 and 60 DAS and harvest. Weed dry weight was low (12.90 g/m^2) at 60 DAS and at harvest (13.67 g/m^2). Kashyap *et al*. (2019) also reported that at 30 and 60 DAS and harvest, SSB

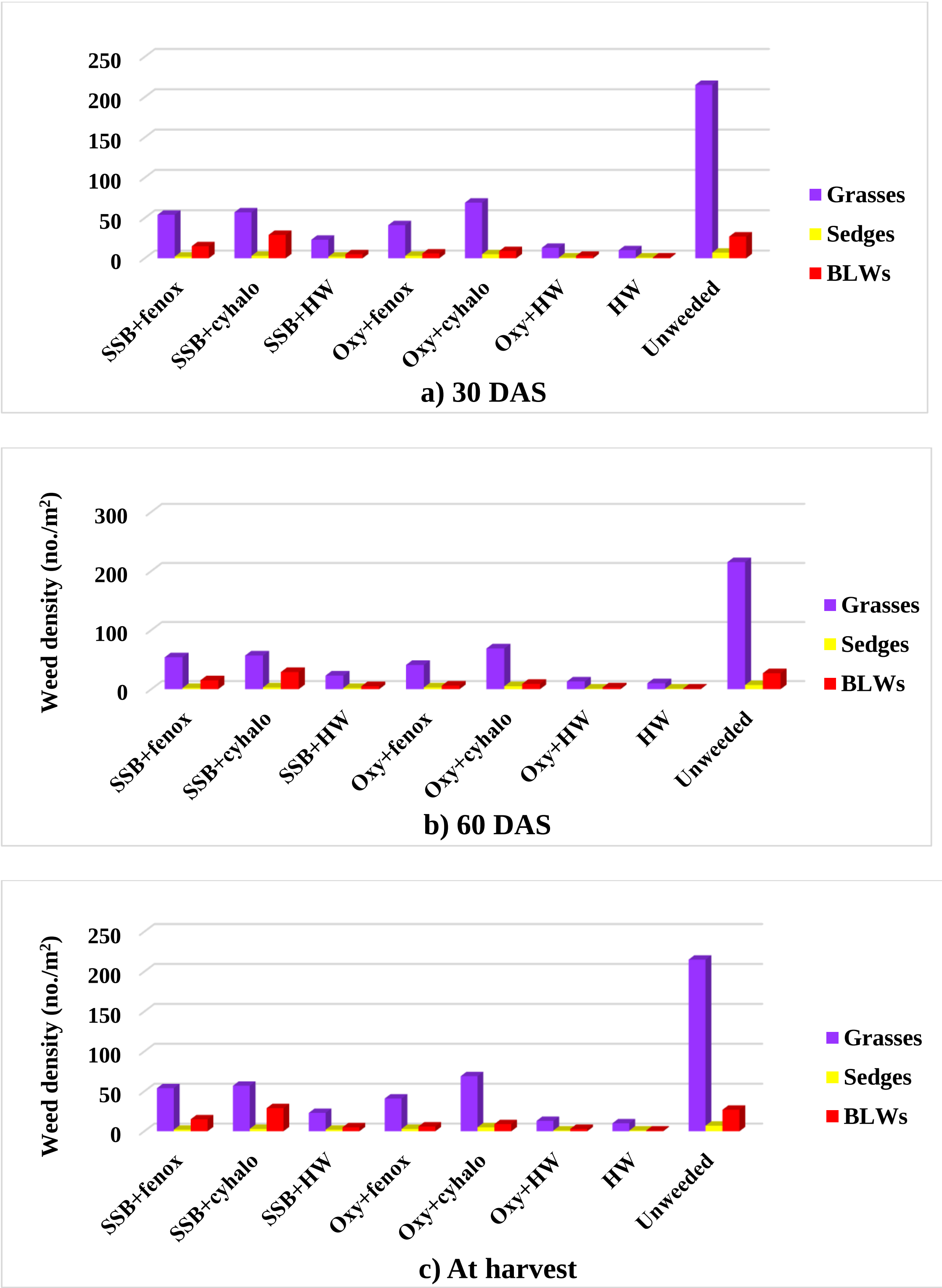


Figure 43. Effect of IWM treatments on weed density (no./m^2) at various stages of the crop

followed by one hand weeding at 45 DAS reduced the weed density with higher WCE.

Among the herbicide combinations, application of oxyfluorfen + fenoxaprop-p- ethyl (T_4) gave promising results in controlling *S. interrupta* population, reducing the density of grasses and total weeds. Rao *et al*. (2007) and Abraham *et al*. (2010) observed that oxyfluorfen efficiently controlled grasses, sedges and BLWs up to 45 DAS and thereby lower weed density. Singh *et al.* (2004) reported that fenoxaprop-p-ethyl effectively controlled grass species like *Echinochloa colona*, *Echinochloa crus-galli*, *Leptochloa chinensis* and *Ischaemum rugosum.* The effectiveness of fenoxaprop-p-ethyl in decreasing the density and dry weight of grassy weeds was reported by Mallick *et al.* (2009).

Hence, for management of *S. interrupta* density and dry weight, pre-emergence application of oxyfluorfen and post- emergence application of fenoxaprop-p-ethyl was effective. The mode of action was by inhibition of protoporphyriongen oxidase (PS-II inhibitor) by oxyfluorfen and enzyme acetyl-co.A-carboxylase by fenoxaprop-p-ethyl. Jacob e*t al.* (2017) reported that pre-emergence application of oxyfluorfen and post-emergence application of fenoxaprop-p-ethyl resulted in lowest density and dry weight of *Leptochloa chinensis* in direct seeded rice.

The other treatments, *viz*., SSB+ fenoxaprop–p–ethyl (T_1) and SSB+ cyhalofop-butyl (T_2), oxyfluorfen + cyhalofop-butyl (T_5) were on par with respect to weed density and dry weight of grasses and total weed count at 30 DAS, 60 DAS and harvest.

SSB followed by application of post-emergence herbicides could not give effective control, indicating that herbicide application was not effective in reducing the weed population especially that of *S. interrupta.* Increased temperature and little rainfall after application of herbicide led to germination and growth of a fresh flush of *S. interrupta* from the seed reserves in the soil, as was evident from the data.

Unweeded control recorded highest density of weeds (249 no./m^2) and highest dry weight (173.61 g/m^2) at all stages of rice, which indicates the intensity of *S. interrupta* competition in the experimental field (Figure 44).

Highest N, P and K removal was noticed in unweeded control irrespective of stages of crop growth due to high weed dry matter production. The removal was 10.40 kg/ha N, 0.85 kg/ha P and 11.34 kg/ha K in unweeded plot at 60 DAS whereas in hand weeded plots, the corresponding values were 0.38 kg/ha N, 0.04 kg/ha P and 0.38 kg/ha K (Figure 45; Table 68). This is in line with the findings of Maity and Mukherjee (2011) who reported removal of 34.40 kg/ha N, 7.40 kg/ha P and 37.80 kg/ha K in complete weedy situation. However, actual removal of nutrients by weeds in hand weeded control plots would have been still higher than this, if the nutrient removal by the weeds removed from hand weeded control has been accounted.

Both at 30 and 60 DAS, lowest removal of major nutrients N, P and K was observed in hand weeding treatment (T_6), followed by SSB + hand weeding at 45 DAS (T_3). A removal of 2.88 kg/ha of N was noticed in the treatment oxyfluorfen+ hand weeding at 45 DAS, which was in tune with the high dry matter production registered in this treatment. P removal by weeds in unweeded control was 0.85 kg/ha while the treatments SSB+ cyhalofop-butyl, oxyfluorfen+ fenoxaprop-p-ethyl and oxyfluorfen+ cyhalofop-butyl were on par with removal of 0.37, 0.34 and 0.29 kg/ha, respectively.

At 60 DAS, highest K removal of 11.34 kg/ha was observed in unweeded control which was statistically superior to other treatments, and the lowest removal was in hand weeded plot which was nil at 30 and 1.16 kg/ha 60 DAS, respectively.

1.2 **Studies on crop**

A) Plant growth parameters

Among various treatments, tallest plants with 32.73 cm height at 30 DAS was recorded in SSB + hand weeding, at 45 DAS (T_3) and at 60 DAS the hand weeded plot (T_7) and SSB + fenoxaprop-p-ethyl (T_1) recorded tallest plants with height of

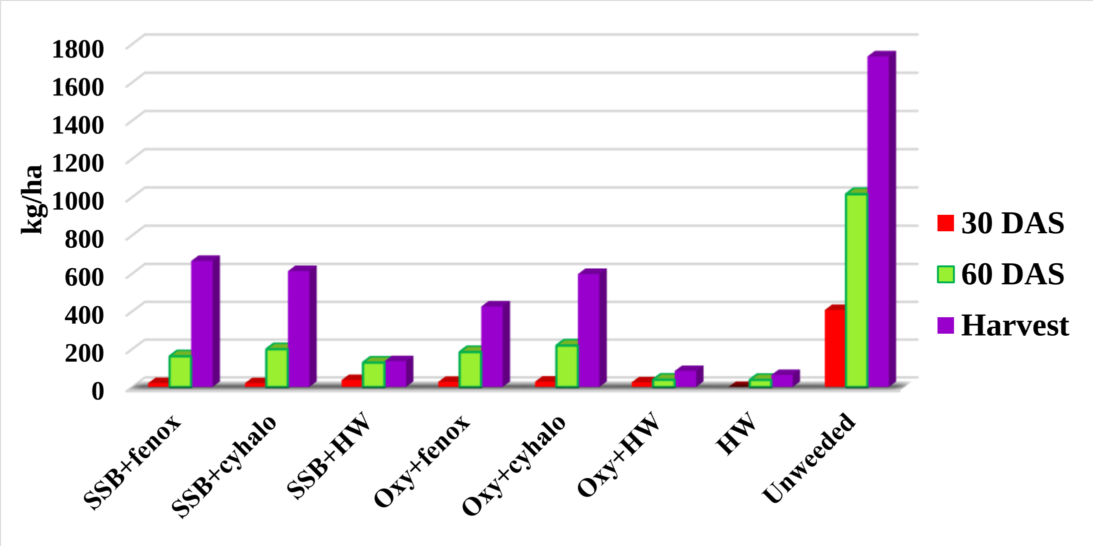
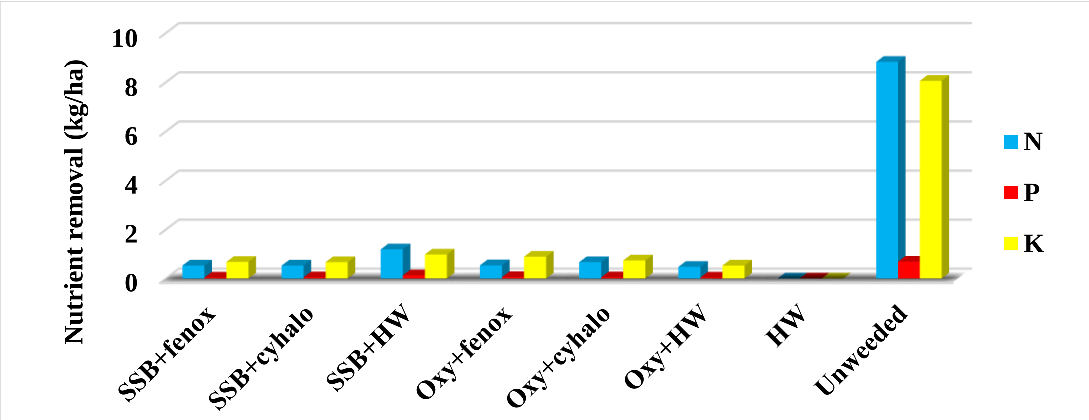
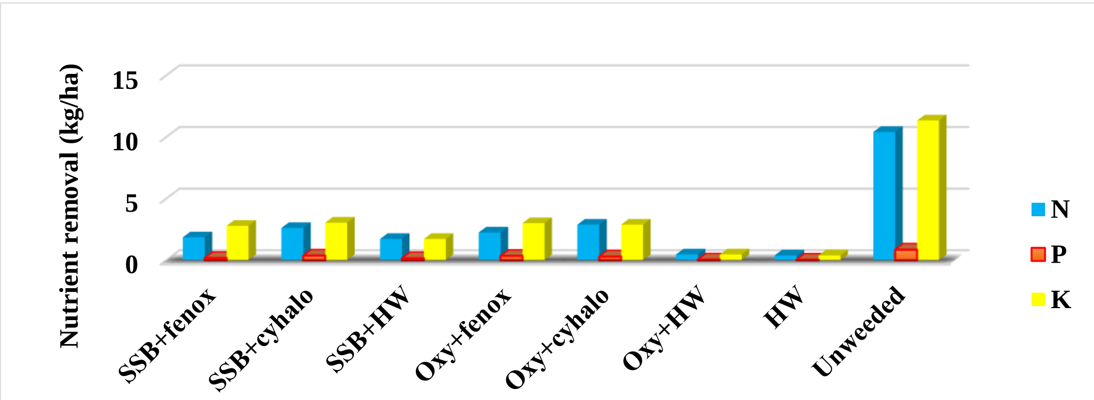


Figure 44. Effect of IWM treatments on weed dry weight (kg/ha)



a) 30 DAS



b) 60 DAS

Figure 45. Effect of IWM treatments on nutrient removal by weeds (kg/ha)

52.46 cm and 51.80 cm, which might have been due to less weed competition and more space available from early growth phase leading to increase in height.

At 60 DAS, SSB + cyhalofop-butyl (T_2), oxyfluorfen+ hand weeding (T_6) and SSB + hand weeding at 45 DAS (T_3) recorded tallest plants with 50.80 cm, 50.47 and 48.10 cm respectively, which was perhaps due to less weed competition during early growth phase, leading to increase in height (Table 69). However, as growth advanced, hand weeding recorded highest plant height while there was no significant difference between other treatments, and unweeded control recorded lowest plant height at all stages of the plant.

At 30 DAS and 60 DAS hand weeding registered maximum number of tillers/m2. Similar results were also reported by Lakshmi *et al*. (2006). Tiller count decreased by 71 % and 79 % during 30 DAS and 60 DAS respectively in unweeded control compared to hand weeding which resulted from severe competition from weeds. At this stage hand weeding twice was statistically superior to all other treatments. Hence it could be deduced that in spite of the expense involved in hand weeding, rice benefitted in terms of growth when compared to herbicide treatments.

B) Yield and yield attributes

Highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding (T_7) (Table 70). Several authors like Subhalakshmi and Venkataramana (2009), Hasanuzzamam *et al.* (2009) and Maity and Mukerjee (2011) reported an increase in yield and yield attributes due to hand weeding. Unweeded control registered a reduction in number of panicles/m^2 to an extent of 80 %. A reduction observed in tiller count/m^2 adversely affected the number of productive tillers also. Weed competition also lowered filled grains/panicle by 79 % in unweeded plot compared to hand weeding twice, showing the intensity of competition and loss caused by *S. interrupta*, which inhibited the growth and development of rice leading to decreased production and productivity. The test weight of grains did not differ significantly in treatments except hand weeding, probably because it was a varietal character decided by the genetic makeup of the plant.

The treatments oxyfluorfen+ hand weeding (T_6), SSB + hand weeding at 45 DAS (T_3) and oxyfluorfen+ fenoxaprop-p-ethyl (T_4) were on par with hand weeding treatment at 45 DAS and all of them recorded significantly higher number of panicles/m^2 and filled grains/panicle compared to rest of the treatments. Similar results were also reported by Mishra *et al*. (2007) and Singh *et al*. (2007a).

The highest grain yield of 4560 kg/ha was recorded in hand weeding plot where WCE of 96% was recorded (Figures 46 and 47, Table 71). Maity and Mukherjee (2011) also reported that hand weeding resulted in higher WCE (97.07 %) and hence, higher grain yield was obtained. Verma *et al*. (2004) reported that in DSR a WCE of 90.6% by hand weeding leading to a higher grain yield of 3.6 t/ha.

SSB+ hand weeding at 45 DAS was the next best treatment with a grain yield of 4239 kg/ha with a WCE of 92 %. Dixit and Varshney (2008) reported that application of fenoxaprop-p-ethyl resulted in higher number of panicles and filled grains, and consequently higher grain yield. Similar results were also reported by Sindhu *et al*. (2011). The treatment oxyfluorfen+ hand weeding was also best at 45 DAS, recording a grain yield of 4079 kg/ha with WCE of 95 %. Reshma (2014) and Priya *et al*. (2017) also reported that application of oxyfluorfen as pre-emergence spray followed by hand weeding increased WCE and higher grain yield.

However, the full extent control of *S. interrupta* was not achieved by these herbicides because of congenial climate for growth and development of *S. interrupta* during crop growth period and large seed bank with high population density of *S. interrupta* in experimental field. *S. interrupta* thrived in the field, with complete canopy coverage and competed for crop growth factors and hence adversely affected the yield. This is evident from the weed dry matter production of 1736 kg/ha in unweeded plot at harvest.

It could be seen from the pooled data that yield reduction due to weeds, especially *S. interrupta,* was 35 %, 40 % and 43 % in treatments SSB+ fenoxaprop-

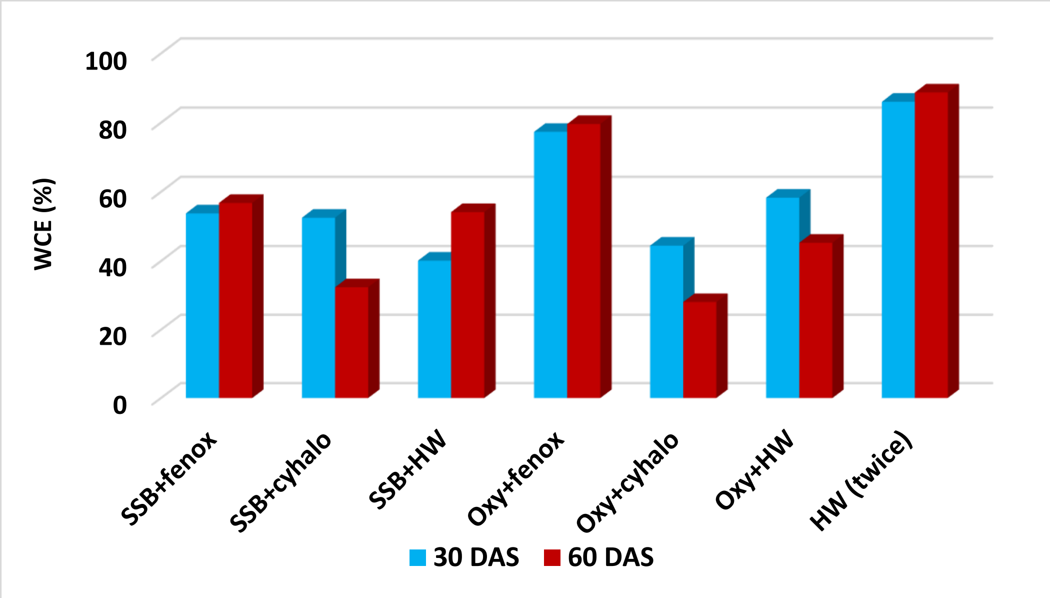


Figure 46. Effect of IWM treatments on weed control efficiency (WCE) (%)

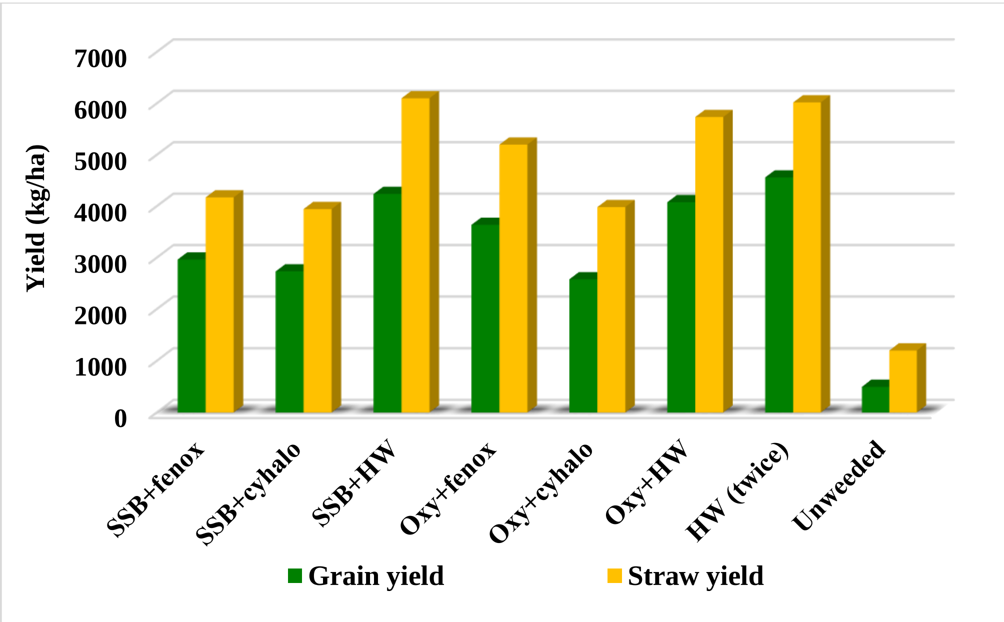


Figure 47. Effect of IWM treatments on grain and straw yield of rice (kg/ha)

p-ethyl (T_1), SSB + cyhalofop-butyl (T_2), oxyfluorfen + hand weeding (T_7) respectively, where the highest weed dry matter production was recorded (Figure 47). The WI of 43% and 40% was recorded in treatments oxyfluorfen + cyhalofop-butyl (T_6) and SSB+ cyhalofop-butyl (T_2) respectively and both were statistically on par (Table 74). It can be inferred that *S. interrupta* population which produce dry matter production up to 60 kg/ha will not impart competitive effect on rice plants, so that yield and yield parameters are affected. In unweeded control, grain and straw yield reduction was to the tune of 89 % and 80 % respectively due to severe competition from weeds.

Straw yield also followed the same trend of grain yield. Hand weeding (T_7), SSB + hand weeding at 45 DAS (T_3) and oxyfluorfen + hand weeding at 45 DAS (T_6) recorded highest straw yield followed by oxyfluorfen + fenoxaprop-p-ethyl, with all other treatments on par with each other except unweeded control. The plants in hand weeded plots were superior to other treatment plants in terms of plant growth, number of tillers and yield parameters which thus resulted in higher grain and straw yields and had highest WCE of 96%.

The HI ranged from 0.29-0.42, the highest value being resulted in hand weeding, followed by oxyfluorfen + hand weeding at 45 DAS, SSB + fenoxaprop-p-ethyl and SSB + fenoxaprop-p-ethyl, with remaining treatments were on par. Lowest HI was obtained in unweeded control due to severe weed competition. This is due to the fact that magnitude of reduction in grain yield due to weed competition was more compared to reduction in straw yield.

The treatments could thus be ranked in decreasing order of effectiveness as hand weeding twice at 20 and 40 DAS, stale seed bed before sowing and either going for application of fenoxaprop-p-ethyl or pre-emergence application of oxyfluorfen, and one hand weeding at 45 DAS or post-emergence application of fenoxaprop-p-ethyl.

In areas where the grass population, especially of *S. interrupta*, is very high, application of fenoxaprop-p-ethyl was more beneficial than cyhalofop-butyl, though both had similar mode of action *i.e.*, inhibition of acetyl co-enzyme A carboxylase (ACCase). It was also clear that application of oxyfluorfen + cyhalofop-butyl was not as effective as oxyfluorfen+ fenoxaprop-p-ethyl in terms of *S. interrupta* control.

C) Nutrient uptake by rice at 60 DAS

The uptake of N, P and K by rice is a function of straw yield, grain yield and its nutrient content. The highest N, P and K uptake was in hand weeded treatment (40.07 kg/ha, 4.84 kg/ha and 75.30 kg/ha), SSB + hand weeding at 45 DAS (39.49 kg/ha, 3.95 kg/ha and 67.64 kg/ha) and oxyfluorfen + hand weeding at 45 DAS (35.39 kg/ha, 4.81 kg/ha and 64.01 kg/ha). The favourable growth conditions due to high WCE of 96%, 95% and 92% in the respective treatments resulted in better uptake of nutrients. Oxyfluorfen+ cyhalofop-butyl recorded lower N, P and K uptake (19.84 kg/ha, 1.58 kg/ha and 22.39 kg/ha). In unweeded control the N, P and K uptake by rice was very low (2.59 kg/ha, 0.15 kg/ha and 3.25 kg N, P and K/ha respectively) which resulted in highest nutrient removal of 10.40 kg N /ha, 0.85 kg P /ha and 11.34 kg K /ha by weeds compared to 0.38 kg N/ha, 0.04 kg P/ha and 0.38 kg K/ha in hand weeded plot. This huge removal of nutrient by weeds resulted in poor growth and dry matter production of rice in unweeded control.

D) Economics of weed control

An analysis of the economics of rice cultivation showed that the treatments SSB+ hand weeding at 45 DAS registered highest B:C ratio of 1.9 with high returns of Rs. 77,803/ha. The treatments oxyfluorfen + hand weeding at 45 DAS and hand weeding at 20 and 45 DAS (T_7) registered a B:C ratio of 1.8 and 1.7 respectively. The sequential application of oxyfluorfen and fenoxaprop–p–ethyl was also best with B:C ratio of 1.8 and net returns of Rs. 64,432/-. Hence, it could be concluded that the best integrated treatments for control of *S. interrupta* are SSB + hand weeding at 45 DAS or oxyfluorfen+ hand weeding at 45 DAS or pre-emergence application of oxyfluorfen *fb* post-emergence application of fenoxaprop–p–ethyl.

Summary

6. SUMMARY

The research programme entitled “Biology and management of *Sacciolepis interrupta* Willd. Stapf in rice” was carried out during 2016-2019 at the Department of Agronomy, College of Horticulture. Survey, pot culture, laboratory and field experiments were conducted to study the biology, particularly the growth, reproduction, propagation, dormancy and germination requirements, of *S. interrupta* occurring in major rice tracts of Kerala. It was also aimed to study the efficacy of different pre- and post-emergence herbicides, individually as well as in an integrated manner, in controlling *S. interrupta*, so as to develop an effective recommendation for management of the weed.

Part I. Distribution and morphological study of *S. interrupta* in major rice tracts of Kerala

Surveys were conducted in the major rice tracts of Kerala *viz*., *Kole, Kuttanad* and Palakkad, and *S. interrupta* was found to occur in all the three locations. *S. interrupta* co-existed with rice and occupied field bunds, irrigation channels, marshy areas and stream banks.

For monitoring and comparing plant community changes over time, weed density, frequency and abundance were used as indices. In surveyed areas of Palakkad, a total of 15 species dominated and out of them, *S. interrupta* recorded highest density, frequency, abundance, relative density, relative frequency and summed dominance ratio followed by *Leptochloa* sp. In *Kole* tract, a total of 11 species were recorded in surveyed areas, with *S. interrupta* and weedy rice recording highest values for the various indicies, while in *Kuttanad*, *Echinochloa crus-galli* was found to be the major weed out of 12 species, followed by *S. interrupta* and *Salvinia molesta*.

Comparison of weed vegetation analysis indices in different rice tracts of Kerala showed that the highest weed species richness (R) of 15 was in Palakkad tract compared to other two tracts, bringing out the dominance of weeds, primarily *S.*

interrupta, under dryland and direct seeded conditions. Simpson diversity (D), Shannon-Wiener diversity (H) and Evenness (J) indices were highest in Kuttanad and *Kole*, *i.e.*, 0.9, 2.3 and 0.95, and 0.8, 2.2 and 0.94 respectively, whereas in Palakkad tract it was 0.7, 1.5 and 0.57 respectively, showing a high degree of domination of one species in Palakkad tract and a larger diversity of weed species in other two tracts. These studies indicated the probability of *S. interrupta* becoming a serious weed problem in direct seeded rice in Palakkad rice tract of Kerala, and attaining the status of a dominant weed like weedy rice in other rice tracts also.

Based on morphological characters of fifteen types of *S. interrupta* morphotypes collected from surveyed areas, three groups: A, B and C, were formed using scree plot of principal component analysis (PCA). The first two PCA corresponded to whole percentage variance in the data, as they possessed Eigen value of >1. PC1 and PC2 together accounted for 81.7% of total variations of which PC1 accounted for 61.9% and PC2 accounted for 19.8%. PC1 was related to all morphological characters except width of spikelets and PC2 was related to characters like plant height, panicle length, leaf length, leaf width and dry matter production/plant.

The first component data (PC1) was efficient in grouping and separating one group from others. Group A (green variegated) referred to the morphotypes from Palakkad with medium stature and narrow light green leaves having green coloured panicles (4-6 nos./plant), and oblong spikelets (311-348 spikelets/panicle), with length and width varying between 4.6-4.8 mm and 0.9-1.3 mm respectively. Severe infestation of *S. interrupta* group A in the surveyed locations of Palakkad rice tract was observed where semi-dry system of rice cultivation was followed, with saturated soil conditions, near neutral pH, low organic carbon and low nutrient status.

Group B (purple variegated) contained morphotypes from *Kole* tract with tall statured plants and narrow dark green leaves having purple coloured panicles (4-6 nos./plant), enlongated spikelets (311-348 spikelets/panicle), spikelet length of 4.6-

4.8 mm and width of 0.9-1.3 mm. These morphotypes of *S. interrupta* were dominant in acidic pH, medium organic carbon and submerged soils of *Kole* lands.

Kuttanad tract types were categorized into Group C (green-purple variegated) and were short statured, profuse tillering plants with broad dark green leaves having bicoloured green and purple panicles (6-8 nos./plant), oblong to bulged spikelets (378-391 spikelets/panicle), and short spikelets with length of 4.1-4.5 mm and width of 1.6-1.8 mm. Their density was prominently high in highly acidic and nutrient rich submerged soils of *Kuttanad.*

Part II. Biology of *S. interrupta*

S. interrupta was observed to be a narrow leaved monocot grass weed having fibrous root system and the stems were erect or leaning with creeping or geniculate habit with rooting at lower nodes and glabrous nodes. Leaves were lanceolate with 15 to 50 cm length and 0.4 to 4 cm width, and were either glabrous or sparsely pilose. The plant height varied from 70 to 112 cm, number of leaves from 3 to 7, leaf length from 19 to 78, leaf width from 0.4 to 3.8 mm and the dry weight ranged from 1.52 g to 1.77 g per plant.

Inflorescence was an erect, compact, terminal panicle, about 8 to 30 cm long and was of either interrupted or spiciform type. The spikelets were ovate or lanceolate, either green coloured or green coloured with violet variegations and about 2.1 to 4.8 cm long. The flowers of *S. interrupta* were violet or purple or white in colour. The manner of flowering of spikelets in the inflorescence was seen to be non-uniform in all the locations. Flowering began from random position on the inflorescence, and progressed in the same manner. There was no distinct pattern in flower opening. The seeds were very small, oval to oblong shaped, light brown to dark brown in colour, and the total seed production capacity ranged from 121-872 per panicle, with seed weight per plant of 182 to 1065 g and 1000 seed weight of 2.2 g to 4.2 g.

Studies revealed that seeds of *S. interrupta* were dispersed with high levels of induced dormancy and they underwent dormancy for a period of six to nine months (September to April). Although seeds were dormant they remained viable up to two years. Scarification and stratification treatments could not break the dormancy and seed germination was strongly influenced both by temperature and light, higher temperatures of 38^0C and continuous light for a period of 14 days triggering the germination, indicating that *S. interrupta* was positively photoblastic. Highest germination percentage was seen in 3^{rd} and 4^{th} weeks of June.

The absolute requirement of light for germination indicated the response to burial depths. About 72 % of seeds germinated when they were placed on the surface (0 cm), 44 % at 2 cm depth and 12 % at 5cm depth of placement by end of 4 weeks after sowing. *S. interrupta* was able to germinate in both upland as well as flooded conditions.

Seed longevity studies revealed that prolonged seed persistence of *S. interrupta* seeds could be expected, and a persistent seed bank due to secondary dormancy would favour the periodic reappearance of species and increase in the soil seed bank.

Part III. Management of *S. interrupta* in rice

A. Management through pre-emergence herbicides

Response of weeds

Weed flora in the experimental area during 2017 and 2019 comprised of mainly *S. interrupta*, *Oryza sativa* f. *spontanea*, *Leptochloa chinensis* and *Echinochloa crus-galli* among grasses. The sedges present in 2017 was *Fimbristylis miliacea*, while it was *Cyperus iria* in 2019. The main broad leaved weeds (BLWs) were *Cyanotis axillaris* and *Commelina diffusa* in both the years.

Among them *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest in both the years. Hand weeding (T_6) followed by stale seed bed (T_5)

plots had lowest population of *S. interrupta* and unweeded control (T_7) recorded the highest population.

Among different treatments, the highest total weed density, weed density of grasses, sedges and BLWs and weed dry weight at 30 DAS, 60 DAS and at harvest was in unweeded control (T_7) and lowest in hand weeded plot followed by stale seedbed (T_5). Among the herbicide treatments, at 30 DAS oxyfluorfen resulted in lowest total weed density, density of grasses and weed dry weight, whereas at 60 DAS and at harvest oxadiargyl and oxyfluorfen were on par. Pretilachlor and pendimethalin herbicide treatments were not so effective in controlling grasses, especially *S. interrupta.*

Highest N, P and K removal was noticed in unweeded control irrespective of stage of crop growth due to high weed dry matter production. The uptake was 14.26 kg/ha N, 2.40 kg/ha P and 13.86 kg/ha K in unweeded plot at 60 DAS whereas in hand weeded plots, the corresponding values were 0.38 kg/ha N, 0.05 kg/ha P and 0.49 kg/ha K.

Crop growth and yield

At 30 DAS, the greatest height was recorded in stale seed bed plot (T_5) which was on par with oxadiargyl (T_4). Hand weeded plot (T_6) recorded greatest plant height at 60 DAS, followed by the treatments stale seed bed and oxadiargyl which were on par with each other. At harvest stage also, plant height followed the same trend and hand weeded plot recorded the greatest plant height followed by the treatment stale seed bed. Other treatments were on par except for unweeded control (T_7), which had lowest plant height at all three stages of crop growth.

At 30 DAS, significantly higher number of tillers/m^2 was recorded by the hand weeded plot (T_6), and the second highest number of tillers/m^2 was recorded by stale seed bed treatment (T_5). At 60 DAS also the hand weeding treatment recorded significantly higher number of tillers/m^2 followed by oxadiargyl (T_4) and stale seedbed treated plots (T_5).

At harvest stage, significantly higher tiller count (236.67 nos./m^2) was recorded in hand weeded plot (T_6) followed by stale seed bed (179.33 nos./m^2), and the lowest was in unweeded control (63 nos./m^2), followed by the treatments pendimethalin (84.33 nos./m^2) and pretilachlor (91.33 nos./m^2).

Highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding plot (T_6). The treatments stale seed bed, oxadiargyl and oxyfluorfen were the next best treatments with respect to panicles/m^2 and were statistically superior to other herbicide treatments. The number of filled grains per panicle ranged from 31 to 90. The test weight of grain did not differ significantly between treatments and was in the range of 25 to 27g, and it was lowest in unweeded control.

Highest weed control efficiency of 90 and 87 % was obtained in hand weeded and stale seed bed plots respectively, followed by oxadiargyl (63.35%) and oxyfluorfen (60.43%). The harvest index was more or less constant, ranging from 0.35 to 0.44.

The highest nutrient uptake for N, P and K was in hand weeded control. Stale seed bed followed by oxadiargyl treatments resulted in second highest N and K uptake, and stale seed bed followed by oxyfluorfen plots recorded the second highest P uptake.

Hand weeding resulted in highest net returns in both the years. Stale seedbed was the next best with a B:C ratio of 1.9 and 2.0 in respective years. Among the herbicide treatments oxyfluorfen resulted in highest profits of Rs. 43,092 and 40,117 and B:C ratios of 1.6 and 1.5 during 1st and 2nd year, respectively. Oxadiargyl was second best after oxyfluorfen with a B:C ratio of 1.5 during both years.

B. Management through post-emergence herbicides

Response of weeds

Weed flora in the experimental area during 2017 and 2019 comprised of mainly *S. interrupta*, *Oryza sativa* f. *spontanea*, *Leptochloa chinensis* and *Echinochloa crus-galli* among grasses. The sedges present were *Cyperus* spp and the main broad leaved weeds (BLW) was *Cyanotis axillaris* in both the years.

Among them *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest in both the years. Hand weeding (T_7), fenoxaprop-p-ethyl (T_4) and cyhalofop-p-butyl (T_1) recorded lowest population of *S. interrupta* whereas unweeded control (T_8) recorded the highest population of *S. interrupta.*

Among different treatments, the highest total weed density, weed density of grasses, sedges and BLWs and weed dry weight at 30 DAS, 60 DAS and at harvest was in unweeded control (T_8) and it was lowest in hand weeded plot (T_7). The next best treatment with respect to grass control was fenoxaprop-p-ethyl (T_4) which had lowest density and weed dry weight of grasses especially *S. interrupta,* and thereby low total density and dry weight. Cyhalofop-butyl (T_1) was also efficient in controlling the grassy weed population. The other treatments bispyribac sodium (T_2), penoxsulam (T_3), triafamone + ethoxysulfuron (T_5), and cyhalofop-butyl + penoxsulam (T_6) were not effective and were on par with respect to weed density of grasses and total weed count at 30 DAS, 60 DAS and at harvest.

Highest N, P and K removal was noticed in unweeded control irrespective of stage of crop growth due to high weed dry matter production. The removal was 14.40 kg/ha N, 1.27 kg/ha P and 11.24 kg/ha K in unweeded plot at 60 DAS whereas in hand weeded plots, the corresponding values were 2.18 kg/ha N, 0.17 kg/ha P and 1.87 kg/ha K. Both at 30 and 60 DAS, lowest removal of major nutrients N, P and K was observed in hand weeding treatment (T_6), followed by fenoxaprop-p-ethyl (T_4).

Crop growth and yield

At 30 DAS, the greatest height was recorded in hand weeded plot (T_7) (42.63 cm) and lowest height of 15.28 cm was in unweeded control (T_8). All other treatments were on par with respect to plant height at 30 DAS. Hand weeded plot (T_7) recorded greatest plant height at 60 DAS, followed by the treatments cyhalofop-butyl+ penoxsulam (T_5) and triafamone + ethoxysulfuron (T_6) which were on par with each other. At harvest stage also, plant height followed the same trend and unweeded control (T_8) had lowest plant height.

Hand weeded plot recorded significantly higher number of tillers/m^2 at all stages of observation and was significantly superior to all other treatments during both the years. Fenoxaprop-p-ethyl (T_4) was next best followed by cyhalofop-butyl (T_1) and lowest tiller count was observed in unweeded control as per pooled data.

As observed from pooled data highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding plot (T_7). The treatments fenoxaprop-p-ethyl and cyhalofop-butyl were next best treatments with respect to panicles/m^2 and were statistically superior compared to other treatments. The number of filled grains per panicle ranged from 25 to 115 and it was highest in hand weeded treatment followed by fenoxaprop-p-ethyl. The test weight did not differ significantly between the treatments and was in the range of 24 to 26g.

In first year, the highest grain yield of 2260 kg/ha was recorded in the treatments hand weeding (T_7) followed by cyhalofop-butyl (T_1) (1302 kg/ha) and fenoxaprop–p–ethyl (T_4) (1247 kg/ha) which were on par, whereas in the 2^{nd} year it was significantly higher under hand weeding treatment (3649 kg/ha) followed by fenoxaprop–p–ethyl (2299 kg/ha) and the next best was cyhalofop-butyl with 1983 kg/ha. Penoxsulam was statistically superior to the other treatments bispyribac sodium, cyhalofop-butyl+ penoxsulam and triafamone + ethoxysulfuron which were on par with each other. Unweeded control (T_8) produced significantly lower grain yield of 517 kg/ha.

Straw yield also followed similar trend as grain yield. The treatments which recorded statistically comparable straw yields were hand weeding, cyhalofop-butyl and fenoxaprop–p–ethyl. Lowest straw yield was obtained in unweeded control. The HI ranged from 0.29-0.41, the highest being in hand weeding followed by fenoxaprop-p-ethyl and cyhalofop-butyl, and the lowest in unweeded control. As observed from pooled data highest weed control efficiency of 80 % was obtained in hand weeded plot, followed by fenoxaprop-p-ethyl (62%) and cyhalofop-butyl (58%).

The highest uptake of N, P and K of 23.03 kg/ha, 3.34 kg/ha and 35.04 kg/ha respectively was noticed in hand weeded control and it was lowest in unweeded control. Cyhalofop-butyl followed by fenoxaprop-p-ethyl treatments resulted in second highest N and K uptake and cyhalofop-butyl applied plot recorded the second highest P uptake.

An analysis of economics of rice cultivation showed that during the first year all the treatments registered net loss, indicating the intensity of *S. interrupta* dominance and the failure of herbicides to control the weed. However during second year, highest returns (Rs. 50,964/-) and B:C ratio (1.6) were achieved by hand weeding, which was the best treatment. Among the post-emergence herbicides fenoxaprop-p-ethyl was best with highest returns of Rs. 19,624 and B:C ratio of 1.3, and it was followed by the treatment cyhalofop-butyl with net returns of Rs. 5,173/-.

C. Integrated weed management

Response of weeds

Weed flora in the experimental area during 2019 consisited of mainly *S. interrupta, Oryza sativa* f. *spontanea, Echinochloa crus-galli* and *Paspalum conjugatum* among grasses. The sedges present were *Fimbristylis miliacea* and *Cyperus* spp and the main broad leaved weeds (BLW) were *Cyanotis axillaris, Commelina diffusa* and *Ludwigia perennis*.

Among the weeds, *S. interrupta* was found to be the most dominant at 30, 60 DAS and at harvest. Hand weeding (T_7) and oxyfluorfen+ hand weeding at 45 DAS (T_4) recorded lowest population of *S. interrupta* whereas unweeded control (T_8) recorded the highest population of *S. interrupta.*

Among different treatments, the highest total weed density, population of grasses, sedges and BLWs and weed dry weight at different crop growth stages was in unweeded control (T_8). The lowest weed density and dry weight was seen in hand weeded plot (T_7) *i.e.*, (3, 6 and 10 no.s/m^2) and (0, 3.73 and 6.37 g/m^2) at 30 DAS, 60 DAS and harvest respectively.

Among the herbicide combinations, application of oxyfluorfen+ fenoxaprop-p-ethyl (T_4) gave promising results in controlling *S. interrupta* population, and reduced the density of grasses and total weeds. The treatments SSB+ fenoxaprop–p–ethyl (T_1), SSB+ cyhalofop-butyl (T_2), and oxyfluorfen + cyhalofop-butyl (T_5) were on par with respect to weed density and dry weight of grasses and total weed count at 30 DAS, 60 DAS and harvest. Due to appearance of new flushes of *S. interrupta* throughout the growth of rice, hand weeding at least once at 40-50 DAS seemed to be an indispensable operation.

Highest N, P and K removal was noticed in unweeded control irrespective of stages of crop growth due to high weed dry matter production.

Crop growth and yield

Tallest plants were recorded in SSB+ hand weeding (T_3) at 45 DAS. At 30 DAS and at 60 DAS, hand weeded plot (T_7) and SSB+ fenoxaprop-p-ethyl (T_1) recorded tallest plants. However, as growth advanced, plants in hand weeded plots recorded greatest plant height and there was no significant difference between other treatments. Unweeded control recorded lowest plant height at all stages of the plant.

At 30 DAS and 60 DAS, hand weeding registered highest number of tillers/m^2. The next best treatments with respect to tiller count were oxyfluorfen + hand weeding at 45 DAS and SSB+ hand weeding at 45 DAS. Lowest number of tillers/m^2 was noticed in unweeded control.

Highest number of panicles/m^2, filled grains/panicle as well as grain and straw yield were registered in hand weeding treatments. SSB+ hand weeding at 45 DAS (T_3) and oxyfluorfen + hand weeding at 45 DAS (T_6) were also on par with hand weeded plots with respect to number of panicles/m^2.

It was observed that highest number of grains/panicle was recorded in treatments hand weeding (T_7), oxyfluorfen + hand weeding at 45 DAS (T_6) and SSB+ hand weeding at 45 DAS (T_3), and they were followed by oxyfluorfen + fenoxaprop–p–ethyl (T_4). In unweeded control plot there were only 19 grains/panicle. The test weight (1000 grain weight) was in the range of 24.13 g to 26.80 g, with unweeded treatment recording the lowest value and hand weeding along with oxyfluorfen + hand weeding at 45 DAS and SSB+ hand weeding at 45 DAS resulting in the highest value.

The highest grain yield of 4560 kg/ha was recorded in hand weeding plot where the WCE was 96%. SSB+ hand weeding at 45 DAS was the next best treatment with a grain yield of 4239 kg/ha and a WCE of 92%. The treatment oxyfluorfen+ hand weeding at 45 DAS was also on par and recorded a grain yield of 4079 kg/ha with WCE of 95%. The treatments SSB+ fenoxaprop-p-ethyl (T_1), SSB+ cyhalofop-butyl (T_2), and oxyfluorfen+ hand weeding (T_7) recorded lower yields with higher weed dry matter production.

Straw yield followed the same trend as grain yield. Hand weeding (T_7), SSB+ hand weeding at 45 DAS (T_3) and oxyfluorfen+ hand weeding at 45 DAS (T_6) recorded highest straw yield followed by oxyfluorfen+ fenoxaprop-p-ethyl, and all other treatments were on par with each other except unweeded control. The HI ranged from 0.29-0.42, the highest being in hand weeding, oxyfluorfen+ hand weeding at 45 DAS, SSB+ fenoxaprop-p-ethyl and SSB+ fenoxaprop-p-ethyl, and remaining other treatments were on par except for unweeded control.

The highest N, P and K uptake was in hand weeded treatment (40.07 kg/ha, 4.84 kg/ha and 75.30 kg/ha), SSB+ hand weeding at 45 DAS (39.49 kg/ha, 3.95 kg/ha and 67.64 kg/ha) and oxyfluorfen+ hand weeding at 45 DAS (35.39 kg/ha, 4.81 kg/ha and 64.01 kg/ha), whereas it was lowest in unweeded control.

An analysis of the economics of rice cultivation shows that the treatments SSB+ hand weeding at 45 DAS and oxyfluorfen + hand weeding at 45 DAS registered higher B:C ratio of 1.9 and 1.8 with high returns of Rs.77,803/ha and Rs.71,639/ha respectively. The herbicide combination oxyfluorfen + fenoxaprop–p–ethyl was also good with B:C ratio of 1.8 and net returns of Rs. 64,432/ha.

Conclusion

The results of the experiments on management of *S. interrupta* with different pre-emergence, post-emergence and integrated treatments are concluded as follows:

- Hand weeding was the most efficient method for control of *S. interrupta* at all stages in all the experiments.
- Stale seedbed stood out as one of the best method for efficient control of *S. interrupta* by destroying the soil seed bank. Apart from stale seedbed, pre-emergence application of oxyfluorfen @ 0.15 kg/ha and oxadiargyl @ 0.30 kg/ha can be recommended
- Fenoxaprop-p-ethyl @ 0.060 kg/ha and cyhalofop-butyl @ 0.080 kg/ha can be recommended as best post emergence herbicides for control of *S. interrupta* compared to other treatments, especially in a situation where the weed *S. interrupta* is dominant.
- The best integrated treatments for control of *S. interrupta* were SSB+ hand weeding at 45 DAS or oxyfluorfen @ 0.15 kg/ha + hand weeding at 45 DAS or pre-emergence application of oxyfluorfen @ 0.15 kg/ha *fb* post emergence application of fenoxaprop–p–ethyl @ 0.060 kg/ha.

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Appendix

Appendix- 1

Details of cost of cultivation

Sl.No.	Particulars	Men/ha (Rs. 600/day)	Women/ha (Rs. 600/day)	Amount (Rs./ha)
1	Cleaning the field	-	8	4800/-
2	Ploughing twice) @ Rs. 500/hr			18,000/-
3	Sowing+ basal fertilizer application	3	3	3600/-
4	Herbicide spraying@ Rs. 600/acre	1		1500/-
5	Hand weeding twice		50	30,000/-
6	Plant protection chemical spraying @ Rs. 600/ acre	1		1500/-
7	Fertilizer and top dressing @ Rs. 600/acre	1		1500/-
8	Harvesting		55	33,000/

Appendix- II

Details of cost of inputs

Sl. No.	Particulars	Quantity/ha	Amount (Rs.)
1	Urea@ Rs. 5.7/kg Factom phos @ Rs. 14.8/kg MOP @ Rs. 15.7/kg	120 kg 175 kg 75 kg	684/- 2590/- 1178/-
2	Seed @ Rs. 27/kg	100 kg	2700/-
3	PP chemicals	-	600/-
4	Oxyfluorfen	638 ml	1279/-
5	Pretilachlor	1500 ml	768/-
6	Pendimethalin	5000 ml	2350/-
7	Oxadiargyl	300 g	1956/-
8	Cyhalofop-butyl	800 ml	2400/-
9	Bispyribac sodium	250 ml	1732.5/-
10	Penoxsulam	115.20 ml	25/-
11	Fenoxaprop-p-ethyl	895.5 ml	1271/-
12	Triafamone+ethoxysulfuron	67 g	2500/-
13	Cyhalofop-butyl+penoxsulam	150 g	4170/-

Biology and mangement of *Sacciolepis interrupta* (Willd.) Stapf in rice

By

PUJARI SHOBHA RANI

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ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

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Faculty of Agriculture

Kerala Agricultural University

Department of Agronomy
COLLEGE OF HORTICULTURE
KERALA AGRICULTURAL UNIVERSITY
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA
2020

Abstract

Sacciolepis interrupta is a tropical grass weed which mimics rice crop at early stages of growth and of late has been appearing as a major weed in many rice growing areas. In India, it is reported in rice growing areas of eastern India and Kerala. In Kerala, the occurrence of *S. interrupta* was earlier confined to semi dry rice cultivation in Palakkad districts however, now it has been reported in wet seeded as well as transplanted rice culture in other parts of the State.

Knowledge on biology and ecology of weeds and their interaction with crops play a key role in weed management. The research programme entitled 'Biology and management of *Sacciolepis interrupta* (Willd.) Stapf in rice', included field survey, laboratory, pot culture and field experiments to study the biology, growth, propagation, dormancy and germination requirements of *S. interrupta*. The study assessed the efficacy of different pre and post-emergence herbicides, individually as well as in an integrated manner, so as to develop an effective recommendation for management of *S. interrupta* in direct seeded rice.

Surveys were conducted twice in the major rice tracts of Kerala *viz*., *Kole*, *Kuttanad* and Palakkad. The results of the survey suggested the probability of *S. interrupta* becoming a problem weed in rice tracts of Kerala, and attaining the status of a dominant weed like weedy rice. The density and dominance indices clearly indicated the severity of this weed in the surveyed areas. Based on morphological characters of different morphotypes found in the surveyed areas, *S. interrupta* could be grouped into three groups: A, B and C, which might have evolved as an adaptation to the existing habitat, cultural practices and climatic conditions.

Group A (green variegated) refered to morphotypes from Palakkad with medium stature and narrow light green leaves and having green coloured panicles (4-6 nos./plant), oblong spikelets (311-348 spikelets/panicle), and spikelet length and width varying between 4.6-4.8 mm and 0.9-1.3 mm respectively. Group B (purple variegated) from *Kole* tract, with tall statured plants and narrow dark green leaves,

had purple coloured panicles (4-6 nos./plant), and enlongated spikelets (311-348 spikelets/panicle), with spikelet length of 4.6-4.8 mm and width of about 0.9-1.3 mm. *Kuttanad* tract types were categorized into Group C (green-purple variegated), which were short statured, profuse tillering plants with broad dark green leaves having bicoloured green and purple panicles (6-8 nos./plant), oblong to bulged spikelets (378-391 spikelets/panicle), and short spikelets with length of 4.1-4.5 mm and width of 1.6-1.8 mm.

Sacciolepis interrupta is a C_4, grass weed having fibrous root system, and stems were erect or leaning with creeping or geniculate habit. Nodes were glabrous with roots at lower nodes. Leaves were lanceolate; either glabrous or sparsely pilose. The plant height varied from 70 to 112 cm, and inflorescence was an erect, compact, terminal panicle, about 8 to 30 cm long, of either interrupted or spiciform type. The spikelets were ovate or lanceolate, either green or green with violet variegations and about 2.1 to 4.8 mm long. The flowers of *S. interrupta* were violet or purple or white in colour. The seeds were very small, oval to oblong in shape, light brown to dark brown in colour, and 1000 seed weight varied from 2.2 g to 4.2 g.

Germination studies revealed that seeds of *S. interrupta* were dispersed with high levels of induced dormancy and were able to germinate both in upland as well as flooded conditions. Seed germination was strongly influenced by seasonal variations in temperature and light. Higher temperatures of 33^0C to 38^0C with continuous light of 14 hours triggered germination. Seeds placed on soil surface and at 2 cm depth had higher rate of germination and emergence. Seed longevity studies revealed prolonged seed persistence of upto one year. A persistent seed bank due to secondary dormancy favoured the periodic reappearance of species and increase in the soil seed bank. Different methods of propagation *i.e*., by seeds, culm cuttings and root clumps were observed. High regeneration capacity of different plant parts promoted its survival and spread.

Field experiments were conducted in 2017 and 2019 at Chithali, Palakkad in a farmers' field where the infestation of *Sacciolepis* was very high. Different pre-

and post-emergence herbicides and integrated methods were tested for management of *S. interrupta.*

The pre-emergence herbicide treatments included oxyflourfen, pretilachlor, pendimethalin, oxadiargyl, stale seedbed for 14 days, hand weeding at 20 and 40 DAS, and unweeded control. Hand weeding was the most efficient method for control of *S. interrupta.* Stale seedbed was found to give efficient control of the weed by depleting the soil seed bank. Among pre-emergence herbicides, oxyfluorfen @ 0.15 kg/ha and oxadiargyl @ 0.10 kg/ha were found effective, however, weed control lasted only upto 30 DAS.

The post-emergence treatments included cyhalofop-butyl, bispyribac sodium, penoxsulam, fenoxaprop–p–ethyl, two commericial pre-mix formulations triafamone + ethoxysulfuron and cyhalofop-butyl+ penoxsulam, hand weeding at 20 and 40 DAS, and unweeded control. Fenoxaprop-p-ethyl @ 0.06 kg/ha and cyhalofop-butyl @ 0.08 kg/ha was found to be better post-emergence herbicides, resulting in improved yield attributes and grain yield of 2299 kg/ha and 1983 kg/ha respectively.

Integrated weed management treatments included stale seed bed + fenoxaprop–p–ethyl, stale seed bed + cyhalofop-butyl, stale seed bed + hand weeding, oxyfluorfen + fenoxaprop–p–ethyl, oxyfluorfen + cyhalofop-butyl, oxyfluorfen + hand weeding @ 45 DAS, hand weeding at 20 and 45 DAS and unweeded control. Stale seed bed followed by hand weeding at 45 DAS or pre-emergence application of oxyfluorfen @ 0.15 kg/ha followed by hand weeding at 45 DAS, could be recommended as an integrated method for control of *S. interrupta,* as these treatments gave significantly higher weed control efficiency and resulted in high grain yields and B:C ratios of 4239 kg/ha and 1.9; 4079 kg/ha and 1.8 respectively.

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സംഗ്രഹം

നെല്ലിന്റെ ഒരു പ്രധാന കളയായ പൊള്ളക്കളയുടെ ജീവശാസ്ത്രവും നിയന്ത്രണ മാർഗ്ഗങ്ങളും കണ്ടെത്താനായി 2017 മുതൽ 2019 വരെയുള്ള കാലയളവിൽ വെള്ളാനിക്കര ഹോർട്ടികൾച്ചറൽ കോളേജിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി

ഈ പഠനത്തിൽ പൊള്ളക്കളയുടെ വളർച്ചയും, പ്രജനനവും, വിത്ത് മുളയ്ക്കാനായി വേണ്ടി വരുന്ന അനുയോജ്യ സാഹചര്യങ്ങളും മറ്റും മനസ്സിലാക്കുന്നതിനു വേണ്ടി തൃശ്ശൂർ, കോൾ, കുട്ടനാട്, പാലക്കാട് എന്നിവിടങ്ങളിലെ നെൽപ്പാടങ്ങളിൽ ഒരു സർവ്വേ നടത്തുകയുണ്ടായി. തുടർന്ന് പാലക്കാട് ചിതലി പഞ്ചായത്തിലെ ഒരു കർഷകന്റെ പാടത്ത് പൊള്ളക്കളയെ നിയന്ത്രിക്കുന്നതിനുള്ള നിയന്ത്രണ മികവ് പരീക്ഷിച്ചു പരീക്ഷണം നടത്തി. വിവിധ നിർഗ്ഗമനപൂർവ്വ കളനാശിനികളും നിർഗ്ഗമനോത്തര കളനാശിനികളും തനിച്ചും, അവയെ സംയോജിപ്പിച്ചും, ആണ് പരീക്ഷണങ്ങൾ നടത്തിയത്.

പൊള്ളക്കളയുടെ ഉയരം ഏതാണ്ട് 70 മുതൽ 112 സെ. മീ വരെ ആണ്. കതിരിന് 8 മുതൽ 30 സെ.മീ വരെ നീളം ഉണ്ട്. പൂക്കളുടെ നിറം വൈലറ്റ്/ പർപ്പിൾ അല്ലെങ്കിൽ വെള്ള ആണ്. തവിട്ട് കലർന്ന ചെറിയ ഓവൽ ആകൃതിയുള്ള വിത്തുകളാണ് ഇവയുടേത്. വിത്ത് വെള്ളക്കെട്ടുള്ള സ്ഥലങ്ങളിലും ഉയർന്ന പ്രദേശങ്ങളിലും മുളയ്ക്കുന്നതായി കണ്ടു. വിത്തുകൾ കൂടാതെ തണ്ടുകൾ വഴിയും വേരിൻ കഷണങ്ങളിലൂടെയും പ്രജനനം നടക്കുന്നുണ്ട്.

പൊള്ളക്കളയുടെ നിയന്ത്രണത്തിന് നെല്ല് വിതച്ച് 3 ദിവസത്തിനുള്ളിൽ ഓക്സിഫ്ലൂർഫെൻ @ 0.15 കി.ഗ്രാം/ ഹെക്ടർ, ഓക്സാഡൈയാർജിൽ @ 0.30 കി.ഗ്രാം/ഹെക്ടർ എന്നീ നിർഗ്ഗമനപൂർവ്വ കളനാശിനികൾ തളിക്കുന്നത് ഫലപ്രദമാണെന്ന് കണ്ടെത്തി. നിർഗ്ഗമനോത്തര കളനാശിനികളിൽ ഫെനോക് സാപ്രോപ്പ്. പി. ഈതൈൽ @ 0.06 കി.ഗ്രാം/ഹെക്ടർ അല്ലെങ്കിൽ സൈഹാലോഫോപ് ബ്യൂട്ടൈൽ @ 0.08 കി.ഗ്രാം/ഹെക്ടർ പൊള്ളക്കളയ്ക്കു

എതിരെ ഏറ്റവും ഫലപ്രദമാണെന്ന് കണ്ടെത്തി. നെല്ല് വിതച്ച് 15 മുതൽ 20 ദിവസത്തിനുള്ളിൽ നിർഗ്ഗമനോത്തര കള നാശിനികൾ തളിക്കണം

സംയോജിത കളനിയന്ത്രണ മാർഗ്ഗങ്ങളിൽ സ്റ്റെയ്ൽ സീഡ്ബെഡ് (കളകൾ മുളയ്ക്കാനനുവദിച്ചശേഷം നശിപ്പിക്കുന്ന രീതി) അവലംബിച്ചശേഷം നാല്പത്തിയഞ്ചാം ദിവസം കള കൈ കൊണ്ട് നീക്കുകയോ അല്ലെങ്കിൽ നിർഗ്ഗമനപൂർവ്വ കളനാശിനിയായ ഓക്സിഫ്ലൂർഫെൻ @ 0.15 കി.ഗ്രാം/ഹെക്ടർ പ്രയോഗത്തിനുശേഷം, നാല്പത്തിയഞ്ചാം ദിവസം കള പറിച്ചു നീക്കുകയോ ചെയ്യുന്നത് പൊള്ളക്കളയെ നിയന്ത്രിക്കുന്നതിന് ഫലപ്രദമാണെന്ന് കണ്ടെത്തി.