WEED MANAGEMENT IN UPLAND RICE (*Oryza sativa* L.) INTERCROPPED IN COCONUT

By

RAVIKIRAN
(2016-11-121)

THESIS

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To

My

Beloved Guide

Dr. Elizabeth K Syriac

DECLARATION

I, hereby declare that this thesis entitled **"WEED MANAGEMENT IN UPLAND RICE (*Oryza sativa* L.) INTERCROPPED IN COCONUT"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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LIST OF ABBREVIATIONS

Ad	Absolute density
ALS	Acetolactate synthase
ANOVA	Analysis of variance
BCR	Benefit cost ratio
BLW	Broad leaved weeds
CD	Critical difference
CFU	Colony forming units
cm	Centimetre
DAHA	Days after herbicide application
DAS	Days after sowing
DAT	Days after transplanting
DMP	Dry matter production
DSR	Direct seeded rice
dS m^{-1}	Decisiemens per metre
day^{-1}	Per day
EC	Electrical Conductivity
et al.	Co-workers or Co-authors
FAO	Food and Agriculture Organization
Fb	Followed by
FYM	Farmyard manure
Fig.	Figure
g	Gram

ha	Hectare
HI	Harvest index
HWT	Hand weeding twice
i.e.	That is
IIRR	Indian Institute of Rice Research
JBHA	Just before herbicide application
K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
L	Litre
LD	Lethal dose
LAI	Leaf area index
m	Metre
m^2	Square metre
mg	Milligram
mm	Millimeter
mL	Millilitre
M ha	Million hectare
M t	Million tonnes
MSL	Mean sea level
N	Nitrogen
NS	Non significant

No.	Number
P	Phosphorus
pH	Potenz hydrogen
$Panicle^{-1}$	Per panicle
POP	Package of Practices
RBD	Randomized Block Design
Rd	Relative density
RH	Relative humidity
₹ ha^{-1}	Rupees per hectare
SEm	Standard error of means
Spp.	Species
TRF	Triphenyl formazon
t ha^{-1}	Tonnes per hectare
var.	Variety
WCE	Weed control efficiency
WDWC	Weed dry weight in control plot
WDWT	Weed dry weight in treated plot

LIST OF SYMBOLS

°C	Degree Celsius
@	At the rate of
%	Per cent
₹	Rupees
μ	Micro

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.), is the principal food for more than 50 per cent people and contributes about one-fifth to the total calories consumption of the world (Singh *et al.*, 2012). Globally, rice crop occupies 158 million ha of arable land. The production and productivity of rice is 744.9 M t and 4.71 t ha^{-1}, respectively (FAO, 2014). Asia alone accounts for over 90 per cent of global rice production and consumption. To meet food and nutritional requirements, the projected demand for rice by 2030 has been estimated at 904 M t for world and 824 M t for Asian region (Kubo and Purevdroj, 2004). India alone would require about 156 M t of rice by the year 2030 at annual increment of 3 M t in the current rice production (Dass *et al.*, 2016).

Rice is commonly grown either by transplanting or by direct seeding. In transplanted rice, where land is puddled and three to four weeks old seedlings are transplanted. Transplanted rice have advantages of reducing weed population, enhancing nutrient uptake by creating anaerobic condition, facilitate transplanting and easy seedling establishment. But it adversely affects soil physical properties by dismantling soil aggregates, forming hard pans at shallow depths which hinders the root development of non-rice crop grown in rice based cropping system and greater emission of methane gas in atmosphere contributing global warming and urged for alternative methods.

Direct seeded rice (DSR) offers certain advantages like labour savings, timely sowing, less drudgery, early crop maturity by 7-10 days, less water requirement, high tolerance to water deficit, low production cost, less methane emission and also preserves natural resources especially ground water and maintains physical properties of soil. Hence, direct seeding instead of conventional transplanting is gaining momentum in India. Water scarcity is becoming severe in many rice growing areas in the world, but introduction of DSR can reduce water use in rice production. For increasing area under rice in Kerala the most viable option is to popularize its cultivation in uplands mainly as intercrop of coconut. Rice and Maize are the two cereal crops recommended for intercropping in coconut gardens (KAU, 2016). In DSR, weed and crop seeds germinate at the same time resulting in greater competition for space, light, moisture and nutrients from early stage of crop growth which brings down the yield drastically.

Weed management is an important aspect for obtaining higher crop yield as weeds are silent, malignant and massive forces, which reduce yield drastically. Traditional methods of weed management practices like hand weeding or pulling by sickle are widely adopted for control of weeds in rice. These practices are tedious, time consuming, labour intensive, costly and not possible to practice over an extensive area. Chemical weed control is more economical, less time consuming, less expensive and provides early weed control and crop establishes in weed free environment.

Powles and Yu (2010) found that indiscriminate use of herbicides is driving agro-ecosystems toward declining species diversity and in many situations, leading to herbicide resistance. Currently available rice herbicides have a low efficacy and narrow spectrum of activity when they are used alone (Singh, 2008; Chauhan, 2012). New generations herbicides which are applied at very low doses are more effective in controlling all category weeds and these herbicides are less toxic to mammals and reduced risk of environmental pollution.

Season-long and sustainable weed control can't be achieved by the use of any single weed management approach because of variation in dormancy and growth habits of weeds (Chauhan, 2012). So integration of weed management approaches is necessary to achieve effective, sustainable and long-term weed control in upland rice. Stale seedbed (SSB) is a preventive weed control method based on the principle of flushing out germinal weed seeds prior to the planting of the crop, depleting the seed bank in the surface layer of soil which reduces weed pressure during crop period. Adoption of SSB reduces the weed infestation and improves the efficacy of other weed management methods. The combination of chemical and cultural or physical control measures (Pendimethalin followed by (fb) manual weeding and pendimethalin fb bispyribac sodium fb manual weeding) has proved better for obtaining higher growth and yield from rice than the application of chemical herbicides, cultural and mechanical control alone (Shendage *et al.*, 2107).

With this background, the present study was carried out with the following objective:

- To standardise an eco-friendly and economic weed management strategy for upland rice intercropped in coconut.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Rice (*Oryza sativa* L.), the primary source of food for more than half of the world's population and is regarded as the world's most important food crop. In the traditional system of rice cultivation, rice seedlings are transplanted into puddled soil. Soil is puddled through intensive tillage and it requires water and labour for cultivation and transplanting. Upland rice offers many advantages *viz.*, saves labour, less water requirement, low production cost, more profit besides less methane emission and maintenance of soil structure. Despite, several advantages, the major production obstacle encountered in upland rice cultivation is severe weed infestation and these weeds compete with rice for all inputs. The use of herbicides alone may not provide effective and season-long weed control. Hence, an attempt has been made to devise the weed management strategy through integration of ecological, physical and chemical method of weed control in rainfed upland rice.

In this chapter, a detailed review of research work done on weed management in rice with emphasis on upland rice is presented.

2.1. UPLAND RICE ECO-SYSTEM

Upland rice (*Oryza sativa* L.) constitutes 17 per cent area under rice in India. Upland rice can be grown in diverse systems, ranging from shifting cultivation to relatively intensive systems, utilizing animal or mechanized tillage and rotations with other crops such as cotton, legumes and other cereals (De Datta, 1981). Transplanted rice system is labour, water and energy intensive and is becoming less profitable as these resources are increasingly scarce. Upland rice showed promise under several ecologies and production systems to overcome these challenges, and is considered as a potential way to conventional rice production system.

About 11-18 per cent irrigation water can be saved through direct seeded rice (DSR) (Tabbal *et al.,* 2002) and reduces total labour requirement of 11-66 per cent compared to puddled transplanted rice, depending on location, season and type of DSR practiced (Kumar *et al.*, 2009; Rashid *et al.*, 2009).

Upland rice can be grown on both flat and slopy fields which are not bunded, but are prepared and seeded under dry conditions and depending upon rainfall (De Datta and Feuer, 1975; Fageria *et al.*, 1997).

2.2. WEED FLORA IN RICE

Weeds are diverse in their composition and competition depends on soil, climate, cropping system and management factors. Moody (1990) reported that the number of weed species present in a field largely depends on the associated environment and cropping systems. According to Mahajan *et al.* (2009), aerobic rice systems are infested by a number of weed species.

Mishra *et al.* (2006) observed 24 different species of weeds belonging to 11 families in upland rice. Among them, *Digitaria ciliaris, Cyperus esculentus, Cyperus rotundus, Sporobolus diander, Eleusine indica, Cynodon dactylon, Echinocloa colona* and *Paspalum scrobiculatum* were monocot weeds and *Oldenlandia corymbosa, Ludwigia parviflora, Ageratum conyzoides, Borreria hispida, Celosia argentea, Eclipta alba, Cleome viscosa* and *Commelina benghalensis* were dicot weeds.

The weed flora comprised of *Ipomoea maxima, Digera arvensis, Convolvulus arvensis, Parthenium hysterophorus, Cynodon dactylon, Acalypha indica, Brachiaria eruciformis, Dinebra retroflexa, Euphorbia geniculate, Amischophacelus cuculata* and *Heteropogon contortus* were predominant in upland rice (Jadhav, 2013).

In another study, Singh *et al.* (2016) observed that *Echinochloa colona, Alternanthera sessilis, Panicum maximum, Cyperus rotundus, Leptochloa chinensis, Eleusine indica* (L.), *Caesulia axillaris, Commelina benghalensis, Ischaemum* *rugosum, Trianthema monogyna, Phyllanthus niruri, Paspalum distichum*and *Digitaria sanguinalis* were the most predominant weeds in dry-seeded rice.

Grassy weeds contribute 78-96 per cent to the total weed biomass in an aerobic rice field (Singh *et al.*, 2008). Madhukumar *et al.* (2013) observed that the predominant weed flora in the experimental field of upland rice included broad leaved weeds (BLW) like *Commelina benghalensis, Ageratum conyzoides, Mollugo disticha, Spilanthus acmella, Phyllanthus niruri, Acanthospermum hispidum, Protulaca oleracea, Cynotis axillaries, Stachytarpheta indica, Celosia argentea, Parthenium hysterophorus* and *Aeschynomene indica.* Among grasses, *Echinochloa colona, Digitaria marginata, Chloris barbata, Eleusine indica, Dactyloctenium aegyptium* and *Cynodon dactylon* were predominant and among sedges, *Cyperus rotundus.*

The weeds *Echinochloa crus-galli, Echinochloa colona, Dactyloctenium aegyptium, Leptochloa chinensis, Elusine indica, Cyperus rotundus, C. iria, Trianthema portulacastrum, Ipomoea aquatica* and *Portulaca oleracea* were identified in DSR (Khaliq *et al.*, 2012). Mahajan *et al.* (2014) identified the major weed flora present in dry DSR as *Alternanthera sessilis* (L.), *Digera arvensis*, *Echinochloa colona*, *Leptochloa chinensis*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Cyperus rotundus*, *Cyperus iria* L., *Commelina benghalensis*, and *Eragrostis* spp.

The major grass weeds observed in aerobic rice were *Eleusine indica, Echinocloa colona, Cynodon dactylon* and the BLW were *Alternanthera sessillis, Commelina benghalensis* L., *Eclipta alba* L., *Ipomoea purpurea, Physalis minima, Corchorus aestuans, Cyanotis cristata, Bacopa monnieri, Phyllanthus niruri* and *Ageratum conyzoides* and sedge was *Cyperus rotundus* (Prashanthi *et al.*, 2017).

Echinochloa crusgalli and *Echinochloa stagnina* among the grass weeds; *Cyperus iria* and *Fimbristylis miliacea* among the sedges; *Lindernia crustacea,* *Ludwigia perennis* and *Sphenoclea zeylanica* among the BLW were reported to be the major weed flora (Sindhu *et al.*, 2010). The major weed flora infesting the dry DSR were *Cynodon dactylon, Cyperus rotundus, Cyperus iria, Echinochloa crusgalli, Echinochloa colona, Fimbristylis dichotoma, Palantus nirui* (Bhurer *et al.*, 2013). Mutumba and Odongo (2015) reported that more weed species diversity was observed in upland rice fields compared to lowland rice fields and BLW and grasses were dominant compared to sedges.

2.3. CRITICAL PERIOD OF CROP WEED COMPETITION

The critical period for weed control is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses (Zimdahal 1988). According to Knezevic *et al.* (2002), the critical period of weed control is an intermission in the crop growth period which must be kept weed free to prevent yield loss. Singh *et al.* (2008) reported that the critical period of crop weed competition for DSR is longer *i.e.*, 15-45 DAS (days after sowing). Heavy crop-weed competition causes low productivity of DSR because of early emergence of weeds along with crop seedling and their rapid growth results in severe competition for resource like space, nutrients and light (Brar and Bhullar, 2013).

In DSR, weed infestation is severe and is one of the serious limiting factors in realizing the yield potential (Rao *et al.*, 2007). The rice and weeds have similar requirements of resources for their growth and development (Chauhan *et al.*, 2014).

Bahar and Singh (2004) reported that in dry seeded rice, weed emergence was the highest during 30 days of crop growth (84.6%). According to Das *et al.* (2017), the competition among weeds and rice is more serious when the rice weeds characters like root system, morphology and growth habits resemble to rice plants. The crop's competitiveness against weeds was positively correlated with the crop attributes like, early canopy coverage, higher value of leaf area index (LAI), higher growth of root in terms of dry root weight, volume and length and competitiveness against weeds.

The rice plant height and dry matter production was reduced by high weed density and more weed competition (Suja and Abraham, 1991). Effective weed control upto 45 days after emergence of rice crop was necessary in the fields with high weed densities (Zhang *et al.*, 2003)

Ampong-Nyarko and De Datta (1991) reported that the relative competitive ability of annual and perennial weeds depend on the weed species and method of rice cultivation. In DSR, weed management up to 40 DAS is essential to reduce the weed competition for light, nutrient and water (Johnson, 1996). Prasuna and Rammohan (2015) reported that in aerobic rice, weed infestation and competition are more compared to transplanted rice due to simultaneous emergence of rice seedling and weeds.

2.4. WEED MANAGEMENT

Weeds reduce rice yield by competing with rice for moisture, nutrients and light. Productivity of rice crop is mainly determined by planting time, location specific variety and weed control methods. Weed management is essential for economical rice production.

2.4.1. Non Chemical Weed Management

2.4.1.1 Hand Weeding (HW)

Hand weeding is one of the traditional method of weed control, HW is still effective in controlling weeds in rice crop. According to Rao *et al.* (2007), in DSR system, HW is more expensive than herbicides for weed control. Hand weeding is the most efficient weed control method if weed infestation is less and labour expenditures are normal (Beltran *et al.*, 2012).

Singh *et al.* (2009) reported that complete weed control in aerobic rice system requires more than 100 man-days ha^{-1} in one growing season. Maity and Mukherjee (2011) reported that in dry DSR, HW at 15, 30 and 50 DAS recorded higher WCE of

97.07 per cent, lower weed index of 2.75 per cent and higher grain yield of 3.45 kg ha^{-1}. Akbar *et al.* (2011) reported that in aerobic rice system, performing HW three times (4, 6 and 8 weeks after sowing) during the crop season reduced weed infestation by 95 per cent and increased grain yield by 30 per cent over the unweeded control.

Verma *et al.* (2004) revealed that in DSR, HW at 20 and 40 DAS recorded lower weed population (15.2 m^{-2}), lower weed dry weight (2.05 t ha^{-1}), higher WCE of 90.6 per cent and higher grain yield of 3.66 t ha^{-1}. Three HW at 2, 4 and 6 weeks after sowing in aerobic rice decreased weed density by 90 per cent and increased grain yield by 77 per cent (Mubeen *et al.*, 2014).

2.4.1.2 Stale Seedbed (SSB) Method

According to Hill *et al.* (2006), stale seedbed is a classical preventive weed control technique in which the soil is cultivated three to six weeks before sowing of crop, thus providing weed seeds a favorable environment for germination. Also, in response to cultivation, a number of seeds are brought to the soil surface. Irrigation of soil before and after cultivation for preparing the SSB enhances germination of weed seeds. The germinated weeds are then killed by employing tillage or a non-selective herbicide. Stale seedbed method reduced the weed seed bank in the top layer of soil by enhancing weeds to germinate and subsequent killing by manual tillage (Marahatta *et al.*, 2017).

Stale seedbed is based on the principle of flushing out germinal weed seeds prior to the planting of the crop, depleting the seed bank in the surface layer of soil thus causing reduction of subsequent weed seedling emergence. High rice yield can be attained if SSB weed control method is combined with other weed management practices, especially with herbicides (Jordan and Bollich, 2002).

The SSB method can be helpful in lowering weed infestation in order to improve the efficacy of other weed control methods. Stale seed bed is a no-cost weed control, productivity facilitating system in lowland rice (John and Mathew, 2001). For the success of SSB method, seedbed preparation, water management and duration of SSB are the important factor to be considered (Azmi and Johnson, 2001). Relatively higher number of grains panicle^{-1}, grain and straw yield, lower sterility and higher harvest index were observed in SSB than normal seedbed.

Pandey *et al.* (2009) reported that the lower number and dry weight of weeds, higher grain yield and net returns were recorded under SSB compared to traditional seedbed preparation. Sindhu *et al.* (2010) revealed that SSB with paraquat resulted in reduced weed density compared with SSB with hoeing and in terms of grain yield, straw yield and uptake of nutrients also the SSB treatments were superior to normal sowing.

Stale seedbed treatments resulted in reduction of weedy rice plant density to the tune of 39.83 per cent to 63.72 per cent during first year and 58.27 to 76.99 per cent during second year in wet DSR (Ameena, 2015). According to Chen (2001), SSB technique is an efficient method to manage weedy rice. Chaudhary *et al.* (2006) reported that the energy utilization for HW practice in rice crop was found lower under SSB (690 MJ ha^{-1}) than traditional seedbed (925 MJ ha^{-1}). According to Bhurer *et al.* (2013), stale seed bed fb pendimethalin 30 EC @1 kg ha^{-1} fb bispyribac @ 25 g ha^{-1} at 20 DAS was the best alternative for manual HW practices giving higher net return per unit investment.

2.4.2. Chemical Weed Management

Chemical weed control in DSR become more popular because of more weed infestation and labour problem for timely HW practice. Chauhan (2012) reported that use of herbicide in DSR is very necessary because of the simultaneous emergence of weed and rice seedling and weeds like *Echinochloa* spp. are morphologically similar to rice seedling.

Herbicide usage become limited in DSR as it cause phytotoxicity to rice because simultaneous emergence of weeds and rice seedling (De Datta and Bernasor, 1973).

According to Singh *et al.* (2006), sequential use of herbicides or the application of herbicide mixture was very effective in controlling complex weed flora and for increased grain yield in dry seeded rice. Chemical weed control play an important role in reducing weed pressure in upland rice especially when it is combined with other weed management methods and application of single PE or post emergence (PoE) herbicide may not provide effective and efficient control of weeds because of complex weed flora in DSR (Mahajan *et al.*, 2013).

2.4.2.1. Post Emergence Herbicides (PoE)

Continuous use of PE herbicides in high dose causes shift in weed flora and long persistence in soil causing herbicide resistance in weeds (Singh *et al.*, 2009). According to Mahajan *et al.* (2013), PE herbicides are usually applied within 3 DAS, limiting the application time window and soil moisture decides the efficacy of herbicides. Hence, it is necessary to use PoE herbicide for effective weed management in DSR.

2.4.2.2. Penoxsulam

Penoxsulam is a post emergence herbicide belonging to triazolopyrimidine sulfonamide group. It's mode of action is inhibiting acetolactate synthase (ALS) enzyme in susceptible species. It is absorbed through leaves, shoots and roots and translocated to meristematic tissues in plants (Kogan *et al.*, 2011; Hamel. 2012).

Penoxsulam is a broad spectrum herbicide which is effective against BLW, grasses and sedges (Jabusch and Tjeerdema, 2005). Kaur *et al.* (2017) revealed that in soil and water, half-life of penoxsulam at 20, 25 and 30 g ha^{-1} ranged from 6.40-7.88 days and 3.40-5.12 days, respectively and also reported that herbicide residues in soil, rice grain and straw at harvest were below the maximum residue limit of 0.01 $\mu g\ g^{-1}$.

Application of penoxsulam resulted in 99 per cent and 97 per cent control of *Echinochloa crusgalli* and *Brachiaria platphyalla* (Ottis *et al.*, 2003). Application of penoxsulam @ 25 g ha^{-1} at 0-5 DAT was found effective in controlling all categories of weeds and recorded the lowest biomass (7.3 g m^{-2} and 10.6 g m^{-2}), lower weed index (5.0% and 7.4%), higher WCE (59.8% and 76%) and higher grain yield (6.1 and 5.8 t ha^{-1}) in 2006 and 2007, respectively (Prakash *et al.*, 2013). Also they concluded that penoxsulam @ 25 g ha^{-1} applied at 0-5 DAT can be recommended to replace tedious and expensive HW practice of weed control in rice.

According to Khaliq *et al.* (2014), the treatment penoxsulam fb fenoxaprop recorded the lowest weed density and weed dry weight. Saranaraj *et al.* (2017) reported that penoxsulam 21.7 per cent SC applied at different doses have not shown any phytotoxic symptoms on rice crop and use of penoxsulam in rice is completely safe. They also revealed that application of penoxsulam @ 22.5 g ha^{-1} recorded higher WCE of 95.81 per cent and grain yield of 5.04 t ha^{-1} and application of penoxsulam fb pretilachlor resulted in effective control of *Echinochloa crusgalli* and *Echinochloa colona*.

According to Singh *et al.* (2015), the synergistic effect of tank mix application of penoxsulam + cyhalofop-butyl (150 g ha^{-1}) along with insectides (chloropyriphos @ 125 g ha^{-1}), fungicide (carbendazim @ 125 g ha^{-1}) and fertilizer (urea @ 2%) in the weed control was confirmed as these could reduce the weed dry weight by 85.00, 82.40 and 82.80 per cent, respectively. Sanodiya and Singh (2017) observed lower weed density of all species and weed biomass and higher WCE were recorded with penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS.

Prakash *et al.* (2013) reported that application penoxsulam 24 SC @ 25 g ha^{-1} at 0-5 DAT was most efficient to control different types of weeds and their growth and recorded the lowest weed dry weight, weed persistence index and weed index, and the highest grain yield and straw yield and the highest herbicidal efficiency index. They also concluded that penoxsulam 24 SC @ 25 g ha^{-1} applied at 0-5 DAT may be recommended to replace the laborious, time consuming and expensive HW practices of weed management in transplanted *Kharif* rice. Penoxsulam 22.5 g ha^{-1} fb one HW at 35 DAS recorded lower density of grasses, broad-leaved weeds and sedges at 60 DAS and higher WCE and it could be recommended for effective weed management and higher yield in dry direct seeded rice (Netam *et al.*, 2018).

Sequential application of oxadiargyl @ 100 g ha^{-1} fb application of penoxsulam @ 25 g ha^{-1} resulted in the lowest density, weeds dry weight and higher WCE of 86 per cent and grain yield in wet seeded rice (Sairamesh *et al.*, 2015). Saranraj *et al.* (2018) reported that PE application of penoxsulam @ 22.5 g ha^{-1} + HW 30 DAT recorded the highest WCE, grain yield and lower weed index and also revealed that penoxsulam applied at different dosages (20, 22.5, 25, 27.5 and 50 g ha^{-1}) did not any residual effect on germination, growth and yield of succeeding green gram crop.

Pal *et al.* (2009) concluded that to replace the tedious and expensive HW practice of weed control in transplanted rice, application of penoxsulam 24 SC @ 22.5 g ha^{-1} at 8-12 DAT can be recommended which was effective to control all category of weeds and recorded higher grain yield. Post emergence application of penoxsulam @ 25 g ha^{-1} controlled weeds effectively and resulted in significantly lower density, dry weight of weeds and higher WCE of 84.34 per cent and higher number of panicles m^{-2}, grains $panicles^{-1}$, thousand grain weight and grain yield (Singh *et al.*, 2016).

Application of PoE herbicide penoxsulam 24 SC @ 25 g ha^{-1} was found effective to check dry weight and density of all kind of weeds and resulted in higher grain yield (Khare *et al.*, 2014). Penoxsulam @ 22.5 g ha^{-1} recorded the lowest weed density, weed dry matter and the highest grain yield and it could be recommended for effective and economic weed management in transplanted rice (Sasna *et al.*, 2016).

Echinochloa colona was completely controlled by penoxsulam @ 22.5 g ha^{-1} (Pratap *et al.*, 2016).

Singh *et al.* (2015) found that compatibility of penoxsulam + cyhalofop-butyl with carbendazim @ 150 + 125g ha^{-1} was found more effective to reduce the density of *E. colona* and *P. maxicum*. Pratap *et al.* (2016) concluded that application of post-emergence herbicide penoxsulam + cyhalofop-butyl @ 135 g ha^{-1} was found effective in controlling weeds with the highest WCE and higher grain yield.

According to Menon *et al.* (2016), PoE herbicide penoxsulam + cyahalofop was effective against *Echinochloa spp.* Singh *et al.* (2016) reported that penoxsulam + cyhalofop-butyl recorded very low weed biomass of 76 per cent and 86 per cent and highest tiller production of 84 per cent and 130 per cent than the weedy check in 2010 and 2011, respectively and they concluded that penoxsulam + cyhalofop-butyl was the best treatment, which recorded the lower weed dry weight, higher number of tiller and grain yield.

2.4.2.3. Metsulfuron methyl + Chlorimuron ethyl

Metsulfuron methyl + chlorimuron ethyl is a post emergent herbicide belonging to sulfonyurea group, very effective for controlling BLW and sedges. Singh *et al.* (2016) reported that efficiently weed control with 100 per cent control of *C. rotundus* with either pyrazosulfuron fb fenoxaprop or metsulfuron methyl + chlorimuron ethyl.

Metsulfuroon methyl + chlorimuron ethyl recorded the lowest density of sedges and non-grassy weeds compared to application of butachlor alone, anilofos and pretilachlor (Singh *et al.*, 2004). Sah *et al.* (2012) revealed that sequential application of metsulfuron methyl + chlrimuron ethyl (25 g ha^{-1}) fb 2, 4- D (0.5 kg ha^{-1}) at 20 DAT recorded higher grain yield. Koushik *et al.* (2013) reported that the lowest weed density and weed dry matter and the highest WCE were recorded with metsulfuron methyl + chlorimuron ethyl.

Application of post-emergent chlorimuron ethyl @ 9 g and 12 g ha^{-1} significantly reduced the population of *Cyperus rotundus* (Dubey *et al.*, 2000). Application of metsulfuron methyl + chlorimuron ethyl @ 15 g ha^{-1} + 2, 4-D @ 0.5 kg ha^{-1} at 8 DAT was found effective in controlling weeds and maximizing grain yield (Mukherjee and Singh, 2004). In transplanted rice, higher WCE and grain yield were registered by the application of butachlor @ 1.0 kg ha^{-1} at 3 DAT fb metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20 DAT compared with season long weed free condition (Mukherjee and Maity. 2011). Application of pendimethalin @ 0.75 kg ha^{-1} at 3-5 DAS fb PoE metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 20-25 DAS resulted in effective control of weeds and produced higher grain yield (Hemalatha *et al.*, 2017).

Singh and Tewari (2005) reported that application of metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} was found effective in controlling BLW and sedges. Pre-emergence (PE) application of pretilachlor @ 500 g ha^{-1} at 3 DAS fb metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 21 DAS fb HW at 35 DAS effectively managed all category of weeds in aerobic rice (Singh *et al.*, 2008). Application of pendimethalin @ 1 kg ha^{-1} fb bispyribac-sodium @ 25 g ha^{-1} and chlorimuron-ethyl + metsulfuron-methyl @ 4 g ha^{-1} recorded lower density of *E. glabrescens*, *Cyperus* spp. and *Ammania* spp and the highest WCE at 45 DAS and the highest number of productive tillers, filled grains panicle^{-1} and grain yield (Singh *et al.*, 2017).

Menon *et al.* (2016) reported that application of bispyribac-sodium @ 25 g ha^{-1} + premix of chlorimuron-ethyl and metsulfuron-methyl @ 4 g ha^{-1} at 25 DAT recorded the lowest dry matter production of weed and highest WCE and grain yield in rice. They also reported that *Ludwigia parviflora* was effectively controlled by chlorimuron-ethyl + metsulfuron-methyl in combination with other herbicides.

The highest net income and benefit: cost ratio were observed in sequential application of butachlor at 2 DAS and metsulfuron-methyl + chlorimuron-ehtyl at 21

DAS (Gopinath and Kundu, 2008). For controlling complex weed flora and increasing productivity and profitability of transplanted rice, post-emergence tank-mix application of bispyribac-sodium with pre-mix metsulfuron methyl + cholrimuron ethyl could be recommended (Kaur *et al.*, 2016). Kaur *et al.* (2017) concluded that application of metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} recorded effective control of BLW and sedges in transplanted rice and significantly higher grain yield of 7.31 t ha^{-1}.

2.5. EFFECT OF HERBICIDES ON GROWTH ATTRIBUTES

Significantly higher plant height, dry matter accumulation, number of tillers m^{-2}, crop growth rate and LAI were recorded in stale seedbed using glyphosate @ 1 kg ha^{-1}, compared to SSB using shallow tillage (Singh, 2013). Application of penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS recorded higher plant height, number of tillers m^{-2}, dry matter accumulation, LAI and chlorophyll content in upland rice (Sanodiya and Singh, 2017). Significantly higher plant height, no. of tillers hill^{-1}, dry matter accumulation and LAI were recorded with penoxsulam @ 22.5 g ha^{-1} fb one HW (Netam *et al.*, 2018).

Hand weeding at 15 and 30 DAS had significantly better performance of growth attributes *i.e.*, dry matter production, number of tillers m^{-2} and LAI compared to herbicidal treatments *viz.*, butachlor + 2,4-D, pendimethalin + 2,4-D and fenoxaprop-p-ethyl + ethoxysulfuron (Singh and Singh, 2012). Prasuna and Rammohan (2015) observed that pretilachlor @ 0.75 kg ha^{-1} and pendimethalin @ 1.00 kg ha^{-1} fb bispyribac sodium @ 35 g ha^{-1} at 20 DAS recorded higher values of number of tillers, plant height and LAI.

Application of pre-emergence herbicide butachlor @ 1.5 kg ha^{-1} + HW registered higher plant height and plant dry weight in transplanted rice indicating the significance of a follow up HW treatment (Rekha *et al.*, 2002). Application of pretilachlor @ 750 g ha^{-1} recorded higher plant height at maturity (Payman and Singh, 2008). Application of pre-emergence herbicide bensulfuron methyl + pretilachlor @ 60 g + 600 g ha^{-1} recorded significantly higher plant height and was on par with two HW at 20 and 40 DAS and oxyfluorfen @ 90 g ha^{-1} at 3 DAS + 2, 4-D as post-emergence at @ 500 g ha^{-1} at 25 DAS (Madhukumar *et al.*, 2013).

2.6. EFFECT OF HERBICIDES ON YIELD ATTRIBUTES, YIELD AND WEED INDEX

Rajendran and Kempuchetty (1999) reported that application of pretilachlor @ 0.3 kg ha^{-1} fb HW at 25 DAS recorded the highest number of panicles. Application of butachlor @ 1 kg ha^{-1} fb clomazone @ 0.15 kg ha^{-1} + @ propanil 0.30 kg ha^{-1} recorded significantly higher grain yield (2.6 t ha^{-1}) in upland rice (Mishra *et al.*, 2006). Significantly higher number of panicles m^{-2} was recorded with the application of pendimethalin @ 1.0 kg ha^{-1} fb HW at 30 DAS compared to weedy check in direct seeded semi-dry rice (Rao *et al.*, 2008).

Application of penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS registered higher panicle length, panicle weight (g panicle^{-1}), panicle number m^{-2}, number of grains panicle^{-1}, test weight and grain yield and the lowest weed index (Sanodiya and Singh, 2017). Netam *et al.* (2018) reported that application penoxsulam @ 22.5 g ha^{-1} at 2-3 leaf stage of weeds fb one HW at 35 DAS recorded significantly higher thousand grain weight, number of panicles hill^{-1}, number of grains panicle^{-1} and grain yield.

Significantly higher number of productive tillers was observed with the application of bensulfuron methyl + pretilachlor @ 60 g + 600 g ha^{-1} + one intercultivation at 40 DAS in aerobic rice (Sunil *et al.*, 2010). Stale seedbed method recorded significant higher number of productive tillers and percentage of filled grains (Renu *et al.*, 2000). Application of pre-emergence herbicide bensulfuron methyl + pretilachlor @ 60 g + 600 g ha^{-1}recorded significantly higher number of productive tillers in aerobic rice (Madhukumar *et al.*, 2013).

Yield attributes *viz.*, panicles m^{-2}, grains $panicle^{-1}$ and thousand grain weight were significantly influenced by adoption of different weed control methods (Singh *et al.*, 2013). Penoxsulam + cyhalofop-butyl with urea 2 per cent at @ 150 + 125 g ha^{-1} was found compatible and recorded maximum grain yield (Singh *et al.*, 2015).

The lowest weed dry weight and the highest grain yield was observed with pre-emergence application of pendimethalin @ 1 kg ha^{-1} fb HW at 30 DAS in direct seeded semi dry rice (Rao *et al.*, 2008). Pre-emergence application of pendimethalin 0.75 kg ha^{-1} fb PoE application of bispyribac sodium @ 20 g ha^{-1} registered significantly higher rice grain yield (Walia *et al.*, 2008). Singh *et al.* (2016) reported that sequential application of pendimethalin as PE fb bispyribac sodium + azimsulfuron as PoE recorded the highest grain yield of 3.43 t ha^{-1}, maximum number of effective tillers m^{-2} (375), emphasizing the significance of the follow up application of PoE herbicides after an early PoE herbicide.

Yield loss due to weed infestation as indicated by weed index depends on several factors like weed species, weed density, growth rate, rice cultivars, management practices and rice ecosystem. Yield loss due to weeds in rice can be expressed not only in quantity of rice harvest but also in decreased quality of grain.

Okafor and De datta (1976) reported that *C. rotudus* was the predominant weed, with a potential of 50 per cent yield reduction in DSR. Weed infestation reduced the grain yield by 68-100 per cent for DSR, 22-36 per cent for modern *'boro'* rice and 16-48 per cent for transplanted '*aman*' rice (Mamun *et al.*, 1993). Weed infestation is one of the serious problem affecting productivity in DSR, leading to more than 50 per cent yield loss (Singh *et al.*, 2000). Madhukumar *et al.* (2013) reported that yield loss was to the extent of 91.70 per cent due to crop-weed competition in aerobic rice.

Yield reduction due to weed infestation vary from 50-60 per cent and sometimes it results in complete failure of rice crop (Singh and Mani, 1981). Weeds are the major constraint in rice due to favorable atmosphere during *Kharif* season and weeds compete rice crop and causes yield reduction upto 30.2 per cent in DSR (Singh *et al.* 2005). In Kerala, heavy infestation of weedy rice alone has caused a reduction in the yield by 30 to 60 per cent depending on intensity of infestation (Abraham *et al.*, 2012).

Prakash *et al.* (2013) found that application of penoxsulam @ 25 g ha^{-1} recorded the lowest weed index (5.0-7.4 %) resulting in 36-41 per cent of increase in grain yield of rice over non-weeded control. Hemalatha *et al.* (2017) reported that yield reduction in dry seeded rice due to weeds was 63.5 per cent; however it reduced substantially to 0.1 percent in pendimethalin @ 0.75 kg ha^{-1} (PE) fb metsulfuron-methyl + chlorimuron ethyl @ 4 g ha^{-1} (PoE). Penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS registered 114.8 per cent increase in grain yield over unweed control (Sanodiya and Singh, 2017).

2.7. EFFECT HERBICIDES ON NUTRIENT UPTAKE BY RICE

Application of pre emergence herbicide pendimethalin @ 0.75 kg ha^{-1} fb one HW at 30 DAS recorded higher N, P and K uptake by rice crop (Ramamoorthy, 1991). Nutrient uptake in rice was the highest in three HW treatment compared to pendimethlin @ 0.75 kg ha^{-1} fb bispyribac @ 0.03 kg ha^{-1} treatment (Brar and Bhullar, 2013). Shendage *et al.* (2017) reported that minimum uptake of nutrients by rice was observed under weedy check than any other weed control treatments.

Mishra *et al.* (2006) reported that pre-emergence application butachlor @ 1 kg ha^{-1} recorded 43.0 kg of nitrogen, 8.09 kg of phosphorus and 48.74 kg of potassium by upland rice. According to Hemalatha *et al.* (2017), uptake of nitrogen, phosphorus and potassium by rice in dry seeded rice was higher in pendimethalin @ 0.75 kg ha^{-1} as PE fb metsulfuronmethyl + chlorimuron ethyl @ 4 g ha^{-1} as PoE and it was comparable with HW @ 20 and 40 DAS.

2.8. EFFECT OF HERBICIDES ON WEED DENSITY

Significant reduction of total weed population was observed in HW at 20, 40 and 60 DAS compared to sequential application of PE and PoE herbicides (Brar and Bhullar, 2013). Application of PoE herbicide metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 25 days after transplanting (DAT) recorded lower weed density at 45 and 70 days after application (Kaur *et al.*, 2017).

Pratap *et al.* (2016) reported that significantly lower density of *L. chinensis* was observed in pretilachlor @ 750 g ha^{-1} fb ethoxysulfuron @ 18.75 g ha^{-1} and pretilachlor @ 750 g ha^{-1} fb readymix of metsulfuron methyl + chlorimuron ethy @ 4 g ha^{-1}; however, the lowest total weed density was observed in the treatment applied with readymix of penoxsulam + cyahalofop-butyl @ 135 g ha^{-1}. According to Devi and Singh (2018), HW at 20 and 40 DAS and application of bispyribac @ 25 g ha^{-1} + azimsulfuron @ 17.5 g ha^{-1} + non-ionic surfactant (NIS) @ 0.25 per cent at 15-20 DAS were found effective in reducing the weed infestation and weed growth.

Application of herbicides significantly reduced weed population over no herbicide treatments throughout crop growth and the lowest weed population was observed when butachlor @ 1 kg ha^{-1} was applied (Mishra *et al.*, 2006). Application of butachlor 1.0 kg ha^{-1} at 3 DAT fb metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 25 DAT recorded minimum weed population and it was comparable with HW at 20 and 40 DAT (Halder and Patra, 2007).

Significantly lower density of grasses, BLW and sedges were noticed in aerobic rice by the application of bensulfuron methyl + pretilachlor @ 60 g + 600 g ha^{-1} and it was statistically on par with HW at 20 and 40 DAS and oxyfluorfen as PE @ 90 g ha^{-1} fb 2, 4-D as PoE @ 500 g ha^{-1} at 25 DAS (Madhukumar *et al.*, 2013).

2.9. EFFECT OF HERBICIDES ON WEED DRY WEIGHT AND WEED CONTROL EFFICIENCY

Application of pretilachlor + safener @ 0.45 kg ha^{-1} + passing cono weeder at 30 DAS + HW at 30 DAS recorded the lowest dry weight of grasses, sedges and BLW and the highest weed control efficiency (WCE) of 98 per cent in drum seeded rice (Jagadeesha *et al.*, 2009). According to Walia *et al.* (2012), application of pendimethalin @ 0.75 kg ha^{-1} fb application of bispyribac @ 30 g ha^{-1} recorded the lowest weed dry weight and the highest WCE.

Readymix of penoxsulam + cyahalofop-butyl @ 135 g ha^{-1} recorded the highest WCE of 98.2 per cent (Pratap *et al.*, 2016). Kaur *et al.* (2017) reported that application of metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 25 DAT resulted in substantial reduction in dry weight and density of BLW and sedges resulting in better WCE (90.3% and 85.3% at 45 and 70 days after application respectively), compared to its lower dose (3 g ha^{-1}), metsulfuron alone @ 4 g $ha^{-1}$and azimsulfuron @ 20 g ha^{-1}.

Jadhav (2013) reported that application of butachlor @ 1.5 kg ha^{-1} fb one HW recorded the lowest weed dry weight and highest WCE of BLW and grasses at 30 and 60 DAS compared to pretilachlor @ 0.5 kg ha^{-1} (PE), fenoxaprop @ 60 g ha^{-1} (PoE) and sesbenia (braodcast) + 2,4-D sodium salt @ 0.5 kg ha^{-1} at 30 DAS. Sequential application of pendimethalin @ 0.75 kg ha^{-1} (PE) fb application of metsulfuron-methyl + chlorimuron-ethyl @ 4 g ha^{-1} (PoE) recorded higher WCE (89.7%), which was statistically on par with HW at 20 and 40 DAS (90.6%) and it was found effective in reducing total weed biomass also (Hemalatha *et al.*, 2017). Application of pretilachlor @ 0.5 kg ha^{-1} fb bispyribac sodium @ 35 g ha^{-1} as PoE recorded the lowest weed dry weight and the highest WCE (Chadachanakar *et al.*, 2017).

2.10. EFFECT OF HERBICIDES ON NUTRIENT REMOVAL BY WEEDS

Direct seeded rice has a higher requirement of nutrient as compared to transplanted rice because of higher plant density and greater production of biomass in the vegetative phase (Dingkuhn *et al.*, 1990 and Schnier *et al.*, 1990) and also due to substantial removal of nutrients by weeds.

Weeds from weedy check plot depleted 14.5 to 18.8 kg of N, 0.9 kg of P_2O_5 and 9.1 to 12.1 kg of K_2O in upland rice (Moorthy and Mitra, 1990). According to Singh *et al.* (2013), weeds grow faster than crops and thus compete for nutrients, water and other resources and they also reported that weeds removed the highest quantity of nutrients *i.e.,* from the unweeded control plot. N and P removal by weeds were reduced by three HW in DSR compared to herbicide treatment *viz.,* pendimethalin @ 0.75 kg ha^{-1} fb bispyribac sodium @ 0.03 kg ha^{-1} (Brar and Bhullar, 2013). Sanodiya and Singh (2017) reported that nutrient depletion by weeds depends on dry matter accumulation of weeds in respective treatments and significantly lower nutrient removal by weeds was recorded in penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS compared to other herbicidal treatments.

Singh *et al.* (2005) revealed that removal of nutrients by weeds was lower in anilophos @ 0.3 kg ha^{-1} + 2, 4-D @ 0.4 kg ha^{-1} + one HW treatment (3.74 kg N ha^{-1}, 1.54 kg P_2O_5 ha^{-1}, 4.26 kg K_2O ha^{-1}). Weedy check treatment recorded the highest removal of nutrients by weeds (46.37 kg N ha^{-1}, 32.46 kg P ha^{-1}, 70.17 kg K ha^{-1}) in drum seeded rice, compared to the use of herbicides *viz.,* pretilachlor + safener, butachor and anilophos and mechanical methods *viz.,* use of conoweeder and HW. (Jagadeesha *et al.*, 2009).

Weed infestation in rice field resulted in depletion of 234.2 kg N ha^{-1}, 17.6 kg P $ha^{-1}$and 292.7 kg K ha^{-1} and tank-mix application of bispyribac with ethoxysulfuron, or with chlorimuron + metsulfuron and its sequential application with pendimethalin recorded the lowest depletion of NPK by weeds at harvest (Kaur *et al.*, 2016).

Hemalatha *et al.* (2017) reported that weedy check treatment registered significantly higher removal of nitrogen, phosphorus and potassium while it was minimum with herbicidal treatments *viz.*, pendimethalin, orthosulfuron, ethoxysulfuron and metsulfuron methyl + chlroimuron ethyl and HW.

2.11. EFFECT OF HERBICIDES ON SOIL MICROBIAL POPULATION

Milosevic and Govedarica (2002) reported that soil micro-organisms play vital role in the soil-plant-herbicide-fauna-man relationship as they are involved in the degradation process of herbicides. The plots treated with azimsulfuron and metsulfuron methyl + chlorimuron ethyl enhanced the count of bacteria and fungi in wetlands (Nishan, 2012).

According to Araujo *et al.* (2003), application of glyphosate increased the population of actinomycetes in soil. On the day of herbicide spray, weedy check and HW treatments recorded the highest viable count of bacteria compared to herbicide treated plots, but after 20 days herbicide application the population of bacteria were at par with HW treatment (Singh and Singh, 2009).

Soil micro-organisms are considered as indicators of soil quality and health and are involved in various biochemical process resulting in the release of nutrients to the plants (Schloter *et al.*, 2003). Rajagopal (2013) found that population of soil bacteria and fungi increased with spraying of bensulfuron methyl + pretilachlor and azimsulfuron. Kaur *et al.* (2014) reported that herbicidal treatments recorded significantly higher microbial population compared to unweeded control in DSR, which indicates that micro-organism utilizes herbicides as sources of C during the degradation process.

Adhikary *et al.* (2014) concluded that herbicides exhibit severe toxic effect immediately after application. Later on, microorganisms are involved in the degradation of herbicide and then the degraded organic herbicides provide carbon rich substrates which enhances the microbial population in the rhizosphere.

Tyagi *et al.* (2018) observed that toxic effect of herbicides on soil micro-organisms is only temporary and the adverse effect of herbicides was gradually reduced with passage of time.

2.12. EFFECT OF HERBICIDES ON SOIL ENZYME ACTIVITY

Dehydrogenase activity is considered as indication of metabolic activity of the microbial population in soil. Activity of dehydrogenase enzyme in soil depends on the metabolic state of the soil or on the biological activity of the microbial population than on any free enzyme present (Ross, 1970). Shilpashree and Kotur (2009) found a significant positive correlation between the activity of enzymes and organic carbon content and also observed that surface soil containing higher organic matter content showed higher dehydrogenase activity.

Sebiomo *et al.* (2011) reported that dehydrogenase enzyme activity in soil is used for measuring the harmful effects of herbicide application on the soil microbial biomass and application of glyphosate recorded the highest soil dehydrogenase activities after the second and sixth week of treatment when compared to other herbicide treatments.

Application of herbicides significantly stimulated the activity of dehydrogenase enzyme in soil (Baruah and Mishra, 1986). Herbicides treated plots recorded higher activities of dehydrogenase enzyme; higher the concentration of butachlor, higher the dehydrogenase activity (Hang *et al.*, 2002). Vandana *et al.* (2012) reported that application of butachlor @ 1 kg ha^{-1} at 3 DAT recorded the highest activity of urease enzyme at 45 and 60 DAT. Application of butachor, pyrazosulfuron, paraquat and glyphosate herbicides increased the activity of urease and dehydrogenase from 7^{th} day to 28^{th} day of incubation (Baboo *et al.*, 2013).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation entitled "Weed management in upland rice (*Oryza sativa* L.) intercropped in coconut" was undertaken during *Kharif* season (June - October) of 2017 in Coconut Research Station (CRS), Balaramapuram, Kerala. The main objective of the experiment was to standardize an ecofriendly and economic weed management strategy for upland rice intercropped in coconut.

3.1. EXPERIMENTAL SITE

3.1.1 Location

The study was conducted in the coconut garden of CRS, Balaramapuram. The experiment site is located at 8^0 23' 55.10328" North latitude and 77^0 1' 48.9774" East longitude, at an altitude of 9 m above mean sea level.

3.1.2 Climate and Season

The experiment site has warm humid tropical climate. The study was conducted during *Kharif* season *i.e* June – October, 2017. The meteorological data mean temperature, relative humidity and rainfall recorded standard week wise, during the cropping period were collected from Agromet observatory, CRS, Balarampuram.

3.1.3 Soil

The soil of the experiment site belongs to the textural class of red sandy loam. A composite soil sample was collected before the experiment from 0-15 cm and analyzed for its mechanical composition and chemical properties (Table 1 and 2).

3.1.4. Cropping History of Experimental Site.

The experimental site is a plantation comprising of 55 years old west coast tall variety planted at a spacing of 7.6 m X 7.6 m and banana was cultivated as intercrop during the previous season.

Table 1. Mechanical composition of soil in the experimental field

Sl. No.	Fractions	Content in soil,%	Method
1	Sand	66.43	Bouyoucos Hydrometer Method (Bouyoucos, 1962
2	Silt	18.24	
3	Clay	15.16	

Table 2. Chemical properties of the soil of the experimental area

Sl. No.	Parameters	Content	Method used
1	Soil reaction	4.6 (Very strongly acidic)	pH meter (1:2.5 soil water ratio) (Jackson, 1973)
2	EC, dSm^{-1}	0.10 (Safe)	Conductivity meter (1:2.5 soil water ratio) (Jackson, 1973)
3	Organic carbon, %	0.81 (High)	Walkley and Black rapid titration method (Walkley and Black, 1934)
4	Available N, kg ha^{-1}	282.8 (Medium)	Alkaline permanganate method (Subbiah and Asijia, 1956)
5	Available P, kg ha^{-1}	36.04 (Medium)	Bray colorimetric method (Jackson, 1973)
6	Available K, kg ha^{-1}	105.6 (Low)	Ammonium acetate method (Jackson, 1973)

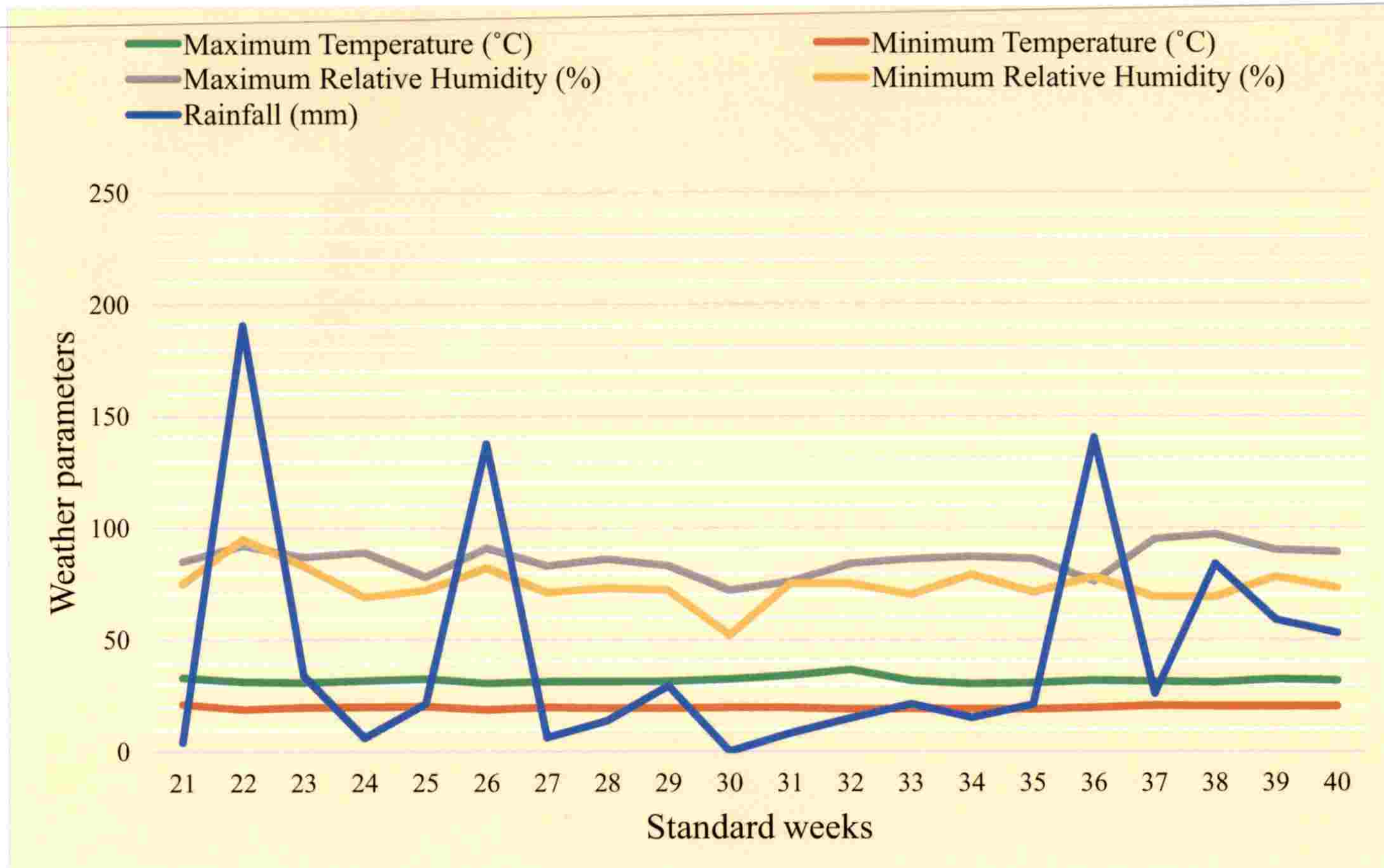


Fig 1. Weather data during the crop period (June 2017 to October 2017)

3.2. MATERIALS

3.2.1 Crop Variety

The rice variety *Prathyasa* (MO-21) released from Rice Research Station, Moncompu, Kerala was used for the experiment. It is a short duration variety (100-110 days) with red, long bold grains, photo insensitive, moderately resistant to gall midge, BPH, sheath blight and sheath rot.

3.2.2 Source of Seed

The paddy seed was obtained from Rice Research Station, Moncompu, Kerala.

3.2.3 Manures and Fertilizers

The organic manure source used for experiment was well decomposed dry cow dung containing 0.55 per cent N, 0.23 per cent P_2O_5 and 0.46 per cent K_2O. Fertilizers were applied as urea (46 % N), rajphos (20 % P_2O_5) and muriate of potash (60 % K_2O).

3.2.4 Herbicides

The technical information, toxicity data and others available information of the herbicides used in the study *viz.*, penoxsulam and metsulfuron methyl + chlorimuron ethyl are given in Table 3

Table 3. Technical information of the herbicides used in the study.

Common name	Penoxsulam	Metsulfuron methyl + Chlorimuron ethyl
1. Chemical name	2-(2,2-difluoroethoxy)-N-(5,8- dimethoxy [1,2,4] triazol [1,5-c]pyrimidin-2-yl)-6 (trifluoromethyl) benzene sulfonamide	Methyl 2-{{{{(4-methoxy-6methyl-1-1,3,5-traizin-2yl) amino}carbonyl}amino}sulfonyl} benzoate+ ethyl 2{{{{(4-cloro-6-methoxy-pyrimidin-2-yl)amino}carbonyl}amino}sulfonyl} benzoate}
2. Trade name	Granite	Almix
3. Formulation	24 % SC	10 + 10 % WP
4. Physical state colour and odour	Off white liquid, musty odour	Grey colour powder
5. Acute oral toxicity LD 50 (rats)	>5000 mg kg^{-1}	>5000 mg kg^{-1}
6. Manufacturer	Dow Agro Chemicals	DuPont

3.3 METHODS

3.3.1 Design and Lay Out

Design	:	Randomized Block Design (factorial)
No. of treatment combinations	:	16 (8x2)
Replication	:	3
Gross plot size	:	5 m x 4 m
Net plot size	:	3.6 m x 3.8 m
Spacing	:	20 cm x 10 cm

3.3.2 Treatment Details

1. Factor A - Stale seedbed methods (S)-2

s_1 : Stale seedbed with mechanical removal of weeds

s_2 : No stale seedbed

2. Factor B - Weed management methods (M)-8

m_1 : Penoxsulam @ 20 g ha^{-1} at 10-15 DAS followed by hand weeding at 35-40 DAS

m_2 : Penoxsulam @ 25 g ha^{-1} at 10-15 DAS followed by hand weeding at 35-40 DAS

m_3 : Penoxsulam @ 30 g ha^{-1} at 10-15 DAS followed by hand weeding at 35-40 DAS

m_4 : Penoxsulam @ 20 g ha^{-1} at 10-15 DAS followed by metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 35-40 DAS

m_5 : Penoxsulam @ 25 g ha^{-1} at 10-15 DAS followed by metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 35-40 DAS

m_6 : Penoxsulam @ 30 g ha^{-1} at 10-15 DAS followed by metsulfuron methyl + chlorimuron ethyl @ 4 g ha^{-1} at 35-40 DAS

m_7 : Hand weeding twice (15 and 35 DAS)

m_8 : Weedy check (unweeded control)

3.3.3 Field Preparation and Lay Out

For stale seedbed the experimental area was ploughed twice with garden tiller, soil was brought to a fine tilth and weeds and stubbles were removed. Land was leveled, lay out was done and irrigation was provided to facilitate germination of weed seeds. After one week, emerged weeds were killed by gentle, mechanical raking of surface soil. For no stale seedbed, land was prepared just before sowing of the crop and laid out as per the treatments.

3.3.4 Seeds and Sowing

Healthy seeds were dibbled at a spacing of 20 cm x 10 cm in individual plot @ 80 kg ha^{-1} on 10-06-2017 during the *Kharif* season.

3.3.5 Application of lime

Recommended dose of lime (600 kg ha^{-1}) was applied in two splits, first dose of 350 kg ha^{-1} at the time of last ploughing and second dose of 250 kg ha^{-1} at one month after sowing.

3.3.6 Application of Manures and Fertilizer

Dry cow dung was applied at the time of last ploughing. Recommended chemical fertilizers, N: P_2O_5: K_2O @ 60: 30: 30 kg ha^{-1} as per *Package of Practices Recommendations: Crops* (KAU, 2016) were applied to crop. One third dose of nitrogen and potassium and full phosphorus were applied as basal and remaining nitrogen and potassium applied were applied in equal splits at 40 and 60 DAS.

3.3.7 Water Management

The experiment plots were irrigated to field capacity during non-rainy period, once in a week.

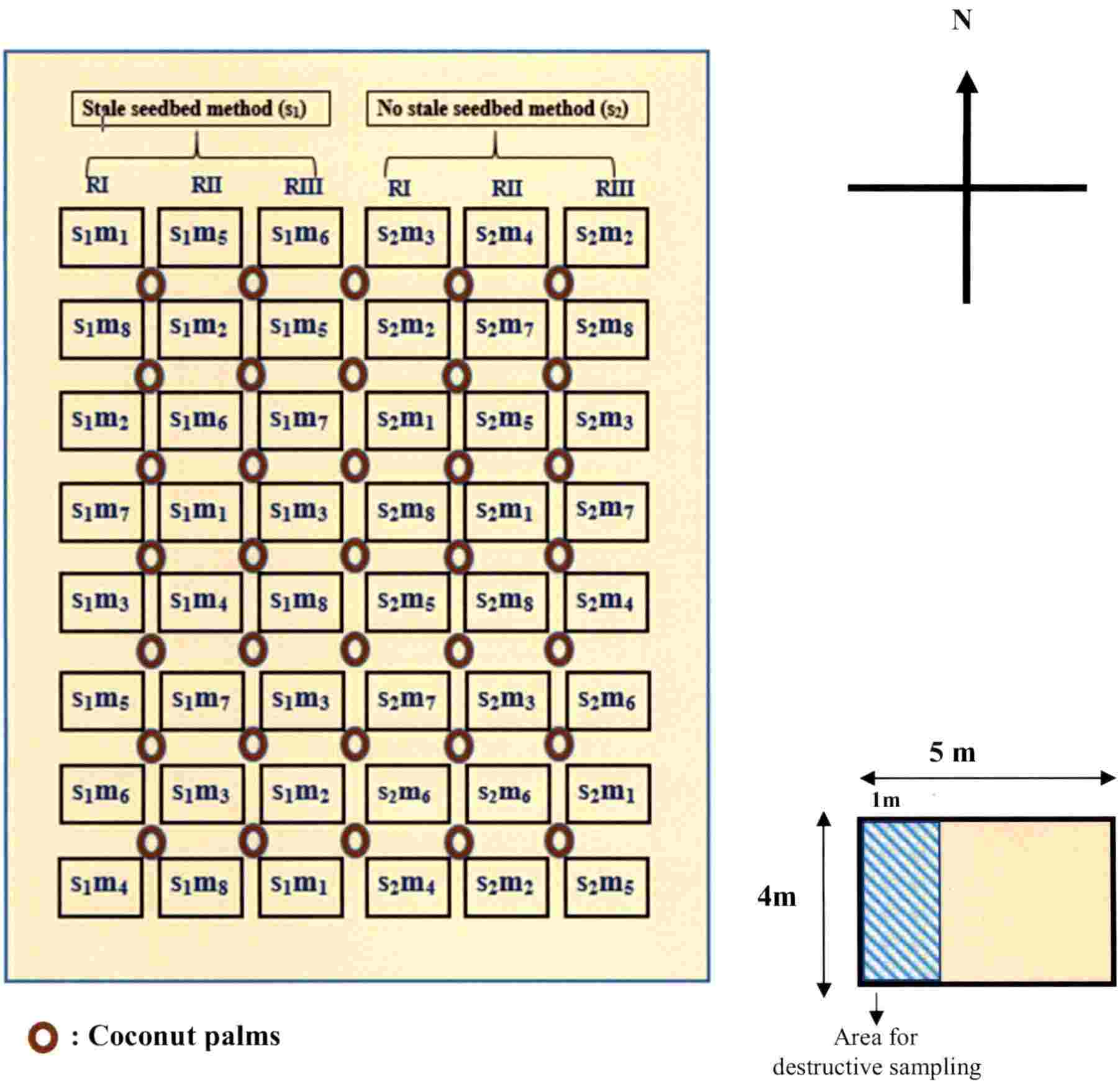


Fig 2. Layout of the experimental field

Plate 1. Layout of the experimental field

Plate 2. General view of the experimental field

3.3.8 Weed Management

Herbicide solutions were prepared in water as per the treatments and herbicides were sprayed at 15 DAS and 35 DAS with pneumatic sprayer. Hand weeding was done at 15 DAS and 35 DAS.

3.3.9 Plant Protection

One spray of quinalphos (1000 mL ha^{-1}) was given against rice folder attack at the seedling stage of the crop and two sprays of malathion (750 mL ha^{-1}) were given against rice bug at flowering and milky stage of rice crop. No incidence of disease was noticed during the cropping period.

3.3.9 Harvest

The crop was harvested when the grains attained maturity, leaving two rows on all sides as border. The net plot area was harvested separately, threshed, winnowed and weight of grains and straw from individual plots were recorded, after sun drying.

3.4 OBSERVATIONS ON WEEDS

3.4.1 Floristic Composition

Weeds from the experimental site during the period of experiment were identified and recorded.

3.4.2 Absolute Density (Ad)

Number of weeds was recorded from the randomly selected quadrat (0.25 m X 0.25 m) in each plot. The weeds were categorized into grasses, sedges and broad leaved weeds. The absolute density of weeds were counted at 15, 30 and 60 DAS using the formula suggested by Philips (1959).

Absolute density = total number of weeds of a given species in m^2

3.4.3 Relative Density (Rd)

Relative density of grasses, sedges and broad leaf weeds were worked out at 15, 30 and 60 DAS using the formula put forward by Philips (1959).

$$\text{Relative density} = \frac{\text{Absolute density of species}}{\text{Total absolute densities of all the species}} \times 100$$

3.4.4 Weed Dry Weight

Weed dry weight was recorded at 15, 30 and 60 DAS by placing quadrat randomly in each plot. The weeds in the quadrat were pulled out along with roots, washed and categorized into grasses, sedges and broad leaf weeds. The collected weeds were dried under shade and oven dried at 70 ± 5^0 C to a constant weight and dry weight was recorded as g m^{-2}.

3.4.5 Weed Control Efficiency

Weed control efficiency was worked out in percentage by adopting the formula suggested by Mani and Gautham (1973).

$$\text{WCE} = \frac{\text{WDWC - WDWT}}{\text{WDWC}} \times 100$$

where, WCE = Weed Control Efficiency

WDWC = Weed dry weight from treatment which recorded maximum number of weeds (weedy check)

WDWT = Weed dry weight from treatment for which weed control efficiency has to be worked out.

3.5 OBSERVATIONS ON CROP

3.5.1 Growth Attributes

3.5.1.1 Plant Height

Height of the plant was recorded at 30 and 60 DAS and at harvest, from five plants from each net plot, selected at random. The height of plant was measured from the base of the plant to the tip of the longest leaf at vegetative stage and to the tip of the longest ear head at harvest stage. The mean observations were expressed in cm.

3.5.1.2 Number of Tillers m^{-2}

The number of tillers was counted from 0.25 m x 0.25 m area using quadrat randomly and was expressed in number m^{-2} at 30 and 60 DAS and at harvest.

3.5.1.3 Leaf Area Index

The length and breadth of the fourth leaf from five randomly selected primary tillers were measured in each plot at 30 and 60 DAS. Leaf area was then calculated by the method suggested by Palanisamy and Gomez (1974)

Leaf area = K (L x B)

K = 0.75 (Yoshida *et al.*, 1976)

L = leaf length (cm)

B = Maximum breadth of the leaf (cm)

LAI was calculated as fallows

$$LAI = \frac{\text{Total leaf area tiller}^{-1} \times \text{number of tillers m}^{-2}}{\text{Area occupied by tillers m}^{-2}}$$

3.5.1.4 Dry Matter Production (DMP)

Five plants were randomly uprooted from each plot leaving the border rows at harvest. The plant samples were dried under shade and later oven dried at 80 ± 5^0 C to a constant weight. The total DMP was calculated and was expressed in kg ha^{-1}.

3.5.1.5 Herbicide Phytotoxicity

The herbicide treated plots were observed closely and the visual symptoms of herbicide toxicity on rice plants were recorded, seven days after herbicide application. Phytotoxicty was rated on a visual scale of 1-10, where 1 indicates no phytotoxicity and 10 indicates total crop damage.

3.5.2 Yield Attributes and Yield

3.5.2.1 Number of Panicles m^{-2}

From each plot, number of panicles was recorded from unit area of net plot using quadrat of size 0.25 m^{-2} and mean number was calculated and expressed m^{-2}.

3.5.2.2 Number of Spikelets Panicle^{-1}

Number of spikelets $panicle^{-1}$ was counted from five panicles selected randomly from the observation plants at harvest and average was recorded.

3.5.2.3 Percent Filled Grains

From the randomly selected panicles, the number of filled and unfilled grains were recorded and per cent filled grains was worked out using the following formula.

$$\text{Per cent filled grains} = \frac{\text{Number of filled grains panicle}^{-1}}{\text{Number of total grains panicle}^{-1}} \times 100$$

3.5.2.4 Thousand Grain Weight

One thousand grains from each plot were drawn at random, dried and weighed at 14 per cent moisture content and weight was expressed in g.

3.5.2.5 Grain Yield

The net plot area was harvested individually, cleaned and dried in sun to a moisture content of 14 per cent. The grain yield was recorded and expressed in t ha^{-1}.

3.5.2.6 Straw Yield

The straw from net plot area was dried under sun to a constant weight and straw yield was expressed in t ha^{-1}.

3.5.2.7 Harvest Index

The harvest index was worked out using the following formula suggested by Donald and Hamblin (1976).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.5.2.8 Weed Index

Weed index was worked out using the formula suggested by Gill and Vijayakuamar (1969).

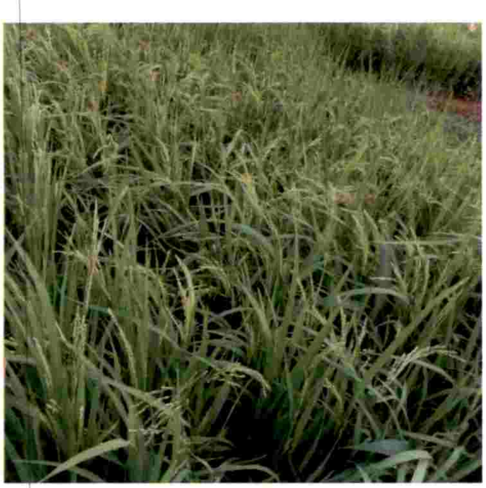
$$WI = \frac{X-Y}{X} \times 100 \quad \text{where}$$

X = Yield from the treatment which recorded the minimum number of weeds

Y = Yield from the treatment for which weed index is to be computed

a. Seedling stage

b. Maximum tillering stage



c. Flowering stage

d. Harvest stage

Plate 3. Different stages of crop growth

3.6 CHEMICAL ANALYSIS

3.6.1 Nutrient Uptake by Crop and Weeds

The total uptake of nitrogen, phosphorus and potassium by rice plant at harvest and weeds at 60 DAS were calculated as the product of nutrient content and the respective plant dry weight and expressed as kg ha^{-1}.

3.6.2 Nutrient Status of the Soil before and after the Experiment

Composite soil sample was collected from the experimental area before the experiment. After the experiment soil samples were collected from individual plots. The air dried soil samples were analyzed for available nitrogen, phosphorus and potassium status as per the procedure detailed in Table 2.

3.7 MICROBIAL COUNT IN SOIL

Soil samples were collected with soil auger just before herbicide application and 15 and 30 days after herbicide application for observing the microbial population of soil. The total count of bacteria, fungi and actinomycetes were assessed by serial dilution plate technique (Johnson and Curl, 1972). Nutrient agar medium was used for growing bacteria, Kenknight's agar medium for actinomycetes and Martin's Rose Bengal agar Medium for fungi. The Microbes were grown in petri dishes containing the respective media.

3.8 ENZYME STUDIES

Soil samples for enzyme studies were collected just before herbicide application and 15 days after herbicide application. Four samples were collected from each plot, mixed thoroughly to form a composite sample and stored in polythene bag at 4^0 C. The enzyme assay was completed within a week.

3.8.1 Dehydrogenase Activity

Activity of dehydrogenase enzyme was determined by the method described by Casida *et al.*, (1964) and expressed as µg triphenyl formazon (TPF) g^{-1} soil day^{-1}.

3.8.2 Urease Activity

The urease activity of soil was determined by the method described by Watts and Crisp (1954) and expressed as µg urea hydrolyzed g^{-1} soil h^{-1}.

3.9 ECONOMIC ANALYSIS

For analyzing the economics of cultivation, net income and benefit cost ratio were worked out based on the cost of cultivation and prevailing market price of the produce.

3.9.1 Net Income

Net income in ₹ ha^{-1} was computed using the formula

Net income (₹ ha^{-1}) = Gross income – cost of cultivation

3.9.2 Benefit Cost Ratio

Benefit cost ratio was calculated using the formula

$$BCR = \frac{\text{Gross income (₹ ha}^{1})}{\text{Cost of cultivation (₹ ha}^{1})}$$

3.10 STATISTICAL ANALYSIS

The data recorded from the experiment were subjected to Analysis of Variance technique (ANOVA) as applied to Randomized Block Design (factorial) described by Cochran and Cox (1965). The data which required transformation were appropriately transformed and then analyzed. Whenever significance was observed, CD values at 5 % level of significance were worked out for comparison.

RESULTS

4. RESULTS

An experiment titled "Weed management in upland rice (*Oryza sativa* L.) intercropped in coconut" was undertaken to standardize an ecofriendly and economic weed management strategy for upland rice intercropped in coconut. The data collected were statistically analyzed and the results of the experiment are presented in this chapter.

4.1 OBSERVATIONS ON WEEDS

4.1.1. Floristic Composition

Weed species present in the experimental field during the study were collected, identified and categorized into broad leaved weeds, grasses and sedges. The results on floristic composition are presented in Table 4.

4.1.2. Absolute Density

4.1.2.1 Absolute Density of Broad Leaved Weeds (BLW)

Data on absolute density of BLW at 15, 30 and 60 DAS are presented in Tables 5a and 5b.

Stale seedbed (SSB) methods significantly influenced the absolute density of broad leaved weeds (BLW) at 15, 30 and 60 DAS. Stale seedbed method (s_1) recorded significantly lower absolute density of BLW compared to no SSB method (s_2) at 15, 30 and 60 DAS.

The result indicated that the absolute density of BLW was significantly influenced by the weed management methods at 30 and 60 DAS only. At 30 and 60 DAS, application of penoxsulam @ 30 g ha^{-1} at 10-15 DAS followed by (fb) metsulfuron methyl + chlorimuron ethyl (MM+CE) @ 4 g ha^{-1} at 35-40 DAS (m_6) recorded the lowest absolute density of BLW (13.33 and 5.33 m^{-2}, respectively). At 30 DAS, m_6 was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4

Table 4. Floristic composition observed in the experimental field

Common Name	Scientific Name	Family
BROAD LEAVED WEEDS		
Prickly Chaff Flower	*Achyranthes aspera*	Amarantheceae
Indian Acalypha	*Acalypha indica*	Euphorbiaceae
Alligator weed	*Alternanthera sessilis*	Amarantheceae
Stonebreaker	*Phyllanthus niruri*	Phyllanthaceae
Touch-me-not plant	*Mimosa pudica*	Fabaceae
Indian sarsaparilla	*Hemidesmus indicus*	Apocynaceae
False buttonweed	*Spermacoce ocymoides*	Rubiaceae
Chay root	*oldenlandia umbellata*	Rubiaceae
GRASSES		
Crow foot grass	*Dactyloctenium aegyptium*	Poaceae
East indian bristle grass	*Setaria barbata*	Poaceae
Goosegrass	*Eleusine indica*	Poaceae
Weedy rice	*Oryza sativa f. spontanea*	Poaceae
Barnyard grass	*Echinochloa crusgalli*	Poaceae
Southern crabgrass	*Digitaria ciliaris*	Poaceae
SEDGES		
Alkali bulrush	*Scirpus maritimus*	Cyperaceae
Nutsedge	*Cyperus rotundus*	Cyperaceae

Table 5a. Effect of weed management practices on absolute density of broad leaved weeds

Treatments	Absolute density of broad leaved weeds (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	52.00 (1.64)	24.16 (4.85)	12.42 (3.31)
s_2 - No SSB	114.9 (1.91)	28.67 (5.10)	16.17 (3.84)
SEm±	0.064	0.067	0.111
CD (0.05)	0.187	0.195	0.321
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	149.3 (2.06)	18.67 (4.28)	8.00 (2.82)
m_2 – Penox. @ 25 g ha^{-1} fb HW	126.6 (1.89)	37.33 (6.32)	8.67 (2.88)
m_3 – Penox. @ 30 g ha^{-1} fb HW	81.33 (1.86)	16.00 (3.98)	17.33 (4.13)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	57.33 (1.70)	14.00 (3.68)	10.33 (3.15)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	92.00 (1.87)	24.00 (4.88)	10.00 (3.02)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	69.00 (1.74)	13.33 (3.64)	5.33 (2.28)
m_7 - Hand weeding twice (15 and 35 DAS)	52.67 (1.57)	28.00 (5.26)	23.33 (4.75)
m_8 - Weedy check (unweeded control)	39.33 (1.51)	60.00 (7.74)	31.33 (5.57)
SEm±	0.129	0.134	0.313
CD (0.05)	NS	0.389	0.907

NS - Non significant

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

Table 5b. Interaction effect of SSB methods and weed management methods on absolute density of broad leaved weeds

Interactions (S x M)	Absolute density (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	82.67 (1.87)	22.66 (4.76)	8.00 (2.83)
s_1m_2	40.00 (1.56)	18.66 (5.16)	10.67 (3.22)
s_1m_3	68.00 (1.83)	18.66 (4.32)	14.67 (3.80)
s_1m_4	38.66 (1.54)	9.33 (3.04)	7.33 (2.66)
s_1m_5	73.33 (1.85)	24.00 (4.89)	5.33 (2.28)
s_1m_6	57.33 (1.63)	12.00 (3.46)	4.00 (2.00)
s_1m_7	28.00 (1.40)	33.33 (5.76)	16.00 (3.98)
s_1m_8	28.00(1.44)	54.67 (7.39)	33.33 (5.73)
s_2m_1	216.0 (2.25)	14.67 (3.80)	8.00 (2.81)
s_2m_2	213.3 (2.22)	56.00 (7.48)	6.67 (2.55)
s_2m_3	94.66 (1.90)	13.33 (3.64)	20.00 (4.46)
s_2m_4	76.00 (1.87)	18.67 (4.32)	13.33 (3.64)
s_2m_5	110.6 (1.90)	24.00 (4.88)	14.66 (3.77)
s_2m_6	80.67 (1.84)	14.66 (3.82)	6.67 (2.55)
s_2m_7	77.33 (1.74)	22.66 (4.76)	30.67 (5.52)
s_2m_8	50.67 (1.59)	65.33 (8.08)	29.33 (5.40)
SEm±	0.183	0.189	0.313
CD (0.05)	NS	0.550	0.907

NS - Non significant

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

g ha^{-1} at 35-40 DAS (m_4) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3). The highest absolute density of BLW (60.00 m^{-2}) at 30 DAS was observed in weedy check (m_8). At 60 DAS, m_6 was statistically comparable with penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively). Weedy check (m_8) recorded the highest absolute density of BLW (31.33 m^{-2}).

Interaction was found to be significant at 30 and 60 DAS. At 30 DAS, the treatment combination s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) registered the lowest absolute density of BLW (9.33 m^{-2}) which was statistically on par with s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS). The highest absolute density of BLW (65.33 m^{-2}) was observed in the treatment combination, s_2m_8 (no SSB with weedy check) at 30 DAS.

At 60 DAS, the lowest absolute density (4.00 m^{-2}) was recorded in s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and it was on par with s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The highest absolute density of BLW (33.33 m^{-2}) was registered in s_1m_8 (SSB with weedy check).

4.1.2.2 Absolute Density of Grasses

The data of absolute density of grasses at 15, 30 and 60 DAS are presented in the Tables 6a and 6b.

Stale seedbed methods did not have any significant effect on absolute density of grasses at 15, 30 and 60 DAS. Weed management methods also did not significantly influence the absolute density of grasses at 15 DAS.

At 30 and 60 DAS, absolute density of grasses was significantly influenced by weed management methods. At 30 DAS, the lowest density of grasses (4.17 m^{-2}) was observed in penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2), which was statistically on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4) and penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1). At 60 DAS, not even a single grass was found in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and this treatment was on par with penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6). The highest absolute density of grasses (15.33 m^{-2}) was registered in weedy check (m_8).

Interaction effect of SSB methods and weed management methods was found to be significant at 30 and 60 DAS. At 30 DAS, the treatment combination s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the lowest absolute density of grasses (1.33 m^{-2}) and it was on par with s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS). The highest absolute density of grasses (24.00 m^{-2}) was recorded in s_2m_7 (no SSB with hand weeding twice (HWT)) at 30 DAS. However, it was on par with s_1m_8 (SSB with weedy check).

At 60 DAS, desnity of grass was found to be zero in s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_3 (no SSB with

Table 6a. Effect of weed management practices on absolute density of grasses

Treatments	Absolute density of grasses (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	15.17 (1.02)	8.71 (2.91)	3.67 (1.80)
s_2 - No SSB	25.16 (1.26)	10.83 (3.14)	3.67 (1.49)
SEm±	0.094	0.099	0.108
CD (0.05)	NS	NS	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	22.00 (1.30)	6.00 (2.39)	0.67 (0.94)
m_2 – Penox. @ 25 g ha^{-1} fb HW	13.33 (1.13)	4.17 (1.96)	0.67 (0.94)
m_3 – Penox. @ 30 g ha^{-1} fb HW	28.00 (1.22)	7.33 (2.78)	0.00 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	26.00 (1.24)	4.66 (2.15)	3.33 (1.89)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	26.67 (1.20)	10.66 (3.31)	4.00 (1.81)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	20.00 (0.95)	9.33 (3.09)	0.67 (0.94)
m_7 - Hand weeding twice (15 and 35 DAS)	14.67 (1.07)	18.00 (4.24)	4.67 (2.05)
m_8 - Weedy check (unweeded control)	10.67 (1.03)	18.00 (4.26)	15.33 (3.86)
SEm±	0.187	0.198	0.215
CD (0.05)	NS	0.577	0.623

NS - Non significant

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

Table 6b. Interaction effect of SSB methods and weed management methods on absolute density of grasses

Interactions (S x M)	Absolute density (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	16.00 (1.22)	2.67 (1.65)	0.00 (0.71)
s_1m_2	16.00 (1.19)	7.00 (2.74)	1.33 (1.18)
s_1m_3	8.00 (0.92)	6.67 (2.65)	0.00 (0.71)
s_1m_4	14.66 (0.89)	6.67 (2.65)	4.00 (2.12)
s_1m_5	36.00 (1.49)	8.00 (2.92)	8.00 (2.92)
s_1m_6	12.00 (0.52)	6.67 (2.65)	1.33 (1.18)
s_1m_7	9.33 (0.96)	12.00 (3.54)	6.67 (2.65)
s_1m_8	9.33 (0.96)	20.00 (4.47)	8.00 (2.92)
s_2m_1	28.00 (1.37)	9.33 (3.12)	1.33 (1.18)
s_2m_2	10.66 (1.06)	1.33 (1.18)	0.00 (0.71)
s_2m_3	48.00 (1.52)	8.00 (2.92)	0.00 (0.71)
s_2m_4	37.33 (1.57)	2.67 (1.65)	2.67 (1.65)
s_2m_5	17.33 (0.91)	13.33 (3.71)	0.00 (0.71)
s_2m_6	28.00 (1.37)	12.00 (3.54)	0.00 (0.71)
s_2m_7	20.00 (1.18)	24.00 (4.94)	2.67 (1.44)
s_2m_8	12.00 (1.10)	16.00 (4.04)	22.67 (4.81)
SEm±	0.265	0.282	0.304
CD (0.05)	NS	0.817	0.882

NS - Non significant

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

penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and these treatment combination were found to be on par with s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), and s_2m_7 (no SSB with HWT). The treatment combination, s_2m_8 (no SSB with weedy check) recorded the highest absolute density of grasses (22.67 m^{-2}).

4.1.2.3 Absolute Density of Sedges

The results on the effect of SSB methods and weed management methods on absolute density of sedges at 15, 30 and 60 DAS are presented in Tables 7a and 7b.

At 15 DAS, no sedge population was observed in any of the experimental plots. Stale seedbed methods had significant effect on absolute density of sedges at 30 and 60 DAS. Stale seedbed method (s_1) had no sedge population at all at 30 DAS whereas no SSB method registered a sedge population of 0.67 m^{-2}. At 60 DAS, SSB (s_1) recorded the lowest absolute density of sedges (2.00 m^{-2}) compared to no SSB method (s_2) with a sedge population of 4.54 m^{-2}.

Absolute density of sedges was significantly influenced by weed management methods at 30 and 60 DAS. At 30 DAS, sedges were not observed in any of herbicide treatment. Only in HWT (m_7) and weedy check (m_8) sedges were observed and weedy check (m_8) was found to have significantly higher density compared to HW twice (m_7). At 60 DAS also no sedge population was observed in herbicide applied plots. Hand weeding twice (m_7) recorded a sedge density of 7.33 m^{-2}. Weedy check (m_8) recorded the highest absolute density of sedges (18.84 m^{-2}) and it was significantly inferior to all other treatments.

Table 7a. Effect of weed management practices on absolute density of sedges

Treatments	Absolute density of sedges (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0	0.00 (0.71)	2.00 (1.16)
s_2 - No SSB	0	0.67 (0.94)	4.54 (1.59)
SEm±	-	0.041	0.067
CD (0.05)	NS	0.120	0.194
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_7 - Hand weeding twice (15 and 35 DAS)	0	0.67 (0.94)	7.33 (2.43)
m_8 - Weedy check (unweeded control)	0	2.00 (1.41)	18.84 (4.32)
SEm±	-	0.083	0.134
CD (0.05)	NS	0.241	0.389

NS - Non significant

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

Table 7b. Interaction effect of SSB methods and weed management methods on absolute density of sedges

Interactions (S x M)	Absolute density (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	0	0.00 (0.71)	0.00 (0.71)
s_1m_2	0	0.00 (0.71)	0.00 (0.71)
s_1m_3	0	0.00 (0.71)	0.00 (0.71)
s_1m_4	0	0.00 (0.71)	0.00 (0.71)
s_1m_5	0	0.00 (0.71)	0.00 (0.71)
s_1m_6	0	0.00 (0.71)	0.00 (0.71)
s_1m_7	0	0.00 (0.71)	1.33 (1.18)
s_1m_8	0	0.00 (0.71)	14.67 (3.84)
s_2m_1	0	0.00 (0.71)	0.00 (0.71)
s_2m_2	0	0.00 (0.71)	0.00 (0.71)
s_2m_3	0	0.00 (0.71)	0.00 (0.71)
s_2m_4	0	0.00 (0.71)	0.00 (0.71)
s_2m_5	0	0.00 (0.71)	0.00 (0.71)
s_2m_6	0	0.00 (0.71)	0.00 (0.71)
s_2m_7	0	1.33 (1.18)	13.33 (3.68)
s_2m_8	0	4.00 (2.12)	23.00 (4.81)
SEm±	-	0.117	0.189
CD (0.05)	NS	0.340	0.550

NS - Non significant

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

Interaction was found significant at 30 and 60 DAS. At 30 DAS, no sedge population was found in any of the treatments under SSB and herbicidal treatments under no SSB method. Only in HWT and weedy check treatments under no SSB method (s_2m_7 and s_2m_8, respectively) sedges were seen and s_2m_8 treatment combination recorded significantly higher sedge density compared to s_1m_7. At 60 DAS, none of herbicidal treatments under both SSB method and no SSB method recorded any sedge density, sedges were totally absent in these treatments. The highest absolute density of sedges (23.00 m^{-2}) was recorded in the treatment combination s_2m_8.

4.1.2.4 Total Weed Density

The results of total weed density at 15, 30 and 60 DAS are presented in Tables 8a and 8b.

Stale seedbed methods had significant effect on total density of weeds at all the stages of observation. Stale seedbed method (s_1) recorded significantly lower total density compared to no SSB method (s_2) at 15, 30 and 60 DAS.

Weed management methods significantly influenced the total weed density at 30 and 60 DAS. At 30 DAS, application of penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4) recorded the lowest total weed density (18.67 m^{-2}), which was on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3). The highest total weed density (79.33 m^{-2}) was registered in weedy check (m_8) which was significantly inferior to all other weed management methods. At 60 DAS, the lowest value for total weed density (6.00 m^{-2}) was observed in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and it was statistically comparable with penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively). Weedy check (m_8) registered the highest total weed density (65.50 m^{-2}) and it was significantly inferior to all other weed management methods.

Table 8a. Effect of weed management practices on total weed density

Treatments	Total weed density (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	67.17 (7.84)	32.71 (5.53)	18.08 (3.95)
s_2 - No SSB	140.08 (11.04)	40.17 (6.13)	24.21 (4.47)
SEm±	0.715	0.108	0.114
CD (0.05)	2.076	0.312	0.332
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	171.3 (12.36)	24.67 (4.94)	8.67 (2.93)
m_2 – Penox. @ 25 g ha^{-1} fb HW	140.0 (10.68)	41.50 (6.26)	9.33 (2.99)
m_3 – Penox. @ 30 g ha^{-1} fb HW	109.3 (9.99)	23.33 (4.82)	17.33 (4.13)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	83.33 (8.83)	18.67 (4.29)	13.67 (3.66)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	118.7 (10.40)	34.67 (5.87)	14.00 (3.71)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	89.00 (8.86)	22.67 (4.74)	6.00 (2.41)
m_7 - Hand weeding twice (15 and 35 DAS)	67.33 (7.53)	46.67 (6.83)	34.67 (5.79)
m_8 - Weedy check (unweeded control)	50.00 (6.84)	79.33 (8.90)	65.50 (8.05)
SEm±	1.431	0.215	0.229
CD (0.05)	NS	0.624	0.664

NS - Non significant

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

Table 8b. Interaction effect of SSB methods and weed management methods on total weed density

Interactions (S x M)	Absolute density (No. m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	98.67 (9.79)	25.33 (5.02)	8.00 (2.83)
s_1m_2	56.00 (7.12)	25.67 (4.96)	12.00 (3.43)
s_1m_3	76.00 (8.69)	25.33 (5.02)	14.67 (3.80)
s_1m_4	53.33 (7.05)	16.00 (3.98)	11.33 (3.35)
s_1m_5	109.3 (10.44)	32.00 (5.65)	13.33 (3.64)
s_1m_6	69.33 (7.60)	18.67 (4.32)	5.33 (2.28)
s_1m_7	37.33 (5.94)	45.33 (6.73)	24.00 (4.85)
s_1m_8	37.33 (6.05)	73.33 (8.56)	56.00 (7.44)
s_2m_1	244.0 (14.93)	24.00 (4.87)	9.33 (3.03)
s_2m_2	224.0 (14.24)	57.33 (7.57)	6.67 (2.55)
s_2m_3	142.6 (11.29)	21.33 (4.61)	20.00 (4.46)
s_2m_4	113.3 (10.60)	21.33 (4.60)	16.00 (3.98)
s_2m_5	128.0 (10.37)	37.33 (6.09)	14.67 (3.77)
s_2m_6	108.6 (10.12)	26.67 (5.16)	6.67 (2.55)
s_2m_7	97.33 (9.13)	48.00 (6.92)	45.33 (6.73)
s_2m_8	62.67 (7.63)	85.33 (9.23)	75.00 (8.66)
SEm±	2.023	0.304	0.323
CD (0.05)	NS	0.882	0.939

NS - Non significant

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

Interaction effect between SSB methods and weed management methods was found significant at 30 and 60 DAS. At 30 DAS, the treatment combination s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) registered the lowest total weed density (16.00 m^{-2}) and it was on par with s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The highest total weed density (85.33 m^{-2}) was recorded in s_2m_8 (no SSB with weedy check).

At 60 DAS, the lowest total weed density (5.33 m^{-2}) was observed in s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and it was statistically comparable with s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). s_2m_8 (no SSB with weedy check) recorded the highest total weed density (75.00 m^{-2}).

4.1.3. Relative Density

4.1.3.1. Relative Density of Broad leaved Weeds

The data on relative density of BLW at 15, 30 and 60 DAS are presented in Tables 9a and 9b.

The effect of SSB methods on relative density of BLW were observed to be non-significant at 15, 30 and 60 DAS.

The effect of different weed management methods on relative density of BLW was found to be significant at 30 and 60 DAS. At 30 DAS, the lowest relative density of BLW (60.26%) was observed in HWT (m_7), which was statistically comparable with

Table 9a. Effect of weed management practices on relative density of broad leaved weeds

Treatments	Relative density of broad leaved weeds (per cent)		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	78.32 (8.87)	71.96 (8.45)	82.52 (8.98)
s_2 - No SSB	79.04 (8.92)	70.29 (8.25)	80.85 (8.93)
SEm±	0.159	0.111	0.160
CD (0.05)	NS	NS	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	84.36 (9.23)	75.65 (8.65)	94.44 (9.69)
m_2 – Penox. @ 25 g ha^{-1} fb HW	81.24 (9.03)	81.08 (8.89)	91.67 (9.51)
m_3 – Penox. @ 30 g ha^{-1} fb HW	79.90 (8.97)	68.25 (8.25)	100 (10.0)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	72.33 (8.52)	73.89 (8.54)	75.24 (8.63)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	78.06 (8.84)	69.29 (8.32)	81.35 (8.95)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	82.72 (9.12)	64.88 (7.72)	94.44 (9.69)
m_7 - Hand weeding twice (15 and 35 DAS)	76.35 (8.78)	60.26 (7.72)	65.39 (8.02)
m_8 - Weedy check (unweeded control)	74.51 (8.66)	75.74 (8.71)	50.96 (7.12)
SEm±	0.317	0.223	0.321
CD (0.05)	NS	0.650	0.933

NS - Non significant

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

Table 9b. Interaction effect of SSB methods and weed management methods on relative density of broad leaved weeds

Interactions (S x M)	Relative density (per cent)		
	15 DAS	30 DAS	60 DAS
s_1m_1	80.47 (9.02)	90.47 (9.51)	88.89 (9.39)
s_1m_2	69.25 (8.34)	64.45 (7.89)	100 (10.0)
s_1m_3	89.20 (9.50)	74.28 (8.62)	100 (10.0)
s_1m_4	77.78 (8.81)	58.89 (7.66)	73.81 (8.51)
s_1m_5	66.50 (8.16)	74.56 (8.64)	100 (10.0)
s_1m_6	91.89 (9.62)	65.00 (8.05)	100 (10.0)
s_1m_7	75.47 (8.74)	73.33 (8.56)	51.65 (7.15)
s_1m_8	76.05 (8.77)	74.77 (8.65)	45.79 (6.76)
s_2m_1	88.27 (9.45)	60.83 (7.80)	100 (10.0)
s_2m_2	93.24 (9.71)	97.70 (9.88)	83.33 (9.02)
s_2m_3	70.59 (8.45)	62.22 (7.89)	100 (10.0)
s_2m_4	66.87 (8.23)	88.89 (9.42)	76.70 (8.76)
s_2m_5	89.61 (9.51)	64.02 (8.00)	62.69 (7.90)
s_2m_6	73.54 (8.61)	64.76 (7.40)	88.89 (9.39)
s_2m_7	77.22 (8.81)	47.20 (6.87)	79.12 (8.88)
s_2m_8	72.99 (8.56)	76.7 (8.76)	56.12 (7.47)
SEm±	0.449	0.317	0.454
CD (0.05)	NS	0.920	1.320

NS - Non significant

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

penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5). The highest relative density of BLW (81.08%) was recorded in penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2). At 60 DAS, weedy check (m_8) recorded the lowest relative density of BLW (50.96%) and it was on par with HWT (m_7). The highest relative density of BLW (100%) was observed in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3).

The interaction between SSB methods and weed management methods had significant effect on relative density of BLW at 30 and 60 DAS. At 30 DAS, the treatment combination s_2m_7 (no SSB with HWT) registered the lowest relative density of BLW (47.20%), which was on par with, s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), The highest relative density of BLW was (97.70%) observed in s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). At 60 DAS, the treatment combination s_1m_8 (SSB with weedy check) recorded the lowest relative density of BLW (45.79%) and it was on par with s_1m_7 (SSB with HWT), s_2m_8 (no SSB with weedy check) and s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS).

4.1.3.2. Relative Density of Grasses

The data on relative density of grasses at 15, 30 and 60 DAS are presented in Tables 10a and 10b.

Stale seedbed methods had significant influence on the relative density of grasses only at 60 DAS. No SSB method (s_2) recorded lower relative density of grasses (7.88%) compared to SSB (s_1).

The effect of weed management methods on relative density of grasses was found significant at 30 and 60 DAS. At 30 DAS, penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the lowest relative density (18.92%) and it was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1). Penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) registered the highest relative density of grasses (40.17%). At 60 DAS, lower values of relative density of grasses observed in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), which was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2). The highest relative density of grasses (24.77%) was recorded in penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4).

The interaction between SSB methods and weed management methods had significant effect on the relative density of grasses at 15 and 30 DAS. At 15 DAS, the treatment combination s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the lowest relative density of grasses (8.11%) and it was statistically on par with s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_7 (no SSB with HWT) and s_1m_8 (SSB with weedy check). The highest relative density of grasses (33.49%) was recorded in the treatment combination s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS).

At 30 DAS, the lowest relative density (2.30%) was recorded by s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and it was on par with s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The treatment combination, s_2m_7 (no SSB with HWT) registered the highest relative density of grasses (49.46%).

Table 10a. Effect of weed management practices on relative density of grasses

Treatments	Relative density of grasses (per cent)		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	21.66 (4.33)	27.97 (5.16)	15.15 (3.23)
s_2 - No SSB	20.94 (4.35)	30.15 (5.15)	7.88 (1.93)
SEm±	0.336	0.192	0.378
CD (0.05)	NS	NS	1.098
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	15.63 (3.89)	24.34 (4.55)	5.56 (1.56)
m_2 – Penox. @ 25 g ha^{-1} fb HW	18.76 (4.02)	18.92 (3.56)	8.33 (1.77)
m_3 – Penox. @ 30 g ha^{-1} fb HW	20.09 (4.34)	31.75 (5.64)	0.0 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	27.67 (4.91)	26.10 (4.71)	24.77 (4.64)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	21.93 (4.25)	30.62 (5.55)	18.65 (3.41)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	17.26 (3.59)	40.17 (6.34)	5.56 (1.56)
m_7 - Hand weeding twice (15 and 35 DAS)	23.56 (4.81)	38.07 (6.13)	11.62 (3.04)
m_8 - Weedy check (unweeded control)	25.47 (4.93)	22.55 (4.76)	17.62 (3.95)
SEm±	0.671	0.384	0.756
CD (0.05)	NS	1.115	2.196

NS - Non significant

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

Table 10b. Interaction effect of SSB methods and weed management methods on relative density of grasses

Interactions (S x M)	Relative density (per cent)		
	15 DAS	30 DAS	60 DAS
s_1m_1	19.52 (4.32)	9.52 (2.80)	0.0 (0.71)
s_1m_2	30.74 (5.43)	35.54 (5.75)	16.67 (2.84)
s_1m_3	10.79 (3.29)	25.71 (5.10)	0.0 (0.71)
s_1m_4	22.22 (4.03)	41.11 (6.43)	23.33 (4.88)
s_1m_5	33.49 (5.60)	25.26 (5.07)	37.30 (6.11)
s_1m_6	8.11 (2.13)	35.00 (5.93)	11.11 (2.41)
s_1m_7	24.52 (4.99)	26.69 (5.21)	17.17 (4.17)
s_1m_8	23.94(4.86)	24.93 (5.00)	15.62 (4.01)
s_2m_1	11.72 (3.46)	39.17 (6.30)	11.11 (2.41)
s_2m_2	6.76 (2.61)	2.30 (1.38)	0.0 (0.71)
s_2m_3	29.40 (5.40)	37.78 (6.18)	0.0 (0.71)
s_2m_4	33.13 (5.78)	11.11 (3.00)	26.19 (4.40)
s_2m_5	10.39 (2.91)	35.98 (6.03)	0.0 (0.71)
s_2m_6	26.42 (5.04)	45.23 (6.76)	0.0 (0.71)
s_2m_7	22.78 (4.64)	49.46 (7.05)	6.06 (1.91)
s_2m_8	27.00 (5.00)	20.17 (4.53)	19.61 (3.88)
SEm±	0.949	0.543	1.070
CD (0.05)	2.754	1.576	NS

NS - Non significant

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

4.1.3.3. Relative Density of Sedges

Data on relative density of sedges at 15, 30 and 60 DAS are depicted in Tables 11a and 11b.

The relative density of sedges at 30 and 60 DAS was found significantly influenced by the SSB methods. Relative density of sedges observed in SSB (s_1) was zero per cent at 30 DAS and it was significantly lower (4.00%) compared to no SSB method (s_2) at 60 DAS.

The different weed management methods had significant effect on relative density at 30 and 60 DAS. All the herbicide applied plots recorded the zero per cent relative density of sedges at 30 and 60 DAS indicating the effectiveness of penoxsulam in controlling this morphological group of weeds. At 30 DAS, these treatments were on par with HWT (m_7). Weedy check (m_8) registered the highest relative density of sedges at both stages.

Interaction effect was found to be significant 30 and 60 DAS. All the herbicide treated plots under SSB method and no SSB method at 30 and 60 DAS, s_1m_7 (SSB with HWT) and s_1m_8 (SSB with weedy check) recorded zero per cent relative density of sedges. The highest relative density of sedge was recorded in s_2m_8 (no SSB with weedy check) at 30 DAS and s_2m_7 (no SSB with HWT) at 60 DAS.

4.1.4. Weed Dry Weight

4.1.4.1. Dry Weight of Broad Leaved Weeds

The results of dry weight of BLW at 15, 30 and 60 DAS are presented in Tables 12a and 12b.

Stale seedbed methods significantly influenced dry weight of BLW only at 15 DAS. Significantly lower dry weight of BLW (0.24 g m^{-2}) was observed in SSB method (s_1) compared to no SSB method (s_2).

Table 11a. Effect of weed management practices on relative density of sedges

Treatments	Relative density of sedges (per cent)		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0	0.0 (0.71)	4.00 (1.39)
s_2 - No SSB	0	1.26 (1.01)	9.81 (2.09)
SEm±	0	0.074	0.127
CD (0.05)	NS	0.216	0.369
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0	0.0 (0.71)	0.0 (0.71)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0	0.0 (0.71)	0.0 (0.71)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0	0.0 (0.71)	0.0 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.0 (0.71)	0.0 (0.71)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.0 (0.71)	0.0 (0.71)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.0 (0.71)	0.0 (0.71)
m_7 - Hand weeding twice (15 and 35 DAS)	0	0.93 (1.13)	22.99 (4.05)
m_8 - Weedy check (unweeded control)	0	4.09 (1.49)	32.25 (5.63)
SEm±	0	0.148	0.253
CD (0.05)	NS	0.431	0.737

NS - Non significant

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

Table 11b. Interaction effect of SSB methods and weed management methods on relative density of sedges

Interactions (S x M)	Relative density (per cent)		
	15 DAS	30 DAS	60 DAS
s_1m_1	0	0.0 (0.71)	0.0 (0.71)
s_1m_2	0	0.0 (0.71)	0.0 (0.71)
s_1m_3	0	0.0 (0.71)	0.0 (0.71)
s_1m_4	0	0.0 (0.71)	0.0 (0.71)
s_1m_5	0	0.0 (0.71)	0.0 (0.71)
s_1m_6	0	0.0 (0.71)	0.0 (0.71)
s_1m_7	0	0.0 (0.71)	3.70 (1.61)
s_1m_8	0	0.0 (0.71)	28.25 (5.29)
s_2m_1	0	0.0 (0.71)	0.0 (0.71)
s_2m_2	0	0.0 (0.71)	0.0 (0.71)
s_2m_3	0	0.0 (0.71)	0.0 (0.71)
s_2m_4	0	0.0 (0.71)	0.0 (0.71)
s_2m_5	0	0.0 (0.71)	0.0 (0.71)
s_2m_6	0	0.0 (0.71)	0.0 (0.71)
s_2m_7	0	1.85 (1.55)	42.28 (6.49)
s_2m_8	0	8.16 (2.28)	36.25 (5.97)
SEm±	0	0.210	0.359
CD (0.05)	NS	0.610	1.043

NS - Non significant

The figures were subjected to square root transformation √(x+0.5) and transformed values are given in parenthesis

Table 12a. Effect of weed management practices on dry weight of broad leaved weeds

Treatments	Dry weight of broad leaved weeds (g m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0.24 (0.47)	0.35 (0.91)	1.50 (1.24)
s_2 - No SSB	0.49 (0.64)	0.34 (0.91)	1.66 (1.23)
SEm±	0.049	0.017	0.106
CD (0.05)	0.143	NS	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0.78 (0.81)	0.14 (0.80)	0.14 (0.79)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0.49 (0.60)	0.78 (1.13)	1.10 (1.19)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0.43 (0.62)	0.24 (0.85)	0.99 (1.14)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.19 (0.39)	0.22 (0.84)	0.66 (1.05)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.28 (0.56)	0.18 (0.82)	0.50 (0.97)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.23 (0.57)	0.11 (0.78)	0.09 (0.76)
m_7 - Hand weeding twice (15 and 35 DAS)	0.24 (0.46)	0.27 (0.87)	0.98 (1.16)
m_8 - Weedy check (unweeded control)	0.21 (0.46)	0.86 (1.08)	8.17 (2.78)
SEm±	0.099	0.035	0.212
CD (0.05)	NS	0.062	0.615

NS - Non significant

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

Table 12b. Interaction effect of SSB methods and weed management methods on dry weight of broad leaved weeds

Interactions (S x M)	Dry weight of broad leaved weeds (g m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	0.48 (0.67)	0.14 (0.80)	0.12 (0.79)
s_1m_2	0.16 (0.38)	0.66 (1.08)	1.28 (1.19)
s_1m_3	0.20 (0.44)	0.31 (0.89)	1.56 (1.35)
s_1m_4	0.18 (0.42)	0.34 (0.91)	0.51 (1.00)
s_1m_5	0.24 (0.49)	0.15 (0.81)	0.77 (1.11)
s_1m_6	0.28 (0.53)	0.08 (0.76)	0.12 (0.79)
s_1m_7	0.10 (0.31)	0.10 (0.78)	0.88 (1.11)
s_1m_8	0.30 (0.54)	1.04 (1.24)	6.74 (2.54)
s_2m_1	1.07 (0.95)	0.14 (0.80)	0.14 (0.80)
s_2m_2	0.81 (0.82)	0.89 (1.18)	0.94 (1.19)
s_2m_3	0.66 (0.80)	0.15 (0.81)	0.40 (0.94)
s_2m_4	0.20 (0.35)	0.09 (0.77)	0.82 (1.09)
s_2m_5	0.31 (0.63)	0.21 (0.84)	0.20 (0.84)
s_2m_6	0.33 (0.60)	0.14 (0.80)	0.04 (0.74)
s_2m_7	0.34 (0.61)	0.45 (0.97)	1.08 (1.20)
s_2m_8	0.13 (0.38)	0.67 (1.08)	9.62 (3.01)
SEm±	0.139	0.049	0.299
CD (0.05)	NS	0.088	NS

NS - Non significant

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

The dry weight of BLW was significantly influenced by weed management methods at 30 and 60 DAS. Application of penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) recorded the lowest dry weight of BLW at 30 and 60 DAS. At 30 DAS, m_6 was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 25 and 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5 and m_4, respectively). At 60 DAS, m_6 was statistically comparable with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 25 and 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5 and m_4, respectively), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), HWT (m_7) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2). Weedy check (m_8) registered the highest dry weight of BLW (0.86 g m^{-2} and 8.17 g m^{-2}) at 30 and 60 DAS respectively.

Interaction effect was found to be significant only at 30 DAS. The treatment combination, s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the lowest dry weight of BLW (0.08 g m^{-2}) at 30 DAS and it was statistically comparable with s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_7 (SSB with HWT), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS).

4.1.4.2. Dry Weight of Grasses

Data on the effect of SSB methods and weed management methods on dry weight of grasses at 15, 30 and 60 DAS are depicted in Tables 13a and 13b.

The dry weight of grasses was significantly influenced by SSB methods only at 30 DAS. At 30 DAS, significantly lower dry weight of grasses (0.04 g m^{-2}) was registered by SSB (s_1) compared to no SSB method (s_2).

Weed management methods significantly influenced the dry weight of grasses at 30 and 60 DAS. At 30 DAS, penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4) recorded the lowest dry weight of grasses (0.02 g m^{-2}) and it was on par with penoxsulam @ 30 and 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3 and m_1 respectively), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) and HWT (m_7). The highest dry weight of grasses (1.49 g m^{-2}) was recorded in weedy check (m_8).

At 60 DAS, no grass weeds were found in penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 25 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and these treatments were on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) and HWT (m_7). Weedy check (m_8) treatment registered the highest dry weight of grasses (21.57 g m^{-2}).

Interaction effect of SSB methods and weed management methods was found to be significant only at 30 DAS. At 30 DAS, the treatment combination s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the lowest dry weight of grasses (0.003 g m^{-2}) and it was on par with all other treatment combination except s_1m_7 (SSB with HWT), s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_8 (no SSB with weedy check).

Table 13a. Effect of weed management practices on dry weight of grasses

Treatments	Dry weight of grasses (g m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0.08 (0.75)	0.04 (0.74)	3.35 (1.41)
s_2 - No SSB	0.12 (0.78)	0.42 (0.89)	3.98 (1.41)
SEm±	0.016	0.008	0.172
CD (0.05)	NS	0.024	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0.08 (0.76)	0.04 (0.74)	0.00 (0.71)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0.06 (0.75)	0.07 (0.75)	0.68 (1.00)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0.17 (0.81)	0.03 (0.73)	0.00 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.11 (0.78)	0.02 (0.73)	0.14 (0.78)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.11 (0.78)	0.11 (0.77)	1.08 (1.08)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.06 (0.75)	0.05 (0.74)	0.00 (0.71)
m_7 - Hand weeding twice (15 and 35 DAS)	0.11 (0.78)	0.10 (0.77)	5.84 (1.65)
$_8$ - Weedy check (unweeded control)	0.03 (0.73)	1.49 (1.30)	21.57 (4.67)
SEm±	0.033	0.017	0.345
CD (0.05)	NS	0.048	1.002

NS - Non significant

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

Table 13b. Interaction effect of SSB methods and weed management methods on dry weight of grasses

Interactions (S x M)	Dry weight of grasses (g m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	0.09 (0.76)	0.02 (0.72)	0.00 (0.71)
s_1m_2	0.10 (0.78)	0.003 (0.71)	1.36 (1.29)
s_1m_3	0.04 (0.73)	0.02 (0.72)	0.00 (0.71)
s_1m_4	0.09 (0.77)	0.008 (0.71)	0.02 (0.72)
s_1m_5	0.13 (0.79)	0.06 (0.74)	2.15 (1.45)
s_1m_6	0.03 (0.73)	0.04 (0.74)	0.00 (0.71)
s_1m_7	0.04 (0.74)	0.16 (0.81)	0.27 (0.86)
s_1m_8	0.04 (0.74)	0.06 (0.75)	23.00 (4.84)
s_2m_1	0.09 (0.76)	0.06 (0.75)	0.00 (0.71)
s_2m_2	0.03 (0.73)	0.12 (0.79)	0.00 (0.71)
s_2m_3	0.31 (0.88)	0.05 (0.74)	0.00 (0.71)
s_2m_4	0.13 (0.80)	0.05 (0.74)	0.26 (0.85)
s_2m_5	0.09 (0.76)	0.16 (0.81)	0.00 (0.71)
s_2m_6	0.10 (0.77)	0.05 (0.74)	0.00 (0.71)
s_2m_7	0.19 (0.83)	0.04 (0.73)	11.40 (2.44)
s_2m_8	0.03 (0.73)	2.91 (1.84)	20.14 (4.49)
SEm±	0.047	0.023	0.484
CD (0.05)	NS	0.068	NS

NS - Non significant

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

The treatment combination, s_2m_8 (no SSB with weedy check) recorded the highest dry weight of grasses (2.91 g m^{-2}).

4.1.4.3. Dry Weight of Sedges

Data on dry weight of sedges at 15, 30 and 60 DAS are presented in Tables 14a and 14b.

The dry weight of sedges was found significantly influenced by SSB methods only at 60 DAS. At 60 DAS, SSB (s_1) recorded lower dry weight of sedges (0.11 g m^{-2}) compared to no SSB method (s_2).

Weed management methods had significant effect on dry weight of sedges only at 60 DAS. All the herbicide treated plot recorded zero dry weight of sedge. Only HW and weedy check treatment recorded the dry weight of sedge. The highest dry weight of sedges (1.58 g m^{-2}) was recorded in weedy check (m_8).

The interaction of SSB methods and weed management methods had significant effect on dry weight of sedges only at 60 DAS. At 60 DAS, dry weight of sedges was nil in all herbicidal plots with or without SSB. The highest dry weight of sedges (2.27 g m^{-2}) was observed in s_2m_8 (no SSB with weedy check).

4.1.4.4. Total Dry Weight of Weeds

Data on total dry weight of weeds are depicted in Tables 15a and 15b.

The total dry weight of weeds was found significantly influenced by SSB methods at 15 and 30 DAS. Stale seedbed (s_1) method registered significantly lower total dry weight of weeds compared to no SSB method (s_2) at 15 and 30 DAS.

Weed management methods exerted significant effect on total dry weight of weeds at 30 and 60 DAS. Penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) recorded the lowest dry weight of weeds at 30 and 60 DAS. At 30 DAS, m_6 was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40

Table 14a. Effect of weed management practices on dry weight of sedges

Treatments	Dry weight of sedges (g m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0	0.00 (0.71)	0.11 (0.77)
s_2 - No SSB	0	0.01 (0.72)	0.41 (0.89)
SEm±	0	0.041	0.009
CD (0.05)	NS	NS	0.027
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0	0.00 (0.71)	0.00 (0.71)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0	0.00 (0.71)	0.00 (0.71)
m_7 - Hand weeding twice (15 and 35 DAS)	0	0.02 (0.72)	0.53 (0.98)
m_8 - Weedy check (unweeded control)	0	0.02 (0.72)	1.58 (1.42)
SEm±	0	0.083	0.019
CD (0.05)	NS	NS	0.055

NS - Non significant

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

Table 14b. Interaction effect of SSB methods and weed management methods on dry weight of sedges

Interactions (S x M)	Dry weight of grasses (g m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	0	0.00 (0.71)	0.00 (0.71)
s_1m_2	0	0.00 (0.71)	0.00 (0.71)
s_1m_3	0	0.00 (0.71)	0.00 (0.71)
s_1m_4	0	0.00 (0.71)	0.00 (0.71)
s_1m_5	0	0.00 (0.71)	0.00 (0.71)
s_1m_6	0	0.00 (0.71)	0.00 (0.71)
s_1m_7	0	0.00 (0.71)	0.02 (0.72)
s_1m_8	0	0.00 (0.71)	0.88 (1.17)
s_2m_1	0	0.00 (0.71)	0.00 (0.71)
s_2m_2	0	0.00 (0.71)	0.00 (0.71)
s_2m_3	0	0.00 (0.71)	0.00 (0.71)
s_2m_4	0	0.00 (0.71)	0.00 (0.71)
s_2m_5	0	0.00 (0.71)	0.00 (0.71)
s_2m_6	0	0.00 (0.71)	0.00 (0.71)
s_2m_7	0	0.03 (0.73)	1.04 (1.24)
s_2m_8	0	0.04 (0.73)	2.27 (1.67)
SEm±	0	0.117	0.027
CD (0.05)	NS	NS	0.078

NS - Non significant

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

Table 15a. Effect of weed management practices on total weed dry weight

Treatments	Total weed dry weight (g m^{-2})		
	15 DAS	30 DAS	60 DAS
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0.32 (0.54)	0.41 (0.59)	4.96 (1.75)
s_2 - No SSB	0.64 (0.73)	0.78 (0.74)	6.71 (1.92)
SEm±	0.052	0.022	0.201
CD (0.05)	0.152	0.066	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0.84 (0.88)	0.16 (0.41)	2.78 (1.34)
m_2 – Penox. @ 25 g ha^{-1} fb HW	0.55 (0.67)	0.84 (0.91)	1.79 (1.40)
m_3 – Penox. @ 30 g ha^{-1} fb HW	0.60 (0.71)	0.27 (0.48)	0.99 (1.14)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.29 (0.53)	0.24 (0.48)	0.80 (1.09)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.46 (0.64)	0.29 (0.53)	1.57 (1.26)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.44 (0.61)	0.13 (0.36)	0.08 (0.76)
m_7 - Hand weeding twice (15 and 35 DAS)	0.36 (0.56)	0.38 (0.60)	7.35 (2.08)
m_8 - Weedy check (unweeded control)	0.28 (0.50)	2.42 (1.51)	31.32 (5.61)
SEm±	0.105	0.045	0.402
CD (0.05)	NS	0.132	1.168

NS - Non significant

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

Table 15b. Interaction effect of SSB methods and weed management methods on total weed dry weight

Interactions (S x M)	Total weed dry weight (g m^{-2})		
	15 DAS	30 DAS	60 DAS
s_1m_1	0.57 (0.74)	0.15 (0.39)	0.12 (0.79)
s_1m_2	0.26 (0.50)	0.66 (0.81)	2.63 (1.62)
s_1m_3	0.23 (0.47)	0.34 (0.51)	1.57 (1.35)
s_1m_4	0.27 (0.50)	0.35 (0.58)	0.53 (1.01)
s_1m_5	0.39 (0.60)	0.20 (0.45)	2.93 (1.69)
s_1m_6	0.40 (0.55)	0.10 (0.30)	0.12 (0.79)
s_1m_7	0.15 (0.38)	0.26 (0.51)	1.18 (1.22)
s_1m_8	0.34 (0.58)	1.28 (1.13)	30.61 (5.55)
s_2m_1	1.12 (1.01)	0.18 (0.43)	5.43 (1.89)
s_2m_2	0.84 (0.85)	1.02 (1.01)	0.94 (1.19)
s_2m_3	0.98 (0.95)	0.20 (0.46)	0.40 (0.94)
s_2m_4	0.30 (0.55)	0.14 (0.37)	1.07 (1.18)
s_2m_5	0.54 (0.80)	0.36 (0.61)	0.21 (0.84)
s_2m_6	0.48 (0.68)	0.19 (0.43)	0.04 (0.74)
s_2m_7	0.59 (0.74)	0.49 (0.70)	13.53 (2.94)
s_2m_8	0.20 (0.43)	3.58 (1.89)	32.03 (5.67)
SEm±	0.199	0.064	0.569
CD (0.05)	NS	0.187	NS

NS - Non significant

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

DAS (m_1), penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3). At 60 DAS, m_6 was statistically comparable penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) and penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively). Weedy check (m_8) registered the highest total dry weight of weeds (2.42 g m^{-2} and 31.32 g m^{-2}) at 30 and 60 DAS respectively.

Interaction between SSB methods and weed management methods was found to be significant only at 30 DAS. At 30 DAS, the treatment combination s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) registered the lowest total weed dry weight (0.10 g m^{-2}) and it was statistically comparable with s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The treatment combination, s_2m_8, (no SSB with weedy check) registered the highest total weed dry weight (3.58 g m^{-2}).

4.1.5. Weed Control Efficiency

Data on weed control efficiency are depicted in Tables 16a and 16b.

Stale seedbed method significantly influenced the weed control efficiency at 30 and 60 DAS. Stale seedbed method (s_1) recorded significantly higher weed control efficiency (88.71% and 84.00%) compared to no SSB method (s_2) at 30 and 60 DAS, respectively.

Weed control efficiency was significantly influenced by the weed management methods at 30 and 60 DAS. The highest weed control efficiency (96.23% and 99.74%) was observed in the plot applied with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) at 30 and 60 DAS, respectively. At 30 DAS, m_6 was on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5). All penoxsulam treatments fb either HW or MM+CE were on par at 60 DAS. Weedy check (m_8) registered the lowest weed control efficiency (32.77% and 2.06%) at 30 and 60 DAS, respectively.

Interaction between SSB methods and weed management methods was found to be significant at 30 and 60 DAS. At 30 DAS, the highest WCE (97.51 %) was registered with s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and it was on par with s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_7 (SSB with HWT) and s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS).

The treatment combination, s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the highest weed control efficiency (99.83%) at 60 DAS, which was on par with all other combinations except s_1m_8, (SSB with weedy check) s_2m_7 (no SSB with HWT) and s_2m_8 (no SSB with weedy check).

Table 16a. Effect of weed management practices on weed control efficiency

Treatments	Weed control efficiency (%)	
	30 DAS	60 DAS
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	88.71 (9.43)	84.00 (8.83)
s_2 - No SSB	78.45 (8.39)	79.48 (8.41)
SEm±	0.037	0.105
CD (0.05)	0.109	0.305
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	95.20 (9.78)	92.34 (9.59)
m_2 – Penox. @ 25 g ha^{-1} fb HW	76.80 (8.78)	94.27 (9.73)
m_3 – Penox. @ 30 g ha^{-1} fb HW	92.92 (9.66)	97.20 (9.88)
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	93.27 (9.68)	97.41 (9.89)
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	92.01 (9.62)	93.82 (9.70)
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	96.23 (9.84)	99.74 (10.01)
m_7 - Hand weeding twice (15 and 35 DAS)	89.44 (9.48)	77.07 (8.73)
m_8 - Weedy check (unweeded control)	32.77 (4.42)	2.06 (1.41)
SEm±	0.075	0.21
CD (0.05)	0.217	0.61

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

Table 16b. Interaction effect of SSB methods and weed management methods on weed control efficiency

Interactions (S x M)	Weed control efficiency (%)	
	30 DAS	60 DAS
s_1m_1	95.35 (9.79)	99.63 (10.01)
s_1m_2	81.67 (9.06)	91.52 (9.59)
s_1m_3	91.86 (9.61)	95.68 (9.81)
s_1m_4	90.65 (9.55)	98.06 (9.93)
s_1m_5	94.23 (9.73)	88.22 (9.39)
s_1m_6	97.51 (9.90)	99.64 (10.01)
s_1m_7	92.87 (9.66)	95.13 (9.78)
s_1m_8	65.54 (8.12)	4.11 (2.11)
s_2m_1	95.05 (9.78)	85.04 (9.18)
s_2m_2	71.92 (8.51)	97.02 (9.88)
s_2m_3	93.98 (9.72)	98.73 (9.96)
s_2m_4	95.88 (9.82)	96.77 (9.86)
s_2m_5	89.79 (9.50)	99.42 (10.00)
s_2m_6	94.94 (9.77)	99.83 (10.02)
s_2m_7	86.02 (9.30)	59.00 (7.68)
s_2m_8	0.00 (0.71)	0.0 (0.71)
SEm±	0.106	0.297
CD (0.05)	0.308	0.862

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

4.2. OBSERVATION ON CROP

4.2.1. Growth Attributes

4.2.1.1 Plant Height

The results of the plant height at different growth stages *viz*., 30 DAS, 60 DAS and at harvest are presented in the Tables 17a and 17b.

Stale seedbed methods exerted significant effect on plant height at 60 DAS only. At 60 DAS, SSB with mechanical removal weeds (s_1) recorded significantly higher plant height (76.60 cm) compared to no SSB method (s_2).

Weed management methods significantly influenced plant height at 30, 60 and harvest stage. At 30 DAS, penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1) recorded the highest plant height (38.86 cm) and which was statistically comparable with HWT (m_7), penoxsulam @ 20, 25 and 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4, m_5 and m_6, respectively), and weedy check (m_8). The lowest plant height (34.67 cm) was registered by penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) at 30 DAS. At 60 DAS, the highest plant height (77.36 cm) was recorded by penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2), which was on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3, respectively), HWT (m_7) and penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4).Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) recorded the lowest plant height of 66.88 cm. At harvest, plant height was the highest (101.9 cm) in plot treated with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and it was on par penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), penoxsulam @ 25 and 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2 and m_1, respectively), HWT (m_7) and penoxsulam @ 25 and 20 g ha^{-1} at 10-15 DAS fb MM+CE

Table 17a. Effect of weed management practices on plant height and phytotoxicity

Treatments	Plant height (cm)			Phytotoxicity (1-10)
	30 DAS	60 DAS	Harvest	
A - Stale seed bed methods (S)				
s_1 – SSB with mechanical removal of weeds	36.91	76.60	98.08	1
s_2 - No SSB	36.84	71.08	96.45	1
SEm±	0.417	0.791	0.814	-
CD (0.05)	NS	2.295	NS	NS
B - Weed management methods (M)				
m_1 – Penox. @ 20 g ha^{-1} fb HW	38.86	75.73	98.7	1
m_2 – Penox. @ 25 g ha^{-1} fb HW	35.23	77.36	98.73	1
m_3 – Penox. @ 30 g ha^{-1} fb HW	34.67	75.54	101.9	1
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	37.72	73.2	97.43	1
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	36.99	66.88	97.47	1
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	36.81	75.87	99.6	1
m_7 - Hand weeding twice (15 and 35 DAS)	38.04	74.17	97.7	1
m_8 - Weedy check (unweeded control)	36.67	72.00	86.57	1
SEm±	0.834	1.582	1.629	-
CD (0.05)	2.422	4.59	4.726	NS

NS - Non significant

Table 17b. Interaction effect of SSB methods and weed management methods on plant height and phytotoxicity

Interactions (S x M)	Plant height (cm)			Phytotoxicity
	30 DAS	60 DAS	Harvest	
s_1m_1	38.56	76.94	95.73	1
s_1m_2	37.90	82.67	103.13	1
s_1m_3	33.34	76.68	102.4	1
s_1m_4	39.28	78.00	98.47	1
s_1m_5	33.72	65.57	96.63	1
s_1m_6	38.57	80.8	100.27	1
s_1m_7	35.78	77.73	97.07	1
s_1m_8	38.12	74.43	89.93	1
s_2m_1	39.16	74.51	101.6	1
s_2m_2	32.55	72.04	94.33	1
s_2m_3	36.00	74.40	101.4	1
s_2m_4	36.16	68.40	96.40	1
s_2m_5	40.27	68.20	97.30	1
s_2m_6	35.06	70.93	98.93	1
s_2m_7	40.29	70.60	98.93	1
s_2m_8	35.21	69.57	83.20	1
SEm±	1.18	2.237	2.303	-
CD (0.05)	3.425	NS	NS	NS

NS - Non significant

@ 4 g ha^{-1} at 35-40 DAS (m_5 and m_4, respectively). The lowest plant height was recorded by weedy check (m_8).

Interaction between SSB methods and weed management methods was found significant at 30 DAS. At 30 DAS, the treatment combination s_2m_7 (no SSB with HWT) registered the highest plant height (40.29), which was statistically comparable with s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_8 (SSB with weedy check) and s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The treatment combination s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the lowest plant height (32.55 cm).

4.2.1.2 Number of Tillers m^{-2}

The data on effect of SSB methods and weed management methods on number of tillers m^{-2} are presented in Tables 18a and 18b.

Stale seedbed methods had significant effect on the number of tillers m^{-2} at 30 DAS and harvest. At both the stages SSB with mechanical removal weeds (s_1) recorded significantly higher tiller number compared to no SSB method (s_2).

Weed management method also exerted significant effect on number of tiller m^{-2} at 30, 60 DAS and harvest. At 30 DAS, penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1) recorded the highest number of tillers m^{-2} (523.3), which was statistically on par with penoxsulam @ 30 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3 and m_2, respectively). The lowest number of tillers m^{-2} (386.5) was recorded by penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5). At 60 DAS, the highest number of tillers m^{-2} (648.0) was registered by the plot treated

Table 18a. Effect of weed management practices on number of tillers

Treatments	Tillers m^{-2}		
	30 DAS	60 DAS	Harvest
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	479.7	574.3	381.2
s_2 - No SSB	394.0	560.1	321.3
SEm±	15.545	8.982	5.462
CD (0.05)	45.11	NS	15.851
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	523.3	552.0	381.3
m_2 – Penox. @ 25 g ha^{-1} fb HW	457.0	563.0	344.7
m_3 – Penox. @ 30 g ha^{-1} fb HW	492.0	560.0	372.0
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	429.3	648.0	374.7
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	386.5	635.3	403.3
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	410.7	578.2	404.7
m_7 - Hand weeding twice (15 and 35 DAS)	394.3	536.3	295.0
m_8 - Weedy check (unweeded control)	401.8	464.7	234.0
SEm±	31.092	17.964	10.924
CD (0.05)	90.23	52.132	31.701

NS - Non significant

Table 18b. Interaction effect of SSB methods and weed management methods on number of tillers

Interactions (S x M)	Tillers m^{-2}		
	30 DAS	60 DAS	Harvest
s_1m_1	502.7	526.7	433.3
s_1m_2	518.0	576.7	366.7
s_1m_3	502.7	516.0	401.3
s_1m_4	454.7	645.3	412.0
s_1m_5	457.3	660.0	414.7
s_1m_6	530.7	622.0	434.7
s_1m_7	440.0	546.0	313.3
s_1m_8	431.7	501.3	273.3
s_2m_1	544.0	577.3	329.3
s_2m_2	396.0	549.3	322.7
s_2m_3	481.3	604.0	342.7
s_2m_4	404.0	650.7	337.3
s_2m_5	315.7	610.7	392.0
s_2m_6	290.7	534.3	374.7
s_2m_7	348.7	526.7	276.7
s_2m_8	372.0	428.0	194.7
SEm±	43.969	25.405	15.449
CD (0.05)	NS	73.725	NS

NS - Non significant

with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4), which was on par with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5). The lowest number of tillers m^{-2} (464.7) was observed in weedy check (m_8).

Among the treatments, the highest number of tillers m^{-2} (404.6) was noticed with m_6 (penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) at harvest, which was on par with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5), penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1) and penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4). The lowest number of tillers m^{-2} (234.0) was registered in weedy check (m_8).

The interaction effect of SSB methods and weed management methods was found to be significant only at 60 DAS. At 60 DAS, the highest number of tillers m^{-2} (660)was recorded in s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and it was on par with s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The treatment combination, s_2m_8 (no SSB with weedy check) registered the lowest number of tillers m^{-2} (428).

4.2.1.3 Leaf Area Index (LAI)

The LAI recorded at 30 and 60 DAS are presented in the Tables 19a and 19b.

The data on LAI indicated that the effect of SSB methods on LAI was significant only at 60 DAS. Significantly higher LAI (7.00) was observed in SSB (s_1) compared to no SSB (s_2).

Effect of weed management methods on LAI was significant at both 30 and 60 DAS. At 30 DAS, the highest LAI (2.94) was recorded with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), which was statistically on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4). Weedy check (m_8) treatment recorded the lowest LAI of 1.48. At 60 DAS, the plot treated with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) registered the highest LAI (7.56) and it was on par with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) and penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4). The lowest LAI (4.72) was observed with weedy check (m_8).

Interaction effect of SSB methods and weed management methods was found to be non significant at both 30 and 60 DAS.

4.2.1.4 Dry matter Production

The data on dry matter production at harvest are furnished in Table 19a and 19b.

Stale seedbed methods significantly influenced the dry matter production of upland rice. Stale seed bed method (s_1) recorded significantly higher dry matter production (6471 kg ha^{-1}) compared to no SSB, with a dry matter production of 5639 kg ha^{-1}.

The dry matter production was found significantly influenced by the weed management methods also. Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the highest dry matter production (6708 kg ha^{-1}), which was statistically comparable with all weed management methods except weedy check (m_8). Weedy check (m_8) recorded the lowest dry matter production (4393 kg ha^{-1}), among the weed management methods.

The interaction did not have any significant effect on dry matter production.

Table 19a. Effect of weed management practices on leaf area index (LAI) and dry matter production (DMP)

Treatments	LAI		DMP ($kg\ ha^{-1}$)
	30 DAS	60 DAS	Harvest
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	2.38	7.00	6471
s_2 - No SSB	2.22	6.64	5639
SEm±	0.088	0.082	147.69
CD (0.05)	NS	0.239	428.6
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	2.94	7.00	6397
m_2 – Penox. @ 25 g ha^{-1} fb HW	2.36	7.53	6708
m_3 – Penox. @ 30 g ha^{-1} fb HW	2.31	6.76	6511
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.51	7.27	5852
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.13	6.89	6469
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.41	7.56	5886
m_7 - Hand weeding twice (15 and 35 DAS)	2.27	6.82	6225
m_8 - Weedy check (unweeded control)	1.48	4.72	4393
SEm±	0.177	0.164	295.38
CD (0.05)	0.513	0.477	857.2

NS - Non significant

Table 19b. Interaction effect of SSB methods and weed management methods on leaf area index (LAI) and dry matter production (DMP)

Interactions (S x M)	LAI		DMP (kg ha^{-1})
	30 DAS	60 DAS	Harvest
s_1m_1	2.67	7.11	6751
s_1m_2	2.41	8.03	7364
s_1m_3	2.35	6.94	7012
s_1m_4	3.04	7.63	6217
s_1m_5	2.22	6.98	6873
s_1m_6	2.77	8.01	6612
s_1m_7	2.16	6.69	6476
s_1m_8	1.44	4.6	4461
s_2m_1	3.22	6.89	6042
s_2m_2	2.32	7.04	6051
s_2m_3	2.28	6.59	6009
s_2m_4	1.98	6.91	5486
s_2m_5	2.03	6.8	6064
s_2m_6	2.04	7.11	5161
s_2m_7	2.37	6.94	5974
s_2m_8	1.52	4.84	4325
SEm±	0.25	0.233	417.75
CD (0.05)	NS	NS	NS

NS - Non significant

4.2.1.5 Herbicide Phytotoxicity

The data on herbicide phytotoxiciy on rice crop are presented in Table 17a and 17b.

Phytotoxicity observations on rice crop were recorded at 7 DAHA (days after herbicide application). Phytotoxicty was rated on a visual scale of 1-10, where 1 indicates no phytotoxicity and 10 indicates total crop damage. The data on phytotoxicity ratings were the same in all the experimental plots, indicating that there was no phytotoxic symptoms on rice plants in any of the herbicide treated plots.

4.2.2. Yield Attributes and Yield

4.2.2.1 Number of Panicles m^{-2}

The data on the effect of SSB and weed management methods on number of panicles m^{-2} is depicted in Table 20a and 20b.

The panicle number m^{-2} was not significantly influenced by SSB methods. However, SSB (s_1) recorded higher panicle number m^{-2} (272.1) compared to no SSB treatment (s_2).

The weed management methods had significant effect on this yield attribute. The highest number of panicles m^{-2} (307.0) was recorded by penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) which was on par with penoxsulam @ 30 and 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6 and m_4 respectively) and penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3, respectively). Weedy check treatment (m_8) registered the lowest panicle number (153.3) and it was significantly inferior to all the other treatments.

Interaction was found significant. The treatment combination s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the highest number of panicle m^{-2} (328.0) which was statistically comparable with s_2m_6 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS). The lowest panicles m^{-2} (136) recorded by s_2m_8 (no SSB with weedy check).

4.2.2.2 Number of Spikelets Panicle^{-1}

The results on the effect of stale seed bed and weed management methods on the number of spikelets $panicle^{-1}$ are presented in Table 20a and 20b.

Stale seed bed methods had significant effect on the number of spikelets $panicle^{-1}$. The stale seed bed with mechanical removal of weeds (s_1) recorded significantly higher number of spikelets $panicle^{-1}$ (77.83) compared to no stale seed bed (s_2) with a spikelet number of 71.80 $panicle^{-1}$.

The different weed management methods tested had significant effect on number of spikelets $panicle^{-1}$. The highest number of spikelets $panicle^{-1}$ (84.03) was recorded by penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1) and it was statistically on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), HWT at 15 and 35 DAS (m_7) and penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6). Weedy check (m_8) recorded the lowest value (57.70).

Interaction effect of stale seed bed methods and weed management methods on number of spikelets $panicle^{-1}$ was found significant. The treatment combination s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the highest number of spikelets $panicle^{-1}$ (89.13), which was statistically comparable with s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-

40 DAS), s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and s_1m_7 (SSB with HWT). The lowest spikelets panicle^{-1} was recorded in s_2m_8 (no SSB with weedy check).

4.2.2.3 Per cent Filled Grains

Data on per cent filled grains are depicted in Table 20a and 20b.

The per cent filled grains was found significantly influenced by the SSB methods. SSB (s_1) recorded significantly higher per cent filled grains (84.99) compared to no SSB (s_2) (81.14).

Weed management methods also exerted significant effect on per cent filled grains. Among the weed management methods, penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the highest per cent filled grains (86.97) which was statistically comparable with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1), penoxsulam @ 30 and 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6 and m_5, respectively), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and HWT at 15 and 35 DAS (m_7). Weedy check (m_8) recorded the lowest per cent filled grains of 72.77.

Interaction between SSB methods and weed management methods did not have any significant influence on per cent filled grains.

4.2.2.4 Thousand Grain Weight

The data on thousand grain weight are presented in Tables 20a and 20b.

Thousand grain weight was significantly influenced by SSB methods. Significantly higher thousand grain weight (27.44 g) was registered by SSB with mechanical removal weeds (s_1) compared to no SSB (s_2).

The thousand grain weight was significantly influenced by weed management methods. Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded

Table 20a. Effect of weed management practices on panicles m^{-2}, spikelets $panicle^{-1}$, per cent filled grains and thousand grain weight.

Treatments	Panicles m^{-2}	Spikelets $panicle^{-1}$	Per cent filled grains	Thousand grain weight (g)
A - Stale seed bed methods (S)				
s_1 – SSB with mechanical removal of weeds	272.1	77.83	84.99	27.44
s_2 - No SSB	260.8	71.80	81.14	26.93
SEm±	4.462	1.073	0.408	0.148
CD (0.05)	NS	3.113	3.313	0.432
B - Weed management methods (M)				
m_1 – Penox. @ 20 g ha^{-1} fb HW	295.3	84.03	85.81	27.64
m_2 – Penox. @ 25 g ha^{-1} fb HW	265.3	77.67	86.97	28.09
m_3 – Penox. @ 30 g ha^{-1} fb HW	284.0	81.40	84.13	27.86
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	301.3	68.20	80.32	27.05
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	307.0	70.73	85.61	26.63
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	306.0	78.16	85.74	27.41
m_7 - Hand weeding twice (15 and 35 DAS)	219.3	80.50	83.18	27.38
m_8 - Weedy check (unweeded control)	153.3	57.70	72.77	25.43
SEm±	8.924	2.146	2.282	0.297
CD (0.05)	25.899	6.227	6.625	0.864

NS - Non significant

Table 20b. Interaction effect of SSB methods and weed management methods on panicles m^{-2}, spikelets $panicle^{-1}$, per cent filled grains and thousand grain weight.

Interactions (S x M)	Panicle m^{-2}	Spikelets $panicle^{-1}$	Per cent filled grains	Thousand grain weight (g)
s_1m_1	310.7	88.93	83.47	27.74
s_1m_2	274.7	78.87	87.99	28.72
s_1m_3	298.7	86.33	89.37	27.87
s_1m_4	309.3	70.73	81.19	27.49
s_1m_5	286.0	66.93	87.09	27.15
s_1m_6	293.3	89.13	90.61	27.68
s_1m_7	233.3	82.06	82.06	26.80
s_1m_8	170.7	59.60	78.11	26.03
s_2m_1	280.0	79.13	88.15	27.53
s_2m_2	256.0	76.66	85.94	27.46
s_2m_3	269.3	76.47	78.90	27.84
s_2m_4	293.3	65.67	79.45	26.62
s_2m_5	328.0	74.53	84.13	26.1
s_2m_6	318.7	67.20	80.87	27.13
s_2m_7	205.3	78.93	84.30	27.95
s_2m_8	136.0	55.80	67.42	24.84
SEm±	12.62	3.034	3.228	0.421
CD (0.05)	36.626	8.806	NS	NS

NS - Non significant

the highest thousand grain weight (28.09 g) and it was on par with penoxsulam @ 30 and 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3 and m_1, respectively), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and HWT (m_7). Weedy check recorded the lowest thousand grain weight of 25.43 g.

The interaction was found to be non significant. However, the treatment combination s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the highest thousand grain weight of 28.72 g.

4.2.2.5 Grain Yield

Data on the effect of SSB methods and weed management methods on grain yield are furnished in Table 21a and 21b.

Stale seedbed methods significantly influenced the grain yield of upland rice raised as intercrop in coconut garden. Compared to no SSB (s_2) with a grain yield of 2.57 t ha^{-1}, SSB (s_1) recorded significantly higher grain yield of 2.90 t ha^{-1}.

Weed management methods also significantly influenced the grain yield. Among the weed management methods, application of penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the highest grain yield (3.23 t ha^{-1}) which was on par penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3, respectively) with a grain yield of 3.05 and 3.04 t ha^{-1}. However, m_1 was on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and penoxsulam @ 25, 30 and 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5, m_6 and m_4, respectively). Weedy check recorded the lowest grain yield (1.40 t ha^{-1}) which was significantly inferior to all other weed management methods.

The interaction was found to be non significant.

4.2.2.6 Straw Yield

The results on the effect of SSB methods and weed management methods on straw yield are presented in Tables 21a and 21b.

The straw yield of upland rice was found significantly influenced by SSB methods. Significantly higher straw yield (3.57 t ha^{-1}) was registered by SSB (s_1) compared to no SSB (s_2).

Weed management methods did not show any significant effect on the straw yield.

The interaction of SSB methods and weed management methods also did not exert any significant effect on the straw yield. However, the treatment combination s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) recorded the highest straw yield of 3.91 t ha^{-1}.

4.2.2.7 Harvest Index

The data on the effect of SSB methods and weed management methods on harvest index are depicted in Tables 21a and 21b.

The SSB methods did not influence the harvest index of rice.

Weed management methods had significant influence on harvest index. Harvest index was the highest (0.48) in penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively) and penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4 and m_6, respectively). These treatments were on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) and HWT (m_7). Weedy check (m_8) registered the lowest harvest index (0.32) and was significantly inferior to all other treatments.

The interaction effect of SSB methods and weed management methods was found to be non significant.

4.2.2.8 Weed Index

The results on weed index which is the measure of per cent yield reduction due to weeds are furnished in Tables 21a and 21b.

Stale seedbed methods exerted significant effect on weed index. Significantly lower weed index was observed in SSB (s_1) compared to no SSB method (s_2).

Effect of weed management methods on harvest index was found to be significant. The lowest weed index (8.98 %) was recorded with penoxsulam applied @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 S (m_2) which was significantly superior to all other weed management treatments. This treatment was followed by m_1 (penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS and m_1 was on par with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) and penoxsulam @ 25 and 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5 and m_6, respectively). Weedy check (m_8) recorded the highest weed index of 60.70 per cent.

Interaction effect was also found to be significant. The treatment combination s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the lowest weed index (11.90%), which was statistically on par with s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_1 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_4 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_2 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and s_2m_5 (no SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1}

Table 21a. Effect of weed management practices on grain yield, straw yield, weed index and harvest index

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Weed index	Harvest index
A - Stale seed bed methods (S)				
- SSB with mechanical removal of weeds	2.90	3.57	18.44 (3.93)	0.45
s_2 - No SSB	2.57	3.07	27.61 (5.08)	0.45
SEm±	0.046	0.137	0.174	0.009
CD (0.05)	0.134	0.397	0.506	NS
B - Weed management methods (M)				
m_1 – Penox. @ 20 g ha^{-1} fb HW	3.05	3.35	14.24 (3.51)	0.48
m_2 – Penox. @ 25 g ha^{-1} fb HW	3.23	3.48	8.98 (2.46)	0.48
m_3 – Penox. @ 30 g ha^{-1} fb HW	3.04	3.47	14.34 (3.80)	0.47
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.8	3.06	21.31 (4.61)	0.48
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.94	3.53	17.16 (4.20)	0.46
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	2.82	3.07	20.60 (4.44)	0.48
m_7 - Hand weeding twice (15 and 35 DAS)	2.6	3.63	26.85 (5.20)	0.43
m_8 - Weedy check (unweeded control)	1.4	3.00	60.70 (7.82)	0.32
SEm±	0.093	0.274	0.349	0.018
CD (0.05)	0.269	NS	1.013	0.054

NS - Non significant

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

Table 21b. Interaction effect of SSB methods and weed management methods on grain yield, straw yield, weed index and harvest index

Interactions (S x M)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Weed index	Harvest index
s_1m_1	3.13	3.62	11.90 (3.31)	0.46
s_1m_2	3.55	3.81	0.0 (0.71)	0.48
s_1m_3	3.13	3.88	11.73 (3.44)	0.45
s_1m_4	2.96	3.26	16.54 (4.09)	0.48
s_1m_5	2.96	3.91	16.68 (4.14)	0.43
s_1m_6	3.16	3.45	10.91 (3.34)	0.48
s_1m_7	2.72	3.76	23.45 (4.87)	0.44
s_1m_8	1.55	2.91	56.29 (7.53)	0.35
s_2m_1	2.96	3.09	16.58 (3.72)	0.49
s_2m_2	2.91	3.14	17.95 (4.22)	0.48
s_2m_3	2.95	3.06	16.95 (4.16)	0.49
s_2m_4	2.63	2.86	26.08 (5.13)	0.48
s_2m_5	2.93	3.14	17.63 (4.26)	0.48
s_2m_6	2.48	2.68	30.28 (5.54)	0.48
s_2m_7	2.48	3.5	30.25 (5.53)	0.42
s_2m_8	1.24	3.09	65.11 (8.10)	0.29
SEm±	0.13	0.387	0.493	0.026
CD (0.05)	NS	NS	1.433	NS

NS - Non significant

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

at 35-40 DAS). The highest weed index (65.11%) was recorded in s_2m_8 (no SSB with weedy check).

4.3. CHEMICAL ANALYSIS

4.3.1. Nutrient Uptake by Crop

4.3.1.1 Nitrogen Uptake

The results on nitrogen uptake by crop at harvest stage are presented in Tables 22a and 22b.

Stale seedbed methods had significant effect on N uptake. Significantly higher nitrogen uptake (87.16 kg ha^{-1}) was recorded by SSB (s_1) compared to no SSB method (s_2).

Nitrogen uptake was significantly influenced by the weed management methods also. Among the treatments, penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) recorded the highest nitrogen uptake (92.47 kg ha^{-1}), which was statistically on par with penoxsulam @ 20 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_2, respectively), HWT (m_7) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5). The lowest nitrogen uptake (54.26 kg ha^{-1}) was registered by weedy check (m_8).

Interaction between SSB methods and weed management methods did not show any significant influence on N uptake by rice crop.

4.3.1.2 Phosphorus Uptake

The results on phosphorus uptake by crop at harvest are presented in Tables 22a and 22b.

The effect of SSB methods on phosphorus uptake was observed to be significant. SSB (s_1) registered higher phosphorus uptake (8.53 kg ha^{-1}) and it was significantly superior to no SSB (s_2) method.

Weed management methods also exerted significant influence on phosphorus uptake. The highest phosphorus uptake (8.94 kg ha^{-1}) was recorded by penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5) and it was statistically comparable with penoxsulam @ 20, 30 and 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1, m_3 and m_2, respectively) and HWT (m_7). The phosphorus uptake was the lowest (4.86 kg ha^{-1}) in weedy check (m_8).

The interaction of SSB methods and weed management methods influenced phosphorus uptake significantly. The treatment combination s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the highest phosphorus uptake (10.38 kg ha^{-1}), which was on par with s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), s_2m_7 (no SSB with HWT). The lowest phosphorus uptake was recorded by s_1m_8 (SSB with weedy check) of 4.67 kg ha^{-1}.

4.3.1.3. Potassium Uptake

Results on crop uptake of potassium at harvest are presented in Tables 22a and 22b.

Stale seedbed methods significantly influenced the uptake of potassium by crop. Stale seedbed recorded significantly higher potassium uptake (68.73 kg ha^{-1}) compared to no SSB method (s_2).

Weed management methods could not influence the potassium uptake by crop, significantly. Interaction of SSB methods and weed management methods also did not show any influence on potassium uptake.

Table 22a. Effect of weed management practices on nutrient uptake by crop

Treatments	Nutrient uptake (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	87.16	8.53	68.73
s_2 - No SSB	70.43	7.09	58.91
SEm±	2.678	0.224	2.979
CD (0.05)	7.773	0.65	8.646
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	86.15	8.90	63.62
m_2 – Penox. @ 25 g ha^{-1} fb HW	86.02	8.17	65.81
m_3 – Penox. @ 30 g ha^{-1} fb HW	92.47	8.81	73.67
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	76.7	7.45	56.91
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	81.92	8.94	64.93
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	67.99	7.50	67.62
m_7 - Hand weeding twice (15 and 35 DAS)	84.65	7.84	67.34
m_8 - Weedy check (unweeded control)	54.26	4.86	50.7
SEm±	5.357	0.447	5.958
CD (0.05)	15.547	1.299	NS

NS - Non significant

Table 22b. Interaction effect of SSB methods and weed management methods on nutrient uptake by crop

Interactions (S x M)	Nutrient uptake (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
s_1m_1	100.16	10.38	68.56
s_1m_2	87.48	9.63	76.53
s_1m_3	106.36	10.14	73.70
s_1m_4	87.08	8.51	60.08
s_1m_5	92.35	9.98	70.35
s_1m_6	74.53	8.01	80.71
s_1m_7	92.86	6.91	67.51
s_1m_8	56.09	4.67	52.43
s_2m_1	72.14	7.41	58.68
s_2m_2	84.56	6.72	55.10
s_2m_3	78.57	7.49	73.64
s_2m_4	66.32	6.39	53.74
s_2m_5	71.48	7.89	59.50
s_2m_6	61.46	6.99	54.52
s_2m_7	76.44	8.77	67.16
s_2m_8	52.43	5.05	48.96
SEm±	7.576	0.633	8.426
CD (0.05)	NS	1.837	NS

NS - Non significant

4.3.2. Nutrient Removal by Weeds

4.3.2.1 Nitrogen Removal by Weeds

The data on nitrogen removal by weeds are statistically analyzed and presented in the Tables 23a and 23b.

Stale seedbed methods did not exert any significant effect on nitrogen removal by weeds. However, lower nitrogen removal by weeds (0.49 kg ha^{-1}) was observed with SSB (s_1) compared to no SSB method (s_2).

Nitrogen removal by weeds was significantly influenced by the weed management methods. The lowest removal of nitrogen by weeds (0.02 kg ha^{-1}) was observed in plots treated with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and it was statistically on par with all weed management methods except weedy check. Weedy check (m_8) recorded the highest removal of nitrogen by weeds (3.59 kg ha^{-1}).

Interaction effect was found to be non-significant.

4.3.2.2 Phosphorus Removal by Weeds

The results on phosphorus removal by weeds at 60 DAS are presented in Tables 23a and 23b.

Phosphorus removal by weeds was not significantly influenced by SSB methods.

Weed management methods exerted significant influence on P removal by weeds. The lowest phosphorus removal by weeds (0.001 kg ha^{-1}) was registered in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and it was statically comparable with all weed management methods except weedy check. Weedy check (m_8) recorded the highest P removal by weeds (0.276 kg ha^{-1}).

Table 23a. Effect of weed management practices on nutrient removal by weeds

Treatments	Nutrient removal by weeds (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	0.49	0.065	0.75
s_2 - No SSB	0.83	0.044	1.26
SEm±	0.14	0.013	0.274
CD (0.05)	NS	NS	NS
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	0.35	0.036	0.31
m_2 – Penox. @ 25 g ha^{-1} fb HW	0.20	0.018	0.30
m_3 – Penox. @ 30 g ha^{-1} fb HW	0.14	0.015	0.14
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.11	0.007	0.09
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.14	0.017	0.16
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	0.02	0.001	0.01
m_7 - Hand weeding twice (15 and 35 DAS)	0.72	0.068	1.64
m_8 - Weedy check (unweeded control)	3.59	0.276	5.37
SEm±	0.279	0.026	0.549
CD (0.05)	0.811	0.074	1.593

NS - Non significant

Table 23b. Interaction effect of SSB methods and weed management methods on nutrient removal by weeds

Interactions (S x M)	Nutrient removal by weeds (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
s_1m_1	0.01	0.002	0.01
s_1m_2	0.26	0.027	0.48
s_1m_3	0.20	0.023	0.21
s_1m_4	0.04	0.007	0.04
s_1m_5	0.25	0.032	0.30
s_1m_6	0.02	0.001	0.01
s_1m_7	0.12	0.02	0.18
s_1m_8	3.00	0.411	4.74
s_2m_1	0.68	0.071	0.61
s_2m_2	0.15	0.008	0.11
s_2m_3	0.07	0.006	0.08
s_2m_4	0.18	0.007	0.15
s_2m_5	0.03	0.002	0.03
s_2m_6	0.02	0.001	0.01
s_2m_7	1.33	0.116	3.10
s_2m_8	4.18	0.141	6.00
SEm±	0.395	0.036	0.776
CD (0.05)	NS	0.105	NS

NS - Non significant

Interaction between SSB methods and weed management methods showed significant effect on phosphorus removal by weeds. The lowest P removal by weeds (0.001 kg ha^{-1}) was registered in the treatment combination s_1m_6 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), which was on par with all other treatment combinations except s_1m_8 (SSB with weedy check), s_2m_7 (no SSB with HWT) and s_2m_8 (no SSB with weedy check). The highest phosphorus removal by weeds (0.411 kg ha^{-1}) was observed in the treatment combination s_1m_8.

4.3.2.3 Potassium Removal by Weeds

The data on potassium removal by weeds are presented in Tables 23a and 23b.

Stale seedbed methods did not influence the potassium removal by weeds.

The potassium removal by weeds varied significantly with different weed management methods. Among the weed management methods, the lowest K removal by weeds (0.01 kg ha^{-1}) was observed in the plot treated with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and it was statistically comparable with all other herbicidal treatments. Weedy check (m_8) recorded the highest potassium removal by weeds (5.37 kg ha^{-1}).

Interaction effect of SSB methods and weed management methods was found to be non significant.

4.3.3. Available NPK Status of Soil after the Experiment

4.3.3.1. Available Nitrogen Status of Soil

The data on available nitrogen status of soil after the experiment are presented in Tables 24a and 24b.

Stale seedbed method exerted significant effect on available soil nitrogen status. The treatment s_1 (stale seed bed with mechanical removal of weeds) recorded significantly higher available N (281.6 kg ha^{-1}) compared to no SSB method with the available nitrogen status of 263.9 kg ha^{-1}.

The available soil nitrogen status varied significantly under various weed management methods. The highest available nitrogen status (298.6 kg ha^{-1}) was registered by penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1) which was statistically on par with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4) and HWT (m_7). Weedy check (m_8) registered the lowest available nitrogen status (233.6 kg ha^{-1}).

The interaction between SSB and weed management methods also significantly influenced the available soil nitrogen status. The treatment combination s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), recorded the highest available nitrogen status of 333.6 kg ha^{-1} which was significantly superior to all other treatment combination. The lowest available soil nitrogen status (230.2 kg ha^{-1}) was observed in s_1m_8 (SSB with weedy check).

4.3.3.2. Available Phosphorus Status of Soil

The results on available phosphorus status of soil are presented in Tables 24a and 24b.

Available phosphorus status of soil was significantly influenced by SSB methods. Higher available phosphorus status of soil (35.62 kg ha^{-1}) was recorded by the SSB (s_1) compared to no SSB method (s_2).

Available phosphorus status was found significantly influenced by various weed management methods also. The phosphorus content of soil was the highest (39.73 kg ha^{-1}) in penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6) and it was statistically on par with penoxsulam @ 20 and 30g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3), HWT (m_7) and penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5), while weedy check (m_8) recorded the lowest soil phosphorus status (22.91 kg ha^{-1}).

The interaction of SSB and weed management methods had significant effect on available soil phosphorus. The highest available soil phosphorus status (48.74 kg ha^{-1}) was recorded by s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS), which was statistically comparable with s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS) and s_2m_7 (no SSB with HWT). The lowest available soil phosphorus status (21.09 kg ha^{-1}) was recorded in s_2m_8 (no SSB with weedy check).

4.3.3.3. Available Potassium Status of Soil.

The data on available soil potassium status after the experiment are presented in Tables 24a and 24b.

Stale seedbed methods had significant effect on available soil potassium status. Significantly higher available soil potassium (131.2 kg ha^{-1}) status was recorded in no SSB (s_2) compared to SSB (s_1).

Weed management methods also showed significant effect on available soil potassium status. The treatment (m_3) penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3) registered the highest available soil potassium (166.0 kg ha^{-1}) which was superior to all other treatments. The lowest soil available potassium status (90.38 kg ha^{-1}) was recorded in penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1).

Interaction was also found to be significant. The highest available soil potassium status (199.2 kg ha^{-1}) was recorded in the treatment combination s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) and it was superior to all other treatment combinations. The treatment combination, s_1m_8 (SSB with weedy check) registered the lowest value for available soil potassium status (63.40 kg ha^{-1}).

Table 24a. Effect of weed management practices on available NPK status of soil

Treatments	Available NPK (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
A - Stale seed bed methods (S)			
s_1 – SSB with mechanical removal of weeds	281.6	35.62	118
s_2 - No SSB	263.9	32.6	131.2
SEm±	3.848	0.817	3.001
CD (0.05)	11.17	2.371	8.708
B - Weed management methods (M)			
m_1 – Penox. @ 20 g ha^{-1} fb HW	298.6	38.88	90.38
m_2 – Penox. @ 25 g ha^{-1} fb HW	274.7	30.98	124.0
m_3 – Penox. @ 30 g ha^{-1} fb HW	263.4	37.29	166.0
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	288.5	30.72	109.0
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	268.5	35.23	141.9
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	274.7	39.73	147.1
m_7 - Hand weeding twice (15 and 35 DAS)	279.8	37.14	111.8
m_8 - Weedy check (unweeded control)	233.6	22.91	106.7
SEm±	7.696	1.634	6.001
CD (0.05)	22.34	4.742	17.42
Initial status of soil	282.8	36.04	105.6

Table 24b. Interaction effect of SSB methods and weed management methods on available NPK status of soil

	Available NPK (kg ha^{-1})		
Interactions (S x M)	Nitrogen	Phosphorus	Potassium
s_1m_1	333.7	48.74	73.77
s_1m_2	288.5	29.98	128.5
s_1m_3	263.4	35.96	199.2
s_1m_4	296.1	29.32	76.75
s_1m_5	283.5	44.68	154.7
s_1m_6	271.0	41.36	153.1
s_1m_7	286.0	30.2	94.44
s_1m_8	230.2	24.74	63.4
s_2m_1	263.4	29.02	107.0
s_2m_2	260.9	31.98	119.5
s_2m_3	263.4	38.62	132.8
s_2m_4	281.0	32.12	141.2
s_2m_5	253.4	25.78	129.2
s_2m_6	278.5	38.1	141.2
s_2m_7	273.5	44.09	129.2
s_2m_8	237.1	21.09	150.0
SEm±	10.884	2.311	8.487
CD (0.05)	31.59	6.707	24.63

4.4 MICROBIAL COUNT IN SOIL

4.4.1. Fungal Population in Soil

The data on population of fungi in the soil at 15 and 30 DAHA are depicted in Tables 25a and 25b.

Stale seedbed methods and weed management methods did not have any significant effect on the fungal population at 15 and 30 DAHA. But compared to fungal population (35 x 10^{-3} CFU g^{-1} wet soil) just before herbicide application, a substantial increase in fungal population was observed.

4.4.2. Bacterial Population in Soil

Data on population of bacteria in soil at 15 and 30 DAHA are presented in Tables 26a and 26b.

Bacterial population was not significantly influenced by SSB methods and weed management methods at 15 and 30 DAHA. A substantial increase in bacterial count was observed at 15 and 30 DAHA compared to pre-treatment values (172 x 10^{-6} CFU g^{-1} wet soil).

4.4.3. Actinomycetes Population in Soil

The population of actinomycetes in soil at 15 and 30 DAHA are presented in Tables 27a and 27b.

In general, increased population of actinomycetes was observed in all the weed management methods, at 15 and 30 DAHA compared to pre-treatments values (5 x 10^{-4} CFU g^{-1} wet soil). However no significant variation was observed among the weed management practices at 15 and 30 DAHA, with respect to actinomycetes population.

Table 25a. Effect of weed management practices on the population of soil fungi

Treatments	Population of fungi x 10^{-3} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	68.83	57.04
s_2 - No SSB	65.04	55.21
SEm±	1.600	1.432
CD (0.05)	NS	NS
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	69.17	54.17
m_2 – Penox. @ 25 g ha^{-1} fb HW	62.83	54.17
m_3 – Penox. @ 30 g ha^{-1} fb HW	70.83	56.83
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	65.67	59.17
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	61.83	56.00
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	68.50	55.17
m_7 - Hand weeding twice (15 and 35 DAS)	69.67	57.50
m_8 - Weedy check (unweeded control)	67.00	56.00
SEm±	3.200	2.864
CD (0.05)	NS	NS

NS - Non significant

Table 25b. Interaction effect of SSB methods and weed management methods on the population of soil fungi

Interactions (S x M)	Population of fungi x 10^{-3} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
s_1m_1	70.00	53.67
s_1m_2	64.67	56.33
s_1m_3	75.00	57.33
s_1m_4	68.00	59.33
s_1m_5	62.33	57.67
s_1m_6	68.00	54.67
s_1m_7	74.00	59.67
s_1m_8	68.67	57.67
s_2m_1	68.33	54.67
s_2m_2	61.00	52.00
s_2m_3	66.67	56.33
s_2m_4	63.33	59.00
s_2m_5	61.33	54.33
s_2m_6	69.00	55.67
s_2m_7	65.33	55.33
s_2m_8	65.33	54.33
SEm±	4.525	4.051
CD (0.05)	NS	NS

NS - Non significant

Table 26a. Effect of weed management practices on the population of soil bacteria

Treatments	Population of bacteria x 10^{-6} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	179.1	176.6
s_2 - No SSB	183.3	177.9
SEm±	2.181	2.785
CD (0.05)	NS	NS
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	186.8	175.2
m_2 – Penox. @ 25 g ha^{-1} fb HW	175.0	183.5
m_3 – Penox. @ 30 g ha^{-1} fb HW	181.8	185.0
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	180.5	168.7
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	181.0	173.3
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	183.8	176.3
m_7 - Hand weeding twice (15 and 35 DAS)	175.5	181.3
m_8 - Weedy check (unweeded control)	185.0	174.7
SEm±	4.362	5.569
CD (0.05)	NS	NS

NS - Non significant

Table 26b. Interaction effect of SSB methods and weed management methods on the population of soil bacteria

Interactions (S x M)	Population of bacteria x 10^{-6} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
s_1m_1	187.0	167.3
s_1m_2	165.0	188.7
s_1m_3	176.7	196.7
s_1m_4	175.7	166.0
s_1m_5	182.0	173.7
s_1m_6	177.7	172.7
s_1m_7	178.3	172.7
s_1m_8	190.3	175.0
s_2m_1	186.7	183.0
s_2m_2	185.0	178.3
s_2m_3	187.0	173.3
s_2m_4	185.3	171.3
s_2m_5	180.0	173.0
s_2m_6	190.0	180.0
s_2m_7	172.7	190.0
s_2m_8	179.7	174.3
SEm±	6.168	7.876
CD (0.05)	NS	NS

NS - Non significant

Table 27a. Effect of weed management practices on the population of soil actinomycetes

Treatments	Population of actinomycetes x 10^{-4} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	8.29	7.04
s_2 - No SSB	8.17	7.42
SEm±	0.383	0.329
CD (0.05)	NS	NS
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	7.17	7.50
m_2 – Penox. @ 25 g ha^{-1} fb HW	7.50	6.50
m_3 – Penox. @ 30 g ha^{-1} fb HW	7.17	7.33
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	9.67	8.00
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	8.17	6.83
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	8.33	7.50
m_7 - Hand weeding twice (15 and 35 DAS)	8.83	6.83
m_8 - Weedy check (unweeded control)	9.00	7.33
SEm±	0.765	0.658
CD (0.05)	NS	NS

NS - Non significant

Table 27b. Interaction effect of SSB methods and weed management methods on the population of soil actinonomycetes

Interactions (S x M)	Population of actinomycetes x 10^{-4} CFU g^{-1} wet soil	
	15 DAHA	30 DAHA
s_1m_1	6.67	7.00
s_1m_2	7.33	6.67
s_1m_3	7.67	6.33
s_1m_4	11.0	8.33
s_1m_5	8.00	6.67
s_1m_6	8.00	7.33
s_1m_7	9.00	6.33
s_1m_8	8.67	7.67
s_2m_1	7.67	8.00
s_2m_2	7.67	6.33
s_2m_3	6.67	8.33
s_2m_4	8.33	7.67
s_2m_5	8.33	7.00
s_2m_6	8.67	7.67
s_2m_7	8.67	7.33
s_2m_8	9.33	7.00
SEm±	1.082	0.930
CD (0.05)	NS	NS

NS - Non significant

4.5. ENZYME STUDIES

4.5.1. Dehydrogenase Activity

The data on the dehydrogenase activity in soil at 15 DAHA are presented in Table 28a and 28b.

Compared to pre-treatment value there was increase in dehydrogenase activity in SSB and reduction in no SSB. The data on dehydrogenase activity in soil indicated that the effect of SSB methods on dehydrogenase activity was significant at 15 DAHA. Significantly higher dehydrogenase activity in soil (12.18 μg TPF g^{-1} soil day^{-1}) was observed in SSB (s_1) compared to no SSB (s_2).

Weed management methods had significant effect on dehydrogenase activity in soil at 15 DAHA. Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the highest dehydrogenase activity in soil (15.27 μg TPF g^{-1} soil day^{-1}), which was statistically comparable with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_4). Compared to the control treatments (HWT and weedy check), all the herbicidal treatments recorded significantly higher dehydrogenase activity. Hand weeding twice (m_7) and Weedy check (m_8) recorded lower values of dehydrogenase activity (7.60 μg TPF g^{-1} soil day^{-1} and 6.18 μg TPF g^{-1} soil day^{-1}, respectively) compared to the pre-treatment value of 12.01 μg TPF g^{-1} soil day^{-1}.

Interaction was also found to be significant at 15 DAHA with the treatment combination, s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recording the highest dehydrogenase activity in soil (16.97 μg TPF g^{-1} soil day^{-1}), and it was on par with s_2m_4 (no SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS), s_1m_5 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS)and s_2m_3 (no SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS). The lowest activity (4.93 μg TPF g^{-1} soil day^{-1}) was observed in s_2m_7 (no SSB with HWT).

4.5.2. Urease Activity

The data on urease activity in soil at 15 DAHA are presented in Tables 28a and 28b.

Compared to the pre-treatment value (77.03 μg urea hydrolyzed g^{-1} soil h^{-1}), considerable decrease in the urease activity was observed at 15 at DAHA. However, at 15 DAHA, urease activity in soil was not significantly influenced by SSB methods and weed management methods.

4.6. ECONOMIC ANALYSIS

Data on economics of weed management methods and SSB methods are presented in Tables 29a and 29b.

4.6.1. Net Income

The data on net income of upland rice cultivation as influenced by SSB methods showed that the net income was comparatively high under SSB method (₹ 27,848/- ha^{-1}) compared to no SSB method (₹ 19,747/- ha^{-1}).

Weed management methods also showed considerable effect on net income. The highest net income (₹ 36,090/- ha^{-1}) was observed in penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) and it was fb penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3, respectively). Weedy check recorded the negative net income of ₹ -1,728/- ha^{-1}.

Among the stale seedbed - weed management methods interactions, s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) recorded the highest net income (₹ 44,433/- ha^{-1}) fb, s_1m_3 (SSB with penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) with a net income of ₹ 34,387/- ha^{-1} and s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) with a net income of ₹ 34,087/- ha^{-1}.

Table 28a. Effect of weed management practices on enzyme activity at 15 DAHA

Treatments	Dehydrogenase enzyme activity, µg TPF g^{-1} soil day^{-1}	Urease enzyme activity, µg urea hydrolyzed g^{-1} soil h^{-1}
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	12.18	45.40
s_2 - No SSB	10.67	43.23
SEm±	0.339	0.933
CD (0.05)	0.984	NS
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	11.78	41.37
m_2 – Penox. @ 25 g ha^{-1} fb HW	15.27	45.59
m_3 – Penox. @ 30 g ha^{-1} fb HW	12.72	43.69
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	14	46.97
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	11.99	43.45
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	11.88	45.2
m_7 - Hand weeding twice (15 and 35 DAS)	7.6	44.33
m_8 - Weedy check (unweeded control)	6.18	43.96
SEm±	0.678	1.866
CD (0.05)	1.969	NS

NS - Non significant

Table 28b. Interaction effect of SSB methods and weed management methods on enzyme activity at 15 DAHA

Interactions (S x M)	Dehydrogenase enzyme activity, µg TPF g^{-1} soil day^{-1}	Urease enzyme activity, µg urea hydrolyzed g^{-1} soil h^{-1}
s_1m_1	13.57	41.81
s_1m_2	16.97	43.81
s_1m_3	10.93	44.4
s_1m_4	11.41	49.74
s_1m_5	15.83	42.76
s_1m_6	13.2	49.17
s_1m_7	10.26	45.82
s_1m_8	5.28	45.7
s_2m_1	9.99	40.93
s_2m_2	13.57	47.37
s_2m_3	14.51	42.98
s_2m_4	16.58	44.19
s_2m_5	8.153	44.14
s_2m_6	10.56	41.22
s_2m_7	4.93	42.84
s_2m_8	7.08	42.21
SEm±	0.959	0.933
CD (0.05)	2.784	NS

NS - Non significant

4.6.2. Benefit Cost Ratio

Stale seedbed methods influenced the B : C ratio of rice. SSB method (s_1) registered substantially higher B : C ratio (1.48) compared to no SSB (s_2). Weed management methods also influenced B : C ratio, considerably. Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) recorded the highest B : C ratio (1.63) and it was fb penoxsulam @ 20 and 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_1 and m_3, respectively). The lowest B : C ratio (0.97) was observed in weedy check (m_8).

Among the interactions, s_1m_2 (SSB with penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS) registered the highest B : C ratio of 1.77 compared to 1.30 in SSB with HWT (s_1m_7) and 1.0 in SSB with weedy check (s_1m_8). B : C ratio values were comparatively low in all no SSB with weed management method combinations.

Table 29a. Effect of weed management practices on net income and B:C ratio

Treatments	Net income (₹)	B:C ratio
A - Stale seed bed methods (S)		
s_1 – SSB with mechanical removal of weeds	27,848	1.48
s_2 - No SSB	19,747	1.35
B - Weed management methods (M)		
m_1 – Penox. @ 20 g ha^{-1} fb HW	31,667	1.56
m_2 – Penox. @ 25 g ha^{-1} fb HW	36,090	1.63
m_3 – Penox. @ 30 g ha^{-1} fb HW	30,597	1.54
m_4 – Penox. @ 20 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	24,863	1.45
m_5 – Penox. @ 25 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	30,104	1.54
m_6 – Penox. @ 30 g ha^{-1} fb MM + CE @ 4 g ha^{-1}	24,118	1.42
m_7 - Hand weeding twice (15 and 35 DAS)	14,667	1.23
m_8 - Weedy check (unweeded control)	-1,728	0.97

Table 29b. Interaction effect of SSB methods and weed management methods on net income and B:C ratio

Interactions (S x M)	Net income (₹)	B:C ratio
s_1m_1	34,087	1.6
s_1m_2	44,433	1.77
s_1m_3	34,387	1.59
s_1m_4	27,910	1.48
s_1m_5	30,579	1.53
s_1m_6	32,485	1.55
s_1m_7	19,272	1.3
s_1m_8	-371	1.00
s_2m_1	29,247	1.53
s_2m_2	27,748	1.5
s_2m_3	26,806	1.48
s_2m_4	21,816	1.41
s_2m_5	29,628	1.54
s_2m_6	15,752	1.29
s_2m_7	10,061	1.15
s_2m_8	-3085	0.93

DISCUSSION

5. DISCUSSION

Upland rice cultivation is evolved as a potential alternative to lowland rice cultivation. Weeds are the major pests that affect the upland rice yield to the greatest extent. Use of traditional high dose herbicides is effective for controlling weeds but continuous use has resulted in resistances and residue related problems. Integration of eco-friendly management options like stale seedbed (SSB) method with low dose high efficacy (LDHE)/ new generation herbicides is the need of the time. Hence, the present study entitled "Weed management in upland rice (*Oryza sativa* L.) intercropped in coconut" was undertaken to standardize an ecofriendly and economic weed management strategy for upland rice intercropped in coconut. The results of the field experiment presented in chapter four are discussed briefly in this chapter.

5.1 OBSERVATION ON WEEDS

5.1.1. Floristic Composition

Weed composition and competition is dependent on soil, climate, cropping and management factors. The rice establishment and rice ecosystems determines the weed composition and degree of weed infestation in rice. Regarding floristic composition, there was substantial diversity of weed flora in the experimental field. Grasses were the dominant weed flora in the rice field followed by broad leaved weeds (BLW). Sedge population was very low. The observations made on the weed flora revealed that broad leaved weeds (eight species) were more diverse followed by grasses (six species) and sedges (two species) in the rice field. Such diversity in rice weed flora have been documented by Madhukumar *et al.* (2013), Sunil *et al.* (2010), Prashanthi *et al.* (2017) and Mishra and Singh (2008). Major broad leaved weeds in the experimental field were *Achyranthes aspera, Acalypha indica, Alternanthera sessilis, Phyllanthus niruri, Mimosa pudica, Hemidesmus indicus, Spermacoce ocymoides* and *Oldenlandia umbellata.* Grasses were *Dactyloctenium aegyptium, Setaria barbata, Eleusine indica,* *Oryza sativa f. spontanea, Echinochloa crusgalli* and *Digitaria ciliaris*. Sedges were *Scirpus maritimus* and *Cyperus rotundus.*

5.1.2. Quantitative Assessment of the Response of Weeds to Weed Management Treatments

As suggested by Rao (2000), the most common parameters for assessing the quantitative response of weeds to weed management treatments are density and dry weight of weeds. The vegetation analysis parameters used in the present study for assessing the impact of weed management treatments on weed growth are absolute density, relative density, weed dry weight and weed control efficiency (WCE).

The weed management methods adopted in the present study exerted significant influence on the population of different categories of weeds. Stale seedbed method was found to be effective in reducing the density of broad leaved weeds and sedges. This method recorded significantly lower density of broad leaved weeds and sedges compared to no SSB method at all stages of observations *viz.,* 15, 30 and 60 days after sowing (DAS). Stale seedbed method, involved land preparation to promote germination of weeds before the sowing and the emerged weeds were killed, thus depleting the weed seed bank in the surface soil layers. This could be the reason for the significant reduction in weed population in SSB compared to no SSB. However, grasses were not effectively controlled by SSB; this may be because grasses were propagated mainly through vegetative propagules and so SSB could not control late emerging grass weeds. Renu *et al.,* (2000) and Singh (2013) also reported significant reduction of weed density in SSB methods.

All the weed management methods suppressed the growth of all categories of weeds and recorded significantly lower weed population compared to weedy check. Penoxsulam @ 20 and 30 g ha^{-1} followed by (fb) metsulfuron methyl + chlorimuron ethyl (MM+CE) recorded the lowest total weed density at 30 and 60 DAS, respectively. However, these treatments were comparable with penoxsulam @ 30 g ha^{-1} fb HW at 30 DAS and penoxsulam @ 20 and 25 g ha^{-1} fb HW at 60 DAS indicating that either

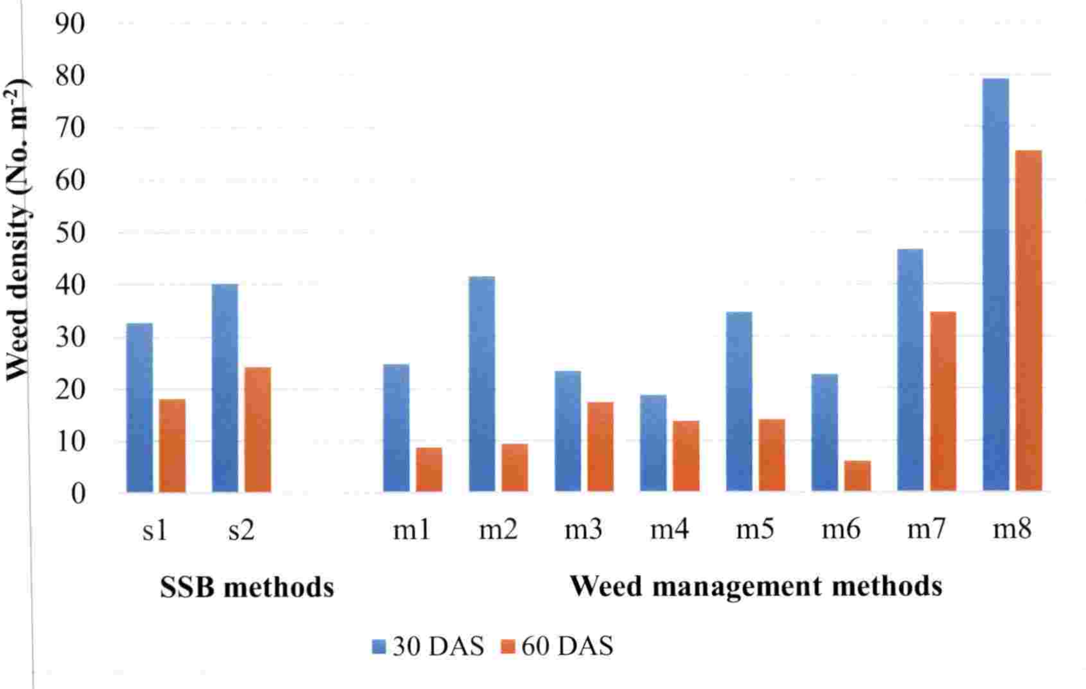


Fig 3. Effect of weed management practices on total weed density (No. m^{-2})

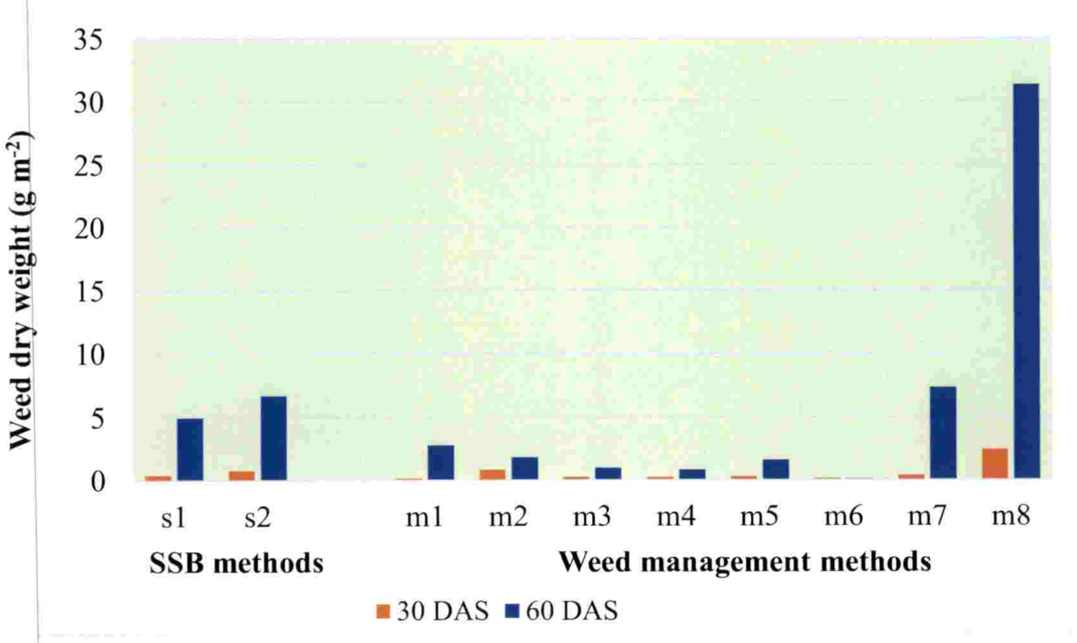


Fig 4. Effect of weed management practices on total weed dry weight (g m^{-2})

MM+CE or HW can be integrated with penoxsulam for effective control of all categories of weeds in upland rice. This is because of the effective control of weeds by penoxsulam during initial stages and MM+CE or HW during the later stages of crop growth. This is in agreement with the findings of Singh *et al.* (2008) who reported that pre emergence application of pretilachlor @ 500 g ha^{-1} fb MM+CE @ 4 g ha^{-1} at 21 DAS and HW at 35 DAS effectively controlled all categories of weeds in aerobic rice. The findings of Mukherjee and Maity (2011) and Hemalatha *et al.* (2017) are also in agreement with these results.

The better suppression of weed growth in penoxsulam treatments might be due to the revolutionary dual systemic action of this chemical as it is absorbed mainly by leaves and secondarily by roots in the target plants as pointed out by Larelle *et al.* (2003). The effectiveness of penoxsulam fb HW treatments were reported earlier by Netam *et al.* (2018) and Mukherjee and Maity (2011) thus emphasising the favorable effect of integration of chemical and mechanical methods of weed control resulting in broad spectrum control of weeds. Effectiveness of penoxsulam in reducing weed population was earlier reported by Sasna *et al.* (2016), Khare *et al.* (2014), Singh *et al.* (2016) and Pal *et al.* (2009). Weedy check treatment recorded significantly higher weed population compared to all other weed management methods.

Stale seedbed combined with application of penoxsulam fb MM+CE or HW significantly reduced the population of all categories weeds. Corroboratory results were reported by Bhurer *et al.* (2013) and Sindhu *et al.* (2010) on the effectiveness of SSB combined with herbicide in controlling weeds.

The results on relative density of weeds indicated the superiority of penoxsulam fb HW treatments in reducing the density of grasses. This is because the grass sp. *Setaria barbata* was the predominant one in the experimental field and MM+CE is known for its ineffectiveness in controlling grasses. All the herbicide treatments (penoxsulam fb HW and penoxsulam fb MM+CE) and the control treatment hand weeding twice (HWT) were very effective in reducing the sedges. Regarding BLW, the relative density data indicated that, HWT as well as penoxsulam at higher rates (25 and 30 g ha^{-1}) fb MM+CE or HW were effective.

To assess the competitiveness of weed management treatments, weed dry weight is considered as an important parameter. Stale seedbed methods significantly reduced the dry weight of all categories of weeds compared to no SSB at 15 and 30 DAS. In SSB, first flushes of weeds were removed before sowing the rice crop, thus depleting the weed seed bank. Might be due to this, SSB registered significantly lower dry weight of weeds compared to no SSB. Pandey *et al.* (2009) also observed similar reduction of dry weight of weeds in SSB compared to normal sowing.

The influence of the weed management methods on weed dry weight was more or less in conformity with the results on weed growth pattern discussed earlier. All the herbicidal treatments and the control treatment HWT significantly reduced the total dry weight of weeds at 30 and 60 DAS compared to weedy check. The weedy check registered the highest total weed dry weight at 30 and 60 DAS (2.42 g m^{-2} and 31.32 g m^{-2}, respectively). The unchecked weed growth might have exploited the available nutrients in greater amount resulting in better weed growth and dry matter accumulation by weeds. This explains the poor growth and yield of the crop in this treatment. At 30 DAS, penoxsulam @ 20 and 30 g ha^{-1} fb either MM+CE or HW were found to register significantly lower total weed dry weight whereas at 60 DAS, which corresponds to the grain formation stage, all the penoxsulam treatments *i.e.*, penoxsulam @ 20, 25 and 30 g ha^{-1} fb either MM+CE or HW were very effective in reducing the total weed dry weight indicating the effectiveness of the post-emergence herbicide penoxsulam in reducing the weed problem in upland rice. The effectiveness of application of penoxsulam at 10 DAS fb HW at 35 DAS in reducing the total weed dry weight in dry direct seeded rice is reported by Sanodiya and Singh (2017) also. Similar findings on the effectiveness of penoxsulam in reducing the weed dry weight

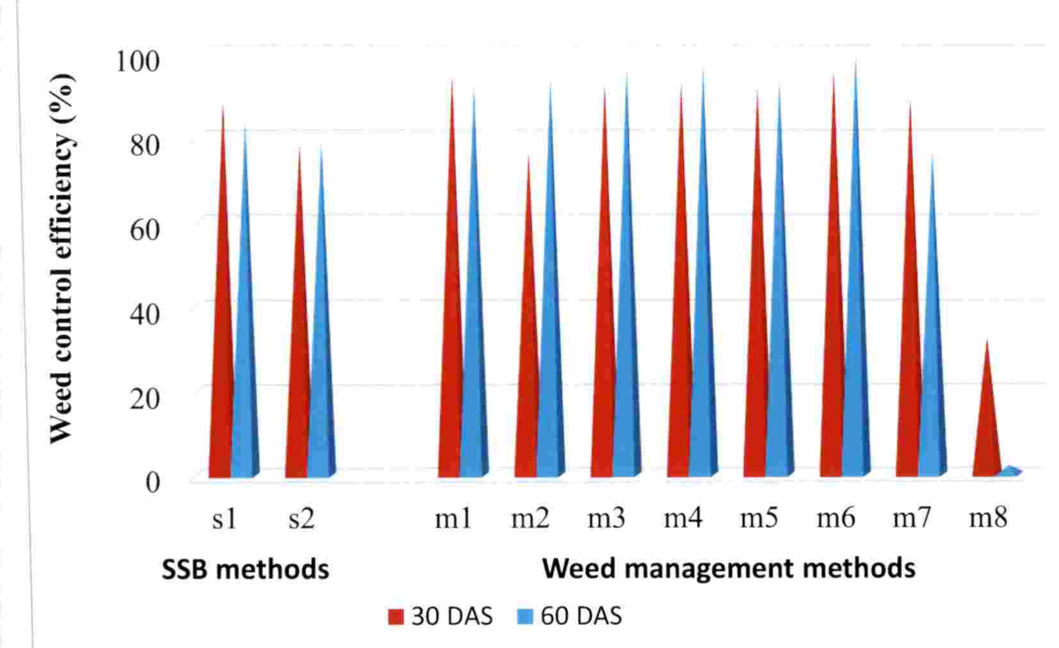


Fig 5. Effect of weed management practices on weed control efficiency (%)

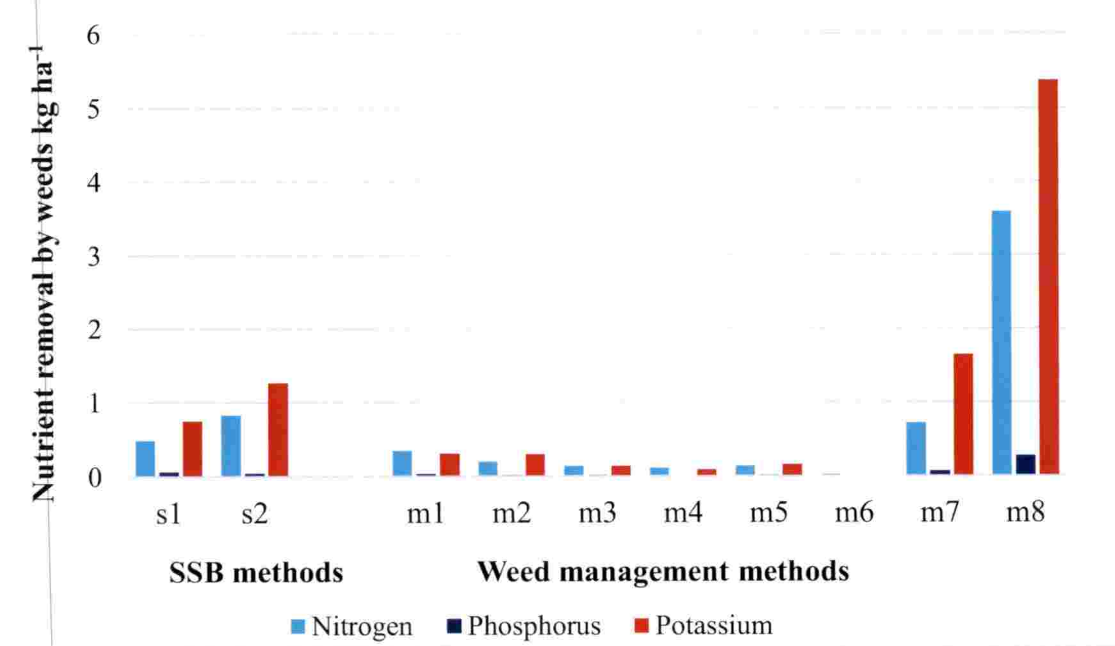


Fig 6. Effect of weed management practices on nutrient removal by weeds (kg ha^{-1})

were reported by Khaliq *et al.* (2014), Prakash *et al.* (2013), Sasna (2014) and Sairamesh *et al.* (2015).

Interaction of SSB method and weed management methods was significant at 30 DAS with respect to its effect on total weed dry weight. The treatment combination s_1m_6 registered the lowest value emphasizing the favourable effect of integration of SSB method with post emergence herbicides in reducing weed dry weight. However, at 60 DAS interaction of SSB method and weed management methods was not significant.

Stale seedbed method registered significantly higher WCE compared to no SSB method, further emphasizing the effectiveness of SSB in reducing the dry weight of weeds since WCE is a worked out parameter based on weed dry weight. Higher weed growth and dry matter accumulation in no SSB resulted in poor WCE in those treatments.

Among the weed management methods, almost all the herbicidal treatments effectively controlled weeds and recorded higher WCE. All the tested doses of penoxsulam, fb either HW or MM+CE treatments effectively controlled the weeds which resulted in lower total weed population and its dry weight thus resulting in high WCE. Weedy check treatment recorded significantly lower WCE due to poor control of weed infestation, as a result causing higher weed population and dry weight. Similar findings on the better WCE of penoxsulam were reported by Singh *et al.* (2016), Saranraj *et al.* (2017) and penoxsulam fb HW by Netam *et al.* (2018) and Sanodiya and Singh (2017). Better WCE of follow up application of MM+CE was reported by Singh *et al.* (2017).

Stale seedbed with penoxsulam fb either HW or MM+CE was found to be effective in realising higher WCE at 60 DAS as the combined effect of SSB and herbicide action effectively controlled weeds and recorded lower dry weight of weeds.

5.1.3. Nutrient Removal by Weeds

Weed management methods significantly influenced the nutrient removal by weeds. Significantly lower nutrient removal by weeds was noticed in all the herbicidal treatments compared to the control treatments, HWT and weedy check. All the herbicidal treatments recorded significantly lower dry weight of weeds compared to HW and weedy check treatment and this could have resulted in comparatively low nutrient removal in these treatments. Weedy check treatment recorded the highest dry weight of weeds thus resulting in significantly higher nutrient uptake by weeds, since nutrient uptake is the product of nutrient content and dry matter accumulation. Unchecked weed growth in upland rice in the present study depleted 3.59 kg ha^{-1} N, 0.276 kg ha^{-1} P and 5.37 kg ha^{-1} K, whereas in penoxsulam fb HW treatments it ranged from 0.14 to 0.35 kg ha^{-1} N, 0.015 to 0.036 kg ha^{-1} P and 0.14 to 0.3 kg ha^{-1} K. Similar findings were reported by Hemalatha *et al.* (2017) according to whom the weedy check treatment registered significantly higher quantity of nitrogen, phosphorus and potassium removal while it was minimum with herbicidal treatments. Sanodiya and Singh (2017) reported that nutrient depletion by weeds depends on dry matter accumulation of weeds and significantly lower nutrient removal by weeds was recorded in penoxsulam @ 35 g ha^{-1} at 10 DAS fb one HW at 35 DAS. The nutrient uptake by weeds is directly related to weed population and dry matter accumulation of weeds and inversely related to rice grain yield (Raju and Reddy, 1986).

5.2. OBSERVATIONS ON CROPS

5.2.1. Growth Attributes

. The results of the present investigation revealed the importance of weed management practices in enhancing growth attributes of rice crop.

Stale seedbed significantly influenced the growth attributes and recorded significantly higher values for plant height at 60 DAS, number of tillers m^{-2} at 30 DAS and at harvest, dry matter production (DMP) at harvest and leaf area index (LAI) at 60 DAS. In SSB, removal of weeds before sowing eliminated the weed completion during the early crop period giving a good start to the crop plants enabling them to smother the late emerging weed flushes. This might have resulted in enhanced growth attributes of the rice crop in SSB compared to no SSB.

Weed management methods also significantly influenced the crop growth attributes like plant height, LAI, tiller number m^{-2} and DMP. All the herbicidal treatments (penoxsulam fb HW or penoxsulam fb MM+CE) and HWT recorded significantly higher plant height and DMP at harvest. Penoxsulam fb MM+CE treatments recorded higher number of tillers m^{-2} at 60 DAS and at harvest. But at harvest penoxsulam fb HW treatments were able to produce tillers on par with these treatments. This is because, in the initial period of crop growth all the herbicidal treatments effectively controlled weeds and reduced weed competition thus providing weed free environment which enhanced this growth attribute. Another interesting observation is that the tiller number m^{-2} were comparatively higher in weedy check at 30 and 60 DAS (401.8 and 464.7, respectively), but decreased drastically at harvest (234.0). Srinivasan and Palaniappan (1994) reported that severe weed infestation throughout the crop growth period increased tiller mortality and decreased the grain and straw yield in weedy check.

At 30 and 60 DAS, LAI were significantly influenced by weed management methods and penoxsulam fb either HW or MM+CE significantly increased this growth attribute. All the herbicidal treatments *i.e.*, penoxsulam fb either HW or MM+CE and HWT significantly increased DMP at harvest. Due to the better control of weeds in these treatments, the competition for the resources *viz.*, light, space and nutrients might have been substantially reduced in these treatments. Dry matter production depends on the potential ability of plant population for photosynthesis which in turn depend on the leaf area, nutrient uptake and favourable environmental conditions (De Datta, 1981). In the present study, LAI and nutrient uptake were substantially higher in those weed management methods which were effective in controlling weeds. This might have accelerated the crop growth resulting in high DMP. The late emerged weeds were controlled by follow up application of MM+CE or HW thus providing congenial environment for better expression of these growth attributes.

Weedy check treatments recorded the lowest values for all the growth attributes, might be due to more infestation of weeds thus suppressing the crop growth due to severe competition for resources like nutrients and space. These results were well corroborating with the findings of Netam *et al.* (2018) who reported that significantly higher plant height, number of tillers hill^{-1}, dry matter accumulation and LAI were recorded with penoxsulam 22.5 g ha^{-1} fb one HW. Corroboratory results on the favourable effect of penoxsulam fb HW on plant height, tiller number and dry matter production were reported by Sanodiya and Singh (2017). Similar findings were reported by Khare *et al.* (2014) and Sasna (2014).

Integration of SSB with penoxsulam @ 20, 25 and 30 g ha^{-1} fb either HW or MM+CE was also found to be very effective in enhancing the growth attributes of upland rice.

5.2.2. Herbicide Phytotoxicity on Crop.

Application of early post-emergence herbicide penoxsulam at 15 DAS did not show any phytotoxicity on rice crop based on visual scoring done 7 days after herbicide application, indicating the safety of the herbicide for rice crop. This result is supported by the findings of Malik *et al.* (2011), Prakash *et al.* (2013), Reddy *et al.* (2016) and Saranraj *et al.* (2017), who opined that application of penoxsulam did not have any phytotoxicity symptom on rice crop.

5.2.3. Yield Attributes and Yield

The data on yield attributes and yield clearly indicated that effective weed control especially during the critical period of crop-weed competition had a positive role in determining yield attributes and yield.

Stale seedbed methods significantly influenced the yield attributes *viz.*, spikelets panicles, per cent filled grain and thousand grain weight. Stale seedbed

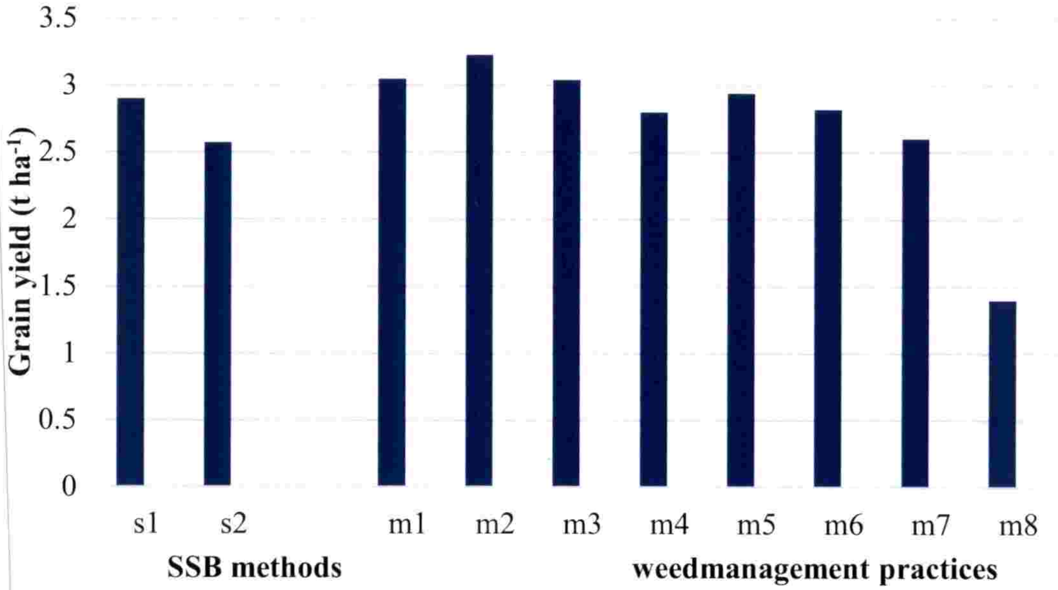


Fig 7. Effect of weed management practices on grain yield (t ha^{-1})

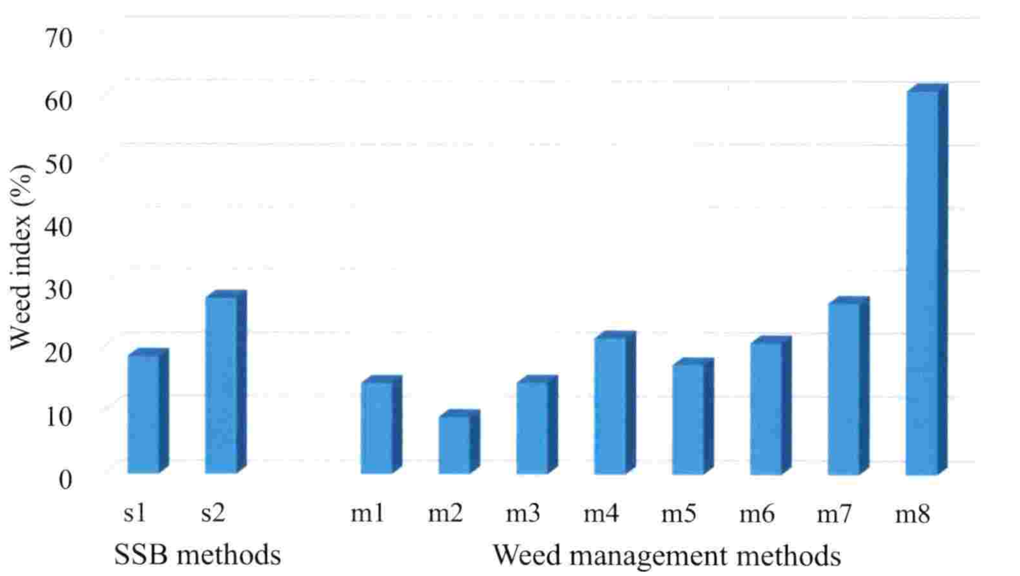


Fig 8. Effect of weed management practices on weed index (%)

method recorded significantly higher values for all these yield attributes. Dry matter production was also significantly higher for SSB compared to no SSB, thus contributing to better expression of yield attributes in SSB. Yield can be limited by either the supply of assimilates (source) during grain filling or by the number and capacity of kernels to be filled (sink) or by source and sink simultaneously (Fischer, 1983; Ventakeswaralu and Visperas, 1987; Evans, 1993). In the present study both source and sink were not found to be limiting in SSB thereby resulting in significantly higher yield. Similar findings were reported by Marahatta *et al.* (2017) that relatively higher number of grains panicle^{-1} and lower sterility per cent were observed in SSB than normal seedbed. Stale seedbed method recorded significantly higher number of productive tillers m^{-2} and percentage of filled grains compared to normal sowing (Renu *et al.*, 2000).

Weed management methods also significantly influenced the yield attributes. Penoxsulam @ 20, 25 and 30 g ha^{-1} fb HW treatments recorded significantly higher values for yield attributes like percent filled grains and thousand grain weight. This is due to the effective control of weeds especially grasses resulting in lesser competition, which allows the rice crop for better expression of yield attributes. It is interesting to note that not even a single grass weed was found in the treatment in which penoxsulam @ 30 g ha^{-1} fb HW was given and it was statistically on par with penoxsulam on par with penoxsulam @ 20 and 25 g ha^{-1} fb HW indicating the effectiveness of these treatments in controlling this category of weeds. The grain filling as evidenced by per cent filled grains and thousand grain weight were better in the more vigorous plants and the lowest in plants which were constantly competing with weeds for resources. Better expression of yield attributes like thousand grain weight and number of grains panicle^{-1} by the application of penoxsulam fb HW treatments was reported by Netam *et al.* (2018) also. Similarly Singh *et al.* (2016) reported significantly higher number of panicles, number of grains panicle^{-1} and thousand grain weight by the application of penoxsulam @ 25 g ha^{-1}. Khare *et al.* (2014) observed that per cent filled grains was significantly higher for penoxsulam @ 25 g ha^{-1} in DSR in non-puddled soil. Sanodiya and Singh (2017) also reported the beneficial effect of penoxsulam fb HW treatment on thousand grain weight and number of grains $panicle^{-1}$.

Penoxsulam fb HW treatments (m_2, m_1 and m_3) alone registered significantly higher grain yield compared to penoxsulam fb MM+CE and HWT treatments. Even though total weed density, dry weight and WCE were comparable for penoxsulam fb MM+CE treatments also, it was not manifested in grain yield, might be because these treatments were not at all effective in controlling new flushes of grasses as evidenced by relative density of grasses at 60 DAS. However, compared to weedy check all the weed control treatments (penoxsulam @ 20, 25 and 30 g ha^{-1} fb either HW or MM+CE and HWT) recorded significantly higher grain yield. Nutrient removal in penoxsulam fb HW treatments was negligible (0.14 to 0.35 kg ha^{-1} N; 0.015 to 0.036 kg ha^{-1} P and 0.14 to 0.31 kg ha^{-1} K) and the better availability of nutrients resulting in better uptake by rice crop (86.02 to 92.47 kg ha^{-1} N, 8.17 to 8.81 kg ha^{-1} and 63.62 to 73.67 kg ha^{-1} K) might have resulted in better expression of yield attributes and higher yield in these treatments. According to Yoshida (1981) and Fageria (2007) N is one of the most important nutrients in increasing yield components of rice especially thousand grain weight. In the present study also, significantly higher uptake of nitrogen in the penoxsulam fb HW treatments might have resulted in better thousand grain weight in these treatments. Enhanced grain yield is the resultant of yield attributes and therefore, maximum expression of yield attributes *viz.*, per cent filled grains and thousand grain weight, owing to reduced crop-weed competition in penoxsulam fb HW treatments resulted in higher grain yield in these treatments. These results are in close conformity with the findings of Netam *et al.* (2018) and Sanodiya and Singh (2017).

5.2.4. Nutrient Uptake by Crop

Nutrient uptake by crop was also significantly influenced by SSB methods. Stale seedbed method recorded significantly higher uptake of NPK by crop compared to no SSB method. This might be due to lower weed population and dry matter

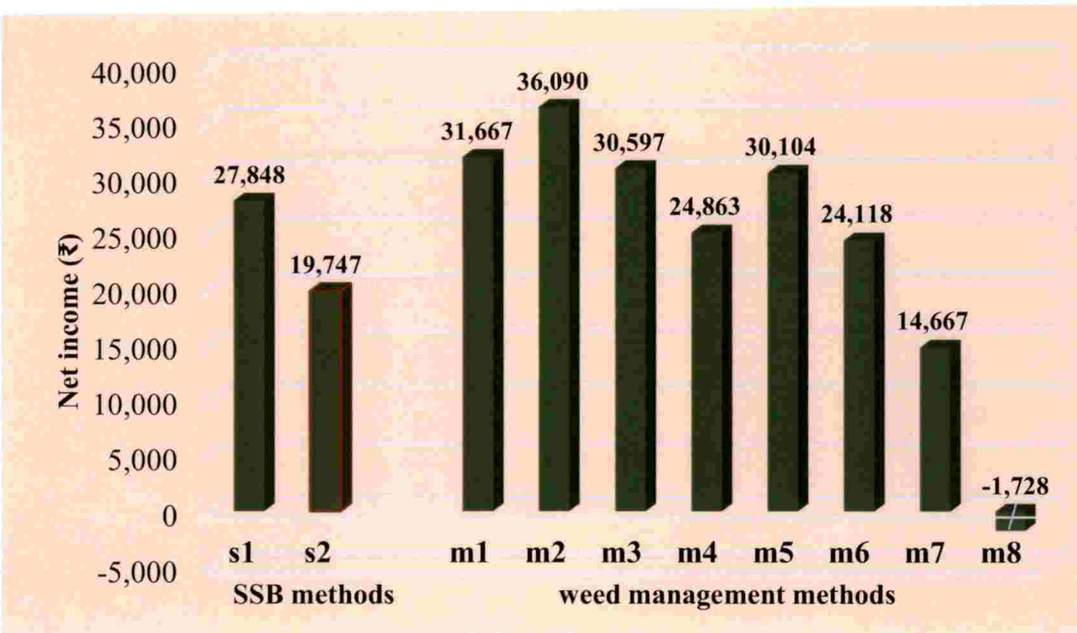


Fig 11. Effect of weed management practices on net income (₹)

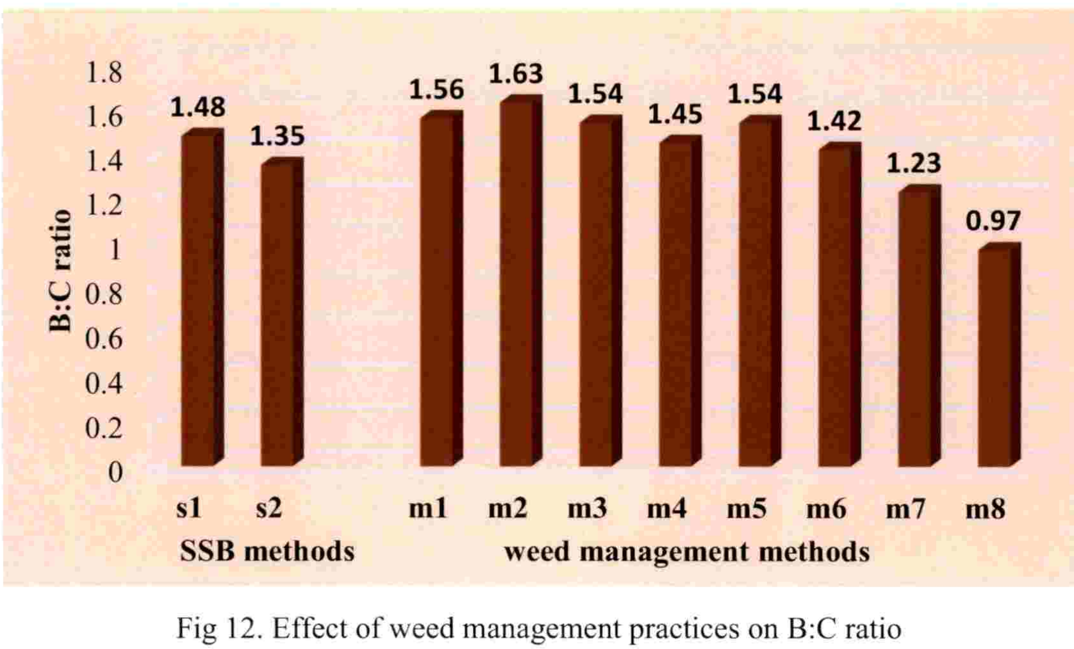


Fig 12. Effect of weed management practices on B:C ratio

production of weeds in SSB method, which provided favourable environment for the crop to absorb more nutrients. Corroboratory results were reported by Sindhu *et al.* (2010).

Weed management methods also significantly influenced the nitrogen and phosphorus uptake by crop. Among the weed management methods, all the penoxsulam fb HW treatments recorded significantly higher uptake values for N and P. Penoxsulam @ 25 g ha^{-1} fb MM+CE also recorded significantly higher N and P uptake by the crop, along with HWT. Weeds were effectively controlled by all the above treatments and recorded lower dry weight of weeds. This reduced competition from weeds provides weed free environment, which enabled the crop to absorb more nutrient. Similar observations were also made by Jacob and Syriac (2005) and Shendage *et al.* (2017)

Integration of SSB with penoxsulam fb either HW or post emergence application of MM+CE at 35 DAS also increased the uptake of phosphorus significantly.

5.3. NUTRIENT STATUS OF SOIL

Stale seedbed methods significantly improved the available N and P status of soil after the experiment. No SSB method recorded relatively low available nitrogen and phosphorus status which was even lower than initial status. Weed population was more in no SSB method which might have resulted in higher nutrient depletion from soil compared to SSB method, resulting in significantly lower available N and P status of soil.

All the weed management methods resulted in significantly higher available nitrogen, phosphorus and potassium status in soil compared to weedy check. All the herbicidal treatments and HWT effectively controlled weeds and recorded lower values for weed dry weight and the weed free environment might have caused reduced depletion of nutrients through weeds. So the status of available soil nutrients was not

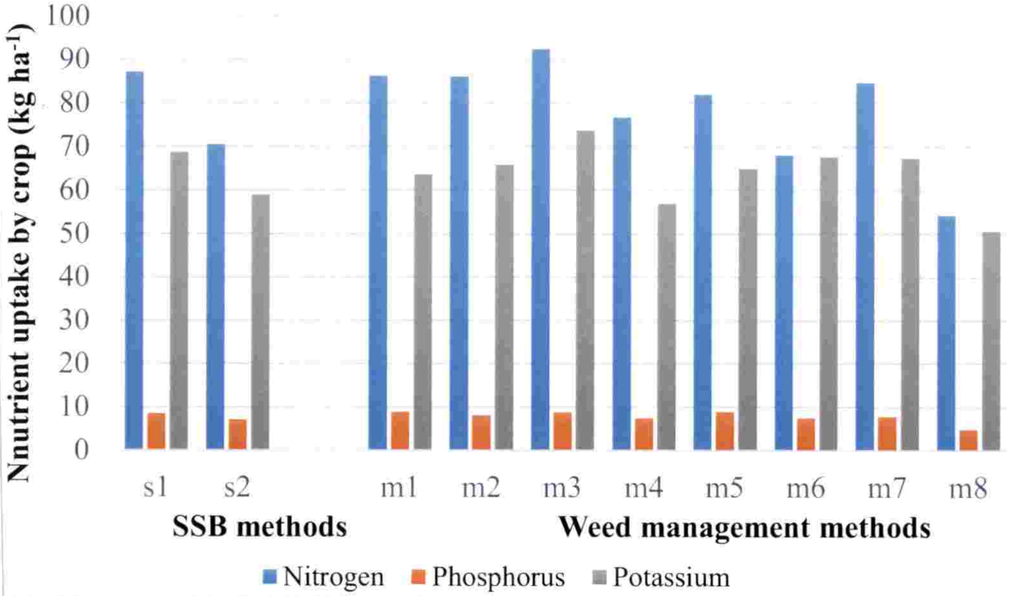


Fig 9. Effect of weed management practices on nutrient uptake by crop (kg ha^{-1})

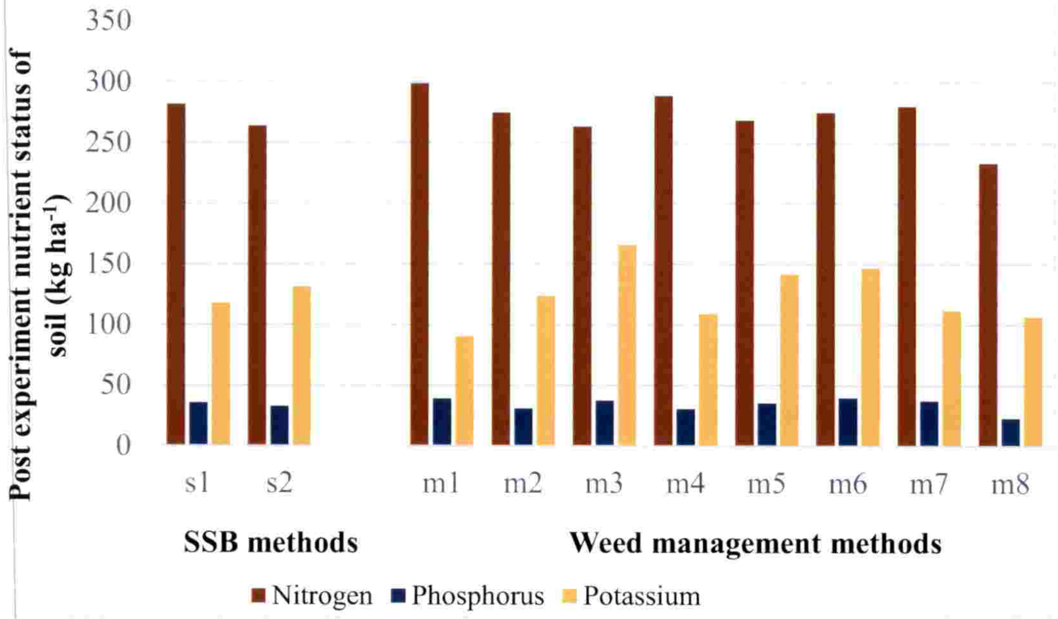


Fig 10. Effect of weed management practices on post experiment nutrient status of soil (kg ha^{-1})

much affected compared to initial status. Weedy check treatment recorded higher density and dry weight of weeds causing more depletion of nutrients by weeds resulting in low available nutrient status of soil emphasising that weeds are capable of removing large quantities of nutrient elements from the soil thus adversely affecting crop growth. Similar findings were reported by by Sasna (2014); Dayaram (2013) and Jacob (2002).

Integration of SSB method with penoxsulam fb HW also resulted in better available nutrient status of soil indicating the effectiveness of these treatments in maintaining the nutrient status of soil by reducing nutrient depletion through weeds.

5.4. ECONOMICS

Stale seedbed method registered substantially higher net income (₹ 27,848/-) and B:C ratio (1.48) compared to no SSB method. Even though the cost involved for preparing SSB is higher than no SSB, better control of weeds resulting in higher grain yield compensated for it, resulting in substantially high net income and B:C ratio. Pandey *et al.* (2009) reported that SSB method recorded higher net returns compared to traditional seedbed.

All the herbicidal treatments recorded higher net income and B:C ratio compared to HWT. Even though the herbicidal treatments and HWT were comparable and significantly reduced the weed dry weight, the cost of weed control was much higher in HWT, bringing down the net income and B:C ratio substantially, thus favouring chemical weed control. Penoxsulam @ 25 g ha^{-1} fb HW recorded the highest net income (₹ 36,090/-) and B:C ratio (1.63). Compared to penoxsulam fb MM+CE treatments, penoxsulam fb HW treatments recorded higher net income and BC ratio. In penoxsulam fb HW treatments, the labour used for weeding was comparatively less because the broad spectrum herbicide penoxsulam effectively controlled weeds and the late emerging weeds for HW were very low resulting in less cost for penoxsulam fb HW treatments. The highest grain yield and less labour cost for HW in penoxsulam fb HW (m_2) treatment might be the reason for obtaining the highest net income and B:C ratio. Netam *et al.* (2016) and Sanodiya and Singh (2017) also reported similar results that application of penoxsulam fb HW registered the highest net returns and benefit: cost ratio. In penoxsulam fb MM+CE treatments, irrespective of weed pressure, the follow up application of MM+CE was carried out, thus increasing the cost for weed control, resulting in lower net income and B:C ratio compared to penoxsulam fb HW treatments.

Integration of SSB with penoxsulam @ 25 g ha^{-1} fb HW registered the highest net income (₹ 44,433/-) and B:C ratio (1.77). Combination of SSB method with herbicidal treatment effectively controlled weeds which resulted in higher grain yield of rice. This could be the reason for realising the highest net income and B:C ratio. It is rightly pointed out by Chaudhary *et al.* (2006) that energy utilization for HW practice in dry upland rice crop was found lower under SSB (690 MJ ha^{-1}) than traditional seedbed (925 MJ ha^{-1}). Bhurer *et al.* (2013) and Singh (2013) reported that adoption of SSB fb herbicides resulted in higher net return per unit investment.

5.5. POPULATION DYNAMICS OF SOIL MICROBES

Soil micro-organisms play a vital role in the soil-plant-herbicide-fauna-man relationship as they take part in the degradation of herbicides (Milosevic and Govedarica, 2002). Herbicides can cause both qualitative and quantitative changes in the microbial population (Saeki and Toyota, 2004). Sensitivity to a given herbicide varies greatly among the different microbial species and strains. Stimulatory or depressive effect of herbicides on the microbial population may depend on the toxicity of the applied herbicide (Abdel-Mallek *et al.*, 1994), type, concentration and mode of action of the applied herbicide, environmental conditions, group of micro-organisms, bioavailability and persistence (Zain *et al.*,2013).

5.5.1. Fungal Population

Soil fungi widely distributed in the upper most layer of soil is the dominant organism among the soil microbial group (Chauhan *et al.*, 2006). Fungi are known to be extremely adaptable in different environments due to their ability to breakdown complex substances including herbicides (Das *et al.*, 2006).

In the present study, a substantial increase in fungal population was noticed at 15 and 30 days after herbicide application (DAHA) (ranging from 58.67 to 72.17 x 10^{-3} CFU g^{-1} wet soil and 48.67 to 60.67 x 10^{-3} CFU g^{-1} wet soil, respectively) in weed control treatments compared to the pre-treatment population (35 x 10^{-3} CFU g^{-1} wet soil). Corroboratory results were reported by Raj *et al.* (2015). However, no significant difference was observed between herbicide applied and non-herbicidal plots implying that penoxsulam at tested doses (20, 25 and 30 g ha^{-1}) do not have any adverse effect on fungal population. According to Bhatt *et al.* (2017), after initial reduction (3 DAHA), population of fungi is found to increase and recorded on par results with unsprayed plots (HWT and Weedy check) by 23 DAHA with penoxsulam @ 22.5 g ha^{-1}. Sansa (2014) also reported an initial decline in the population of fungi (6 DAHA) due to the application of penoxsulam. Dayaram (2013) also reported similar decline in the fungi population (6 DAHA) due to the application of herbicides. Corroboratory results on the inhibitory effect of herbicides on the growth of fungi in the initial stages and subsequent increase with passage of time were reported by Deshmukh and Khande (1977) and Choudhary *et al.*, (2008).

5.5.2. Bacterial Population

Total bacterial population in soil is indicative of qualitative changes due to herbicide application. Adverse to no effect or stimulatory effect of herbicides on soil bacterial population were reported by several researchers (Mukhopadhyay, 1980; Devi *et al.*, 2008; Sebiomo *et al.*, 2011)

In the present study, compared to the count of bacteria just before herbicide application (JBHA) (172 x 10^{-6} CFU g^{-1} wet soil), a substantial increase in bacterial count was observed in the experimental field at 15 and 30 DAHA, irrespective of weed management method used. Raj *et al.* (2015) also support this finding. However, no significant variation in total bacterial count was observed between herbicide applied and non-herbicidal (HWT and weedy check) plots implying that the herbicide penoxsulam is not having any adverse impact on soil bacterial population at the tested doses. These results are in agreement with the findings of Bhatt *et al.*, (2017) and Saranraj *et al.*, (2018), who observed no significant variation in total bacterial count in penoxsulam applied and control plots (HWT and weedy check). However, Sansa (2014) reported that there was a decline in the population of soil bacteria at 6 DAHA in penoxsulam (17.5 20.0, 22.5, 25.0 and 30.0 g ha^{-1}) treated plots compared to HWT and weedy check plots. This type of short term inhibitory effect of herbicides on the population of soil bacteria was reported earlier by several workers (Mukhopadhyaya, 1980; Nalayini and Sankaran, 1992). Domsch (1983) observed an initial setback in microbial population consequent to herbicide application and restitution after certain period.

5.5.3. Actinomycetes Population

The population of soil actinomycetes also showed an increasing trend compared to pre-treatment population (5 x 10^{-4} CFU g^{-1} wet soil) at 15 and 30 DAHA. However, between penoxsulam applied plots and non-herbicidal plots, no significant variation was observed in actinomycetes. This might be due to the fact that these micro-organisms are able to degrade herbicides and utilize them as source of biogenic elements for their physiological processes. This results also implies that the delicate biological balance of the soil is very little affected by the application of post emergence herbicide penoxsulam, indicating very low environmental hazard. Bhatt *et al.*, (2017) reported an initial decline in actinomycetes population (3 DAHA) but the population increased subsequently. This could be because, before degradation herbicides have toxic effects on micro-organism reducing their abundance, activity and consequently diversity of their communities. Later on, micro-organisms take part in the degradation process and then the degraded herbicide provide carbon rich substrate which in turn maximize the microbial population in the rhizosphere. Similar results are reported by Saranraj *et al.*, (2018).

Monitoring period is very important for assessing the impact of pesticides and a minimum of 30 days has been recommended for the recognition of persistent effect in soil; a delay of 30 days in the restitution of normality after herbicide application should be considered normal with negligible ecological consequence; a delay of 60 days is not unusual, the ecological consequence being tolerable and a delay of greater than 60 days is unusual with ecological consequences which may eventually be critical (Domsch *et al.*, 1983).

In the present study, there was no decline in the soil microbial population (bacteria, fungi and actinomycetes) at 15 and 30 DAHA compared to that before herbicide application implying that the tested chemical, penoxsulam upto 30 g ha^{-1} is not having any adverse effect on the biological balance of soil. Dissipation kinetics of penoxsulam in soil of rice eco system revealed that half-life of penoxsulam ranged from 6.40 to 7.88 days in soil and from 3.40 to 5.12 days in water at the tested doses of 20, 25 and 30 g ha^{-1} (Kaur *et al.* 2017).

5.9. EFFECT OF HERBICIDES ON ENZYME ACTIVITY

Dehydrogenase enzyme activity in soil is often used as the measure of any disruption caused by pesticides, trace elements or management practices to the soil (Reddy and Faza, 1989; Wilke, 1991). For measuring the harmful effect of herbicide on soil microbial population, dehydrogenase activity is a very important parameter (Sebiomo *et al.*, 2011). Ross (1970) reported that activity of dehydrogenase enzyme in soil depends on the metabolic state of the soil or on the biological activity of the microbial population than any free enzyme present. Dehydrogenase activity is considered as a sensitive bio-indicator of the microbial activity response to herbicide inputs. In the present, among the herbicidal treatments, Compared to pre-treatment values, herbicidal treatments recorded higher dehydrogenase activity. Among the herbicidal treatments, Penoxsulam @ 25 g ha^{-1} fb HW (m_2) recorded the highest activity of dehydrogenase in soil compared to control treatments (HWT and weedy check). This might be due to increase in microbial populations for decomposition of herbicides and utilizing as carbon source. According to Hang *et al.* (2002), the dehydrogenase enzyme activities were higher in herbicide applied plots; higher the concentration of butachlor, higher the dehydrogenase activity.

Perusal of the data on urease activity revealed at 15 DAHA urease enzyme activity was not significantly influenced SSB and weed management methods. However, a drastic decline in the urease enzyme activity in the experimental plots compared to pre-treatment enzyme activity (77.03 μg urea hydrolyzed g^{-1} soil h^{-1}), was observed. Basal application of nitrogen in the form urea might have caused enhancement of urease activity in the experimental plot, as revealed by the higher pre-treatment urease values compared to that recorded at 15 DAHA. Aparna (2000) reported that higher availability of substrate nitrogen and other nutrients promoted urease activity. Rasool et al (2014) reported that, urease activity was stimulated by herbicides under flooded condition than unflooded condition. This explains the decrease in urease activity at 15 DAHA, in the present study, which was carried out in upland soil. When basal nitrogen application was done, copious irrigation was also given for better crop establishment. Contrary to this, application of butachlor, pyrazosulfuron, paraquat and glyphosate herbicides increased the activity of urease and dehydrogenase from 7th day to 28th day of incubation (Baboo *et al.*, 2013).

SUMMARY

6. SUMMARY

The present investigation entitled "Weed management in upland rice (*Oryza sativa* L.) intercropped in coconut" was undertaken at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The main objective of the study was to standardize an eco-friendly and economic weed management strategy for upland rice intercropped in coconut. The field experiment was conducted at Coconut Research Station, Balaramapuram, Thiruvananthapuram, Kerala during June to October 2017. The variety used was *Prathyasa* (MO-21) released from Rice Research Station, Moncompu.

The experiment was laid out in randomized block design (factorial), with sixteen treatment combinations and three replication. The treatments consisted of two stale seedbed methods *viz.*, stale seedbed with mechanical removal of weeds (s_1) and no stale seedbed (s_2) and eight weed management methods *i.e.*, penoxsulam @ 20 g ha^{-1} at 10-15 days after sowing (DAS) fb hand weeding (HW) at 35-40 DAS (m_1), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb metsulfuron methyl + chlorimuron ethyl (MM+CE) @ 4 g ha^{-1} at 35-40 DAS (m_4), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), HW twice at 15 and 35 DAS (m_7) and weedy check (m_8). The results of the experiment are summarized below.

Weed flora of the experimental field was diverse in nature, with eight species of broad leaved weeds, six species of grasses and two species of sedges. *Setaria barbata* was the most predominant species in the experimental field. Grass was the dominant weed flora in the experimental field followed by broad leaved weeds. Sedge population was very low.

Stale seedbed (SSB) method was found to be very effective in reducing the density of broad leaved weeds and sedges. This method recorded significantly lower density of broad leaved weeds and sedges and total weed density compared to no SSB method at all stages of observations *viz.,* 15, 30 and 60 DAS. All the weed management methods recorded significantly lower weed population compared to weedy check. Penoxsulam fb MM+CE treatments were more effective in reducing density of BLW, grasses and sedges. Penoxsulam @ 20 and 30 g ha^{-1} fb MM+CE recorded the lowest total weed density at 30 and 60 DAS, respectively and these treatments were comparable with Penoxsulam fb HW treatments. Weedy check registered the highest total weed density. Stale seedbed combined with application of penoxsulam fb MM+CE or HW was found to be better inreducing the population of weeds.

Dry weight of all categories of weeds was effectively reduced by stale seedbed methods and this treatment registered significantly lower total weed dry weight compared to no SSB at 15 and 30 DAS. All the weed management methods reduced the total dry weight of weeds at 30 and 60 DAS compared to weedy check. Penoxsulam @ 30 g ha^{-1}fb MM+CE (m_6) registered the lowest total weed dry weight at 30 and 60 DAS. The highest total weed dry weight was recorded by weedy check, which was significantly inferior to all other weed management methods.

Stale seedbed method was found effective in controlling weeds and recorded significantly higher WCE compared to no SSB. Among the weed management methods, all penoxsulam doses fb either HW or MM+CE treatments effectively controlled weeds and registered higher WCE.The lowest WCE was observed in weedy check treatment. SSB with all the herbicidal treatments recorded higher WCE.

The growth attributes *viz.,* plant height, number of tillers m^{-2}, DMP and LAI were also significantly influenced by stale seedbed methods. Significantly higher plant height at 30 DAS, number of tillers m^{-2} at 30 DAS, DMP at harvest and LAI at

60 DAS were observed in SSB (s_1), compared to no SSB (s_2).Weed management methods also significantly influenced the crop growth attributes like plant height, LAI, tiller number m^{-2} and DMP. All the herbicidal treatments *i.e.*, penoxsulam fb HW or penoxsulam fb MM+CE and HWT recorded higher plant height and DMP at harvest.Weedy check treatment recorded the lowest values for all the growth attributes. Integration of SSB with penoxsulam @ 20, 25 and 30 g ha^{-1}fb either HW or MM+CE was found to be better in enhancing the growth attributes of upland rice.

Phytotoxicity observations on rice crop were recorded at 7 days after herbicide application indicating that there was no phytotoxic symptoms on rice plants in any of the herbicide treated plots.

Yield attributes *viz.*, spikelets panicles, per cent filled grain and thousand grain weight were significantly influenced by SSB methods. Stale seedbed method recorded significantly higher values for all these yield attributes, compared to no SSB. Weed management methods also significantly influenced the yield attributes. Penoxsulam @ 20, 25 and 30 g ha^{-1}fb HW treatments recorded significantly higher values for yield attributes like percent filled grains and thousand grain weight. Significantly lower values for all theyield attributes were recorded in weedy check.

Stale seedbed method recorded significantly higher grain yield compared to no SSB. Grain yield was also influenced by weed management methods. Penoxsulam @ 25 g ha^{-1}fb HW treatment (m_2) registered the highest grain yield (3.23 t ha^{-1}) which was statistically on par with other penoxsulam fb HW treatments (m_1 and m_3). Weedy check recorded the lowest grain yield (1.40 t ha^{-1}) which was significantly inferior to all other weed management methods.Interaction effect was found to be non-significant.

Compared to no SSB, SSB method recorded significantly higher straw yield. Weed management methods did not have any significant effect on the straw yield. Harvest index was not significantly influenced by SSB methods but weed management methods influenced it. All the herbicidal treatments *i.e.*, penoxsulam @ 20, 25 and 30 g ha^{-1} fb either HW or MM+CE and HWT registered significantly higher value for harvest index compared to weedy check. The lowest harvest index was observed in weedy check treatment (0.32).

Weed index which indicates the percentage yield reduction due to weeds, was influenced by SSB methods and significantly lower weed index was observed in SSB compared to no SSB.Among the weed management methods, penoxsulam @ 25 g ha^{-1} fb HW treatment (m_2) recorded the lowest weed index which was significantly superior to all other weed management methods. Weedy check treatment recorded yield reduction of rice upto 60.70 per cent. The treatment combination, s_1m_1 (SSB with penoxsulam @ 20 g ha^{-1} fb HW) registered the lowest weed index.

Nutrient uptake by crop was also influenced by SSB methods. Stale seedbed method recorded significantly higher uptake of NPK by rice crop (87.16 kg ha^{-1} N, 8.53 kg ha^{-1} kg ha^{-1} P and 68.73 kg ha^{-1} K) compared to no SSB method. Among the weed management methods, all the penoxsulam fb HW treatments, penoxsulam @ 25 g ha^{-1}fb MM+CE and HWT recorded significantly higher uptake of nitrogen and phosphorus. The lowest uptake of nitrogen, phosphorus and potassium by crop was reported in weedy check (54.26 kg N, 4.86 kg P and 50.70 kg K ha^{-1}).

Weed management methods exerted significant effect on nutrient removal by weeds also. Significantly lower nutrient removal by weeds was found in all the herbicidal treatments compared to the control treatments *viz.*, HWT and weedy check. Weedy check treatment recorded the highest depletion of nutrients by weeds (3.59 kg N, 0.276 kg P and 5.37 kg K ha^{-1}).

Stale seedbed method recorded significantly higher available nitrogen and phosphorus status of soil compared to no SSB. All the weed management methods resulted in significantly higher available nitrogen, phosphorus and potassium in soil compared to weedy check. Regarding interaction, SSB with penoxsulam fb HW treatments recorded higher nutrient status of soil.

Substantially higher net income (₹ 27,848/-) and B:C ratio (1.48) were registered by stale seedbed method compared to no SSB. Among the weed management methods, all the herbicidal treatments *i.e.*, penoxsulam @ 20, 25 and 30 g ha^{-1} fb either HW or MM+CE recorded higher net income and B:C ratio compared to HWT. Among the weed management methods, penoxsulam @ 25 g ha^{-1} fb HW recorded the highest net income (₹ 36,090/-) and B:C ratio (1.63). Integration of SSB with penoxsulam @ 25 g ha^{-1} fb HW (s_1m_2) registered the highest net income (₹ 44,433/-) and B:C ratio (1.77).

Population of fungi, bacteria and actinomycetes increased substantially in all the weed management practices, compared to pre-treatment values. No significant variation was found between herbicide applied and non-herbicidal plots, indicating the safety of herbicides for soil microbes.

Dehydrogenase enzyme activity in soil is a good indicator of microbial activity in soil. The results of the study revealed that dehydrogenase activity increased in all the treatments *i.e.*, herbicidal and non-herbicidal compared to pre-treatment values indicating the safety of the herbicide used. Among the weed management methods also, an increased activity of dehydrogenase enzyme was observed in herbicidal plots compared to non-herbicidal plots.

Based on grain yield, weed index and economic analysis, integration of stale seedbed method with the broad spectrum herbicide penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS can be recommended as an eco-friendly and economic weed management practice in upland rice.

FUTURE LINE OF WORK

- The present study needs multi-locational trails to verify the results.
- Study on the persistence and dissipation of herbicide in soil and the factors affecting its degradation, needs investigation.
- A detailed investigation to assess the residue level of penoxsulam in plant parts and soil at varying time intervals is needed.
- Compatibility of the herbicide with beneficial micro-organisms like bio-fertilizer organisms and bio-control agents needs investigation.

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WEED MANAGEMENT IN UPLAND RICE (*Oryza sativa* L.) INTERCROPPED IN COCONUT

By

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Abstract of the thesis

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ABSTRACT

The investigation entitled "Weed management in upland rice (*Oryza sativa* L.) intercropped in coconut" was undertaken during the period, 2017 - 2018 at College of Agriculture, Vellayani, Thiruvananthapuram to standardise an eco-friendly and economic weed management strategy for upland rice intercropped in coconut.

The field experiment was carried out at Coconut Research Station, Balaramapuram, Thiruvananthapuram district during the period from June to October 2017. The variety used was *Prathyasa* (MO-21) released from Rice Research Station, Moncompu. The experiment was laid out in randomized block design (factorial) with sixteen treatment combinations and three replications. The treatments consisted of two stale seedbed methods *viz.*, stale seedbed with mechanical removal of weeds (s_1) and no stale seedbed (s_2) and eight weed management methods *i.e.*, penoxsulam @ 20 g ha^{-1} at 10-15 days after sowing (DAS) fb hand weeding (HW) at 35-40 DAS (m_1), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_3), penoxsulam @ 20 g ha^{-1} at 10-15 DAS fb metsulfuron methyl + chlorimuron ethyl (MM+CE) @ 4 g ha^{-1} at 35-40 DAS (m_4), penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_5), penoxsulam @ 30 g ha^{-1} at 10-15 DAS fb MM+CE @ 4 g ha^{-1} at 35-40 DAS (m_6), HW twice at 15 and 35 DAS (m_7) and weedy check (m_8).

Study of the weed flora of experimental area indicated the dominance of broad leaved weeds (eight *spp.*) followed by grasses (six *spp.*) and sedges (two *spp.*). Stale seedbed method (s_1) recorded significantly lower weed density at all stages of observations (15, 30 and 60 DAS), weed dry weight at 15 and 30 DAS and higher weed control efficiency (WCE) at 30 and 60 DAS compared to no stale seedbed. Among the weed management methods, at 60 DAS, all the penoxsulam doses *i.e.*, 20, 25 and 30 g ha^{-1} at 10-15 DAS fb either HW at 35-40 DAS or MM+CE at 35-40 DAS (m_6, m_4, m_3, m_5, m_1 and m_2) were on par in their effect on total weed dry weight and WCE. Stale

seedbed method (s_1) registered significantly higher plant height at 60 DAS, number of tillers m^{-2} at 30 DAS and at harvest, dry matter production at harvest and LAI at 60 DAS compared to no stale seedbed (s_2). Penoxsulam at different doses fb HW treatments (m_1, m_2 and m_3) recorded higher plant height at 30 and 60 DAS and at harvest, number of tillers m^{-2} at 30 DAS, DMP at harvest and LAI at 30 DAS. None of the herbicide treated plots showed any phytotoxicity symptom on rice crop.

The yield attributes *viz.*, number of spikelets panicle^{-1}, per cent filled grains and thousand grain weight were significantly higher for stale seedbed, compared to no stale seedbed (s_2). Weed management methods also significantly improved yield attributes *viz.*, panilces m^{-2}, spikelets panicles^{-1}, per cent filled grains and thousand grain weight compared to weedy check treatment. Penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) registered the highest values for per cent filled grains and thousand grain weight. Stale seedbed method (s_1) recorded significantly higher grain yield, straw yield and lower weed index compared to no stale seedbed method (s_2). Though penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) registered the highest grain yield (3.23 t ha^{-1}), it was on par with the other penoxsulam fb HW treatments *viz.*, m_1 and m_3. None of the s x m interactions were found statistically significant. Regarding weed index also m_2 registered the lowest value and it was significantly superior to all other weed management methods.

Higher net income (₹ 27, 848/-) and B:C ratio (1.48) were obtained with stale seedbed method (s_1), compared to no stale seedbed (s_2). Application of penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS (m_2) registered the highest net income (₹ 36,090/-) and B: C ratio (1.63). The s_1m_2 registered the highest net income (₹ 44,433/-) and B: C ratio (1.77), among the interactions. The results on soil microbial population revealed that population of fungi, bacteria and actinomycetes increased in all the herbicidal treatments compared to pre-treatment population. Activity of dehydrogenase enzyme also increased significantly in the herbicide applied plots implying the safety of the tested chemicals on soil health.

Based on grain yield, weed index and economic analysis, integration of stale seedbed method with the broad spectrum herbicide penoxsulam @ 25 g ha^{-1} at 10-15 DAS fb HW at 35-40 DAS can be recommended as an eco-friendly and economic weed management practice in upland rice.

സംഗ്രഹം

തെങ്ങിനിടയിൽ കരനെൽ കൃഷി ചെയ്യുന്നതിന് ഏറ്റവും പ്രകൃതി സൗഹൃദവും ലാഭകരവുമായ കള നിയന്ത്രണ മാർഗ്ഗം കണ്ടെത്താൻ 2017 -2018 കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി. തിരുവനന്തപുരം ജില്ലയിലെ ബാലരാമപുരം നാളികേര ഗവേഷണ കേന്ദ്രത്തിൽ 2017 ജൂൺ മുതൽ സെപ്റ്റംബർ വരെയുള്ള കാലയളവിൽ, മങ്കൊമ്പ് നെല്ല് ഗവേഷണ കേന്ദ്രത്തില് നിന്നും വികസിപ്പിച്ചെടുത്ത, പ്രത്യാശ എന്ന ഹ്യസ്വകാല നെല്ലിനം ഉപയോഗിച്ചാണ് പ്രസ്തുത പഠനം നടത്തിയത്.

റാൻഡംമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണ രീതി അവലംബിച്ച് നടത്തിയ പഠനത്തിൽ രണ്ട് കള കിളിർപ്പിച്ചു നശിപ്പിക്കൽ (സ്റ്റെയ്ൽ സീഡ് ബെഡ്) രീതികളും - കള കിളിർപ്പിച്ചു നശിപ്പിക്കുന്നതും അല്ലാത്തതും – എട്ട് വ്യത്യസ്ത കളനിയന്ത്രണ മാർഗ്ഗങ്ങളും [പെനോക്സ്സുലാം 20 ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും കള പറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_1), പെനോക്സ്സുലാം 25 ഗ്രാം ഒരു ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും കള പറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_2), പെനോക്സ്സുലാം 30 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും കള പറിച്ചുനീക്കൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_3), പെനോക്സ്സുലാം 20 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും മെറ്റ്സൽഫ്യൂറോൺ മീതൈൽ + ക്ലോറിമ്യൂറോൺ ഈതൈൽ 4 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_4), പെനോക്സ്സുലാം 25 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും മെറ്റ്സൽഫ്യൂറോൺ മീതൈൽ + ക്ലോറിമ്യൂറോൺ ഈതൈൽ 4 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_5), പെനോക്സ്സുലാം 30 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷവും മെറ്റ്സൽഫ്യൂറോൺ മീതൈൽ + ക്ലോറിമ്യൂറോൺ ഈതൈൽ 4 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ 35-40 ദിവസങ്ങൾക്കുശേഷവും (m_6), രണ്ടു തവണ കള പറിച്ചു നീക്കൽ - വിതച്ച് 15 ദിവസത്തിനുശേഷവും 35 ദിവസത്തിനുശേഷവും (m_7), കളകൾ നീക്കം ചെയ്യാത്ത വീഡി ചെക്ക് (m_8)] പഠനവിധേയമാക്കി.

കള കിളിർപ്പിച്ചു നശിപ്പിക്കുന്ന രീതി അവലംബിക്കുന്നത് കള നിയന്ത്രണത്തിനു മാത്രമല്ല നെല്ലിൻ്റെ വളർച്ചക്കും ഉല്പാദനമികവിനും അനുയോജ്യമാണെന്ന് ബോധ്യപ്പെട്ടു. കള കിളിർപ്പിച്ചു നശിപ്പിക്കുന്നതോടൊപ്പം പെനോക്സ്സുലാം എന്ന കളനാശിനി 25 ഗ്രാം ഹെക്ടറിന് എന്ന തോതിൽ വിതച്ച് 10-15 ദിവസങ്ങൾക്കുശേഷം ഉപയോഗിക്കുകയും ബാക്കി കളകൾ 35-40 ദിവസങ്ങൾക്കുശേഷം പറിച്ചുനീക്കുകയും ചെയ്യുന്നത് വഴി മെച്ചപ്പെട്ട കള നിയന്ത്രണം, മികച്ച വിളവ്, അറ്റാദായം ഇവ ലഭിക്കുമെന്നും പഠനഫലങ്ങൾ സൂചിപ്പിക്കുന്നു.

APPENDICES

APPENDIX 1

Weather data during the crop season (June 2017- October 2017)

	Temperature, ^{0} C		RH, %		Rainfall (mm)
	Maximum	Minimum	Maximum	Minimum	
21	33.08	21.07	85	75	4.01
22	31.2	18.84	92	95	190.6
23	30.8	19.65	87	83	34
24	31.74	19.91	89	69	6.1
25	32.47	20.18	78	72	21.4
26	30.64	18.67	91	82	137.4
27	31.24	19.71	83	71	6.2
28	31.2	19.27	86	73	13.8
29	31.42	19.24	83	72	29.3
30	32.4	19.52	72	52	0
31	33.98	19.58	76	75	8.2
32	36.61	18.84	84	75	14.9
33	31.61	19.02	86	70	21.2
34	30.12	18.87	87	79	15
35	30.62	18.71	86	71	21
36	31.71	19.47	76	78	140.1
37	31.28	20.45	95	69	25.7
38	30.91	20.14	97	69	83.8
39	32.24	20.14	90	78	58.8
40	31.72	20.18	89	73	52.8

APPENDIX-II

Dilution and media used for the estimation of microflora.

Organism	Dilution	Medium
Bacteria	10^6	Nutrient Agar
Fungi	10^4	Martin's Rose Bengal Agar
Actinomycetes	10^5	Kenknight's Agar

APPENDIX-III

1. Nutrient Agar Medium (pH – 7.0)

SL No.	Chemicals	Quantity Required
1	Peptone	5 g
2	Sodium	5 g
3	Beef extract	3 g
4	Agar	20 g
5	Distilled water	1000 mL

2. Kenknight's Agar Medium

Sl. No.	Chemicals	Quantity Required
1	Dextrose	1 g
2	Potassium dihydrogen phosphate	0.1 g
3	Sodium nitrate	0.1 g
4	Potassium chloride	0.1 g
5	Magnesium sulphate heptahydrate	0.1 g
6	Agar	15 g
7	Distilled water	1000 mL

3. Martin's Rose Bengal Agar Medium

Sl. No.	Chemicals	Quantity Required
1	Glucose	10 g
2	Peptone	5 g
3	Potassium dihydogen phosphate	1 g
4	Magnesium sulphate heptahydrate	0.5 g
5	Streptomycin	30 mg
6	Agar	15 g
7	Rose Bengal solution	1 mL of 3.5% solution
8	Distilled water	1000 mL