HERBICIDE BASED WEED MANAGEMENT FOR SEMI DRY RICE (*Oryza sativa* L.)

by

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THESIS

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DECLARATION

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

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LIST OF ABBREVIATIONS

a.i	-	Active ingredient
ALS	-	Acetolactate synthase
B: C ratio	-	Benefit Cost Ratio
BLW	-	Broad Leaved Weeds
BPH	-	Brown Plant Hopper
CD (0.05)	-	Critical difference at 5 % level
cm	-	Centimetre
CPWC	-	Critical Period of Crop Weed Competition
DAS	-	Days after sowing
DAT	-	Days after transplanting
DSR	-	Direct Seeded Rice
day^{-1}	-	Per day
EC	-	Electrical Conductivity
Eg.	-	Example
et al.	-	Co-workers/ Co-authors
Fig.	-	Figure
fb	-	Followed by
g	-	Gram
GM	-	Gall Midge
GR	-	Granules
$g\ m^{-2}$	-	Gram per square metre
$g\ mole^{-1}$	-	Gram per mole
ha	-	Hectare
HI	-	Harvest index
HW	-	Hand weeding
$hill^{-1}$	-	per hill

LIST OF ABBREVIATIONS CONTINUED

i.e.	-	that is
K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
LAI	-	Leaf area index
LTR	-	Leaf Transmission Ratio
m	-	Metre
Mg	-	Milli gram
Mha	-	Million hectare
Ml	-	Milli litre
Mt	-	Metric tonne
m^{-2}	-	per square metre
MSL	-	mean sea level
N	-	Nitrogen
NS	-	Not significant
P	-	Phosphorus
plant $^{-1}$	-	per plant
$panicle^{-1}$	-	per panicle
pH	-	Negative logarithm of hydrogen ion concentration
Ppm	-	Parts per million
q ha^{-1}	-	Quintal per hectare
RH	-	Relative humidity
Rs. Ha^{-1}	-	Rupees per hectare
S	-	Significant
Sem	-	Standard error of mean

LIST OF ABBREVIATIONS CONTINUED

SU	-	Sulfonyl Urea
sp.	-	Species
t ha^{-1}	-	Tonnes per hectare
TPF	-	Triphenyl Formazan
viz.	-	Namely
Vs.	-	Versus
WCE	-	Weed Control Efficiency

LIST OF SYMBOLS

%	-	per cent
°C	-	Degree Celsius
@	-	at the rate of

Introduction

1. INTRODUCTION

Rice production symbolizes the single largest land use for food production on earth and worldwide, rice is grown on 164 Mha with an annual production of about 750 Mt of paddy (FAO, 2013). To meet the global rice demand, it is estimated that about 114 Mt of additional milled rice needs to be produced by 2035 (Singh *et al*., 2015) and therefore, meeting ever increasing rice demand in a sustainable way with shrinking natural resources is a great challenge.

Transplanting in puddled soils with continuous flooding is the most common method of rice crop establishment (Kumar and Ladha, 2011). Puddling causes clogging of macropores, breakage of soil aggregates, and the formation of subsurface shallow hardpans along with effective weed control due to standing water in the field (Kumar *et al*., 2008). But this technique is very laborious, cumbersome, expensive, and time consuming (Sahrawat *et al*., 2010). Another drawback of transplanted rice is huge water consumption which is usually thrice as high as that of other upland crops. Current production systems consume 2500–3000 L of freshwater to produce one kg of paddy (Bouman, 2009). In the traditional establishment method, both puddling and transplanting operations need a large amount of labour (Chauhan and Yadav, 2013). The increasing demand for labour in non-agricultural sectors and increasing labour costs resulting from the migration of rural labour to the cities, creates labour shortage at the critical time of transplanting (Chauhan, 2012). Also, late commencement of monsoon showers and drudgery involved in puddling and manual transplanting delay rice transplanting (Farooq *et al*., 2006). Hence there is a dire need to look for rice production technologies that not only cope with existing limitations but also are affordable and economically viable and secure future food demand.

To overcome the problems associated with traditional rice cultivation, direct seeding of rice seems to be the only viable alternative for rescuing farmers (Nie *et al*., 2012). In many Asian countries growers recently started to shift their rice cultivation practices from the traditional puddled rice to dry seeded rice (Ahmed and Chauhan, 2014). In India, the dry sown (semi dry) system of rice cultivation is a unique and extensively adopted system in 20 per cent rice growing area. In Kerala, it constitutes more than 60 per cent of the area under rice during *Kharif* (Anitha *et al*., 2009). In this system, the early growth of rice, up to 30-40 days is in a dry soil environment and thereafter the field gets submerged with the onset of southwest monsoon. Direct seeding of rice helps to meet the challenges posed by water and labour shortage, time and edaphic conflicts and it promises system sustainability (Chauhan *et al*., 2014). However, dry direct seeding of rice (DSR) is possible only if there is a good crop establishment as well as adequate weed control methods to keep the field free from weeds.

Being the most important biological constraint, weed infestation is very severe in DSR as compared to transplanted rice. Aerobic soil conditions, dry tillage practices and absence of stagnant water during the initial 4-6 weeks are conducive for germination and growth of highly competitive weeds. It is estimated that direct seeded rice yield is reduced by 60 per cent and even 100 per cent due to huge weed infestation (Rao *et al*., 2007). Moreover, in transplanted rice, weeds emerging early in the season are suppressed due to anaerobic environments formed by immediate flooding which is not the case in DSR. The simultaneous emergence of weeds with rice seedlings makes weed control in DSR a difficult task. The conversion to direct seeded rice has resulted in more aggressive weed flora like *Echinochloa* sp., *Cyperus difformis* and *Fimbristylis miliacea* which are more adapted to the conditions of DSR (Bastiians *et al*., 2008). In dry seeded rice, the critical period of weed competition has been reported to be 15-60 days after seeding (Chauhan and Mahajan, 2014) and if weeds can be suppressed effectively by any means during this period, minimal yield losses occur.

Manual weeding is common but its use is decreasing because of labour scarcity at the critical time of weeding and increasing labour costs. In addition some weeds at their early growth stages look similar to rice seedlings making hand weeding difficult in DSR. Chemical methods of weed control are therefore most practical and cost efficient.

Weed management using herbicides has become an integral part of modern agriculture. Herbicides offer greater flexibility of operation and are often cost effective compared with any other method of weed management. New generation herbicides which are applied at very low doses are more effective with low mammalian toxicity and reduced the risk of environmental pollution. Several new generation pre-emergence herbicides alone or supplemented with hand weeding or chemical weeding have been reported to provide a fair degree of weed control (Pellerin and Webster, 2004). However, its efficacy in semi dry system has not been evaluated so far in Kerala. Their selectivity and economic feasibility need to be assessed so as to formulate a low cost herbicide based weed management strategy for semi dry rice system in Kerala.

Keeping the above in view, the present study has been proposed with the following objectives:

- To assess the weed control efficiency of bensulfuron methyl + pretilachlor and pyrazosulfuron ethyl registered as pre- emergence herbicides along with azimsulfuron, a post-emergence herbicide in semi dry rice.
- To assess their selectivity and influence on growth and yield of semi dry rice
- To study the economic feasibility
- To develop a herbicide based weed management strategy for semi dry rice

Review of Literature

2. REVIEW OF LITERATURE

Rice is traditionally grown in Asia by manual transplanting of seedlings into puddled soil (Chauhan, 2013). In the recent years, there have been concerns of labour and water shortages in many areas along with the problem of uncertainty in rainfall in the scenario of climate change. These factors pulled the farmers to shift from transplanting to direct seeded rice (DSR) system. Although there are several advantages of direct seeded rice, weeds are the major constraints in DSR because of the absence of the suppressive effect of standing water on weed growth at crop emergence. Chemical control measures are generally more targeted at the early stage of weed emergence making management options easier and economic. Since the new generation herbicides are getting prevalent nowadays due to less environmental persistence and exceedingly low toxicity to non-target organisms, in this study, entitled "Herbicide based weed management for semi dry rice (*Oryza sativa* L.)", an attempt has been made to evaluate the weed control efficiency of three new generation herbicides *viz.*, bensulfuron methyl + pretilachlor and pyrazosulfuron ethyl registered as pre- emergence herbicides along with azimsulfuron, a post-emergence herbicide. The research works done on the weed management in semi dry rice are reviewed in this chapter. Since research work done on weed management in semi dry rice is limited, relevant literature on direct seeded rice system is also reviewed.

2.1. SEMIDRY SYSTEM

Rice is traditionally grown by transplanting seedlings into puddled soil. Both puddling and transplanting consume a large quantity of water. Rice growers in many areas are likely to have only limited access to irrigation water in the future. By 2025, 13 Mha of Asia's irrigated wetland rice may experience 'physical water scarcity' and 22 Mha of irrigated dry-season rice may suffer from 'economic water scarcity' (Tuong and Bouman 2003). Intensive soil tillage under wet conditions creates a hard pan below the plough zone reduces soil permeability and leads to high losses of water through surface evaporation and percolation (Farooq *et al*., 2011).

In addition to water scarcity there are also concerns about labour availability because of the increasing costs of labour resulting from the migration of rural labour to the cities. In recent years, manual transplanting of rice in some countries has been or is being replaced by direct seeding as growers respond to increased costs or decreased availability of labour or water. Direct seeding has been the principal method of rice establishment since the 1950s in the developing countries. (Pandey and Velasco, 2005).

The increase in production cost, shortage of labour, increased wages and decreased water availability resulted in a shift from transplanting to direct seeding in many Asian countries. In India, dry-seeded rice is extensively practiced in the northwest Indo-Gangetic plains because dry-seeded rice in this region provides the highest opportunity to attain optimal plant density and high water and labour productivity (Chauhan *et al*. 2012).

Direct seeding has the potential to replace transplanted rice (Balasubramanim and Hill, 2000) and is becoming popular as it eliminates many tedious farm operations like puddling and transplanting. Farooq *et al*. (2011) opined that direct seeding of rice (DSR) has several advantages over transplanted rice like direct-seeded crops are more rapidly and easily planted, less labour intensive, consume less water, mature 7 to 10 days earlier and have fewer methane emissions.

According to Matloob *et al*. (2014) direct seeding of rice has evolved as a potential alternative to the current detrimental practice of puddling and nursery transplanting. The associated benefits include higher water productivity, less labour and energy inputs, less methane emissions, elimination of time and edaphic conflicts in the rice–wheat cropping system and early crop maturity.

2.1.1. Weed Problem In Semi Dry Rice

Weeds are more problematic in DSR than in transplanted rice because of
(1) The absence of a head-start advantage over germinated weed seedlings
(2) The absence of standing water that prevents light from reaching weed seeds through a layer of standing water (Baltazar and De Datta 1992). According to Bahar and Singh, (2004) weed emergence was the highest during 30 days of crop growth (84.6 per cent) in dry seeded rice. Prasad (2011) reported that weeds are a serious problem in DSR because dry tillage and aerobic soil conditions are conducive to the germination and growth of many weeds, which can cause grain yield losses from 50 to 90 per cent.

Weeds grow more quickly in DSR than in transplanted rice system (Akwar *et al*., 2011). Weeds causes heavy damage to the direct seeded crop to the tune of 50-100 per cent (Singh *et al*., 2013). Matloob *et al*. (2014) reported that weeds have been recognized as the single largest biological constraint in direct-seeded rice and weed competition can reduce DSR yield by 30–80 per cent and even complete crop failure can occur under specific conditions.

Losses to weeds despite weed management in lowland rice are usually 10 to 20 per cent, and they may be even higher where weeds are not controlled. Yield losses of 17 to 24 per cent occurred in DSR when weeds were allowed to compete with rice until 4 weeks after sowing (Chauhan and Johnson, 2011c). Data on yield losses suggest that there is considerable scope to increase yield with improved weed management strategies in DSR (Chauhan, 2012).

2.1.2. Yield Loss Due To Weed Problem In Semi Dry Rice

Losses due to weeds are indeed much higher than those caused by nitrogen deficiency, pests, or diseases (WARDA, 1996). Weed is as old as agriculture, and from the very beginning farmers realized the interference of weed with crop productivity (Ghersa *et al.,* 2000). In Sri Lanka, weeds accounted for 30-40 per cent of yield losses

(Abeysekera, 2001) while in India, about 33per cent of rice yield losses are caused by weeds (Mukherjee, 2004).

Ramzan (2003) reported a potential rice yield loss of up to 48 per cent, 53 per cent, and 74 per cent in transplanted, direct-seeded in wet conditions, and direct seeded in dry soils respectively. Weeds were reported to reduce rice yields by 12 to 98 per cent depending on the method of rice establishment. Rice yield losses due to uncontrolled weed growth and weed competition were least (12 per cent) in transplanted rice (Singh *et al*., 2005) and highest in aerobic direct- seeded rice on a furrow-irrigated raised-bed system (Singh *et al*., 2008b).

On average rice yield loss due to weed ranges from 15 to 20 per cent but in severe cases the yield loss may exceed 50 per cent (Hasanuzzaman *et al*., 2009) or even 100 per cent (Jayadeva *et al*., 2011a).

Weeds are a serious problem in dry-seeded rice because dry tillage practices and aerobic soil conditions are favourable for germination and growth of weeds, which can cause grain yield losses from 50 to 90 per cent (Chauhan *et al*. 2011; Chauhan and Johnson 2011c; Prasad 2011).

Unchecked weed growth caused average yield losses of 80–100 per cent in upland rice (Akobundu, 1987) and 60 per cent in rainfed lowland rice (Moody, 1990; Moorthy and Rao, 1991). It has been estimated that rice yield decreases by 0.75 kg for every 1 kg of weed biomass produced (Anonymous, 2003). Recently, Chauhan and Opena (2013) reported a 39–41 per cent yield loss in DSR because of weeds (one weeding at 28 DAS) relative to weed-free yield.

Chauhan and Johnson (2011b) reported that yield losses in DSR systems can go as high as 90 per cent if control measures are not taken and timely weed control is therefore crucial in improving the productivity and profitability of DSR.

The general conclusion that can be drawn from studies of weed competition in DSR is that a direct-seeded crop is more vulnerable to weed competition as competitive processes start earlier in the life of the crop and hence require early weed control. The enormous yield losses caused by weeds imply that significant room exists for yield improvement through effective weed management strategies (Matloob *et al*., 2014).

2.1.3. Weed Flora In Semi Dry Rice

According to Kuyeonchung *et al*. (2002) weed diversity and species were strongly affected by the cultivation methods. Changes in cultivation methods resulted in wide variation in species composition and diversity (Tomita *et al*., 2003). More than 50 weed species are reported to cause yield losses in DSR ranging from 30 per cent to 98 per cent (Oerke and Dehne, 2004; Gowda *et al*., 2009).

Regarding the weed flora in direct seeded rice, *Echinochloa crussgalli, Echinochloa colona, Eleusine indica, Eclipta alba, Ludwigia parrillora, Cyperus iria, Cyperus difformis* and *Fimbristylis miliacea* were reported as the major weed species (Verma *et al*., 2004). In dry seeded rice, cleome (*Cleome rutidospermum* Dc.), bermuda grass (*Cynodon dactylon* L.), purple nutsedge (*Cyperus rotundus* L.), crow foot grass [*Dactyloctenium aegypticum* (L.) Willd.], southern crab grass [*Digitaria ciliaris* (Retz.) Koel.], jungle rice [*Echinochloa colona* (L.) Link], goosegrass [*Eleusine indica* (L.) Gaertn.], chinese sprangletop [*Leptochloa chinensis* (L.) Nees], common purslane (*Portulaca oleracea* L.) and horse purslane (*Trianthema portulacastrum* L.) were the major weeds as reported by Chauhan and Abugho (2013).

In rainfed upland rice, *Cynodon dactylon, Eragrostis gangeticum, Setaria glauca, Dactyloctenium aegypticum, Cyperus rotundus, Cyperus iria, Cyperus compressus, Fimbristylis miliaceae, Oldenlandia corymbosa, Ludwigia parviflora, Borreria hispida, Desmodium triflorum, Scoparia dulcis, Sida rhombifolia,* *Phyllanthus niruri, Alysicarpus vaginalis, Cleome viscosa* were the major weed flora (Saha *et al*., 2005).

Major weed species observed in direct seeded rice were *Echinochloa colona* (L). Link, *Echinochloa crusgalli* (L.). Beav, *Dactyloctenium aegyptium* (L.), among grasses, sedges included *Cyperus* spp. and broad-leaf weeds dominated by *Caesulia axillaris*(L.), *Ammania baccifera* (L.), *Eclipta alba* (L.) and *Phyllanthus niruri* (L.). The composition of grasses, broad-leaf and sedges was 35.5, 33.5 and 30.9 per cent in 2010 and 37.7, 32.0 and 30.1 per cent during 2011, respectively (Singh *et al*., 2013).

The increased dominance of sedges in response to DSR has also been reported in Australia and the United States (Gressel, 2002) and India (Singh *et al*., 2008a; Yaduraju and Mishra, 2008). Weedy rice is becoming a problem in direct-seeded rice in Asia, and there are considerable differences in growth among different weedy rice accessions (Chauhan and Johnson, 2010).

In dry seeded rice, *Echinochloa colona* (30.8 per cent), *Echinochloa crussgalli* (15.8 per cent), *Ischaemum rugosum* (26.4 per cent), *Commelina diffusa* (7.6 per cent) and others (8.9 per cent) were the dominating weed species (Bahar and Singh, 2004). *Echinochloa crussgalli, Echinochloa colona, Leptochloa chinensis, Cyperus rotundus, Cyperus difformis, Fimbristylis dichotoma, Commelina benghalensis* and *Cyanotis axillaris* were the dominating weed flora in direct seeded rice as reported by Singh *et al*. (2005).

Weeds such as *Echinochloa crus-galli* (L.) Beauv. and *L. chinensis*, apparently unfamiliar to rice fields (Azmi *et al*., 1993), became widespread and dominant in Malaysian rice fields after the introduction of DSR in 1970s (Azmi *et al*., 2005). In a recent survey in Punjab, the dominant weed species reported by the farmers in DSR fields were *Cyperus iria* L., *Echinochloa colona* (L.), *Eragrostis spp*., *Leptochloa* *chinensis* (L.), *Digitaria sanguinallis* (L.), *Dactyloctenium aegyptium* (L.), *Cyperus rotundus* L., and *Eleusine indica* (L.) (Mahajan *et al*., 2013).

In China, remarkably increased infestation of *Alternanthera philoxeroides Mart*. in rice fields over the last 20 years has been reported (Liu-qing *et al*., 2007). This indicates that some new weed species or weeds that otherwise are not presumably adopted to rice fields show pronounced distribution and dominance in DSR. Hence, adoption of DSR may lead to changes in the number of weed species encountered (narrow-leaved *vs.* broadleaved) and their relative densities and proportions and consequently a whole scenario of intra- and interspecific competition.

2.2 CROP-WEED COMPETITION IN SEMI DRY RICE

Rao, (2000) opined that crop weed competition is complicated because various factors affect the extent to which it occurs and the degree of weed competition is determined by the weed species infesting the area, density of infestation and duration of infestation.

Umapathi *et al.* (2000) observed that grasses were the most competitive in rice followed by sedges and least competitive were the broad leaved plants. According to Abdul *et al*. (2009) weed emergence in relation to crop emergence is an important factor in crop-weed competition.

According to Chauhan *et al*. (2014) rice and rice weeds have similar requirements for growth and development. They compete for limited resources such as nutrient, moisture, light, space etc. Most of the weeds being C_4 plants have higher adaptability and faster growth than rice a C_3 crop. Weeds dominate the crop habitat and rice yield potential is reduced. Among the weeds sedges primarily compete for nutrients as their root systems are fibrous. Similarly, grass weeds also pose serious competition for soil, water and nutrients apart from that for CO_2 and light. Broadleaved weeds have less competition for nutrients with rice because their deep root systems explore the deeper layer for minerals.

According to Kropff *et al*. (1993) the significance of weed and crop densities and their relative time of emergence must also be considered. Weed infestation is particularly severe in the early stages when the crop grows under an aerobic upland environment. In the later stages, aquatic weeds emerge and grow mostly at or below the water surface particularly when the crop stand is poor. An important aspect of weed competition in DSR is that most of the weeds have a C_4 carbon fixation pathway (Caton *et al*., 2004) that imparts a definite competitive edge over C_3 rice as well as weed species.

An estimate showed that weeds could deprive the crops of 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg (Balasubramaniyam and Palaniappan, 2001). Weed infestation depleted the soil by 24.7 kg nitrogen, 5.8 kg phosphorus and 63.4 kg potassium ha^{-1} in one season (Sharma, 2007).

Reddy and Reddy (2008) reported that weeds grow faster and shade the crop plants, if not checked. Even in case of shorter weeds, the lower leaves of crops are shaded by them. Weeds deplete the photosynthetically active radiation resulting in reduction in photosynthetically active radiation in photosynthesis and shortening the life of lower leaves.

Some weed species such as giant sensitive plant (*Mimosa invisa Mart. ex Colla*) and red weed (*Melochia corchorifolia* L.) germinate equally in light and dark and other species such as rice flat sedge (*Cyperus iria* L.) and eclipta [*Eclipta prostrata* (L.)] do not germinate in the dark at all. In the third intermediate group of weed species such as jungle rice [*Echinochloa colona* (L.) Link] and slender amaranth (*Amaranthus viridus* L.) light is not a requirement for germination but light stimulates germination (Chauhan, 2012).

Ghuman *et al.,* (2008) observed that competition between crop and weeds can be modified by manipulating crop geometry as increase in crop density can enhance the crops' share of the total resources. Plant population affected the weed biomass production and it was highest with lower plant population.

2.2.1. Critical Period of Weed Competition in Semi Dry Rice

Critical period of weed competition (CPWC) is an integral part of integrated weed management and can be considered as the first step to design weed control strategy (Amador-Ramirez, 2002). The CPWC is the period of crop life cycle during which weeds must be controlled to prevent unacceptable or economic yield loss (Evans *et al*., 2003).

According to Zimdahl (2004) CPWC is the period before and after which weed growth does not affect crop yield. The critical period of weed competition is longer (15 to 45 DAS) for direct seeded rice (Singh *et al*., 2008b). Abdul *et al*. (2009) reported that the critical period is one of the important alternative weed management strategies in order to minimize the labour requirement for weeding operations, enhance the efficiency of herbicide use and maximize economic returns.

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

The relationship between the duration of weed competition (time of removal) and associated yield reduction in rice is approximately sigmoid. According to El-Desoki (2003) weed competition after 20 days of rice seeding caused a drastic reduction in the number of panicles and grain yield per unit area and a yield increase was proportional to the increasing duration of the weed-free period. Bhat *et al*. (2008) opined that the rice crop recorded the higher plant height (70.63 cm) and dry matter accumulation (1289 g m^{-2}) in weed free plots due to better growth of plants on account of reduced weed competition at critical crop growth stages resulting in increased availability of nutrients, water and light. Weed infestation up to 15 DAS or weed-free for 60 or 75 DAS produced grain yields similar to those of plots kept weed-free throughout the growing season (Singh, 2008).

Field trials of dry-seeded irrigated rice in the Senegal River delta revealed that a 95 per cent weed-free rice yield can be obtained by controlling weeds from 0 to 32 DAS in the wet season and from 4 to 83 DAS in the dry season (Johnson *et al*., 2004). Rao *et al*. (2007) reported that in dry seeded rice, 4-6 weeks may elapse between sowing and permanent flood establishment and controlling weeds during this period is critical to optimise grain yield.

First 30 to 60 days after sowing is considered as critical period for crop-weed competition in case of rainfed lowland rice (Moorthy and Saha, 2005). In rice, weed free period of 30 days is required to avoid the significant loss in rice yield due to weeds (Sharma, 2007). As per the reports of Hasanuzzaman *et al.* (2009), the loss in yield ranges between 15-20 per cent normally and in severe cases the yield losses can be more than 50 per cent depending upon the species and intensity of weeds.

2.2.2. Effect of Weed Competition on Yield Attributing Characters and Yield

As per Dobermann and Fairhurst (2000), estimation of yield losses caused by competition from weeds ranges from 30-100 per cent. Gopinath and Pandey (2004) reported reduction in crop yield due to weeds results from their multifarious ways of interfering with crop growth and culture and weed competition can lower rice grain yield to the extent of 62.6 per cent.

Singh *et al*. (2013) opined that adoption of different weed control practices significantly influenced the yield attributes, *viz.,* panicles m^{-2}, grains per panicle and 1000 grain weight during both the years. The enhanced yield attributes recorded may be due to lower density and dry weight of weeds and higher weed control efficiency which resulted in better growth of rice crop.

In the studies conducted by Sangeetha *et al*., (2009) the lowest number of panicles per plant, panicle length and number of grains per panicle in the unweeded control treatment was due to suppressed crop growth as a result of maximum weed growth in unweeded control. According to Walia *et al*. (2009) among the weed control treatments weed free treatment recorded higher effective tillers and grain yield as compared to partial weedy treatment.

Weed free condition at early stage of growth was found more important than at later stages for getting higher yield of rice (Thapa and Jha, 2002). Raju *et al*. (2003) opined that the control of weeds promoted the yield and yield attributes including productive tillers m^{-2}, number of filled grains per panicle and thousand grain weight in rice. Begum *et al*., (2009) reported that weed free conditions produced more productive tillers and fertile grains per panicle compared to weed density of 500 m^{-2} to 2000 m^{-2}.

From the studies of Mahapatra *et al*. (2002) and Saini and Angiras (2002) it could be inferred that there was a decrease in thousand grain weight due to weed competition. Muthukrishnan *et al.* (2010) reported the lowering of grain quality and cash value of the crop by weed seed contamination.

2.3. WEED MANAGEMENT PRACTICES

2.3.1. Effect of Hand Weeding in Semi Dry Rice

Laskar *et al*. (2005) opined that hand weeding at 20 and 40 DAS recorded the maximum rice grain yield and according to Rao *et al*. (2007) highest reduction in total weed density and total dry weight of weed in hand weeding over the weedy check was possible with the involvement of the intense labour and frequency of the weeding *i.e.* three times during the growing season.

Hand weeding twice on 20 and 40 DAS was found to be superior weed control in dry sown rice. They also recorded higher crop growth parameters, yield attributing characters, grain yield (5444 kg ha^{-1}) and straw yield (5759 kg ha^{-1}) in dry sown rice (Lakshmi *et al*., 2006). Sharma (2007) opined that two hand weedings one as early as possible (10-15 days after sowing) and the second 25-50 days later were generally sufficient in upland rice. Payman and Singh (2008) recorded highest weed control efficiency of 65.52 per cent with two hand weedings at 30 and 45DAS.

Moorthy and Saha (2005) observed that in direct seeded rice hand weeding twice at 20 and 40 DAS recorded lower weed dry weight (0.09 t ha^{-1}) and higher WCE (94.6 per cent) and higher grain yield (3.1 t ha^{-1}). Singh *et al*. (2006) revealed that, hand weeding at 25 and 50 DAS recorded lower weed population (12.25 m^2), lower weed dry weight (91.6 g m^2) and higher grain yield (3.2 t ha^{-1}). Plant height and leaf area index (LAI) were lowest in weedy check and maximum in two hand weedings on 25 and 45 DAS (Singh *et al*., 2008b).

Kandaswamy, (1999) opined that keeping the rice fields weed free exclusively by manual weeding may not be feasible because of high cost, more time and other difficulties involved. As per Melander *et al.* (2005) time consumption for hand weeding varies according to weed density and the success of preceding weed control measures. Saha *et al*. (2005) reported that manual weeding is becoming more and more cost prohibitive and causes drudgery. Khaliq *et al.* (2011) opined that manual weeding although efficient in controlling weeds has been restricted due to several economic and technological factors.

Singh *et al.* (2005) observed that grain yield was significantly lower in dry seeded rice where only hand weedings was done because of early crop-weed competition rather than pre-emergence application of herbicide supplemented with hand weedings. In direct seeded rice under rainfall condition all the weed control methods reduced weed growth significantly over unweeded control and WCE was highest (71.25 per cent) with power weeder followed by hand weeding thrice (70.55 per cent) (Viren *et al*., 2005).

Hazanussaman *et al*. (2009) reported that hand weeding twice controlled the weeds most effectively which produced significantly highest yield and yield contributing characters. Manual weeding is common in many Asian countries; however, this is becoming less popular because of the high wage and non-availability of labour at the critical time of weeding. In addition it is very difficult to get rid of weeds in broadcast rice culture. In the initial stages, some grass weeds are difficult to distinguish from rice plants (Chauhan *et al*., 2013).

2.3.2. Effect of Chemical Weed Control in Semi Dry Rice

Azmi *et al*. (2005) reported that unavailability and increasing cost of labour and the pressing need to raise yield and maintain profits on a progressively limited land base have forced farmers to seek substitutes for manual weed control. Herbicides proved to be one such alternative as they provide superior weed control and are more energy and labour efficient than manual or mechanical methods of weed management. In addition weeds tend to regenerate from roots or rhizomes that are left behind during manual or mechanical weeding and these can be controlled only by the use of herbicides (Chauhan *et al.,* 2014).

Acceptability of herbicides increased rapidly after 1980 due to the easiness of use and lack of need to costly labor. Herbicides look better than other methods because of their performance in decreasing weeds competition, easy usage, economic low cost and less workforce. Therefore, weed control in rice is strongly dependent on herbicides (Ishaya *et al*., 2007). Many researchers working on weed management in direct seeded rice opined that herbicide may be considered to be a viable alternative or supplement to hand weeding (Mahajan *et al*., 2009).

The use of herbicides becomes even more important when weed and rice seedlings emerge simultaneously in DSR and some weeds such as jungle rice and barnyard grass are morphologically similar to rice. Various PRE (pendimethalin, oxadiazon, oxadiargyl, pretilachlor, etc.) and POST (bispyribac-sodium, penoxsulam, fenoxaprop, azimsulfuron, 2, 4-D, metsulfuron-methyl, etc.) herbicides are used in DSR. However those herbicides have a narrow weed control spectrum and low efficacy when used alone and they do not give season-long weed control. Herbicides should therefore be integrated with other cultural management practices to retain them for sustainable and continuous use in the future. Flooding after herbicide application for example, could suppress subsequent growth of weeds, provided there is enough water available for flooding (Chauhan, 2012).

DSR usually has a 4 to 6 week lapse between sowing and permanent flood establishment. Appropriate weed control during this period is essential to optimize grain yield. The use of two or more herbicides sequentially or in combination to broaden the spectrum of chemical weed control can reduce production costs and prevent the development of weeds resistant to certain herbicides (Kelly and Coats, 1999). Akbar *et al*. (2011), Jayasuria *et al*. (2011) and Khaliq *et al*. (2011) have also reported that herbicides were effective for weed management in rice.

Several pre-emergent herbicides, including butachlor, oxyfluorfen, pendimethalin, thiobencarb, oxadiazon and nitrofen alone or supplemented with hand weeding have been reported to provide a fair degree of weed control (Estorninos and Moody, 1988; Janiya and Moody, 1988; Moorthy and Manna, 1993; Pellerin and Webster, 2004).

De Datta and Herdt (1983) reported that chemical weed control in direct seeded rice has gained importance because of higher intensity of weeds coupled with the non-availability of labour for control of weeds in time and its higher cost. Herbicides although may not control weeds as effective as hand weeding, it offers the most practical, effective and economical means of reducing weed problems, crop losses and production cost. The diverse weed flora in dry seeded rice fields usually necessitated the use of two or more herbicides for wide spectrum weed control (Gianessi *et al*., 2002) one at the dry period just before or after rice emergence and the other at the flood period (Kim and Ha, 2005). Integrated weed control with pre-emergence herbicides coupled with one hand weeding proved better weed control strategy in dealing with effective, timely and economic weed suppression (Wibawa *et al*., 2010).

For the last few decades herbicides have been tremendous contributor to agriculture. In large scale rice farming herbicide based weed management has become the smartest and most viable option due to scarcity and high wages of labour (Singh *et al*., 2006). Despite some undesirable side-effects no viable alternative is presently available to shift the chemical dependence for weed management in rice. Many researchers working on weed management in direct seeded rice opined that herbicide may be considered to be a viable alternative or supplement to hand weeding (Anwar *et al*., 2012b).

2.3.2.1.New Generation Chemicals

Despite the obvious advantages of herbicides their use has raised concerns relating to human health and the environment. Hence there is a need for identifying alternative herbicides to give options to the farmers which will not only reduce the total volume of herbicide use but also, the application become easier and economic (Kathiresan, 2001). Herbicides are considered as an alternative or supplement to hand weeding. The development of new improved herbicides for dry seeded rice is also needed (Gupta *et al*., 2003).

Sulfonylureas represent one of the largest classes of herbicides with 27 different active ingredients currently registered around the world. These are helping farmers around the globe to meet their crop protection needs in effective and environmentally sound ways. They continue to be a crucial component of crop protection methodologies as one of the most important advances in crop protection technology in the 21st century. The inhibitory mechanism of sulfonyl ureas is related to the inhibition of acetolactate synthase (ALS), a key enzyme essential for the biosynthesis of valine, leucine and isoleucine that is necessary for protein synthesis leading to the rapid cessation of plant cell division and growth which is absent in animals and humans. Sulfonyl ureas are noted for their high specific activity, which is reflected in the very low application rates required to obtain economic levels of weed control (Samanta *et al*., 2010).

According to Kathiresan (2001), low use rates of new generation herbicides have allowed farmers to achieve higher yields while applying 95-99 per cent less herbicides to their crops. A number of low dosage high efficacy herbicides coming recently under sulfonyl urea group have been found to be suitable alternatives to the old herbicides (Karim *et al*., 2004). All the new- generation herbicides tested showed better control of weeds (weed-control efficiency 79.9-95.1 per cent) and gave higher yields of rice, irrespective of their dose of application (Saha, 2006).

Currently, herbicides with ALS inhibitors are used in dry-seeded rice which have high selection pressure and may exacerbate the problem of herbicide-resistant species. (Chauhan *et al*., 2014).

2.3.2.1.1. Bensulfuron methyl + Pretilachlor

Pretilachlor is a new promising selective herbicide introduced for the control of broad leaved weeds and sedges in transplanted rice and direct seeded rice (Vidotto *et al*., 2004). Its mode of action is by inhibition of cell division and protein synthesis. According to Ghuman *et al.* (2008) application of pretilachlor @ 0.75 kg a.i. ha^{-1} as pre-emergence proved to be very effective in reducing weed dry matter and increasing grain yield up to a significant level as compared to unweeded check. Rajagopal (2013) reported that bensulfuron methyl + pretilachlor @ 75+750 g a.i ha^{-1} was found effective for controlling weed growth especially during the early crop growth stages and gave better grain and straw yield under transplanted system of rice cultivation.

In aerobic rice, pre-emergence application of bensulfuron methyl +pretilachlor (6.6 GR) @ 6+60 g a.i. ha^{-1} +one inter cultivation at 40 days after sowing recorded significantly lower weed population, weed dry weight and higher grain and straw yields resulting in high net returns and B: C ratio (Sunil *et al*., 2010).

Bensulfuron-methyl alone @ 60 g a.i. ha^{-1} or as tank mixture with pretilachlor (50 + 450 g a.i. ha^{-1}) applied at 2 DAS were found to be equally effective in controlling weeds (weed control efficiency 90.0 and 92.2 per cent, respectively) and produced comparable grain yield. Application of bensulfuron-methyl alone at 60 g a.i. ha^{-1} and tank mixture of bensulfuron methyl+ pretilachlor at relatively lower dose of 50+450 g a.i. ha^{-1} proved to be effective for wide spectrum weed control in wet direct-sown rice during dry season (Saha and Rao, 2010).

According to Madhukumar *et al.* (2013a) pre-emergent application of bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i ha^{-1} recorded significantly higher productive tillers per hill (21.32), panicle weight (2.81 g), thousand grain weight (21.80 g), filled spikelets per panicle (88.23), weed control efficiency (91.37) and grain yield (4100 kg ha^{-1}) in aerobic rice.

According to Sanjay *et al*. (2013) application of bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i. ha^{-1} as pre-emergent spray resulted in significantly higher grain yield in aerobic rice. Lower values of weed density, total weed dry weight and weed index, higher values of yield attributes and yield of rice, weed control efficiency of bensulfuron methyl @ 60 g + pretilachlor @ 600 g a.i. ha^{-1} was reported by Teja *et al*. (2015).

2.3.2.1.2. Pyrazosulfuron ethyl

Pyrazosulfuron-ethyl has both foliar and soil activity (Rajkhowa *et al*. 2006). Chauhan and Yadav (2013) reported that pyrazosulfuron ethyl @ 25g a.i. ha^{-1} can be used to manage weeds in dry seeded rice. Ahmed and Chauhan (2014) reported that against broadleaved and sedges pyrazosulfuron performed well (63–70 per cent) *i.e*., broad leaved weeds and 54–70 per cent sedges were controlled by pyrazosulfuron ethyl @ 15 g a.i. ha^{-1} compared to the weedy check.

Results of the study conducted by Mahajan and Chauhan (2013) indicated that the single pre- emergence application of pyrazosulfuron (15 g a.i. ha^{-1}) reduced total weed biomass by 68 per cent compared with the untreated control at flowering stage of the crop. Compared to the untreated control, grain yield following the single application of pyrazosulfuron as pre- emergence, increased by 119 per cent. The single pre-emergence application of pyrazosulfuron increased grains $panicle^{-1}$ by 49 per cent, compared with the untreated check. Pre-emergence application of pyrazosulfuron ethyl proved effective against purple nutsedge, crowfoot grass and jungle rice respectively.

Application of pyrazosulfuron ethyl @ 20 g a.i. ha^{-1} at 10 days after transplanting (DAT) was recommended as an efficient and economic weed management practice for low land rice (Yadav, 2006). Gopal *et al*. (2010) reported that pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} was effective as pre-emergence herbicide for controlling weeds in dry direct seeded rice.

Total weed density (7.53 no. m^{-2}) and weed dry matter (2.3 g m^{-2}) recorded was lowest in pyrazosulfuron-ethyl @ 20 g a.i. ha^{-1}. Among the other weed control treatments higher weed control efficiency was observed with pyrazosulfuron ethyl @ 20 g a.i. ha^{-1} (84.0 per cent) followed by hand weeding twice (83.5 per cent) (Yadav *et al*., 2009). Mandal *et al*. (2013) reported that pyrazosulfuron ethyl in combination with cono-weeder recorded the lowest weed population and dry weight at 40 DAS, higher grain yield (2982 kg ha^{-1}) 20.58 per cent more over weedy check and was equivalent to sole application of pyrazosulfuron ethyl and metsulfuron-methyl + chlorimuron-ethyl.

In a study conducted by Gowda *et al*. (2009) among the various herbicides tried lowest weed population (48 m^{-2}) and dry weight of weeds were observed with pyrazosulfuron ethyl @ 30 g a.i. ha^{-1}. The weed control efficiency was higher for pyrazosulfuron ethyl @ 30 g a.i. ha^{-1} (90.86 per cent) and it recorded significantly taller plant height and higher dry matter production (71.53 cm and 65.37 g $hill^{-1}$ respectively) among the various treatments. The yield attributing parameters *viz*, number of effective tillers $hill^{-1}$, panicle length, filled grains per panicle and 1000 grain weight were found significantly higher with pyrazosulfuron ethyl @ 30 g a.i. ha^{-1}. The highest grain and straw yield among the treatments was recorded under pyrazosulfuron ethyl @ 30 g a.i. ha^{-1}.

2.3.2.1.3. Azimsulfuron

Azimsulfuron is a sulfonamide herbicide having post-emergent action that selectively controls a wide range of weeds in lowland rice (Valle *et al*., 2006). Azimsulfuron @ 25-30 g a.i. ha^{-1} applied 25 days after sowing effectively controlled broad leaved weeds while azimsulfuron alone or tank mixed with almix was not effective against grasses (Ravi *et al.*, 2010).

Azimsulfuron @ 35 g a.i. ha^{-1} applied at 19 DAT recorded significantly lower dry weight of grasses, sedges and broad leaved weeds but the highest grain and straw yield was under azimsulfuron @ 30 g a.i. ha^{-1} (Jayadeva *et al.,* 2009). Results of study conducted by Rajagopal (2013) also reported that azimsulfuron @ 35 a.i. ha^{-1} recorded 100 per cent weed control efficiency at 40 DAT and as a result highest grain and straw yield.

Excellent control of annual and perennial weeds by azimsulfuron in direct sown rice was reported by Pacanoski and Glatkova (2009). Azimsulfuron 50 DF @ 35.0 g ha^{-1} + 0.2 per cent surfactant was found to be effective against sedges, grasses and broadleaf weeds when applied at 20 DAS for direct seeded rice and registered higher grain yield which was on par with standard checks (Sakthivel *et al*., 2009). In studies conducted by Jayadeva *et al*. (2011b) application of azimsulfuron @30 g a.i. ha^{-1}+2.0 per cent non-ionic surfactant applied at 19 DAT followed by one hand weeding at 40 DAT recorded significantly lower weed density and total weed dry weight. It was found to be superior in producing higher grain and straw yield of transplanted rice by effective control of weeds.

Chauhan and Yadav (2013) reported that azimsulfuron @ 30 g ha^{-1} can be used to manage weeds in dry seeded rice. According to Mahajan and Chauhan (2013) the single post emergent application of azimsulfuron (20 g a.i. ha^{-1}) reduced total weed biomass by 72 per cent compared with the untreated control at flowering stage of the crop. Post emergent application of azimsulfuron proved effective against purple nutsedge and crow foot grass. Compared to the nontreated control, grain yield following the single application of azimsulfuron increased by 144 per cent. The single application of azimsulfuron reduced weed biomass by 72 per cent, compared with the nontreated check and increased grains $panicle^{-1}$ by 77 per cent compared with the nontreated check.

Yadav *et al*. (2007) have reported better efficacy of azimsulfuron on sedges in direct seeded rice. There was no phyto-toxicity of azimsulfuron on rice and also there was no residual toxicity on the succeeding crop of wheat (Yadav *et al*., 2008). Singh *et al*. (2009) opined that azimsulfuron is effective against sedges and broad leaf weeds in direct seeded rice particularly against *Cyperus rotundus* a noxious weed in DSR. As dose of azimsulfuron was increased from 25 to 30 g a.i. ha^{-1} weed density and dry weight of weeds reduced at all the crop growth stages. Singh *et al*. (2010) also reported that azimsulfuron alone provided 90 to 95 per cent control of broadleaf weeds and sedges.

2.3.2.2.Oxyfluorfen

Oxyfluorfen, a diphenyl ether compound is a strong contact herbicide effective both as pre and post emergence treatments. In direct seeded puddled rice, pre-emergence application of oxyfluorfen at 0.25 kg ha^{-1} recorded lower weed count (3.6 m^{2}) and lower weed dry weight (5.0 g m^{2}) and higher grain yield (5100 kg ha^{-1}) (Prakash, 1994). Similar results on effectiveness of oxyfluorfen in rice has been reported by ARWR (2011) where pre-emergence application of oxyfluorfen 23.5 per cent EC at 400 g ha^{-1} recorded lower weed density, dry weight and higher WCE at 20 and 40 DAS.

Application of oxyfluorfen at 0.125 kg ha^{-1} registered the highest leaf area Index, dry matter accumulation, number of productive tillers and grain yield in rice (Kathiresan and Manoharan, 2002).

Porwal (1999) reported that pre-emergence application of oxyfluorfen @ 0.2 kg ha^{-1} resulted in lower weed biomass (8.08 g m^{-2}) and higher grain yield (13.35 q ha^{-1}) in direct seeded upland rice. Pellerin and Webster (2004) reported that the use of pre-emergence herbicide, oxyfluorfen alone or supplemented with hand weeding provided a fair degree of weed control in semi dry rice. According to Singh *et al*.

(2005) *Panicum maximum* population was reduced most effectively by oxyfluorfen application. Abraham *et al*. (2010) opined that oxyfluorfen @ 150-200 g ha^{-1} could effectively control weeds of rice such as grasses, sedges and broadleaved weeds if applied as pre-emergent spray at 4 DAT of paddy. Reshma (2014) reported that oxyfluorfen @ 0.15 kg a.i ha^{-1} followed by hand weeding at 20 DAS was effective in managing the weed problem in rice (variety Aiswarya) and produced highest grain and straw yield.

Application of oxyfluorfen at 0.125 kg ha^{-1} + hand weeding recorded lower weed population (17.6 m^2), weed dry weight (12.2 g m^2) and higher grain yield (5345 kg ha^{-1}) in direct sown rice (Kathiresan and Manoharan,2002). Singh *et al*. (2005) revealed that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} resulted in lower weed count (14.7 m^2), weed dry weight (4.4 g m^2) and higher grain yield (4.3 t ha^{-1}) in direct seeded rice. In direct seeded rice pre-emergence application of oxyfluorfen at 0.2 kg ha^{-1} resulted in lower weed dry weight and higher grain yield (Rao *et al*., 2007).

2.4. NUTRIENT UPTAKE BY WEEDS

Depletion of nutrients from soil is a function of dry weight and nutrient content in weed plants. Weeds usually grow faster than crop plants and thus absorb mineral nutrients quicker, resulting in inadequate supply of nutrients to the crop plants. Unweeded control resulted in highest depletion of nutrients by weeds throughout the crop growth period (Singh *et al*., 2013).

Moorthy and Mitra (1991) opined that weed control measures greatly influence the uptake of nutrients by crops and associated weeds. Weeds remove 19.4 to13.7 kg N, 1.5 to 1.8 kg P and 17.4 to 33.7 kg K per hectare from the soil and uptake of N, P and K by rice crop was proportional to WCE. Dharumarajan *et al.* (2009) reported significantly higher N removal (5.55 kg ha^{-1}) was recorded in unweeded control, which was 13.4 times higher than that recorded from herbicide treated plots.

Maximum N removed by weeds was recorded in control plot (9.86 kg ha^{-1}) and the excessive weed growth prevented rice plants from absorbing adequate amount of N nutrients in control plot. However, significantly lowest N removed by weeds was recorded in herbicide treated plots, which was statistically on par with hand weeding twice at 20 and 40 DAT which might be due to less weed biomass (Islam and Kalita, 2014).

In direct sown upland rice nutrient loss was to the tune of 86.5, 12.4 and 134.5 kg N, P and K ha^{-1} respectively under weedy check and loss was reduced to 4.7, 0.7 and 6.9 kg N, P and K ha^{-1}, respectively with two hand weeding at 30 and 50 DAS (Chandrakar and Chandrakar, 1992). In direct seeded rice, uptake of nutrients by weeds was higher in weedy check condition (34.8, 15.6 and 42.3 kg N, P and K ha^{-1}) and among other weed control treatments hand weeding at 20 and 40 DAS recorded higher nutrient uptake by the crop (4.5, 1.9 and 5.2 kg N, P and K ha^{-1} respectively) (Singh *et al*., 2003).

2.5. NUTRIENT UPTAKE BY CROP

Nutrient uptake being a function of dry matter production and partly due to increase in its concentration, application of herbicides gave more total dry matter and registered significantly higher uptake of NPK (Sigh *et al*., 2013).

Weed free check recorded maximum N uptake (92.75 and 85.25 kg ha $^{-1}$), P uptake (47.96 and 44.98 kg ha $^{-1}$) and K uptake (117.60 and 119.33 kg ha $^{-1}$) by crops. This was followed by hand weeding at 25 and 45 DAS (86.01, 87.16 and 44.50, 42.89 and 111.17, 107.80 kg NPK ha $^{-1}$ respectively) as compared to unweeded check (13.19, 15.61 and 6.21, 6.38 and 13.60, 17.67 kg N, P and K ha^{-1}, respectively) (Kumari, 1991).

Weeds competed severely with the direct sown rice for nitrogen supply and the competition started early in the season. Maximum removal of nitrogen from the soil was observed at 60 DAS (127.3 kg N ha $^{-1}$). The maximum uptake of nitrogen by the crop (150.9 kg ha $^{-1}$) was observed on 90th day of growth, in the weed free plots (Sahai and Bhan, 1992). According to Kayam and Tripathi (2007) well managed weed control plots resulted in higher nitrogen uptake.

Madhukumar *et al*. (2013b) reported that bensulfuron methyl + pretilachlor recorded higher nutrient uptake by rice due to lower weed population and weed dry weight in aerobic rice.

2.6. EFFECT OF WEED MANAGEMENT ON ECONOMICS OF SEMI DRY RICE

Under the present situation of unavailability of labourers and high wages, manual weed control is not possible even though it is the best method for weed control. Wibawa *et al*. (2010) stated that chemical weed control appears to hold a great promise in dealing with effective, timely and economic weed suppression.

Hasanuzzaman *et al.* (2007) reported that weed control cost is maximum for hand weeding (2 hand weedings at 30 and 45 DAT) and the lowest for chemical weed management.

Laskar *et al*. (2005) reported that benefit: cost ratio was more in chemical weed control using oxyfluorfen at 0.20 kg ha^{-1} + hand weeding. According to Yadav (2006) pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} recorded higher net income and B: C ratio and Rajagopal (2013) reported that azimsulfuron @ 35 g a.i. ha^{-1} recorded high B: C ratio in transplanted rice.

Sunil *et al*. (2010) reported that pre-emergence application of bensulfuron methyl +pretilachlor (6.6 GR) @ 6+60 g a.i. ha^{-1} +one inter cultivation at 40 days after sowing recorded significantly lower weed population, weed dry weight and higher grain and straw yields resulting in high net returns and B: C ratio. Uma *et al.* (2014) reported bensulfuron methyl 0.6 per cent + pretilachlor 6 per cent fb hand weeding at 40 DAS recorded high net income and B: C ratio in transplanted rice.

2.7. EFFECT OF HERBICIDES ON SOIL DEHYDROGENASE ENZYME

The evaluation of soil enzyme activities may provide useful information on microbial activity and be helpful in establishing the effects of soil specific environmental conditions (Andreoni *et al*., 2004).

Herbicides not only affect the target organisms but also microbial communities in soil. The dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils (Burns, 1978). However soil dehydrogenase was estimated in order to determine overall microbial activity (Baboo *et al*., 2013).

In a study conducted to find the effect of herbicides on dehydrogenase activity in flooded rice soil the dehydrogenase activity increased up to 40 days after transplanting (DAT) after which the activity decreased with no significant difference at 120 DAT. The sharp increase in all treatment at 20 and 40 DAT represents the most active growth period of rice crop and could be due to proliferation of anaerobic micro-flora in the rhizosphere. The stabilized activity of dehydrogenase at lower levels at 120 DAT could be due to the fact that soil attains moisture content between field capacity and permanent wilting point and represents the effect of soil drying on dehydrogenase activity (Rao and Raman, 1998).

The data on microbial population of the soil collected 5 days after herbicide spraying indicated that bensulfuron methyl + pretilachlor and azimsulfuron did not have any harmful effect on the soil microbial population (Rajagopal, 2013).

From this brief review it can be concluded that weeds cause a greater problem in direct seeded (semi dry) rice cultivation. The yield loss in direct seeded semi dry rice is very large and it varies to a greater extent depending on the type of weed flora, intensity of weeds and management practices. Since hand weeding is labourious and ineffective chemical control measures are generally more targeted. As the new generation herbicides are applied at very low doses with less environmental persistence and exceedingly low toxicity to non-target organisms, the present focus is to popularise them. With this background a field study was conducted to evaluate the weed control efficiency of new generation herbicides viz., bensulfuron methyl + pretilachlor and pyrazosulfuron ethyl registered as pre- emergence herbicides along with azimsulfuron, a post-emergence herbicide. The selectivity of these herbicides and their influence on crop growth and yield will also be assessed.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Herbicide based weed management for semi dry rice (*Oryza sativa* L.)" was primarily carried out to formulate a weed management strategy for semi dry rice using three new generation herbicides, *i.e.,* bensulfuron methyl + pretilachlor, pyrazosulfuron ethyl and azimsulfuron. The materials used and the methods adopted are presented in this chapter.

3.1. Site description

The investigations were undertaken in a farmer's field *viz*., Kanjirathadi padasekharam, in Nemom Panchayath, Thiruvananthapuram district, Kerala state, located at 8.5^0 N latitude and 76.9^0 E longitude at an altitude of 29m above mean sea level (MSL).

3.1.1 Climate and season

The field experiment was conducted during the virippu season, *i.e.*, May 2014 to September 2014. A warm humid tropical climate is experienced by the area. The data on various weather parameters, *viz*., weekly rainfall, maximum and minimum temperature, relative humidity and sun shine hours during the period are presented in Appendix I and graphically represented in Fig 1.

3.1.2 Soil

The soil of the experiment site belonged to the textural class of sandy clay and the taxonomical order is Oxisol. A composite sample was used for the determination of physico-chemical properties. For this soil samples were collected from 30 cm depth prior to experiment and the important physico-chemical properties studied are given in Table 1. The soil pH was 5.41 and EC was normal, high in organic carbon, available P and medium in available N and K content.

Fig. 1: Weather data during the crop period (May 2014- October 2014)

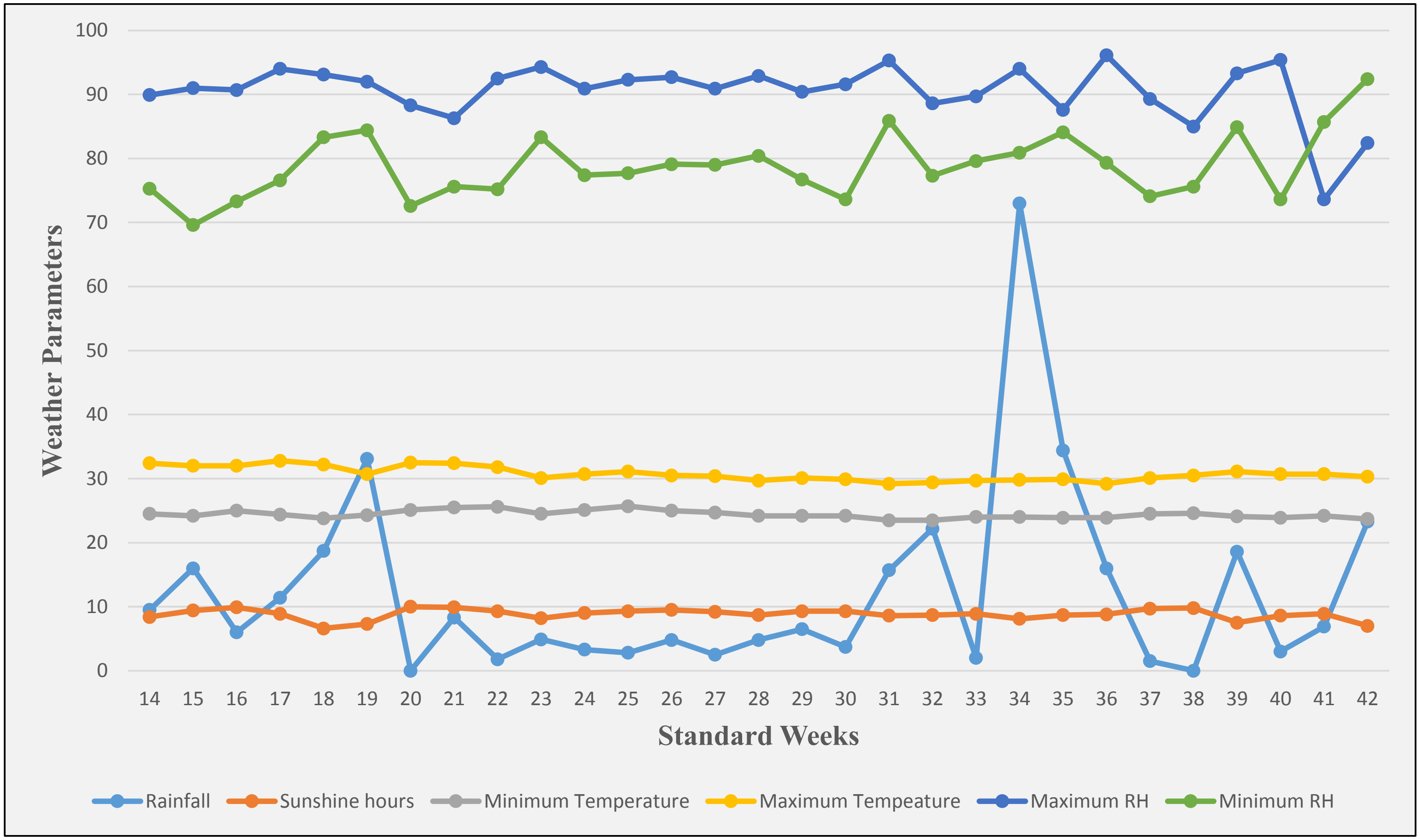


Table 1. Physico-chemical properties of soil at experiment site

Parameters	Content	Status	Methodology
A. Mechanical composition			
Coarse sand (%)	47.05		Bouyoucos Hydrometer Method (Bouyoucos, 1962)
Fine sand (%)	11.40		
Silt (%)	10.05		
Clay (%)	31.50		
Texture		Sandy clay loam	
B. Chemical Properties			
Soil reaction (pH)	5.41	Strongly acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
EC (dS m^{-1})	0.4	Normal	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
Organic carbon (%)	1.8	High	Walkley and Black's rapid titration (Jackson, 1973)
Available N (kg ha^{-1})	575.7	High	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	27.44	High	Bray colorimetric method (Jackson, 1973)
Available K (kg ha^{-1})	188.54	Medium	Ammonium acetate method (Jackson, 1973)

3.1.3 Cropping history of the experimental site

The experimental site was lying fallow during the previous season.

3.2 Materials

3.2.1 Crop and variety

The most popular rice variety of the state *Uma*, was used for the experiment. It was developed by Rice Research Station, Moncompu, Kerala which is a cross between MO6 and Pokkali (Pedigree selection, 1988). It is a medium duration variety having a dormancy period of 3 weeks and suited to all three seasons. Other promising characteristics of the variety are dwarfness, medium tillering, non-lodging, resistant to brown plant hopper (BPH), gall midge (GM) biotype-5 and other major pests.

3.2.2 Manures and fertilizers

The organic manure source used for the experiment was well decomposed dry cow dung containing 0.55 per cent, 0.23 percent P_2O_5 and 0.46 per cent K_2O. Nitrogen, phosphorus and potassium were applied as urea (46 per cent N), rajphose (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) respectively.

3.2.3 Herbicides

The technical information, toxicity data and other available information of the herbicides bensulfuron methyl + pretilachlor, pyrazosulfuron ethyl, oxyfluorfen and azimsulfuron are given in Table 2.

3.3 Methods

3.3.1 Design and Layout

Design	: Randomised Block Design
No. of treatments	: 9+2
Replication	: 3
Plot size	: 5 m x 4 m

3.3.2 Treatments

T_1 : Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre - emergence)

T_2 : T_1 + hand weeding at 40 DAS

T_3 : T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)

T_4 : Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre - emergence)

T_5 : T_4 + hand weeding at 40 DAS

T_6 : T_4 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)

T_7 : Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre - emergence)

T_8 : T_7 + hand weeding at 40 DAS

T_9 : T_7 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)

Control

T_{10} : Hand weeding at 20 and 40 DAS

T_{11} : Weedy check

The pre - emergence herbicides were applied on the next day of sowing and the post emergence herbicide was applied at 25 DAS.

3.3.3 Crop management

All the cultural practices except weed management were carried out as per the Package of Practices Recommendations 'Crops' (KAU, 2011).

3.3.3.1 Main field preparation

As the system of rice culture was semi dry, the land was lying dry at the time of land preparation. The experimental area was ploughed twice, levelled and weeds and stubbles were removed by hand picking. Three blocks with eleven plots each were laid out in randomized design with a plot size of 5 x 4 m^2. The blocks were separated with bunds of 40 cm width and there were 33 plots for the experiment.

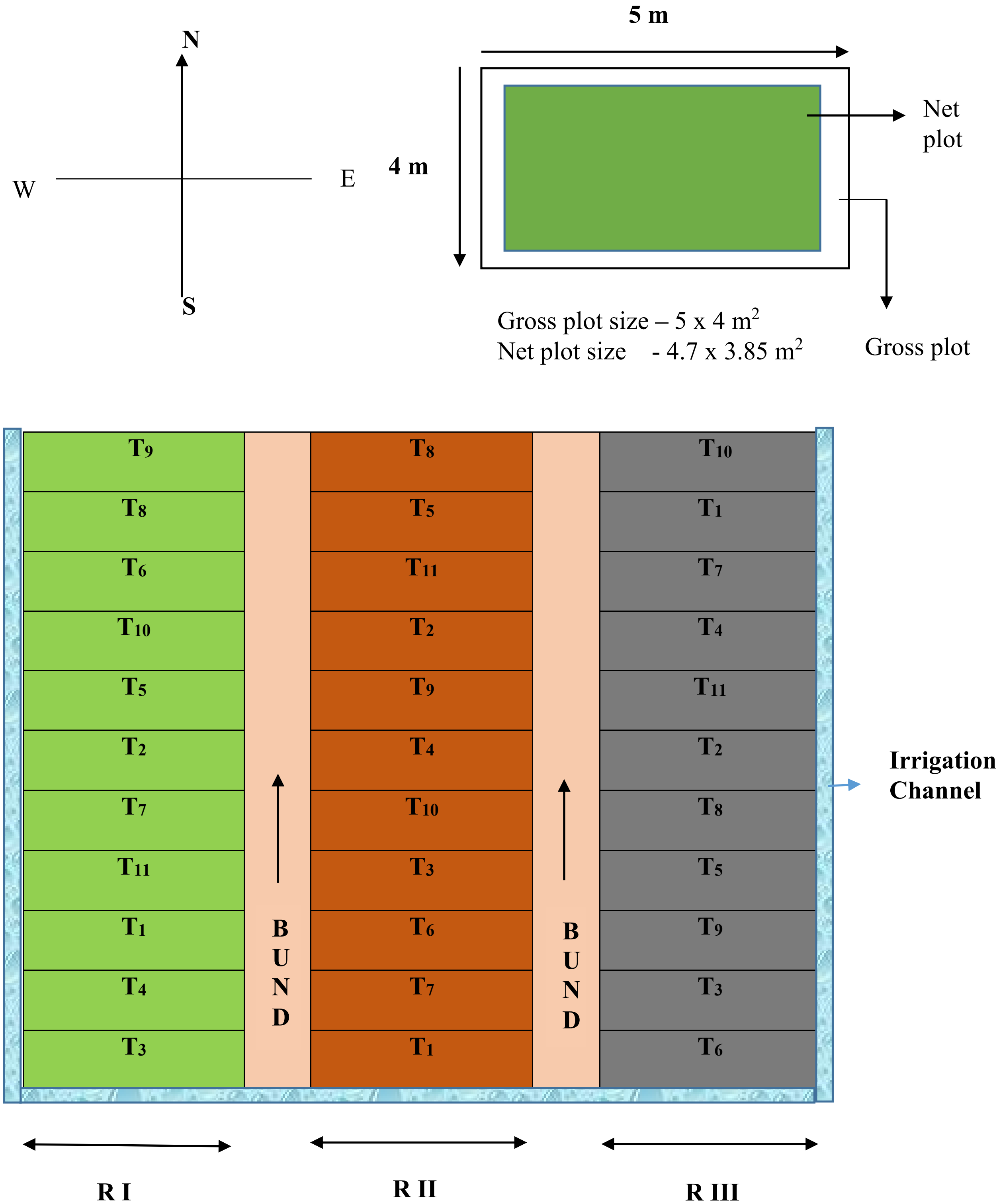


Plate 1: Lay out of the experimental field

Table 2. Technical information of herbicides

Common Name	**Bensulfuron methyl +Pretilachlor**	**Pyrazosulfuron ethyl**
Trade name	Londax Power	Saathi
Chemical name	Methyl α- (4,6-dimethoxypyrimidin-2 ylcarbamoyylsulfamoyl)-o-toluate +2- chloro-N-(2,6-diethylphenyl)-N-(2-propoxyethyl) acetamide	Ethyl 5-(4,6-dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-1-methyl pyrazole-4-carboxylate
Chemical family	Sulfonyl urea herbicide	Sulfonyl urea herbicide
Mode of action	ALS inhibitor	ALS inhibitor
Formulation	0.6% + 6% GR	10% WP
Molecular weight	410.4 + 311.9 $gmol^{-1}$	414.40 $gmol^{-1}$
Physical state, colour, odour	Free flowing granule, Light brown, No appreciable odour	Off-white powder, faint aromatic
Acute oral toxicity LD_{50} (Rats)	> 5000 mg kg^{-1}	> 5000 mg kg^{-1}
Acute dermal toxicity LD_{50} (Rats)	> 2000 mg kg^{-1}	> 2000 mg kg^{-1}
Manufacturer	DuPont	United Phosphorus Limited
Cost (Rs.)	690/4 kg	480/120g

Table 2. Continued

Common Name	**Oxyfluorfen**	**Azimsulfuron**
Trade name	Goal	Segment
Chemical name	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4 (trifluoromethyl) benzene	1-(4,6-dimethoxypyrimidin-2-yl)-3-[1-methyl-4-(2-methyl-2H-tetrazol-5-yl)pyrazol-5-ylsulfonyl]urea
Chemical family	Diphenyl ether herbicide	Sulfonyl urea
Mode of action	Cell membrane destroyer	ALS inhibitor
Formulation	23.5 % EC	50% Dry Flowable (DF)
Molecular weight	361.72 $gmol^{-1}$	424.4 $gmol^{-1}$
Physical state, colour, odour	Crystalline solid, orange to deep red brown, odourless	White powdered solid with a phenolic odour
Acute oral toxicity LD_{50} (Rats)	> 5000 mg kg^{-1}	> 5000 mg kg^{-1}
Acute dermal toxicity LD_{50} (Rats)	> 2000 mg kg^{-1}	> 2000 mg kg^{-1}
Manufacturer	Dow Agro Sciences	DuPont
Cost (Rs.)	190 / 100 ml	960 / 28 g

3.3.3.2 Application of manures and fertilizers

Dry cow dung powder was incorporated at the time of last ploughing. Full dose of phosphorous along with half dose of nitrogen and potassium were applied as basal dose at 15DAS and remaining dose of chemical fertilizers were top-dressed at 45 days after sowing (DAS) as per the Package of Practices Recommendations ‘Crops’ (KAU, 2011).

3.3.3.3 Application of lime

Lime @ 600 kg ha^{-1} was applied in two split doses, the first dose of 350kg ha^{-1} as basal dressing at the time of first ploughing and the second dose of 250 kg ha^{-1} as top dressing one month after sowing. For top dressing, lime was applied one week prior to the application of manures.

3.3.3.4 Sowing

Seeds were dry sown by dibbling at the rate of 2-3 seeds per hole at a spacing of 20 x 10 cm and covered with a thin layer of soil. At the time of sowing the moisture content was above field capacity and the field was under flooding by 45 DAS.

3.3.3.5 Weed management

Herbicides were mixed with water as per the treatments and pre-emergent herbicides were sprayed to soil with a pneumatic sprayer, fitted with a flood jet nozzle in the next day of sowing. Post emergent herbicides were sprayed as per the treatments on to the foliage. Hand weeding was done at 20 and 40 DAS.

3.3.3.6 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.

3.4. Observations

3.4.1 Observations on weeds

3.4.1.1 Weed composition of the experimental field

The weed flora that infested the experimental site were identified and grouped into grasses, sedges and broadleaved weeds.

Plate 2: General view of the experimental field

A: Land preparation and lay out **B: Dibbling**

C: Field at 30 DAS **D: Field at 45 DAS**

E: Field at 60 DAS **F: Field at harvest stage**

Plate 3: Various stages of rice establishment under semi dry system

34.1.2 Vegetative parameters

A quadrat of size 50 x 50 cm was placed at random at two sites in the weed sampling area of each plot. The following observations were recorded from weeds in this area and average values worked out.

3.4.1.3 Absolute density (Ad)

Absolute weed density was calculated using the formula suggested by Philips (1959).

Absolute density = Total number of weeds of a given species m^{-2}

3.4.1.4 Relative density (Rd)

Relative density of various weed species was worked out using the formula put forward by Philips (1959).

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

3.4.1.5 Absolute frequency (Af)

The absolute frequency of each species of weeds was computed according to the equation developed by Philips (1959).

$$\text{Absolute frequency} = \frac{\text{Number of quadrats in which a given species occurred}}{\text{Total number of quadrats used}} \times 100$$

3.4.1.6 Relative frequency (Rf)

Relative frequency of each species of weeds was computed using the relationship developed by Philips (1959).

$$\text{Relative frequency} = \frac{\text{Absolute frequency of a species}}{\text{Total absolute frequencies of all the species}} \times 100$$

3.4.1.7 Importance value (IV)

Importance value was obtained by adding the relative density (Rd) and relative frequency (Rf) of a given species (Kent and Coker, 1992).

Importance value (IV) = Relative density (Rd) + Relative frequency (Rf)

3.4.1.8 Summed dominance ratio (SDR)

Mean summed dominance ratio (SDR) for each species was worked out based on the equation developed by Sen (1981).

$$\text{Summed dominance ratio} = \frac{\text{Relative density} + \text{Relative frequency}}{2}$$

3.4.1.9 Weed dry weight

Weed samples were pulled out along with roots, washed and dried under shade and oven dried at 80 ± 1°C to a constant weight. The dry weight of broad leaved, sedges and grasses were separately recorded and units expressed as g m^{-2}.

3.4.1.10 Weed control efficiency

Weed control efficiency was calculated using the following formula (Upadhyay and Sivanand, 1985).

WCE = (X-Y) /X x 100

WCE = weed control efficiency

X = weed dry weight from treatment which recorded maximum number of weeds (weedy check).

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

3.4.2 Observations on the crop

Ten sample plants were selected at random from the net plot area (avoiding two border rows) of each plot and tagged. The following observations were recorded from the sample plants and the mean values worked out.

3.4.2.1 Plant height

Height of the plant was recorded at 30, 60 DAS and at harvest. The height 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 of the observations were expressed in centimetres.

3.4.2.2 Number of tillers m^{-2}

The number of tillers m^{-2} was counted and the average was worked out at 30, 60 DAS and at harvest.

3.4.2.3 Number of productive tillers m^{-2}

At harvest, the number of productive tillers obtained from the sample hills in the net plot area was expressed as number of productive tillers m^{-2}.

3.4.2.4 Sterility percentage

The number of filled and unfilled grains per panicle was obtained from ten randomly selected panicle separately and chaff percentage was worked out using the following relationship.

$$\text{Sterility percentage (\%)} = \frac{\text{Number of unfilled grains per panicle}}{\text{Number of total grains per panicle}} \times 100$$

3.4.2.5 Thousand grain weight

One thousand grains were counted from the cleaned and dried produce from net plot area and the weight of the grains was recorded in grams.

3.4.2.6 Grain yield

The net plot area was harvested individually, threshed, cleaned, dried and weighed to express the grain yield in kg ha^{-1} at 14 per cent moisture.

3.4.2.7 Straw yield

The straw obtained from net plot area was dried to constant weight under sun and weighed to express the straw yield in kg ha^{-1}.

3.4.2.8 Harvest index (HI)

Harvest index was worked out using the formula suggested by Donald and Hanohlin (1976).

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

3.4.2.9 Pest and disease incidence

Scoring of stem borer, rice bug and sheath blight was done using 0-9 scale (Appendix-II) as per the standard evaluation system developed by the International Rice Research Institute (IRRI, 2002).

3.4.2.10 Herbicide phytotoxicity

The treated plots were observed closely and the visual symptoms of herbicide phytotoxicity on the rice plants were recorded.

3.5 Chemical analysis

3.5.1 NPK content of crop and weeds

The plant samples were dried in an electric hot air oven to constant weight, ground and passed through 0.5 mm sieve. The required quantity of sample was weighed out accurately in an electronic balance, subjected to acid extraction before carrying out the chemical analysis. The weed samples collected at 20, 40, and 60 DAS and at harvest as well as rice hills uprooted at harvest were analysed for total N, P_2O_5, and K_2O.

3.5.1.1 Total nitrogen content

Total nitrogen content was estimated by modified microkjeldal method (Jackson, 1973).

3.5.1.2 Total phosphorous content

Total phosphorus content was found out using Vanadomolybdo phosphoric yellow colour method (Jackson, 1973).

3.5.1.3 Total potassium content

Total potassium content in plant was determined using EEL Flame Photometer (Jackson, 1973).

3.5.2 Nutrient uptake by crop and weeds

The nutrient uptake by crop and weeds were calculated as the product of nutrient content and the respective plant dry weight and expresses as kg ha^{-1}. The total uptake of nitrogen, phosphorus and potassium by the rice plant was calculated at harvest and that of weeds at 20, 40 and 60 DAS.

3.5.3 Nutrient status of the soil before and after the experiment

Soil samples were collected from the experimental area before and after the experiment. The air dried soil samples were analysed for valuable nitrogen, phosphorus and potassium status.

3.6 Economic analysis

For analysing the economics of cultivation, net income and benefit cost ratio were determined based on cost of cultivation and prevailing price of the crop produce.

3.6.1 Net income

Net income was computed using the formula,

Net income (Rs. ha^{-1}) = Gross income – Cost of cultivation

3.6.2 Benefit Cost Ratio (BCR)

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.7 Enzyme studies

The effect of herbicide treatments on the soil microbial activity was studied by analysing the soil dehydrogenase enzyme activity at 15, 30, 45 and 60 DAS. Procedure as described by Casida *et al*. (1964) was used for the determination of dehydrogenase enzyme.

3.8 Statistical Analysis

The data recorded were subjected to Analysis of Variance techniques (ANOVA) as applied to Randomized Block Design described by Cochran and Cox (1965). The data which required transformation were appropriately transformed and analysed. The treatment *vs*. control comparison is denoted as 'S' when significant and 'NS' when not significant.

Results

4. RESULTS

The experiment entitled "Herbicide based weed management for semi dry rice (*Oryza sativa* L.)" was taken up at farmer's field in Nemom block, Vellayani, Thiruvananthapuram, during May, 2014 to September, 2014. The main objective of the study was to evaluate the weed control efficiency and economics of new generation herbicides and to develop a weed management strategy for semi dry rice. The data recorded from the study was analysed statistically and the results are presented in this chapter.

4.1 OBSERVATIONS ON WEEDS

4.1.1 Weed Composition

The different weed species found in the experimental field during the study were collected, identified and classified into grasses, sedges and broadleaved weeds. The results are presented in the Table 3.

4.1.2 Absolute Density

4.1.2.1 Absolute Density of Grasses (number m^{-2})

Data on absolute density of grasses at 15, 30, 45, 60 DAS and at harvest is presented in the Table 4.

The data indicated that the absolute density of grassy weeds was significantly influenced by the weed management practices at 30, 45, 60 DAS and at harvest. At 15 DAS the effect of pre-emergent herbicides on grassy weeds was found to be non-significant whereas at 30, 45, 60 DAS and at harvest, T_{10} (hand weeding twice) recorded the lowest absolute density of grasses. At 45 DAS, T_{10} was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5) and oxyfluorfen *fb* hand weeding (T_8).

Table 3. Major weed composition observed in the experimental field

Common Name	Scientific name	Family
Grasses		
Blood grass (*Naringa*)	*Isachne miliacea*	Poaceae
Kavada	*Echinochloa stagnina*	Poaceae
Weedy rice (*Varinellu*)	*Oryza sativa f. spontanea*	Poaceae
Broad leaved weeds		
False daisy (*Kaiyyonni*)	*Eclipta alba*	Asteraceae
Indian heliotrope (*Thekkada*)	*Heliotropium indicum*	Boraginaceae
Spider weed (*Kattukaduku*)	*Cleome rutidospermum Dc.*	Capparidaceae
Spreading day flower (*Vazhappadathi*)	*Commelina jacobi C.E.C.Fisch*	Commelinaceae
Water primrose (*Neergrampoo*)	*Ludwigia perennis Roxb.*	Onagraceae
Sedges		
Globe finger rush (*Mung*)	*Fimbristylis miliacea (L.) Vahl*	Cyperaceae
Umbrella sedge (*Thalekkettan*)	*Cyperus difformis (L.)*	Cyperaceae
Yellow nut sedge (*Manjakkora*)	*Cyperus iria (L.)*	Cyperaceae
	Cyperus compressus	Cyperaceae

Table 4. Effect of weed management practices on the absolute density of grasses, number m^{-2}

	Treatments	15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	4.33	10.33	16.67	26.33	31.33
T_2	T_1 + hand weeding at 40 DAS	4.33	8.33	3.33	18.00	23.33
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1}(post emergence)	4.00	9.67	18.00	28.00	34.33
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	4.67	10.33	18.67	25.33	30.00
T_5	T_4 + hand weeding at 40 DAS	4.67	10.00	3.00	18.33	22.67
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	5.00	9.67	16.33	29.67	35.67
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	4.67	10.67	20.33	30.00	34.33
T_8	T_7 + hand weeding at 40 DAS	4.33	8.00	3.67	18.33	25.33
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	4.00	10.33	20.67	28.00	34.67
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	5.67	4.67	2.67	15.00	20.33
T_{11}	Weedy check (Control 2)	5.33	10.67	20.33	29.67	35.67
	SEm (±)	-	0.201	0.703	0.362	0.532
	CD (0.05)	NS	0.597	2.090	1.077	1.569
	Treatment *Vs* Control 1	S	S	S	S	S
	Treatment *Vs* Control 2	NS	S	S	S	S

4.1.2.2 Absolute Density of Broadleaved Weeds (number m^{-2})

Data on absolute density of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 5.

The absolute density of broadleaved weeds was significantly influenced by the weed management practices on all the crop growth stages. At 15 DAS none of the pre-emergent herbicide treated plots registered broad leaved weeds. But at 30 DAS lowest weed density was recorded with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6) which was on par with oxyfluorfen *fb* azimsulfuron (T_9). Lowest weed density at 45 DAS was recorded with hand weeding twice (T_{10}) and was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5) and oxyfluorfen *fb* hand weeding (T_8). At 60 DAS and at harvest T_{10} recorded lowest weed density which was on par with T_2, T_3 and T_6 at 60 DAS.

4.1.2.3 Absolute Density of Sedges (number m^{-2})

Data on absolute density of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 6.

At 15 DAS, pyrazosulfuron ethyl *fb* azimsulfuron (T_6) reported lowest density of sedges which was on par with bensulfuron methyl + pretilachlor (T_1), bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) and pyrazosulfuron ethyl *fb* hand weeding (T_5). Lowest density of sedges at 30 DAS was observed with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and was on par with T_6. At 45 DAS and at 60 DAS, hand weeding twice (T_{10}) recorded lowest absolute density for sedges and was on par with T_2.

Table 5. Effect of weed management practices on the absolute density of broad leaved leaves, number m^{-2}

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	19.25 (4.39)	25.90 (5.09)	31.95 (5.65)	42.64 (6.53)
T_2	T_1 + hand weeding at 40 DAS	-	15.96 (3.99)	4.97 (2.23)	8.66 (2.94)	21.57 (4.64)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	3.32 (1.82)	8.66 (2.94)	10.30 (3.21)	18.58 (4.31)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	19.25 (4.39)	25.22 (5.02)	33.31 (5.77)	46.31 (6.81)
T_5	T_4 + hand weeding at 40 DAS	-	16.32 (4.04)	3.65 (1.91)	10.56 (3.25)	21.62 (4.65)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	3.32 (1.82)	7.92 (2.81)	9.64 (3.11)	15.28 (3.91)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	19.97 (4.47)	29.28 (5.41)	39.31 (6.27)	50.63 (7.12)
T_8	T_7 + hand weeding at 40 DAS	-	18.62 (4.31)	4.32 (2.08)	11.65 (3.41)	31.28 (5.59)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	4.62 (2.15)	11.94 (3.46)	18.31 (4.28)	28.18 (5.31)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	13.33	5.97 (2.44)	3.55 (1.88)	7.98 (2.82)	14.64 (3.83)
T_{11}	Weedy check (Control 2)	10.67	29.80 (5.46)	39.22 (6.26)	49.56 (7.04)	61.98 (7.87)
	SEm (±)	-	0.166	0.185	0.133	0.161
	CD (0.05)	-	0.489	0.546	0.392	0.474
	Treatment *Vs* Control 1	S	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S	S

Table 6. Effect of weed management practices on the absolute density of sedges, number m^{-2}

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	7.28 (2.70)	19.92 (4.46)	37.32 (6.11)	57.31 (7.57)	49.97 (7.07)
T_2	T_1 + hand weeding at 40 DAS	6.63 (2.58)	18.66 (4.32)	4.32 (2.08)	12.99 (3.60)	22.32 (4.72)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	8.33 (2.89)	2.31 (1.52)	10.30 (3.21)	16.31 (4.04)	22.99 (4.80)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	8.33 (2.89)	19.28 (4.39)	33.30 (5.77)	52.30 (7.23)	48.65 (6.98)
T_5	T_4 + hand weeding at 40 DAS	7.64 (2.76)	20.31 (4.51)	5.32 (2.31)	14.28 (3.78)	24.65 (4.96)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	6.32 (2.51)	2.64 (1.63)	9.63 (3.10)	15.65 (3.96)	21.30 (4.62)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	8.66 (2.94)	22.30 (4.72)	40.31 (6.35)	59.66 (7.72)	55.31 (7.44)
T_8	T_7 + hand weeding at 40 DAS	8.33 (2.89)	20.93 (4.570	7.28 (2.70)	19.65 (4.43)	25.95 (5.09)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	9.33 (3.05)	4.65 (2.16)	12.30 (3.51)	20.31 (4.51)	23.66 (4.86)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	20.31 (4.51)	5.66 (2.38)	3.61 (1.90)	11.63 (3.41)	20.29 (4.50)
T_{11}	Weedy check (Control 2)	18.65 (4.32)	30.64 (5.54)	48.31 (6.95)	67.98 (8.25)	59.33 (7.70)
	SEm (±)	0.094	0.117	0.122	0.100	0.104
	CD (0.05)	0.279	0.346	0.361	0.296	0.307
	Treatment *Vs* Control 1	S	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S	S

4.1.2.4 Total Weed Density (number m^{-2})

Data on total weed density at 15, 30, 45, 60 DAS and at harvest is presented in the Table 7.

The total weed density was significantly influenced by the weed management practices at all the stages of crop growth. At 15 DAS, lowest total weed density (10.98 m^{-2}) was observed with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) which was on par with all the weed management practices except oxyfluorfen (T_7), oxyfluorfen *fb* azimsulfuron (T_9), hand weeding twice (T_{10}) and weedy check (T_{11}). Lowest density at 30 DAS (15.32 m^{-2}) was recorded with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) which was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6), T_9 and T_{10}. But at 45 and 60 DAS lowest total weed density was reported with T_{10} (9.93 m^{-2}) and was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) and pyrazosulfuron ethyl *fb* hand weeding (T_5).

4.1.3 Relative Density

4.1.3.1 Relative Density of Grasses (per cent)

Data on relative density of grasses at 15, 30, 45, 60 DAS and at harvest is presented in the Table 8.

Weedy check (T_{11}) reported lower relative density of grasses at all stages of crop growth. At 15 DAS, hand weeding twice (T_{10}) recorded lowest relative density of grasses. At 30 DAS, T_{11} was on par with oxyfluorfen *fb* hand weeding (T_8) whereas at 45 DAS T_{11} was on par with all the weed management practices except bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9).

Table 7. Effect of weed management practices on the total weed density, number m^{-2}

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	11.63 (3.41)	49.64 (7.05)	79.92 (8.94)	115.65 (10.75)	124.00 (11.14)
T_2	T_1 + hand weeding at 40 DAS	10.98 (3.31)	42.99 (6.56)	12.58 (3.55)	39.66 (6.30)	67.32 (8.21)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	12.33 (3.51)	15.32 (3.91)	36.97 (6.08)	54.60 (7.39)	75.98 (8.72)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	12.99 (3.60)	48.93 (7.00)	77.32 (8.79)	110.99 (10.54)	124.98 (11.18)
T_5	T_4 + hand weeding at 40 DAS	12.30 (3.51)	46.63 (6.83)	11.96 (3.46)	43.21 (6.57)	68.97 (8.30)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	11.31 (3.36)	15.66 (3.96)	33.99 (5.83)	54.98 (7.41)	72.30 (8.50)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	13.32 (3.65)	52.96 (7.28)	90.00 (9.49)	128.96 (11.36)	140.30 (11.84)
T_8	T_7 + hand weeding at 40 DAS	12.65 (3.56)	47.64 (6.90)	15.31 (3.91)	49.64 (7.05)	82.66 (9.09)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	13.30 (3.65)	19.66 (4.43)	45.00 (6.71)	66.65 (8.16)	86.56 (9.30)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	39.33 (6.27)	16.31 (4.04)	9.93 (3.15)	34.66 (5.89)	55.30 (7.44)
T_{11}	Weedy check (Control 2)	34.60 (5.88)	71.16 (8.44)	107.92 (10.39)	147.28 (12.14)	156.99 (12.53)
	SEm (±)	0.106	0.135	0.133	0.127	0.103
	CD (0.05)	0.314	0.399	0.393	0.375	0.305
	Treatment *Vs* Control 1	S	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S	S

Table 8. Effect of weed management practices on the relative density of grasses, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	37.32 (6.11)	20.85 (4.57)	20.87 (4.57)	22.76 (4.77)	25.27 (5.03)
T_2	T_1 + hand weeding at 40 DAS	39.44 (6.28)	19.35 (4.40)	24.07 (4.91)	45.38 (6.74)	34.68 (5.89)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	32.02 (5.66)	63.09 (7.94)	48.70 (6.98)	51.27 (7.16)	45.20 (6.72)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	35.81 (5.98)	21.20 (4.60)	24.14 (4.91)	22.81 (4.78)	24.01 (4.90)
T_5	T_4 + hand weeding at 40 DAS	37.87 (6.15)	21.39 (4.63)	24.44 (4.94)	42.52 (6.52)	32.88 (5.73)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	43.78 (6.62)	61.73 (7.86)	48.08 (6.93)	53.90 (7.34)	49.38 (7.03)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	34.12 (5.84)	20.17 (4.49)	22.59 (4.75)	23.25 (4.82)	24.48 (4.95)
T_8	T_7 + hand weeding at 40 DAS	34.12 (5.84)	16.73 (4.09)	23.83 (4.88)	36.93 (6.08)	30.64 (5.54)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	29.60 (5.44)	52.63 (7.25)	45.93 (6.78)	41.98 (6.48)	40.06 (6.33)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	14.39 (3.79)	28.53 (5.34)	27.03 (5.20)	43.24 (6.58)	36.78 (6.06)
T_{11}	Weedy check (Control 2)	15.46 (3.93)	14.97 (3.87)	18.85 (4.34)	20.15 (4.49)	22.72 (4.77)
	SEm (±)	0.249	0.149	0.306	0.076	0.088
	CD (0.05)	0.734	0.441	0.903	0.224	0.259
	Treatment *Vs* Control 1	S	NS	NS	S	S
	Treatment *Vs* Control 2	S	S	S	S	S

4.1.3.2 Relative Density of Broadleaved Weeds (per cent)

Data on relative density of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 9.

Pyrazosulfuron ethyl *fb* azimsulfuron (T_6) reported lowest relative density of broad leaved weeds at 30, 45, 60 DAS and at harvest. At 30 DAS, T_6 was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and oxyfluorfen *fb* azimsulfuron (T_9) where at 45 DAS, T_6 was on par with bensulfuron methyl + pretilachlor (T_1), pyrazosulfuron ethyl *fb* hand weeding (T_5) and oxyfluorfen *fb* hand weeding (T_8).

4.1.3.3 Relative Density of Sedges (per cent)

Data on relative density of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 10.

At 15 DAS, lowest relative density of sedges was recorded with hand weeding twice (T_{10}) while at 30 DAS, bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) reported lowest relative density. At 60 DAS, pyrazosulfuron ethyl *fb* azimsulfuron (T_6) recorded lowest relative density of sedges. Lowest relative density at 45 DAS and at harvest was recorded with oxyfluorfen *fb* azimsulfuron (T_9).

4.1.4 Absolute Frequency

4.1.4.1 Absolute Frequency of Grasses

The data on absolute frequency of grass weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 11.

Effect of weed management practices on absolute frequency of grasses was found to be non-significant at 15 DAS and at harvest. At 30 DAS bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand

Table 9. Effect of weed management practices on the relative density of broad leaved weeds, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	38.76 (6.23)	32.34 (5.69)	27.63 (5.26)	34.39 (5.86)
T_2	T_1 + hand weeding at 40 DAS	-	37.09 (6.09)	39.66 (6.30)	21.83 (4.67)	32.00 (5.66)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	21.65 (4.65)	23.43 (4.84)	18.83 (4.34)	24.43 (4.94)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	39.27 (6.27)	32.59 (5.71)	30.03 (5.48)	37.05 (6.09)
T_5	T_4 + hand weeding at 40 DAS	-	35.00 (5.92)	30.61 (5.53)	24.34 (4.93)	31.32 (5.60)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	21.17 (4.60)	23.22 (4.82)	17.57 (4.19)	21.11 (4.59)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	37.68 (6.14)	32.53 (5.70)	30.47 (5.52)	36.07 (6.01)
T_8	T_7 + hand weeding at 40 DAS	-	39.12 (6.25)	28.41 (5.33)	23.45 (4.84)	37.82 (6.15)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	23.43 (4.84)	26.53 (5.15)	27.49 (5.24)	32.47 (5.70)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	31.98	36.54 (6.04)	35.38 (5.95)	23.07 (4.80)	26.45 (5.14)
T_{11}	Weedy check (Control 2)	18.28	41.75 (6.46)	36.30 (6.03)	33.62 (5.80)	39.47 (6.28)
	SEm (±)	-	0.181	0.296	0.130	0.128
	CD (0.05)	-	0.534	0.875	0.385	0.379
	Treatment *Vs* Control 1	S	NS	NS	NS	S
	Treatment *Vs* Control 2	S	S	NS	S	S

Table 10. Effect of weed management practices on the relative density of sedges, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	62.43 (7.90)	40.12 (6.33)	46.74 (6.84)	49.56 (7.04)	43.49 (6.59)
T_2	T_1 + hand weeding at 40 DAS	60.30 (7.77)	43.42 (6.59)	34.77 (5.90)	32.74 (5.72)	33.58 (5.79)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	67.62 (8.22)	15.07 (3.88)	27.81 (5.27)	29.87 (5.47)	30.62 (5.53)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	64.15 (8.01)	39.37 (6.27)	43.10 (6.57)	47.11 (6.86)	42.22 (6.50)
T_5	T_4 + hand weeding at 40 DAS	62.06 (7.88)	43.57 (6.60)	44.58 (6.68)	33.03 (5.75)	35.90 (5.99)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	56.02 (7.48)	16.84 (4.10)	28.36 (5.33)	28.46 (5.33)	28.78 (5.36)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	65.27 (8.08)	42.09 (6.49)	44.79 (6.69)	46.27 (6.80)	41.26 (6.42)
T_8	T_7 + hand weeding at 40 DAS	65.87 (8.12)	43.90 (6.63)	47.40 (6.88)	39.58 (6.29)	33.12 (5.76)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	70.26 (8.38)	23.68 (4.87)	27.33 (5.23)	30.47 (5.52)	28.51 (5.34)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	51.71 (7.19)	34.76 (5.90)	36.22 (6.02)	33.53 (5.79)	33.54 (5.79)
T_{11}	Weedy check (Control 2)	53.96 (7.35)	43.18 (6.57)	44.79 (6.69)	46.18 (6.80)	40.07 (6.33)
	SEm (±)	0.192	0.171	0.209	0.087	0.161
	CD (0.05)	0.566	0.505	0.618	0.257	0.475
	Treatment *Vs* Control 1	S	NS	NS	S	NS
	Treatment *Vs* Control 2	S	S	S	S	S

weeding twice (T_{10}) reported lowest absolute frequency of grasses (25 per cent) while at 45 DAS bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5) and T_{10} recorded lowest absolute frequency of grasses. 100 per cent absolute frequency of grasses was recorded in bensulfuron methyl + pretilachlor (T_1) and oxyfluorfen (T_7). Oxyfluorfen *fb* azimsulfuron (T_9) and T_{10} recorded lowest absolute frequency at 60 DAS.

4.1.4.2 Absolute Frequency of Broadleaved Weeds

Data on absolute frequency of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 12.

At 30 DAS, hand weeding twice (T_{10}) recorded lowest absolute frequency of broad leaved weeds same as that of T_3 and T_6. At 45 and 60 DAS, lowest absolute frequency was recorded with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5) and T_{10}. Bensulfuron methyl + pretilachlor (T_1), pyrazosulfuron ethyl (T_4), oxyfluorfen (T_7) and oxyfluorfen *fb* azimsulfuron (T_9) reported 100 per cent absolute frequency of broad leaved weeds at harvest.

4.1.4.3 Absolute Frequency of Sedges

Data on absolute frequency of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 13.

Pyrazosulfuron ethyl (T_4) reported lowest absolute frequency of sedges at 15 DAS and all other treatments were on par with T_4 except hand weeding twice (T_{10}) and weedy check (T_{11}). At 30 DAS, Bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}) recorded lowest absolute frequency. T_{10} reported lowest absolute frequency at 45, 60 DAS and at harvest also while 100 per cent absolute frequency was observed with bensulfuron methyl + pretilachlor (T_1), pyrazosulfuron ethyl (T_4) and oxyfluorfen (T_7).

Table 11. Effect of weed management practices on the absolute frequency of grasses

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	50.00 (7.07)	82.93 (9.11)	82.93 (9.11)	100.00 (10.00)	100.00 (10.00)
T_2	T_1 + hand weeding at 40 DAS	57.77 (7.60)	47.75 (6.91)	25.00 (5.00)	57.77 (7.60)	82.93 (9.11)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	57.77 (7.60)	25.00 (5.00)	40.71 (6.38)	91.27 (9.55)	100.00 (10.00)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	57.77 (7.60)	82.93 (9.11)	82.93 (9.11)	91.27 (9.55)	100.00 (10.00)
T_5	T_4 + hand weeding at 40 DAS	66.11 (8.13)	40.71 (6.38)	25.00 (5.00)	57.77 (7.60)	82.93 (9.11)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	66.11 (8.13)	25.00 (5.00)	47.75 (6.91)	82.93 (9.11)	91.27 (9.55)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	66.11 (8.13)	82.93 (9.11)	91.27 (9.55)	100.00 (10.00)	100.00 (10.00)
T_8	T_7 + hand weeding at 40 DAS	82.93 (9.11)	40.71 (6.38)	32.38 (5.69)	82.93 (9.11)	91.27 (9.55)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	75.00 (8.66)	40.71 (6.38)	57.77 (7.60)	100.00 (10.00)	100.00 (10.00)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	73.57 (8.58)	25.00 (5.00)	25.00 (5.00)	40.71 (6.38)	82.93 (9.11)
T_{11}	Weedy check (Control 2)	57.77 (7.60)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
	SEm (±)	0.510	0.559	0.489	0.421	0.266
	CD (0.05)	NS	1.65	1.443	1.241	NS
	Treatment *Vs* Control 1	NS	S	S	S	S
	Treatment *Vs* Control 2	NS	S	S	NS	NS

Table 12. Effect of weed management practices on the absolute frequency of broad leaved weeds

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	75.00 (8.66)	82.93 (9.11)	91.27 (9.55)	100.00 (10.00)
T_2	T_1 + hand weeding at 40 DAS	-	66.11 (8.13)	32.38 (5.69)	57.77 (7.60)	82.93 (9.11)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	40.71 (6.38)	57.77 (7.60)	66.11 (8.13)	91.27 (9.55)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	75.00 (8.66)	82.93 (9.11)	91.27 (9.55)	100.00 (10.00)
T_5	T_4 + hand weeding at 40 DAS	-	66.11 (8.13)	32.38 (5.69)	57.77 (7.60)	82.93 (9.11)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	40.71 (6.38)	57.77 (7.60)	66.11 (8.13)	91.27 (9.55)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	82.93 (9.11)	91.27 (9.55)	100.00 (10.00)	100.00 (10.00)
T_8	T_7 + hand weeding at 40 DAS	-	82.93 (9.11)	40.71 (6.38)	66.11 (8.13)	91.27 (9.55)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	50.00 (7.07)	66.11 (8.13)	82.93 (9.11)	100.00 (10.00)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	82.93	40.71 (6.38)	32.38 (5.69)	57.77 (7.60)	66.11 (8.13)
T_{11}	Weedy check (Control 2)	91.27	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
	SEm (±)	-	0.469	0.564	0.476	0.271
	CD (0.05)	-	1.386	1.662	1.404	0.800
	Treatment *Vs* Control 1	S	S	S	NS	S
	Treatment *Vs* Control 2	S	S	S	S	NS

Table 13. Effect of weed management practices on the absolute frequency of sedges

	Treatments	15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	40.71 (6.38)	66.11 (8.13)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
T_2	T_1 + hand weeding at 40 DAS	50.00 (7.07)	57.77 (7.60)	32.38 (5.690	66.11 (8.13)	82.93 (9.11)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	40.71 (6.38)	32.38 (5.69)	40.71 (6.38)	75.00 (8.66)	91.27 (9.55)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	32.38 (5.69)	66.11 (8.13)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
T_5	T_4 + hand weeding at 40 DAS	50.00 (7.07)	57.77 (7.60)	32.38 (5.69)	66.11 (8.13)	82.93 (9.11)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	40.71 (6.38)	32.38 (5.69)	40.71 (6.38)	75.00 (8.66)	91.27 (9.55)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	40.71 (6.38)	66.11 (8.13)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
T_8	T_7 + hand weeding at 40 DAS	40.71 (6.38)	57.77 (7.60)	32.38 (5.69)	75.00 (8.66)	91.27 (9.55)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	50.00 (7.07)	40.71 (6.38)	40.71 (6.38)	82.93 (9.11)	100.00 (10.00)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	100.00 (10.00)	32.38 (5.69)	25.00 (5.00)	50.00 (7.07)	75.00 (8.66)
T_{11}	Weedy check (Control 2)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)	100.00 (10.00)
	SEm (±)	0.531	0.569	0.535	0.269	0.255
	CD (0.05)	1.566	1.679	1.578	0.795	0.754
	Treatment *Vs* Control 1	S	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S	NS

4.1.5 Relative Frequency

4.1.5.1 Relative Frequency of Grasses (per cent)

The data on relative frequency of grasses at 15, 30, 45, 60 DAS and at harvest is presented in the Table 14.

Lowest relative frequency of grasses at 15 DAS was observed with weedy check (T_{11}) which was on par with hand weeding twice (T_{10}). At all other stages, effect of weed management practices on relative frequency of grasses was found to be non-significant.

4.1.5.2 Relative Frequency of Broadleaved Weeds (per cent)

The data on relative frequency of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 15.

Effect of weed management practices on relative frequency of broad leaved weeds was found to be non-significant at all stages of observation.

4.1.5.3 Relative Frequency of Sedges (per cent)

The data on relative frequency of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 16.

Effect of weed management practices on relative frequency of sedges was found to be non-significant at all the stages.

4.1.6 Importance Value

4.1.6.1 Importance Value of Grasses

The data on Importance valve of grasses at 15, 30, 45, 60 DAS and at harvest is presented in the Table 17.

Table 14. Effect of weed management practices on the relative frequency of grasses, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	33.33 (5.77)	36.86 (6.07)	31.09 (5.58)	34.33 (5.86)	33.33 (5.77)
T_2	T_1 + hand weeding at 40 DAS	33.03 (5.75)	27.03 (5.20)	27.64 (5.26)	31.41 (5.60)	33.18 (5.76)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	44.19 (6.65)	25.83 (5.08)	28.95 (5.38)	39.16 (6.26)	35.34 (5.94)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	36.76 (6.06)	36.86 (6.07)	31.10 (5.58)	32.21 (5.68)	33.33 (5.77)
T_5	T_4 + hand weeding at 40 DAS	37.80 (6.15)	24.52 (4.95)	28.51 (5.34)	31.41 (5.60)	33.18 (5.76)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	46.54 (6.82)	25.83 (5.08)	31.33 (5.60)	36.89 (6.07)	33.18 (5.76)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	37.80 (6.15)	35.49 (5.96)	32.20 (5.67)	33.33 (5.77)	33.33 (77)
T_8	T_7 + hand weeding at 40 DAS	43.30 (6.58)	22.17 (4.71)	30.42 (5.52)	36.89 (6.07)	33.19 (5.76)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	42.86 (6.55)	30.51 (5.52)	34.67 (5.89)	37.71 (6.14)	33.33 (5.77)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	28.32 (5.32)	25.83 (5.08)	30.42 (5.52)	27.01 (5.20)	36.89 (6.07)
T_{11}	Weedy check (Control 2)	23.07 (4.80)	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)
	SEm (±)	0.268	0.396	0.339	0.208	0.107
	CD (0.05)	0.791	NS	NS	NS	NS
	Treatment *Vs* Control 1	S	NS	NS	S	S
	Treatment *Vs* Control 2	S	NS	NS	NS	NS

Table 15. Effect of weed management practices on the relative frequency of broad leaved weeds, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	33.33 (5.77)	31.09 (5.58)	31.25 (5.59)	33.33 (5.77)
T_2	T_1 + hand weeding at 40 DAS	-	38.32 (6.19)	35.38 (5.95)	31.70 (5.63)	33.18 (5.76)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	40.83 (6.39)	40.94 (6.40)	28.28 (5.32)	32.21 (5.68)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	33.33 (5.77)	31.10 (5.58)	32.21 (5.68)	33.33 (5.77)
T_5	T_4 + hand weeding at 40 DAS	-	39.98 (6.32)	35.49 (5.96)	31.70 (5.63)	33.18 (5.76)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	40.83 (6.39)	39.02 (6.25)	29.34 (5.42)	33.18 (5.76)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	35.67 (5.97)	32.20 (5.67)	33.33 (5.77)	33.33 (5.77)
T_8	T_7 + hand weeding at 40 DAS	-	45.47 (6.74)	38.51 (6.21)	29.34 (5.42)	33.19 (5.76)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	37.71 (6.14)	39.55 (6.29)	31.09 (5.58)	33.33 (5.77)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	32.20	40.83 (6.39)	38.51 (6.21)	38.62 (6.21)	29.34 (5.42)
T_{11}	Weedy check (Control 2)	36.51	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)
	SEm (±)	-	0.302	0.338	0.268	0.134
	CD (0.05)	-	NS	NS	NS	NS
	Treatment *Vs* Control 1	S	NS	NS	S	S
	Treatment *Vs* Control 2	S	NS	NS	NS	NS

Table 16. Effect of weed management practices on the relative frequency of sedges, per cent

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	27.14 (5.21)	29.38 (5.42)	37.71 (6.14)	34.33 (5.86)	33.33 (5.77)
T_2	T_1 + hand weeding at 40 DAS	28.87 (5.370	33.83 (5.82)	35.38 (5.95)	36.06 (6.01)	33.33 (5.77)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	30.88 (5.56)	32.48 (5.70)	28.95 (5.38)	32.41 (5.69)	32.21 (5.68)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	20.28 (4.50)	29.38 (5.42)	37.56 (6.13)	35.34 (5.64)	33.33 (5.77)
T_5	T_4 + hand weeding at 40 DAS	28.87 (5.37)	34.69 (5.89)	35.49 (5.96)	36.06 (6.01)	33.33 (5.77)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	29.09 (5.39)	32.48 (5.70)	27.57 (5.25)	33.54 (5.79)	33.33 (5.77)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	23.13 (4.81)	28.32 (5.32)	35.49 (5.96)	33.33 (5.77)	33.33 (5.77)
T_8	T_7 + hand weeding at 40 DAS	21.41 (4.63)	31.41 (5.60)	30.42 (5.52)	33.54 (5.79)	33.19 (5.76)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	28.57 (5.35)	30.51 (5.52)	24.66 (4.97)	31.09 (5.58)	33.33 (5.77)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	39.12 (6.25)	32.48 (5.70)	30.42 (5.52)	33.81 (5.81)	33.54 (5.79)
T_{11}	Weedy check (Control 2)	40.20 (6.34)	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)	33.33 (5.77)
	SEm (±)	0.417	0.362	0.399	0.216	0.164
	CD (0.05)	NS	NS	NS	NS	NS
	Treatment *Vs* Control 1	S	NS	NS	NS	NS
	Treatment *Vs* Control 2	S	NS	NS	NS	NS

At 15 DAS, pyrazosulfuron ethyl *fb* azimsulfuron (T_6) recorded highest importance value of grasses which was on par with oxyfluorfen *fb* hand weeding (T_8). Bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) reported highest importance value of grasses at 30 DAS and it was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9) while at 45 DAS, T_9 reported highest importance value and was on par with T_3 and T_6. At 60 DAS and at harvest T_6 recorded highest importance value of grasses which was on par with T_3.

4.1.6.2 Importance Value of Broadleaved Weeds

The data on Importance valve of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 18.

Oxyfluorfen *fb* hand weeding (T_8) recorded highest importance value of broad leaved weeds at 30 DAS which was on par with all other weed management practices except bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9). At 45 DAS, importance value of broad leaved was not influenced by any of the weed management practices. Weedy check (T_{11}) reported highest importance value of broad leaved weeds at 60 DAS and at harvest.

4.1.6.3 Importance Value of sedges

The data on Importance valve of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 19.

At 15 DAS, effect of weed management practices on importance value of sedges was found to be non-significant while at 30 DAS, pyrazosulfuron ethyl *fb* hand weeding (T_5) recorded highest importance value of sedges which was on par with all the weed management practices except bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb*

Table 17. Effect of weed management practices on the importance value of grasses

Treatments		15 DAS	30 DAS	45 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	70.73 (8.41)	57.72 (7.60)	51.97 (7.21)	57.10 (7.56)	58.60 (7.66)
T_2	T_1 + hand weeding at 40 DAS	72.47 (8.51)	46.50 (6.82)	51.97 (7.21)	76.94 (8.77)	67.92 (8.24)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	76.54 (8.75)	89.10 (9.44)	78.01 (8.83)	90.43 (9.51)	80.54 (8.97)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	72.88 (8.54)	58.06 (7.62)	55.29 (7.44)	55.07 (7.42)	57.35 (7.57)
T_5	T_4 + hand weeding at 40 DAS	75.80 (8.71)	46.14 (6.79)	53.39 (7.31)	74.07 (8.61)	66.07 (8.13)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	90.40 (9.51)	87.91 (9.38)	79.76 (8.93)	90.83 (9.53)	82.58 (9.09)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	72.10 (8.49)	55.66 (7.46)	54.80 (7.40)	56.58 (7.52)	57.82 (7.60)
T_8	T_7 + hand weeding at 40 DAS	77.46 (8.80)	39.19 (6.26)	54.33 (7.370	73.89 (8.60)	63.91 (7.99)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	72.52 (8.52)	83.77 (9.15)	80.66 (8.980	79.75 (8.93)	73.40 (8.57)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	42.87 (6.55)	54.43 (7.38)	57.99 (7.62)	70.46 (8.39)	73.74 (8.59)
T_{11}	Weedy check (Control 2)	38.68 (6.22)	48.31 (6.95)	52.19 (7.22)	53.50 (7.31)	56.06 (7.49)
	SEm (±)	0.240	0.301	0.332	0.113	0.091
	CD (0.05)	0.708	0.887	0.978	0.335	0.270
	Treatment *Vs* Control 1	S	NS	NS	NS	S
	Treatment *Vs* Control 2	S	S	NS	S	S

Table 18. Effect of weed management practices on the importance value of broad leaved weeds

	Treatments	15DAS	30DAS	45DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	72.16 (8.49)	63.48 (7.97)	58.95 (7.68)	67.74 (8.23)
T_2	T_1 + hand weeding at 40 DAS	-	75.42 (8.68)	75.30 (8.68)	53.75 (7.33)	65.21 (8.08)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	62.69 (7.92)	64.38 (8.02)	47.15 (6.87)	56.76 (7.53)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	72.63 (8.52)	63.84 (7.99)	62.27 (7.89)	70.38 (8.39)
T_5	T_4 + hand weeding at 40 DAS	-	75.06 (8.66)	66.25 (8.14)	56.31 (7.50)	64.58 (8.04)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	62.28 (7.89)	62.26 (7.89)	47.04 (6.86)	54.35 (7.37)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	73.49 (8.57)	64.74 (8.05)	63.81 (7.99)	69.41 (8.33)
T_8	T_7 + hand weeding at 40 DAS	-	84.74 (9.21)	67.41 (8.21)	52.86 (7.27)	71.06 (8.43)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	61.20 (7.82)	66.31 (8.14)	58.65 (7.66)	65.83 (8.11)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	65.88	77.49 (8.80)	74.85 (8.65)	61.70 (7.86)	55.86 (7.47)
T_{11}	Weedy check (Control 2)	66.86	75.11 (8.67)	69.65 (8.35)	66.96 (8.18)	72.81 (8.53)
	SEm (±)	-	0.268	0.297	0.206	0.142
	CD (0.05)	-	0.790	NS	0.609	0.418
	Treatment *Vs* Control 1	S	NS	NS	NS	S
	Treatment *Vs* Control 2	S	NS	NS	S	S

azimsulfuron (T_9). At 45, 60 DAS and at harvest bensulfuron methyl + pretilachlor (T_1) recorded highest importance value of sedges.

4.1.7 Summed Dominance Ratio

4.1.7.1 Summed Dominance Ratio of Grasses

The data on summed dominance ratio of grasses at 15, 30, 45, 60 DAS and at harvest is presented in the Table 20.

Highest summed dominance ratio of grasses at 15 DAS was observed with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) which was on par with oxyfluorfen *fb* hand weeding (T_8). At 30 and 45 DAS, highest value for summed dominance ratio was recorded with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) which was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9).

4.1.7.2 Summed Dominance Ratio of Broadleaved Weeds

The data on summed dominance ratio of broadleaved weeds at 15, 30, 45, 60 DAS and at harvest is presented in the Table 21.

At 30 DAS, oxyfluorfen *fb* hand weeding (T_8) reported highest summed dominance ratio of broad leaved weeds and was on par with all the weed management practices except T_3, T_6 and T_9. At 45 DAS, the effect of weed management practices on summed dominance ratio of broad leaved weeds was found to be non-significant. At 60 DAS and at harvest T_{11} reported highest summed dominance ratio of broad leaved weeds.

4.1.7.3 Summed Dominance Ratio of Sedges

The data on summed dominance ratio of sedges at 15, 30, 45, 60 DAS and at harvest is presented in the Table 22.

Table 19. Effect of weed management practices on the importance value of sedges

Treatments		15DAS	30DAS	45DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	90.27 (9.50)	69.75 (8.35)	84.52 (9.19)	83.92 (9.16)	73.64 (8.58)
T_2	T_1 + hand weeding at 40 DAS	89.23 (9.45)	77.44 (8.80)	70.55 (8.40)	68.92 (8.30)	66.61 (8.16)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	98.91 (9.95)	47.89 (6.92)	57.07 (7.55)	62.30 (7.89)	62.57 (7.91)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	84.75 (9.21)	68.89 (8.30)	80.67 (8.98)	82.46 (9.08)	72.26 (8.500
T_5	T_4 + hand weeding at 40 DAS	91.04 (9.54)	78.27 (8.85)	80.10 (8.950	69.27 (8.32)	69.21 (8.320
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	85.51 (9.25)	49.63 (7.04)	56.11 (7.49)	62.05 (7.88)	62.84 (7.930
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	88.71 (9.42)	70.59 (8.40)	80.29 (8.96)	79.61 (8.920	72.76 (8.53)
T_8	T_7 + hand weeding at 40 DAS	87.71 (9.370	75.32 (8.68)	78.04 (8.83)	73.18 (8.55)	64.75 (8.050
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	98.84 (9.94)	54.54 (7.39)	52.46 (7.24)	61.56 (7.85)	60.73 (7.790
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	90.85 (9.530	67.34 (8.21)	66.83 (8.17)	67.41 (8.21)	70.24 (8.380
T_{11}	Weedy check (Control 2)	94.17 (9.70)	76.53 (8.75)	78.13 (8.84)	79.51 (8.92)	71.13 (8.43)
	SEm (±)	0.267	0.259	0.342	0.167	0.144
	CD (0.05)	NS	0.765	1.009	0.493	0.426
	Treatment *Vs* Control 1	NS	NS	NS	NS	NS
	Treatment *Vs* Control 2	NS	S	NS	S	NS

Table 20. Effect of weed management practices on the summed dominance ratio of grasses

Treatments		15DAS	30DAS	45DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	35.36 (5.95)	28.86 (5.37)	25.98 (5.10)	28.55 (5.34)	29.30 (5.41)
T_2	T_1 + hand weeding at 40 DAS	36.24 (6.02)	23.25 (4.82)	25.98 (5.10)	38.47 (6.20)	33.96 (5.83)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	38.27 (6.19)	44.55 (6.67)	39.01 (6.25)	45.21 (6.72)	40.27 (6.35)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	36.44 (6.04)	29.03 (5.39)	27.65 (5.26)	27.54 (5.25)	28.68 (5.36)
T_5	T_4 + hand weeding at 40 DAS	37.90 (6.160	23.07 (4.80)	26.70 (5.17)	37.03 (6.09)	33.03 (5.75)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	45.20 (6.72)	43.96 (6.63)	39.88 (6.32)	45.42 (6.74)	41.29 (6.43)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	36.05 (6.000	27.83 (5.28)	27.40 (5.23)	28.29 (5.32)	28.91 (5.38)
T_8	T_7 + hand weeding at 40 DAS	38.73 (6.22)	19.59 (4.43)	27.16 (5.21)	36.95 (6.08)	31.95 (5.65)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	36.26 (6.02)	41.89 (6.47)	40.33 (6.35)	39.88 (6.31)	36.70 (6.06)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	21.44 (4.63)	27.21 (5.22)	29.00 (5.38)	35.23 (5.940	36.87 (6.07)
T_{11}	Weedy check (Control 2)	19.34 (4.40)	24.15 (4.91)	26.10 (5.11)	26.75 (5.17)	28.03 (5.29)
	SEm (±)	0.170	0.213	0.234	0.080	0.065
	CD (0.05)	0.5006	0.627	0.692	0.237	0.191
	Treatment *Vs* Control 1	S	NS	NS	NS	S
	Treatment *Vs* Control 2	S	S	NS	S	S

Table 21. Effect of weed management practices on the summed dominance ratio of broad leaved leaves

Treatments		15DAS	30DAS	45DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	-	36.08 (6.01)	31.74 (5.63)	29.48 (5.43)	33.87 (5.82)
T_2	T_1 + hand weeding at 40 DAS	-	37.71 (6.14)	37.65 (6.14)	26.87 (5.18)	32.60 (5.71)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	31.35 (5.60)	32.19 (5.67)	23.57 (4.86)	28.38 (5.33)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	-	36.31 (6.030	31.92 (5.65)	31.13 (5.58)	35.19 (5.93)
T_5	T_4 + hand weeding at 40 DAS	-	37.53 (6.13)	33.13 (5.76)	28.16 (5.31)	32.29 (5.68)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	31.14 (5.58)	31.13 (5.580	23.52 (4.85)	27.17 (5.21)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	-	36.74 (6.06)	32.37 (5.69)	31.90 (5.65)	34.71 (5.89)
T_8	T_7 + hand weeding at 40 DAS	-	42.37 (6.51)	33.70 (5.81)	26.43 (5.14)	35.53 (5.96)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	-	30.60 (5.53)	33.16 (5.76)	29.32 (5.42)	32.91 (5374)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	32.94	38.74 (6.22)	37.42 (6.120	30.85 (5.55)	27.93 (5.28)
T_{11}	Weedy check (Control 2)	33.43	37.55 (6.13)	34.83 (5.90)	33.48 (5.79)	36.40 (6.03)
	SEm (±)	-	0.189	0.210	0.146	0.100
	CD (0.05)	-	0.558	NS	0.430	0.296
	Treatment *Vs* Control 1	S	NS	NS	NS	S
	Treatment *Vs* Control 2	S	NS	NS	S	S

The effect of weed management practices on summed dominance ratio of sedges was found to be non-significant at 15 DAS. But at 30 DAS, pyrazosulfuron ethyl *fb* hand weeding (T_5) reported highest summed dominance ratio of sedges which was on par with all the weed management practices except bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9). Bensulfuron methyl + pretilachlor (T_1) reported highest summed dominance ratio at 45, 60 DAS and at harvest.

4.1.8 Weed Dry Weight

4.1.8.1 Weed Dry weight of Grasses

The data on dry weight of grasses at 20, 40, 60 DAS and at harvest is presented in the Table 23.

At 20 DAS, the effect of weed management practices on dry weight of grasses was found to be non-significant while at 40 DAS, lowest dry weight of grasses (7.64 g m^{-2}) was recorded with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) followed by pyrazosulfuron ethyl +azimsulfuron (T_6). At 60 DAS hand weeding twice (T_{10}) reported significantly lowest weed dry weight of grasses and was followed by bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5) and oxyfluorfen *fb* hand weeding (T_8).

4.1.8.2 Weed Dry weight of Broadleaved Weeds

The data on dry weight of broadleaved weeds at 20, 40, 60 DAS and at harvest is presented in the Table 24.

At 20 DAS, bensulfuron methyl + pretilachlor (T_1) recorded lowest dry weight of broad leaved weeds (2.33 g m^{-2}) which was on par with all the treatments except hand weeding twice (T_{10}) and weedy check (T_{11}) while at 40 DAS, lowest dry weight of broad leaved weeds (0.88 g m^{-2}) was reported with bensulfuron methyl + pretilachlor

Table 22. Effect of weed management practices on the summed dominance ratio of sedges

	Treatments	15DAS	30DAS	45DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	45.14 (6.72)	34.88 (5.91)	42.26 (6.50)	41.96 (6.48)	36.82 (6.07)
T_2	T_1 + hand weeding at 40 DAS	44.62 (6.68)	38.72 (6.22)	35.28 (5.94)	34.46 (5.87)	33.30 (5.77)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	49.45 (7.03)	23.94 (4.89)	28.54 (5.34)	31.15 (5.58)	31.29 (5.59)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	42.38 (6.51)	34.45 (5.87)	40.34 (6.35)	41.23 (6.42)	36.13 (6.010
T_5	T_4 + hand weeding at 40 DAS	45.52 (6.75)	39.14 (6.26)	40.05 (6.33)	34.63 (5.89)	34.61 (5.880
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	42.76 (6.54)	24.81 (4.98)	28.06 (5.30)	31.03 (5.57)	31.42 (5.610
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	44.35 (6.66)	35.30 (5.94)	40.14 (6.340	39.80 (6.31)	36.38 (6.03)
T_8	T_7 + hand weeding at 40 DAS	43.85 (6.62)	37.66 (6.14)	39.02 (6.25)	36.59 (6.05)	32.37 (5.69)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	49.42 (7.030	27.27 (5.22)	26.23 (5.12)	30.78 (5.55)	30.37 (5.51)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	45.42 (6.74)	33.67 (5.80)	33.41 (5.78)	33.71 (5.81)	35.12 (5.93)
T_{11}	Weedy check (Control 2)	47.09 (6.86)	38.26 (6.19)	39.07 (6.25)	39.76 (6.31)	35.56 (5.96)
	SEm (±)	0.189	0.183	0.242	0.118	0.102
	CD (0.05)	NS	0.541	0.714	0.348	0.301
	Treatment *Vs* Control 1	NS	NS	NS	NS	NS
	Treatment *Vs* Control 2	NS	S	NS	S	NS

Table 23. Effect of weed management practices on the dry weight of grasses, g m^{-2}

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	2.47	13.34	30.29	35.58
T_2	T_1 + hand weeding at 40 DAS	2.49	12.53	14.49	28.52
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.34	7.64	25.09	37.61
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	2.69	16.49	21.81	39.22
T_5	T_4 + hand weeding at 40 DAS	2.65	15.59	14.19	25.10
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.87	9.27	25.07	42.62
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	2.73	16.42	27.48	44.84
T_8	T_7 + hand weeding at 40 DAS	2.50	17.27	15.79	30.56
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.44	9.40	24.71	41.55
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	2.83	10.24	10.92	24.59
T_{11}	Weedy check (Control 2)	2.97	19.88	30.99	48.05
	SEm (±)	0.377	0.50	0.864	0.962
	CD (0.05)	NS	1.476	2.550	2.838
	Treatment *Vs* Control 1	NS	S	S	S
	Treatment *Vs* Control 2	NS	S	S	S

fb azimsulfuron (T_3) and was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6), oxyfluorfen *fb* azimsulfuron (T_9) and hand weeding twice (T_{10}). At 60 DAS and at harvest lowest dry weight was reported with T_{10} which was on par with pyrazosulfuron ethyl *fb* hand weeding (T_5) and T_6.

4.1.8.3 Weed Dry weight of Sedges

The data on dry weight of sedges at 20, 40, 60 DAS and at harvest is presented in the Table 25.

At 20 and 40 DAS same trend was observed for dry weight of sedges as that of dry weight of broad leaved weeds. Lowest dry weight of sedges at 60 DAS (5.39 g m^{-2}) and at harvest (15.22 m^{-2}) was recorded with hand weeding twice (T_{10}) which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) at 60 DAS and with T_2, bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6) at harvest.

4.1.8.4 Total Weed Dry weight

The data on total dry weight of weeds at 20, 40, 60 DAS and at harvest is presented in the Table 26.

At 20 DAS, bensulfuron methyl + pretilachlor (T_1) recorded lowest total weed dry weight (6.55 g m^{-2}) which was on par with all the treatments except hand weeding twice (T_{10}) and weedy check (T_{11}) while at 40 DAS, lowest weed dry weight (10.57 m^{-2}) was recorded with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and oxyfluorfen *fb* azimsulfuron (T_9). At 60 DAS and at harvest, hand weeding twice (T_{10}) recorded lowest total weed dry weight (20.43, 48.56 g m^{-2}) followed by bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) and pyrazosulfuron ethyl *fb* hand weeding (T_5).

Table 24. Effect of weed management practices on the dry weight of broadleaved weeds, g m^{-2}

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	2.33	6.73 (2.59)	16.99 (4.12)	27.75 (5.27)
T_2	T_1 + hand weeding at 40 DAS	2.61	6.52 (2.55)	5.03 (2.24)	13.13 (3.62)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.62	0.88 (0.94)	5.50 (2.35)	11.28 (3.36)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	2.53	6.55 (2.56)	18.09 (4.250	28.57 (5.34)
T_5	T_4 + hand weeding at 40 DAS	2.40	6.29 (2.51)	5.23 (2.29)	12.11 (3.48)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.34	0.90 (0.95)	5.55 (2.36)	8.73 (2.96)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	2.68	7.96 (2.82)	19.96 (4.47)	33.18 (5.76)
T_8	T_7 + hand weeding at 40 DAS	2.70	8.02 (2.83)	6.06 (2.46)	16.83 (4.10)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.58	1.18 (1.08)	8.62 (2.94)	15.99 (4.00)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	6.27	1.00 (1.00)	4.09 (2.02)	8.69 (2.95)
T_{11}	Weedy check (Control 2)	6.53	12.23 (3.50)	26.14 (5.11)	40.43 (6.36)
	SEm (±)	0.279	0.105	0.106	0.131
	CD (0.05)	0.824	0.309	0.312	0.386
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

Table 25. Effect of weed management practices on the dry weight of sedges, g m^{-2}

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	1.75	9.21	26.56 (5.15)	37.48 (6.12)
T_2	T_1 + hand weeding at 40 DAS	1.76	9.56	6.02 (2.45)	16.74 (4.09)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	1.87	2.06	7.56 (2.75)	17.24 (4.15)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	1.81	8.47	24.23 (4.92)	36.49 (6.04)
T_5	T_4 + hand weeding at 40 DAS	1.84	9.10	6.62 (2.57)	18.49 (4.30)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	1.85	2.45	7.25 (2.69)	15.97 (4.00)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	1.95	10.28	27.64 (5.26)	41.49 (6.44)
T_8	T_7 + hand weeding at 40 DAS	2.06	10.63	9.10 (3.02)	19.47 (4.41)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.01	2.41	9.41 (3.07)	17.75 (4.21)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	4.58	2.66	5.39 (2.32)	15.22 (3.90)
T_{11}	Weedy check (Control 2)	4.62	13.67	38.30 (6.19)	44.50 (6.67)
	SEm (±)	0.301	0.498	0.069	0.090
	CD (0.05)	0.895	1.479	0.202	0.266
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

Table 26. Effect of weed management practices on the total weed dry weight, g m^{-2}

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	6.55	29.30	73.86 (8.59)	100.83 (10.04)
T_2	T_1 + hand weeding at 40 DAS	6.86	28.35	25.55 (5.06)	58.44 (7.64)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	6.83	10.57	38.14 (6.18)	66.19 (8.14)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	7.04	31.53	64.16 (8.01)	104.29 (10.21)
T_5	T_4 + hand weeding at 40 DAS	6.89	30.30	26.03 (5.10)	55.70 (7.46)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	7.06	12.61	37.83 (6.15)	67.37 (8.21)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	7.36	34.67	75.10 (8.67)	119.52 (10.93)
T_8	T_7 + hand weeding at 40 DAS	7.26	34.41	30.96 (5.56)	66.92 (8.18)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	7.03	13.00	42.77 (6.54)	75.34 (8.68)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	13.67	14.05	20.43 (4.52)	48.56 (6.97)
T_{11}	Weedy check (Control 2)	14.14	45.85	95.48 (9.77)	132.99 (11.53)
	SEm (±)	0.308	0.899	0.107	0.084
	CD (0.05)	0.907	2.653	0.317	0.248
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

4.1.9 Weed Control Efficiency

4.1.9.1 Weed Control Efficiency of Grasses

The data on weed control efficiency of grasses at 20, 40, 60 DAS and at harvest is presented in the Table 27.

At 20 DAS, effect of weed management practices on weed control efficiency of grasses was found to be non-significant while at 40 DAS bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) reported highest weed control efficiency of grasses (61.44 per cent) and was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6), oxyfluorfen *fb* azimsulfuron (T_9) and hand weeding twice (T_{10}). At 60 DAS and at harvest T_{10} recorded highest weed control efficiency (64.72, 48.85 per cent) which was on par with pyrazosulfuron ethyl *fb* hand weeding (T_5) at 60 DAS.

4.1.9.2 Weed Control Efficiency of Broadleaved Weeds

The data on weed control efficiency of broadleaved weeds at 20, 40, 60 DAS and at harvest is presented in the Table 28.

Highest weed control efficiency of broad leaved weeds (63.74 per cent) at 20 DAS was recorded with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) which was on par with all the treatments except hand weeding twice (T_{10}) and weedy check (T_{11}). At 40 DAS, bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) reported highest weed control efficiency (92.73 per cent) and was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6), oxyfluorfen *fb* azimsulfuron (T_9) and T_{10}. Hand weeding twice (T_{10}) recorded highest weed control efficiency of broad leaved weeds at 60 DAS (84.36 per cent) and at harvest (78.46 per cent) which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6).

Table 27. Effect of weed management practices on weed control efficiency of grasses, per cent

Treatments		20 DAS	40 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	17.12	32.37 (5.78)	3.62 (2.15)	25.65 (5.16)
T_2	T_1 + hand weeding at 40 DAS	16.21	34.57 (5.96)	53.57 (7.39)	40.63 (6.45)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	21.44	61.44 (7.90)	17.66 (4.32)	21.28 (4.72)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	9.62	16.93 (4.23)	30.54 (5.62)	18.03 (4.36)
T_5	T_4 + hand weeding at 40 DAS	10.86	14.86 (3.98)	55.76 (7.53)	47.76 (6.98)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	3.75	53.02 (7.35)	16.36 (4.17)	10.91 (3.45)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	8.58	16.80 (4.22)	13.27 (3.78)	6.65 (2.7)
T_8	T_7 + hand weeding at 40 DAS	16.23	11.03 (3.47)	50.50 (7.18)	36.36 (6.11)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	17.27	52.50 (7.31)	22.70 (4.87)	13.47 (3.80)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	4.74	52.42 (7.31)	64.72 (8.11)	48.85 (7.06)
T_{11}	Weedy check (Control 2)	0.00	0.00	0.00	0.00
	SEm (±)	8.036	0.273	0.206	0.228
	CD (0.05)	NS	0.811	0.614	0.676
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

Table 28. Effect of weed management practices on weed control efficiency of broad leaved leaves, per cent

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	63.74 (8.05)	42.63 (6.61)	34.43 (5.95)	31.20 (5.67)
T_2	T_1 + hand weeding at 40 DAS	58.47 (7.71)	44.04 (6.71)	80.56 (9.03)	67.40 (8.27)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	59.41 (7.77)	92.73 (9.68)	78.75 (8.93)	71.95 (8.54)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	61.02 (7.88)	42.67 (6.61)	29.20 (5.50)	29.25 (5.50)
T_5	T_4 + hand weeding at 40 DAS	63.01 (8.00)	45.58 (6.82)	79.92 (9.00)	70.00 (8.43)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	64.07 (8.07)	92.49 (9.67)	78.49 (8.92)	78.33 (8.91)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	58.80 (7.73)	33.43 (5.87)	23.51 (4.95)	16.59 (4.19)
T_8	T_7 + hand weeding at 40 DAS	58.21 (7.69)	34.38 (5.95)	76.67 (8.81)	58.17 (7.69)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	59.64 (7.79)	90.34 (9.56)	66.54 (8.22)	59.89 (7.80)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	3.32 (2.08)	91.73 (9.63)	84.36 (9.24)	78.46 (8.91)
T_{11}	Weedy check (Control 2)	0.00	0.00	0.00	0.00
	SEm (±)	0.348	0.380	0.224	0.267
	CD (0.05)	1.034	1.128	0.667	0.793
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

4.1.9.3 Weed Control Efficiency of sedges

The data on weed control efficiency of sedges at 20, 40, 60 DAS and at harvest is presented in the Table 29.

At 20 and 40 DAS same trend as that of weed control efficiency of broad leaved weeds was observed for sedges. Hand weeding twice (T_{10}) recorded highest weed control efficiency of broad leaved weeds at 60 DAS (85.83 per cent) and at harvest (65.71 per cent). At 60 DAS T_{10} was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and at harvest, on par with oxyfluorfen *fb* hand weeding (T_8) and oxyfluorfen *fb* azimsulfuron (T_9), T_2, T_3, T_4 and T_5.

4.1.9.4 Total Weed Control Efficiency

The data on total weed control efficiency of weeds at 20, 40, 60 DAS and at harvest is presented in the Table 30.

Total weed control efficiency at 20 and 40 DAS also followed the same trend of weed control efficiency of broad leaved weeds and sedges. At 60 DAS (78.59 per cent) and at harvest (63.47 per cent) highest weed control efficiency was reported with hand weeding twice (T_{10}) followed by pyrazosulfuron ethyl *fb* hand weeding (T_5) and bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) along with T_5 at 60 DAS.

Table 29. Effect of weed management practices on weed control efficiency of sedges, per cent

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	61.74 (7.92)	32.06 (5.75)	30.65 (5.63)	15.18 (4.02)
T_2	T_1 + hand weeding at 40 DAS	61.31 (7.890	29.28 (5.50)	84.26 (9.23)	62.32 (7.96)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	58.66 (7.72)	84.91 (9.27)	80.26 (9.01)	61.22 (7.89)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	60.16 (7.82)	37.32 (6.19)	36.70 (6.14)	17.66 (4.32)
T_5	T_4 + hand weeding at 40 DAS	59.26 (7.76)	32.66 (5.80)	82.70 (9.15)	58.36 (7.70)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	59.40 (7.77)	81.88 (9.10)	80.99 (9.05)	63.96 (8.06)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	57.28 (7.63)	23.97 (5.00)	27.65 (5.35)	5.44 (2.54)
T_8	T_7 + hand weeding at 40 DAS	54.32 (7.44)	20.50 (4.64)	76.23 (8.79)	56.19 (7.56)
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	55.55 (7.52)	82.20 (9.12)	75.41 (8.74)	60.09 (7.82)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	0.98 (1.41)	80.66 (9.04)	85.83 (9.32)	65.71 (8.17)
T_{11}	Weedy check (Control 2)	0.00	0.00	0.00	0.00
	SEm (±)	0.149	0.369	0.090	0.287
	CD (0.05)	0.442	1.096	0.268	0.854
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

Table 30. Effect of weed management practices on total weed control efficiency, per cent

Treatments		20 DAS	40 DAS	60DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	53.57 (7.39)	35.35 (6.03)	22.63 (4.86)	24.08 (5.01)
T_2	T_1 + hand weeding at 40 DAS	51.31 (7.23)	36.19 (6.10)	73.18 (8.61)	56.05 (7.55)
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	51.58 (7.25)	76.81 (8.82)	59.96 (7.81)	50.21 (7.16)
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	50.14 (7.15)	30.72 (5.63)	32.78 (5.81)	21.57 (4.75)
T_5	T_4 + hand weeding at 40 DAS	51.17 (7.22)	28.98 (5.48)	72.72 (8.59)	58.08 (7.69)
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	49.99 (7.14)	72.32 (8.56)	60.15 (7.82)	49.33 (7.09)
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	47.75 (6.98)	23.59 (4.96)	21.30 (4.72)	9.84 (3.29)
T_8	T_7 + hand weeding at 40 DAS	48.56 (7.04)	20.18 (4.60)	67.55 (8.28)	49.68 (7.120
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	50.20 (7.16)	71.53 (8.52)	55.20 (7.50)	43.26 (6.65)
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	2.58 (1.89)	71.32 (8.50)	78.59 (8.92)	63.47 (8.030
T_{11}	Weedy check (Control 2)	0.00	0.00	0.00	0.00
	SEm (±)	0.231	0.208	0.094	0.129
	CD (0.05)	0.686	0.619	0.278	0.383
	Treatment *Vs* Control 1	S	S	S	S
	Treatment *Vs* Control 2	S	S	S	S

4.2 OBSERVATIONS ON CROP

4.2.1 Growth and Growth Attributes

4.2.1.1 Plant Height

The results on the effect of weed management practices on plant height at different stages of crop growth are presented in Table 31.

Plant height of rice varied significantly with the different weed management strategies tested. At 30 DAS maximum plant height (33.51 cm) was observed from pyrazosulfuron ethyl *fb* azimsulfuron (T_6) which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and with hand weeding twice (T_{10}). Maximum plant height at 60 DAS was recorded from T_3 (62.85 cm) which was on par with T_6 and T_{10}. At harvest also same trend was followed. Lowest plant height was observed in weedy check at all stages of crop growth.

4.2.1.2 Number of Tillers m^{-2}

The results on the effect of weed management practices on number of tillers m^{-2} at different stages of crop growth are presented in Table 32.

At 30 DAS highest number of tillers m^{-2} was observed from pyrazosulfuron ethyl *fb* azimsulfuron (T_6) which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) while at 60 DAS highest number of tillers m^{-2} was recorded from T_3 which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), T_6 and hand weeding twice (T_{10}). At harvest also maximum number of tillers m^{-2} was observed from T_3 which was on par with T_{10}. Lowest number of tillers was recorded from unweeded plots at all crop growth stages.

Table 31. Effect of weed management practices on plant height, cm

Treatments		30 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	28.14	52.89	94.84
T_2	T_1 + hand weeding at 40 DAS	28.59	55.00	97.10
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	30.17	62.85	104.34
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	27.37	53.60	94.28
T_5	T_4 + hand weeding at 40 DAS	26.06	55.53	99.64
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	33.51	59.93	104.29
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	27.22	50.86	88.94
T_8	T_7 + hand weeding at 40 DAS	28.38	53.61	89.64
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	27.30	52.71	90.93
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	29.98	59.77	99.85
T_{11}	Weedy check (Control 2)	23.72	44.28	84.44
	SEm (±)	1.50	1.806	3.070
	CD (0.05)	4.41	5.328	9.058
	Treatment *Vs* Control 1	NS	S	NS
	Treatment *Vs* Control 2	S	S	S

Table 32. Effect of weed management practices on number of tillers m^{-2}

Treatments		30 DAS	60 DAS	Harvest
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	263.67	558.00	665.00
T_2	T_1 + hand weeding at 40 DAS	260.00	646.00	838.00
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	308.00	657.00	870.00
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	293.67	525.00	680.00
T_5	T_4 + hand weeding at 40 DAS	290.33	558.00	725.33
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	363.00	656.00	849.00
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	209.00	404.00	542.33
T_8	T_7 + hand weeding at 40 DAS	263.67	536.00	693.00
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	263.67	470.00	677.67
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	308.00	649.67	882.00
T_{11}	Weedy check (Control 2)	187.00	360.00	418.67
	SEm (±)	18.638	24.159	32.067
	CD (0.05)	54.983	71.272	94.599
	Treatment *Vs* Control 1	NS	S	S
	Treatment *Vs* Control 2	S	S	S

4.2.2 Yield Attributes and Yield

4.2.2.1 Number of Productive Tillers m^{-2}

Number of productive tillers m^{-2} was significantly influenced by the treatments and the results are presented in Table33.

Maximum number of productive tillers m^{-2} (529.67) was observed from hand weeding twice (T_{10}) which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6). Lowest number of productive tillers m^{-2} was recorded from weedy check (T_{11}).

4.2.2.2 Number of Spikelets per Panicle

Number of spikelets per panicle was significantly influenced by the treatments and the results are presented in Table 33.

Maximum number of spikelets per panicle was recorded by pyrazosulfuron ethyl *fb* hand weeding (T_5) and it was found to be on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). Weedy check (T_{11}) recorded minimum number of spikelets per panicle.

4.2.2.3 Number of Filled Grains per Panicle

Number of filled grains per panicle was significantly influenced by the treatments and the results are presented in Table 33.

Data on filled grains per panicle also observed the same trend of spikelets per panicle with the maximum number of filled grains per panicle in pyrazosulfuron ethyl *fb* hand weeding (104.64) and it was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). Lowest number of filled grains per panicle was recorded by weedy check (65.78) which was significantly inferior to all other weed management practices.

4.2.2.4 Sterility Percentage

The results are presented in Table 33.

Data showed that weed management practices have no significant influence on the sterility percentage. The sterility percentage was lowest (10.06) in hand weeding twice (T_{10}) and was maximum (19.02) in the weedy check (T_{11}) plots.

4.2.2.5 Grain Yield

The data on grain yield as influenced by the weed management practices are presented in Table 34.

The results indicated that the grain yield was significantly influenced by the various weed management practices. Grain yield recorded was highest (4817.67 ha^{-1}) for bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) and it was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). The lowest yield (2301.67 kg ha^{-1}) was registered by weedy check (T_{11}) which was significantly inferior to all other treatments.

4.2.2.6 Straw Yield

The data on straw yield as influenced by the weed management practices are presented in Table 34.

Among all the treatments, highest straw yield (7969.33 kg ha^{-1}) was recorded by bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). Weedy check (T_{11}) recorded lowest straw yield (4011.00 kg ha^{-1}).

4.2.2.7 Harvest Index (HI)

The results are presented in Table 34.

Data on harvest index indicated that the effect of weed management practices on harvest index was non-significant. Highest harvest index (0.38) was recorded with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}).

4.2.2.8 Thousand Grain Weight

The results are presented in Table 34.

Effect of weed management practices on thousand grain weight was found to be non-significant. Bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) reported highest thousand grain weight of 25.20 g while weedy check recorded the lowest of 20.27 g.

4.2.3. Pest and disease incidence

During the cropping period there was of mild incidence of stem borer (score-1) and random incidence of rice bug (score-7) and both were managed effectively. Mild incidence of sheath blight (score- 1) was also observed and the effect was negligible.

4.2.4. Herbicide phytotoxicity

No phytotoxic symptoms were observed in the crop. Treatments receiving pre-emergent application of oxyfluorfen recorded an unfavourable effect on crop establishment in terms of plant density even though no visual symptoms of phytotoxicity was observed in oxyfluorfen treated plots.

Table 33. Effect of weed management practices on productive tillers m^{-2}, spikelets per panicle filled grains per panicle and sterility percentage

Treatments		productive tillers m^{-2}	spikelets panicle^{-1}	filled grains panicle^{-1}	sterility percentage
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	428.00	102.93	88.03	14.14
T_2	T_1 + hand weeding at 40 DAS	503.33	117.17	104.33	11.02
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	513.67	111.90	100.01	10.58
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	434.67	101.39	85.29	15.83
T_5	T_4 + hand weeding at 40 DAS	491.00	117.86	104.64	11.11
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	509.67	112.14	98.66	11.71
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	383.33	89.20	75.53	14.71
T_8	T_7 + hand weeding at 40 DAS	473.00	94.46	79.39	15.91
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	423.33	98.36	84.27	14.06
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	529.67	112.97	101.58	10.06
T_{11}	Weedy check (Control 2)	362.33	81.81	65.78	19.02
	SEm (±)	18.237	2.522	3.566	3.994
	CD (0.05)	53.799	7.439	10.521	NS
	Treatment *Vs* Control 1	S	S	S	NS
	Treatment *Vs* Control 2	S	S	S	NS

Table 34. Effect of weed management practices on grain yield, straw yield, harvest index and thousand grain weight

	Treatments	grain yield (kg ha^{-1})	straw yield (kg ha^{-1})	harvest index	thousand grain weight (g)
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	3857.33	6491.33	0.37	24.07
T_2	T_1 + hand weeding at 40 DAS	4817.67	7969.33	0.38	24.40
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	4684.33	7749.33	0.38	25.20
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	3601.67	6031.00	0.37	22.23
T_5	T_4 + hand weeding at 40 DAS	4790.67	7825.67	0.38	22.83
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	4673.33	7708.00	0.38	24.20
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	3179.33	5483.67	0.37	23.87
T_8	T_7 + hand weeding at 40 DAS	3474.67	5815.67	0.37	22.57
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	3528.00	6103.33	0.37	23.77
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	4732.00	7793.67	0.38	22.93
T_{11}	Weedy check (Control 2)	2301.67	4011.00	0.36	20.27
	SEm (±)	207.450	256.479	0.010	1.425
	CD (0.05)	611.988	756.627	NS	NS
	Treatment *Vs* Control 1	S	S	NS	NS
	Treatment *Vs* Control 2	S	S	NS	S

4.3 CHEMICAL ANALYSIS

4.3.1 NPK uptake by crop

Results are presented in Table 35.

Nitrogen uptake by the crop was significantly influenced by the weed management practices. At harvest nitrogen uptake was highest (173.38 kg ha^{-1}) with hand weeding twice (T_{10}) which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6). The uptake was lowest (69.97 kg ha^{-1}) under the weedy check (T_{11}).

Data on phosphorus uptake by the crop indicated that weed management practices significantly influenced phosphorus uptake. Highest phosphorus uptake (42.47 kg ha^{-1}) was shown by hand weeding twice (T_{10}) which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6).

Pyrazosulfuron ethyl *fb* azimsulfuron (T_6) reported highest potassium uptake (258.45 kg ha^{-1}) at harvest and found to be on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and hand weeding twice (T_{10}).

Nutrient uptake by crop at harvest was lowest under the weedy check (T_{11}).

4.3.2 Nutrient Removal by Weeds

4.3.2.1 Nitrogen Removal by Weeds

Results obtained at 20, 40 and 60 DAS are presented in Table 36. Nitrogen removal by weeds was significantly influenced by the weed management practices at all the stages of observation. At 20 and 40 DAS nitrogen removal by weeds was lowest

Table 35. Effect of weed management practices on NPK uptake of crop, kg ha^{-1}

Treatments		Nitrogen	Phosphorus	Potassium
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	126.33	33.11	189.54
T_2	T_1 + hand weeding at 40 DAS	170.30	36.02	223.96
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	159.31	40.03	257.62
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	117.81	32.82	167.03
T_5	T_4 + hand weeding at 40 DAS	168.59	33.97	207.31
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	157.98	39.95	258.45
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	114.04	32.36	144.80
T_8	T_7 + hand weeding at 40 DAS	128.83	31.40	132.58
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	127.59	33.68	158.98
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	173.38	42.47	243.67
T_{11}	Weedy check (Control 2)	69.97	30.29	111.21
	SEm (±)	14.266	1.751	19.252
	CD (0.05)	42.085	5.164	56.795
	Treatment *Vs* Control 1	S	S	S
	Treatment *Vs* Control 2	S	S	S

for bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and was on par with pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6) at 20 DAS and with T_6 and hand weeding twice (T_{10}) at 40 DAS. Nitrogen removal by weeds was lowest in T_{10} at 60 DAS and was on par with T_5. Highest nitrogen removal was recorded in unweeded plot.

4.3.2.2 Phosphorus Removal by Weeds

Results obtained at 20, 40 and 60 DAS are presented in Table 37. Phosphorus removal by weeds was significantly influenced by the weed management practices at all crop growth stages. At 20 DAS, significantly lowest (0.118 kg ha^{-1}) phosphorus removal by weeds was reported with pyrazosulfuron ethyl *fb* hand weeding (T_5). At 40 DAS, bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) recorded lowest phosphorus removal (0.45 kg ha^{-1}) by weeds and was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6), oxyfluorfen *fb* azimsulfuron (T_9) and hand weeding twice (T_{10}). At 60 DAS lowest phosphorus removal was reported from T_{10} and was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), T_5 and T_6. Highest phosphorus removal was recorded with weedy check plots.

4.3.2.3 Potassium Removal by Weeds

Results obtained at 20, 40 and 60 DAS are presented in Table 38.

Potassium uptake by weed was significantly influenced by the weed management practices. At 20 and 40 DAS, potassium uptake by weeds was lowest in bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and it was on par with pyrazosulfuron ethyl *fb* azimsulfuron (T_6) at 20 DAS and with T_6 and hand weeding twice (T_{10}) at 40 DAS. At 60 DAS potassium uptake by weed was minimum (2.04 kg ha^{-1}) in T_{10} which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5) and pyrazosulfuron ethyl *fb* azimsulfuron (T_6). At all these stages

Table 36. Effect of weed management practices on nitrogen removal by weed, kg ha^{-1}

Treatments		20 DAS	40 DAS	60 DAS
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	1.06	5.33	13.35
T_2	T_1 + hand weeding at 40 DAS	1.23	5.81	4.42
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	0.80	1.35	4.59
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	1.10	5.74	9.46
T_5	T_4 + hand weeding at 40 DAS	0.99	5.82	3.56
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	0.87	1.74	4.75
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	1.49	6.96	15.13
T_8	T_7 + hand weeding at 40 DAS	1.50	7.53	6.19
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	1.79	3.57	8.49
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	1.58	1.95	2.33
T_{11}	Weedy check (Control 2)	3.84	13.06	22.47
	SEm (±)	0.088	0.395	0.621
	CD (0.05)	0.260	1.175	1.844
	Treatment *Vs* Control 1	S	S	S
	Treatment *Vs* Control 2	S	S	S

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

Treatments		20 DAS	40 DAS	60 DAS
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	0.86	2.09	3.61
T_2	T_1 + hand weeding at 40 DAS	0.43	1.73	1.27
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	0.62	0.45	1.68
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	0.95	2.12	3.36
T_5	T_4 + hand weeding at 40 DAS	0.12	1.94	1.45
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	0.76	0.65	1.39
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	1.05	2.38	4.61
T_8	T_7 + hand weeding at 40 DAS	0.38	2.65	1.78
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	0.99	1.01	2.52
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	1.59	0.70	0.83
T_{11}	Weedy check (Control 2)	2.17	3.99	5.97
	SEm (±)	0.012	0.194	0.209
	CD (0.05)	0.036	0.571	0.620
	Treatment *Vs* Control 1	S	S	S
	Treatment *Vs* Control 2	S	S	S

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

Treatments		20 DAS	40 DAS	60 DAS
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	2.10	4.72	12.37
T_2	T_1 + hand weeding at 40 DAS	2.29	5.01	4.53
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	1.14	0.92	3.49
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	2.32	5.33	11.13
T_5	T_4 + hand weeding at 40 DAS	2.23	5.29	4.35
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	1.15	1.12	3.52
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	3.00	7.23	15.92
T_8	T_7 + hand weeding at 40 DAS	3.09	8.10	7.10
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	2.66	2.48	8.56
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	2.53	1.29	2.04
T_{11}	Weedy check (Control 2)	6.28	10.52	23.65
	SEm (±)	0.281	0.485	0.982
	CD (0.05)	0.836	1.432	2.919
	Treatment *Vs* Control 1	S	S	S
	Treatment *Vs* Control 2	S	S	S

of crop growth potassium uptake was the highest under weedy check (T_{11}) and lowest uptake was reported by T_3 and T_6.

4.3.3 Nutrient Status of Soil after Experiment

The data on nutrient status of the soil after the experiment are presented in Table 39.

Significant difference exists between the treatments on the content of nitrogen, phosphorus and potassium in soil after the experiment. Nitrogen content of soil was maximum in bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) which was on par with bensulfuron methyl + pretilachlor *fb* hand weeding (T_2), pyrazosulfuron ethyl *fb* hand weeding (T_5), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). Highest phosphorus content in soil was also recorded by bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and was on par with T_2, T_6 and T_{10}. Potassium content in soil was highest in T_{10} and was on par with T_2, T_3, T_5 and T_6.

4.4 ECONOMIC ANALYSIS

Data on economics of various treatments worked out were statistically analysed and presented in Table 40.

4.4.1 Net Income

The data on economics of rice cultivation as influenced by the weed management practices showed that the gross income was significantly higher (Rs. 118595.33 ha^{-1}) for bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3), pyrazosulfuron ethyl *fb* hand weeding (T_5), pyrazosulfuron ethyl *fb* azimsulfuron (T_6) and hand weeding twice (T_{10}). But highest net income was recorded by T_6 (49462.00 ha^{-1}) and was on par with T_5, T_2 and T_3.

Table 39. Effect of weed management practices on nutrient status of soil after the experiment, kg ha^{-1}

Treatments		Nitrogen	Phosphorus	Potassium
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	357.08	21.80	135.50
T_2	T_1 + hand weeding at 40 DAS	418.54	22.99	178.60
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	447.39	24.32	185.68
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	363.77	21.89	148.65
T_5	T_4 + hand weeding at 40 DAS	403.52	22.27	173.20
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	418.08	24.30	187.40
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	313.04	20.88	137.10
T_8	T_7 + hand weeding at 40 DAS	303.27	20.85	141.21
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	300.31	20.47	145.51
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	422.30	24.07	187.90
T_{11}	Weedy check (Control 2)	293.68	20.34	124.74
	SEm (±)	24.902	0.675	5.355
	CD (0.05)	73.464	1.991	15.797
	Treatment *Vs* Control 1	NS	S	S
	Treatment *Vs* Control 2	S	S	NS

4.4.2 Benefit Cost Ratio

The benefit cost ratio was significantly influenced by the weed management practices. Among the different weed management practices pyrazosulfuron ethyl *fb* azimsulfuron (T_6) recorded highest benefit cost ratio (1.76) and it was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3). The next highest BC ratio (1.57) was recorded by bensulfuron methyl + pretilachlor *fb* hand weeding (T_2) and pyrazosulfuron ethyl *fb* hand weeding (T_5). Lowest B: C ratio (1.06) was recorded by weedy check (T_{11}).

4.4 ENZYME ANALYSIS

Enzyme analysis was done at 15, 30, 45 and 60 DAS and presented in Table 41.

At 15 DAS oxyfluorfen *fb* azimsulfuron (T_9) recorded highest dehydrogenase enzyme activity followed by application of oxyfluorfen alone. Pyrazosulfuron ethyl treated plots reported significantly higher soil dehydrogenase enzyme activity at 30, 45 and 60 DAS which was on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron (T_3) and weedy check (T_{11}) at 30 DAS. Dehydrogenase enzyme activity was higher at all crop growth stages than enzyme activity recorded before the crop from the experiment field. In general, dehydrogenase enzyme activity was highest at 45 DAS.

Table 40. Effect of weed management practices on economics

Treatments		Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	63615	95397.33	31782.33	1.50
T_2	T_1 + hand weeding at 40 DAS	75615	118595.33	42980.33	1.57
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	66015	115315.33	49300.33	1.75
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	63090	88954.00	25864.00	1.41
T_5	T_4 + hand weeding at 40 DAS	75090	117534.67	42444.67	1.57
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	65490	114952.00	49462.00	1.76
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	63110	79162.67	16052.67	1.25
T_8	T_7 + hand weeding at 40 DAS	74110	85806.67	11696.67	1.16
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	65510	87917.33	22407.33	1.34
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	79890	116350.67	36460.67	1.46
T_{11}	Weedy check (Control 2)	61890	65702.50	3812.50	1.06
	SEm (±)	-	4252.949	4252.949	0.063
	CD (0.05)	-	12546.411	12546.411	0.185
	Treatment *Vs* Control 1	-	S	NS	NS
	Treatment *Vs* Control 2	-	S	S	S

Seed-Rs.37/kg Grain-Rs.18/kg Straw- Rs. 4/kg Oxyfluorfen-Rs.190/100 ml
FYM-Rs.400/ton Urea- Rs.8/kg Rajphos- Rs.10/kg Pyrazosulfuron ethyl-480/120g
MOP-Rs.18/kg Man-Rs.558/day Woman-Rs.250/day Azimsulfuron-960 / 28 g
Bensulfuron methyl + Pretilachlor-Rs. 690/4 kg

Table 41. Effect of weed management practices on the effect of soil dehydrogenase enzyme activity (ppm TPF g^{-1} of soil 24 hr^{-1})

Treatments		15 DAS	30 DAS	45 DAS	60 DAS
T_1	Bensulfuron methyl + Pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre-emergence)	129.64	182.58	205.83	198.70
T_2	T_1 + hand weeding at 40 DAS	136.18	179.84	354.69	282.27
T_3	T_1 + Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	150.09	233.97	232.99	127.13
T_4	Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre – emergence)	172.96	246.97	567.85	256.58
T_5	T_4 + hand weeding at 40 DAS	174.11	131.67	540.68	370.24
T_6	T_4 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	180.14	83.49	159.93	242.19
T_7	Oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre -emergence)	275.47	155.94	230.45	295.82
T_8	T_7 + hand weeding at 40 DAS	239.89	123.69	429.05	336.46
T_9	T_7 +Azimsulfuron @ 30 g a.i. ha^{-1} (post emergence)	290.94	99.45	236.50	316.12
T_{10}	Hand weeding at 20 and 40 DAS (Control 1)	229.61	177.39	326.52	313.36
T_{11}	Weedy check (Control 2)	168.99	235.80	410.29	294.92
	SEm (±)	1.84	10.35	3.14	3.35
	CD (0.05)	5.43	30.52	9.27	9.87
	Treatment *Vs* Control 1	S	NS	NS	S
	Treatment *Vs* Control 2	S	S	S	S

Dehydrogenase activity before treatment application-144.54 ppm TPF g^{-1} of soil 24 hr^{-1}

Discussion

5. DISCUSSION

The dry sown (semi dry) system of rice cultivation is a unique and extensively adopted rainfed rice ecosystem in Kerala which constitute more than 60% of the area under rice during Kharif. The present study entitled "Herbicide based weed management for semi dry rice (*Oryza sativa* L.)" aimed to develop an economically viable weed management strategy for semi dry rice. The results of the study are discussed briefly in this chapter.

5.1 OBSERVATION ON WEEDS

5.1.1 Weed Composition

The result of the present study revealed that there was substantial diversity of weed flora in the experimental site. Since the system was semi dry rice, both upland and wetland weeds were there. Upland weed flora dominated the field up to 45 DAS and thereafter when the field got flooded with monsoon showers wetland weeds occupied the field. The observations made on the weed flora at different stages indicated that broad leaved weeds were more diverse (five species) followed by sedges and grasses (four species each). Broad leaved weeds such as *Cleome rutidospermum*, *Heliotropium indicum and Commelina jacobi* were observed upto flooding whereas sedges *Cyperus iria, Cyperus difformis, Cyperus compressus* and grass species *Echinochloa stagnina, Echinochloa colona,* and *Oryza sativa f. spontanea* were found to be dominant after flooding. The results are in conformity with the findings of Anitha *et al*. (2010) who reported abundance of weeds of diverse nature in direct seeded semi dry system of rice cultivation. The species composition of the accompanying weed flora may change with management practices (Singh *et al*., 2015) and the occurrence of weeds varied with season (Abraham *et al*., 1990). Kuyeonchung *et al*. (2002) also opined that weed diversity was strongly affected by the cultivation methods. Chauhan and Johnson (2010) reported weedy rice as a major problem in direct-seeded rice in

Asia. *Eclipta alba, Ludwigia perennis, Isachne miliacea* and *Fimbristylis miliacea* were present throughout the experiment competing with rice crop. This observation was in conformity with the findings of Singh *et al*. (2005) who reported that in direct seeded rice *Echinochloa colona, Cyperus difformis, Fimbristylis sp.,* and *Commelina sp.* were the dominating weed flora.

5.1.2. Effect of Weed Management Practices on Weed Growth

5.1.2.1. Weed Density

Vegetation analysis parameters *viz*., Absolute density (Ad), Relative density (Rd), Absolute frequency (Af), Relative frequency (Rf), Importance value (IV) and summed dominance ratio (SDR) of grasses, broad leaved and sedges were worked out to study the influence of weed management practices on the relative dominance of different classes of weeds. The most commonly used methods for quantitative assessment of weed response are weed count and weed dry weight (Rana *et al*., 2002).

Vegetation analysis parameters clearly indicated the dominance of broad leaved weeds in terms species diversity. During the early stages, absolute density of grasses recorded was comparatively low. There was significant reduction in the population of all the three different types of weeds with the management practices tested.

The effect of pre-emergent herbicides lasted only up to 15-20 DAS and they were very effective in controlling broad leaved weeds as evidenced by zero absolute density at 15 DAS. There are reports of the effectiveness of pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} in controlling broad leaved weeds and sedges in DSR (Gopal *et al*., 2010). According to Sanjay *et al*. (2013) bensulfuron methyl + pretilachlor @ 0.06 + 0.60 kg a.i. ha^{-1} was effective for controlling weeds in aerobic rice. Mahajan and Chauhan (2013) also reported the effectiveness of pre- emergence application of pyrazosulfuron (15 g a.i. ha^{-1}) in reducing total weed biomass by 68 per cent compared to the untreated control in dry seeded aromatic rice. Thus it could be inferred that both bensulfuron methyl + pretilachlor and pyrazosulfuron ethyl are promising broad spectrum herbicides for early season weed control in semi dry system (Plate: 4). Treatments receiving pre-emergence application of oxyfluorfen recorded higher absolute density of weeds than bensulfuron methyl + pretilachlor or pyrazosulfuron ethyl treated plots. Though no visual symptoms of phytotoxicity was observed in oxyfluorfen treated plots, its unfavourable effect on seed germination reduced the crop density. Reduced crop density at the initial stages might have resulted in higher absolute density of weeds at the critical stages of crop growth in oxyfluorfen treated plots.

From the results, it was evident that the application of pre-emergent herbicides (except oxyfluorfen) followed by hand weeding at 40 DAS, was effective in controlling grasses, sedges and broad leaved weeds. Rajagopal (2013) reported that bensulfuron methyl + pretilachlor was a promising herbicide for early season weed control in transplanted rice. The need for integrating an initial weed management practice with hand weeding at critical stages is supported by reports of Sunil *et al*. (2010) who observed that pre-emergence application of bensulfuron methyl + pretilachlor (6.6 GR) had to be integrated with hand weeding at 40 DAS to obtain satisfactory weed control and higher grain and straw yield.

The diverse weed flora in dry seeded rice fields usually necessitated the use of two or more herbicides for wide spectrum weed control (Gianessi *et al*., 2002). As per Kim and Ha (2005) the first herbicide has to be used at the dry period just before rice emergence and the other at the flood period. In the present study, weed management practices involving application of pre-emergent herbicides followed by post emergent application of azimsulfuron was found effective in reducing broad leaved weeds and sedges. However, the pre-emergent herbicides tried were ineffective in controlling the grass species present during the initial stages *i.e., Isachnea miliacea*. The post emergent herbicide, azimsulfuron was applied at 25 DAS and the treatment effect in

A. Bensulfuron methyl + Pretilachlor

B. Pyrazosulfuron ethyl

C. Oxyfluorfen

D. Weedy Check

Plate 4: Effect of pre-emergent herbicides at 15 DAS

reducing weed density was not evident at 20 DAS. However, its efficiency in managing sedges and broad leaved weeds was clearly shown in the data taken at 40 DAS. At these stages, the weed growth was lower in the plots treated with azimsulfuron. However, grassy weeds like *Echinochloa sp.* and weedy rice that appeared after flooding were not controlled by azimsulfuron application at 25 DAS. This was in conformity with the findings of Pacanoski and Glatkova (2009) who reported that azimsulfuron gave excellent control of annual and perennial weeds in direct sown rice except for perennial grass. Chauhan (2013) reported that due to physiological and morphological similarities with cultivated rice, selective herbicides to control weedy rice are not available. Since, the weed density of grasses were low compared to other weeds, the use of bensulfuron methyl + pretilachlor, pyrazosulfuron ethyl and azimsulfuron resulted in reduced absolute density of weeds at the critical stages of crop growth (Fig: 2).

5.1.2.2 Weed Dry Weight

The data on weed dry weight also followed the same pattern as weed density discussed earlier. Weedy check recorded highest weed dry weight with a steady increase with age at all stages of observation. The effect of azimsulfuron applied at 25 DAS was evident from observation at 40 DAS where the weed dry weight was lowest for weed management practices involving application of pre and post emergent herbicides which corresponds to the critical period of weed management. The effect of weed management practices involving hand weeding at 40 DAS was evident from observations at 60 DAS. At 60 DAS weedy check recorded weed dry weight of 95.48 g m^{-2} whereas it was only 25.55 and 26.03 g m^{-2} in treatments bensulfuron methyl + pretilachlor *fb* hand weeding and pyrazosulfuron ethyl *fb* hand weeding respectively (Fig: 3). Similar results on the effectiveness of a pre-emergent herbicide followed by a post emergent herbicide for lower weed dry weight during critical period of weed

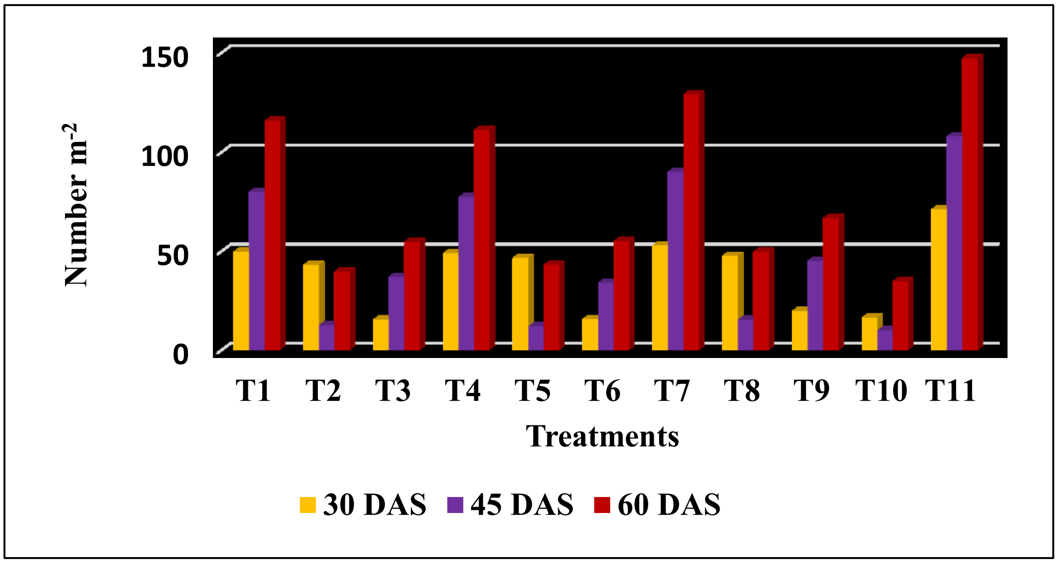
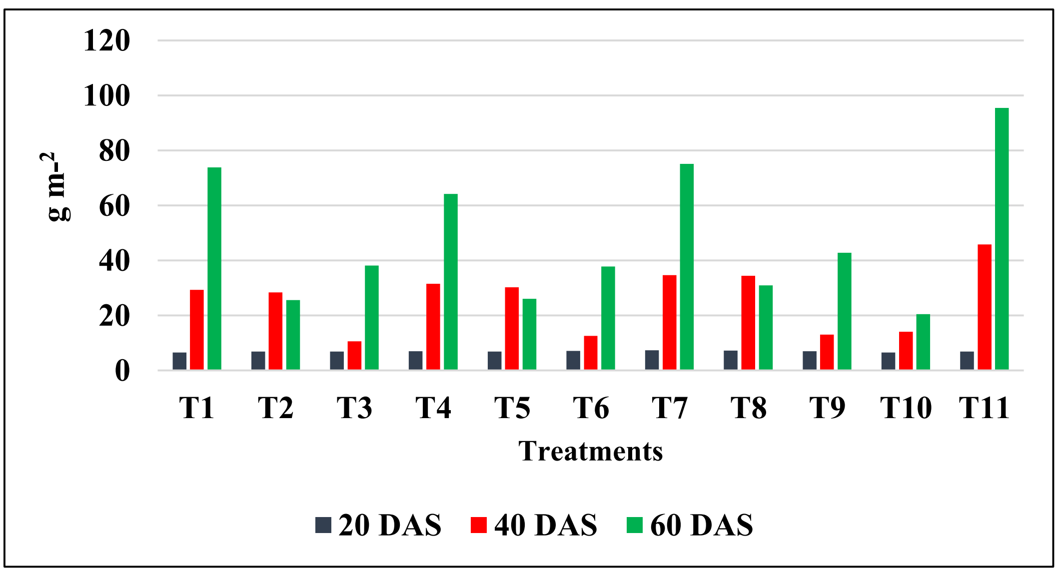


Fig 2: Effect of weed management practices on total weed density (number m^{-2})

Fig 3: Effect of weed management practices on total weed dry weight (g m^{-2})



competition was reported by Uma *et al*. (2014). The weed dry weight recorded by the weedy check was high at all stages of crop growth.

5.1.2.3 Weed Control Efficiency

The relative reduction in weed dry weight due to weed management practices measured by the index weed control efficiency clearly indicated the superiority of the treatment hand weeding twice (20 and 40 DAS) throughout the crop growth period. Pre-emergence application of herbicides followed by post emergence application of azimsulfuron effectively controlled weed growth during the critical period of crop weed competition (40 DAS). Oxyfluorfen *fb* azimsulfuron also recorded weed control efficiency on par with weed control efficiency of other azimsulfuron treated plots at 40 DAS. But the rate of weed infestation was higher for oxyfluorfen treated plots due to the poor crop establishment. Treatments with hand weeding at 40 DAS in combination with pre-emergent herbicide application recorded higher weed control efficiency at 60 DAS and at harvest (Fig: 4). Saha (2006) reported the efficacy of all the new generation herbicides in achieving better weed control efficiency and higher yield of rice irrespective of their dose of application compared to the traditional recommended rice herbicides. Samanta *et al*. (2010) also reported the superiority of sulfonylurea (SU) based products in helping farmers around the globe to meet their crop protection needs in effective and environmentally sound ways.

5.1.2.5 Nutrient Removal by Weeds

Depletion of nutrients from soil is a function of dry weight and nutrient content in weed plants. Unweeded control resulted in highest depletion of nutrient by weeds throughout the crop growth period. This can be attributed to the fact that weeds grow faster than crop plants leading to high crop weed competition. Similar results were reported by Singh *et al*. (2005) who observed that in direct seeded rice, uptake of nutrients by weeds was higher under weedy check (34.8, 15.6 and 42.3 kg N, P and K ha^{-1}). In the present study, nutrient removal by weeds was lowest for hand weeded at 20 and 40 DAS (2.33, 0.83 and 2.04 kg ha^{-1} N, P and K).

Weed management practices involving combination of either hand weeding or post emergence application of azimsulfuron with pre-emergence application of either bensulfuron methyl + pretilachlor or pyrazosulfuron ethyl recorded lower nutrient removal by weeds due to lower weed population and dry weight recorded by these treatments (Fig: 5-7). The results are in conformity with the reports of Yadav (2006), according to which nutrient uptake by weeds was minimum under pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} in transplanted rice. Singh *et al.* (1999) also reported that weed free condition resulted in lower uptake of nitrogen by weeds at harvest.

On the basis of the weed data it could be inferred that bensulfuron methyl + pretilachlor *fb* hand weeding, bensulfuron methyl + pretilachlor *fb* azimsulfuron, pyrazosulfuron ethyl *fb* hand weeding and pyrazosulfuron ethyl *fb* azimsulfuron were the most effective weed management practices which had detrimental impact on weed density and dry matter accumulation.

5.2 OBSERVATIONS ON CROP

5.2.1 Effect of Weed Management Practices on Crop Growth Characters

The results clearly indicated the significance of weed management using new generation herbicides in rice. The data on growth parameters revealed that extent of weed competition was very high under dry direct seeded system which was evident from the significantly low values of plant height and number of tillers recorded under weedy check.

The weed management practices had a favourable effect on plant height with treatments recording high weed control efficiency exhibiting the highest plant height at all stages of observation. Highest plant height was recorded for treatments involving post emergence application of azimsulfuron with pre-emergent herbicides *viz*.,

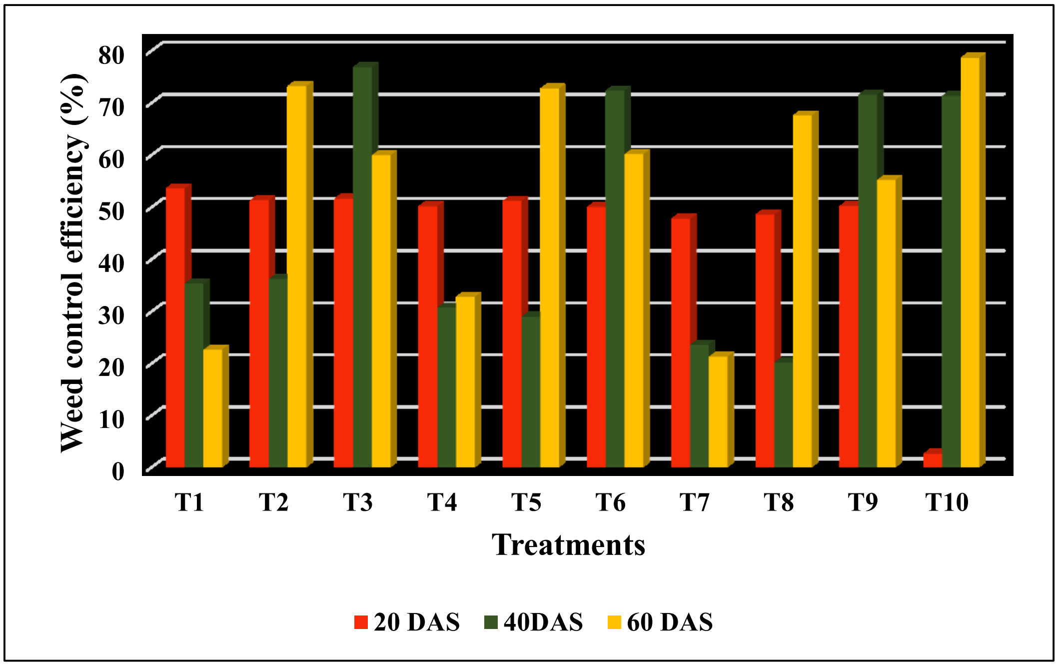


Fig 4: Effect of weed management practices on total weed control efficiency, per cent

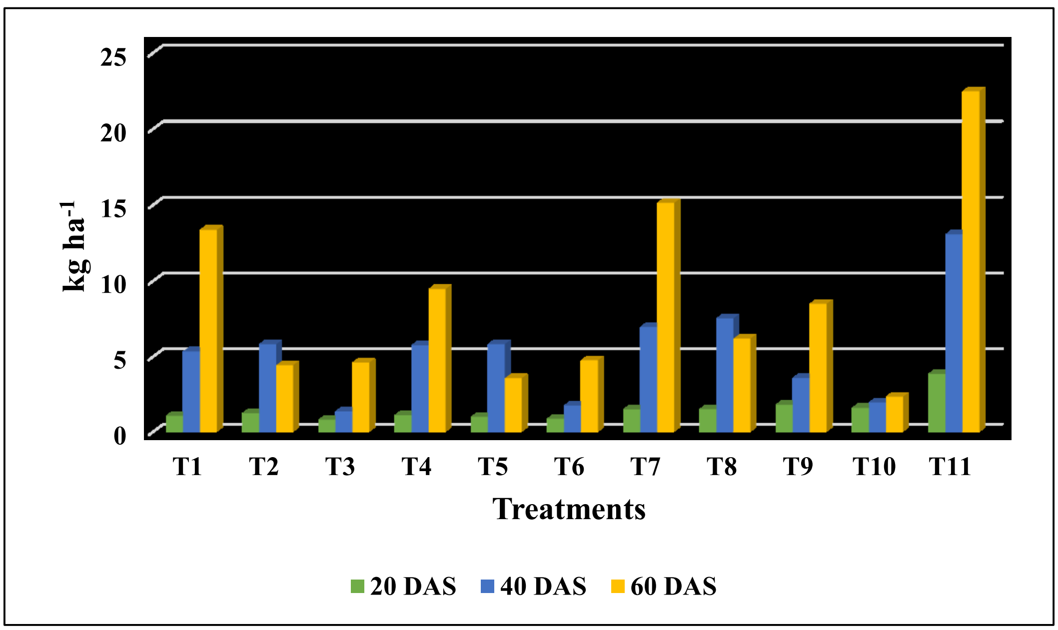


Fig 5: Effect of weed management practices on nitrogen removal by weeds, kg ha^{-1}

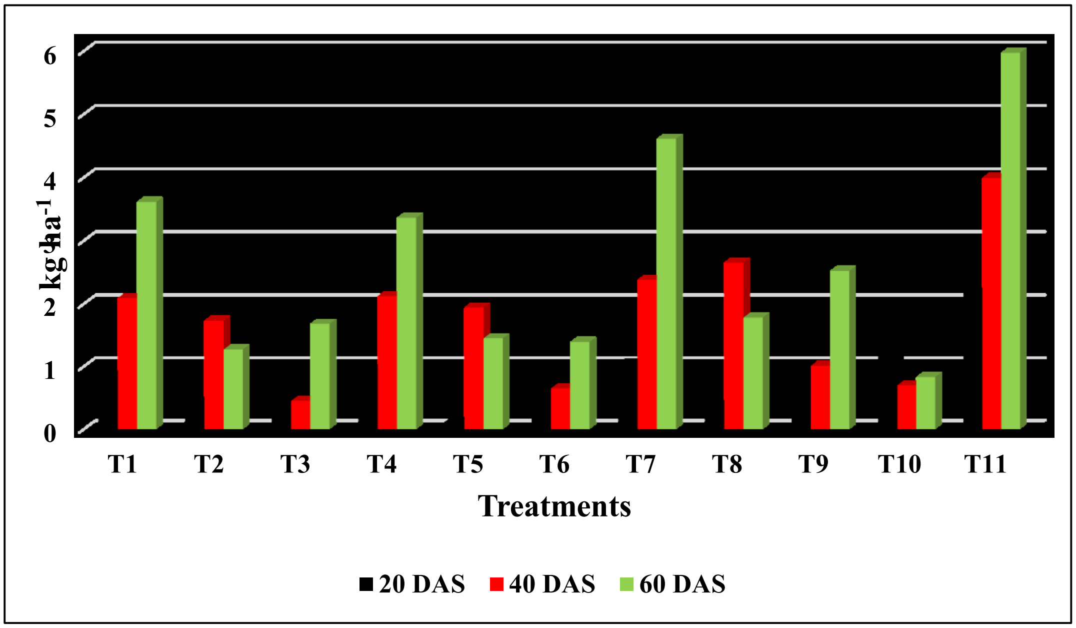


Fig 6: Effect of weed management practices on phosphorus removal by weeds kg ha^{-1}

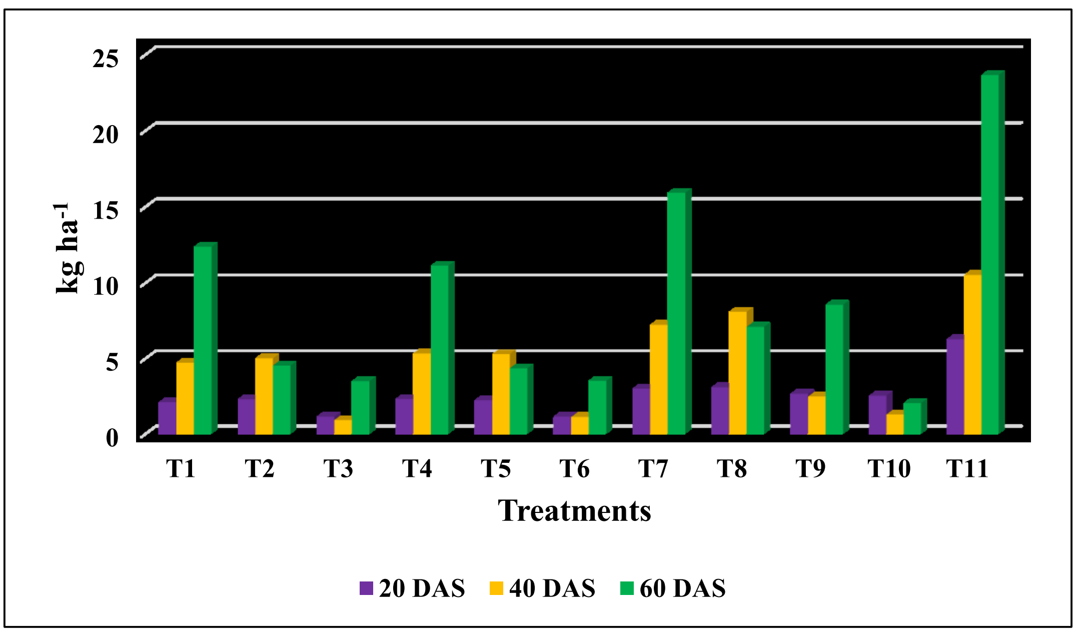


Fig 7: Effect of weed management practices on potassium removal by weeds, kg ha^{-1}

bensulfuron methyl + pretilachlor or pyrazosulfuron ethyl at all stages of crop growth. The increase in plant height was possibly due to better weed suppression at the early growth stage which resulted in maximum utilization of moisture and nutrients by the crop. At harvest, the treatments such as bensulfuron methyl + pretilachlor *fb* hand weeding and pyrazosulfuron ethyl *fb* hand weeding also recorded higher plant height. The crop weed competition was less in these treatments as evident from the low values of absolute density and weed dry matter production.

Grain yield in rice is closely related to the number of productive tillers per unit area which is dependent on the total number of tillers per unit area. At all stages of growth, pre-emergence application of bensulfuron methyl + pretilachlor *fb* azimsulfuron and pyrazosulfuron ethyl *fb* azimsulfuron recorded highest tiller count and it remained on par with hand weeding twice. These treatments were on par with bensulfuron methyl + pretilachlor *fb* azimsulfuron at 60 DAS. This might be due to the lower crop-weed competition on account of better weed control efficiency offered by these treatments.

5.2.2 Effect of Weed Management Practices on Yield Attributing Characters and Yield

Yield is the ultimate reflection of all the yield attributes. The weed management practices enhanced yield and yield attributes considerably over unweeded check. The productive tiller count was found maximum under hand weeding twice (control-1) which remained on par with the weed management practices including pre-emergent herbicides (except oxyfluorfen) *fb* hand weeding and pre-emergent herbicide *fb* azimsulfuron. It was 73-74 per cent higher than weedy check which is perhaps due to the lower tiller production in unweeded check. Radosevich and Roush (1990) reported that crop plants under competitive stress produced fewer tillers and fewer panicle bearing tillers. A similar decrease in panicle production to the tune of 37 per cent due to rice-weed competition was also reported by Biswas *et al*. (1992).

Spikelets panicle^{-1} and filled grains panicle^{-1} was highest for pyrazosulfuron ethyl *fb* hand weeding and was statistically on par with bensulfuron methyl + pretilachlor *fb* either hand weeding or azimsulfuron and with pyrazosulfuron ethyl *fb* azimsulfuron. Even though these treatments recorded lower sterility percentage and higher thousand grain weight, the effect of weed management practices on these aspects were found to be non-significant. These results are well corroborating with the findings of Sangeetha *et al*. (2009) who reported that maximum weed growth in unweeded control resulted in lowest panicles per plant as well as grains per panicle.

Maximum grain yield of 4817.67 kg ha^{-1} was recorded with bensulfuron methyl + pretilachlor *fb* hand weeding which was on par with pyrazosulfuron ethyl *fb* hand weeding, bensulfuron methyl + pretilachlor *fb* azimsulfuron, pyrazosulfuron ethyl *fb* azimsulfuron and with hand weeding twice. The effective control of weeds starting from the early crop growth stage and during the critical period might have resulted in better growth and yield of rice. These results are in conformity with the findings of Awan *et al*. (2015) who reported that application of a single herbicide in dry seeded rice systems often provides sub optimal weed control because of complex weed flora and long critical periods. Also single herbicide application hardly provides satisfactory yield in dry seeded rice because of the narrow spectrum of herbicide activity. According to Singh and Sharma (1994) one pre-emergent herbicide followed by a hand weeding had a significant positive influence on yield attributing characters of rice. Therefore the best weed control option in dry seeded rice system was the application of a pre-emergent herbicide followed by a post emergent herbicide (Chauhan and Opena, 2012) or a pre-emergent herbicide followed by a hand weeding. A maximum straw yield of 7969.33 kg ha^{-1} was recorded with bensulfuron methyl + pretilachlor *fb* hand weeding. As in the case of yield contributing characters, grain and straw yield were also lowest under weedy check which is a reflection of the severe crop weed competition and lesser availability of nutrients to the crop plants. The enhanced yield attributes and yield recorded may be due to lower density and dry weight of weeds and higher weed control efficiency which provided a competition free environment for better uptake of nutrients by the crop. Increase in rice grain yield with increase in weed control efficiency has been reported by so many workers (Kumari and Prasad, 2003; Jayasuriya *et al.*, 2011). Naturally, weedy check resulted in maximum yield loss as evidenced from the studies of Chauhan *et al*. (2015) where the sequential application of pre-emergence followed by post-emergence herbicides produced 58-504 per cent higher rice grain yield than the weedy plots. A weed free healthy crop stand can produce robust grains with more thousand grain weight (Tomar *et al.*, 2003).

The treatments involving application of pre-emergent herbicides alone could control weeds only up to 20 DAS which may be the reason for lower yield in these treatments. Several studies reported that to prevent the simultaneous emergence of weeds with the rice crop pre-emergence herbicides should be applied which allow the crop to grow in a relatively weed free environment in early growth stages (Chauhan and Abhugo, 2013). The results of the present study revealed the importance of maintaining weed free situation upto 60 DAS in semi dry system. As per KAU (2011) it is recommended to keep the field weed free during the critical period of crop weed competition either by hand weeding or by use of herbicides. Chauhan and Mahajan (2014) reported that the first 15 to 60 days after sowing can be considered as critical period for crop-weed competition in dry seeded rice. It was evident from the present study that the yield realized was highest in treatments wherein the field was kept weed free during critical period upto 60 DAS and that is specifically the reason attributable for the better performance of weed management practices involving pre *fb* post emergent herbicide application or pre *fb* hand weeding at 40 DAS. The application of pre-emergent herbicide followed by post-emergent herbicide had higher yields because of its higher WCE upto 40 DAS. However, in plots receiving pre *fb* hand weeding at 40 DAS there was season long weed control upto 60 DAS which contributed to high yield in these plots. The least crop weed competition experienced in these treatments was purely the reason for higher grain and straw yield (Fig: 8).

The yield attributing characters recorded in treatments involving oxyfluorfen application was lower compared to all other weed management practices. The unfavourable effect of oxyfluorfen on rice seed germination was reflected on crop density and growth with a grain yield of 3474.67 kg ha^{-1} in oxyfluorfen *fb* hand weeding and 3528.00 kg ha^{-1} in oxyfluorfen *fb* azimsulfuron. Lower crop density in field led to the occupancy of interspaces by weeds as evident from the higher total weed dry weight recorded in oxyfluorfen treated plots at 40 DAS. Reshma (2014) also reported a grain yield of 3500.00 kg ha^{-1} for oxyfluorfen *fb* hand weeded plots in aerobic rice.

Even though the harvest index exhibited a similar trend as grain yield and straw yield the effect of weed management practices on harvest index was found to be non-significant. Harvest index was observed to increase with weed control efficiency.

5.2.3 Effect of Weed Management Practices on Nutrient Uptake by Crop

Weed management practices significantly influenced the nutrient removal by the crop. As there was not much variation in the content of nutrients the uptake of nutrients followed the same trend as that of dry matter production of crop. In general, highest nutrient uptake was recorded from treatments receiving pre-emergent herbicide (bensulfuron methyl + pretilachlor or pyrazosulfuron ethyl) *fb* post emergent application of azimsulfuron. Higher nitrogen and potassium uptake was reported by bensulfuron methyl + pretilachlor *fb* hand weeding, bensulfuron methyl + pretilachlor *fb* azimsulfuron, pyrazosulfuron ethyl *fb* hand weeding, and pyrazosulfuron ethyl *fb* azimsulfuron along with hand weeding twice. Phosphorus uptake was significantly higher for treatments with pre and post emergent herbicides (bensulfuron methyl + pretilachlor *fb* azimsulfuron, pyrazosulfuron ethyl *fb* azimsulfuron) and hand weeding twice followed by pre-emergence herbicide *fb* hand weeding at 40 DAS. Reduction in weed population and weed dry weight recorded in these treatments provided a competition free environment for rice and in turn enhanced the uptake of nutrients. These results are in agreement with the findings of Madhukumar *et al*. (2013b) who reported that bensulfuron methyl + pretilachlor recorded higher nutrient uptake by rice due to lower weed population and weed dry weight. Lowest uptake of nutrients by the crop was recorded in unweeded plots due to the negative impact on yield attributes imposed by competition from weeds (Fig: 9).

5.2.4 Effect of Herbicide Phytotoxicity on Crop

The pre-emergent herbicides were applied on the next day of sowing on to the soil having sufficient moisture using a sprayer fitted with floodjet nozzle. In the present study, none of the pre-emergent herbicide treatments showed any visual phytotoxic symptoms on the emerging rice seedlings. Though the oxyfluorfen treated plots showed no visual symptoms of phytotoxicity, crop density and growth was lower at the initial stages compared to other weed management practices. On the contrary, Reshma (2014) reported the visual phytotoxic symptoms of oxyfluorfen on crop in aerobic rice upto 15 days after spraying. In case of post emergent herbicide azimsulfuron, no visual symptoms of phytotoxicity was observed in rice which was in line with the findings of Yadav *et al*. (2008).

From the results of the study, it could be concluded that both bensulfuron methyl + pretilachlor and pyrazosulfuron were safe pre-emergent herbicides for dry sown (semi dry) system of rice cultivation without any phytotoxicity to rice plants. Also, for post emergent weed control in semi dry rice system, azimsulfuron can be safely recommended without any phytotoxicity to rice plants. Crop selectivity of pyrazosulfuron ethyl (Halder *et al*., 2005) and bensulfuron methyl + pretilachlor and azimsulfuron (Rajagopal, 2013) was reported earlier in transplanted rice system.

5.3 NUTRIENT STATUS OF SOIL AFTER THE EXPERIMENT

The final nutrient status of the soil was significantly influenced by the various weed management practices. The nutrient status of soil after the experiment registered a marginal decrease over the initial status. Soil nutrient status remained high for

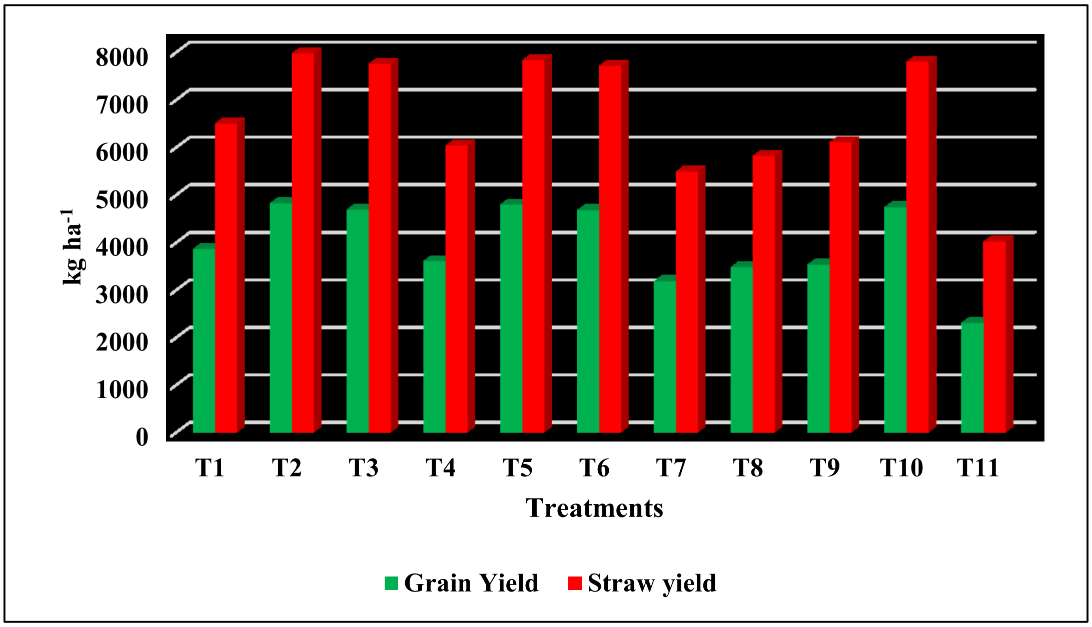


Fig 8: Effect of weed management practices on grain and straw yield, kg ha^{-1}

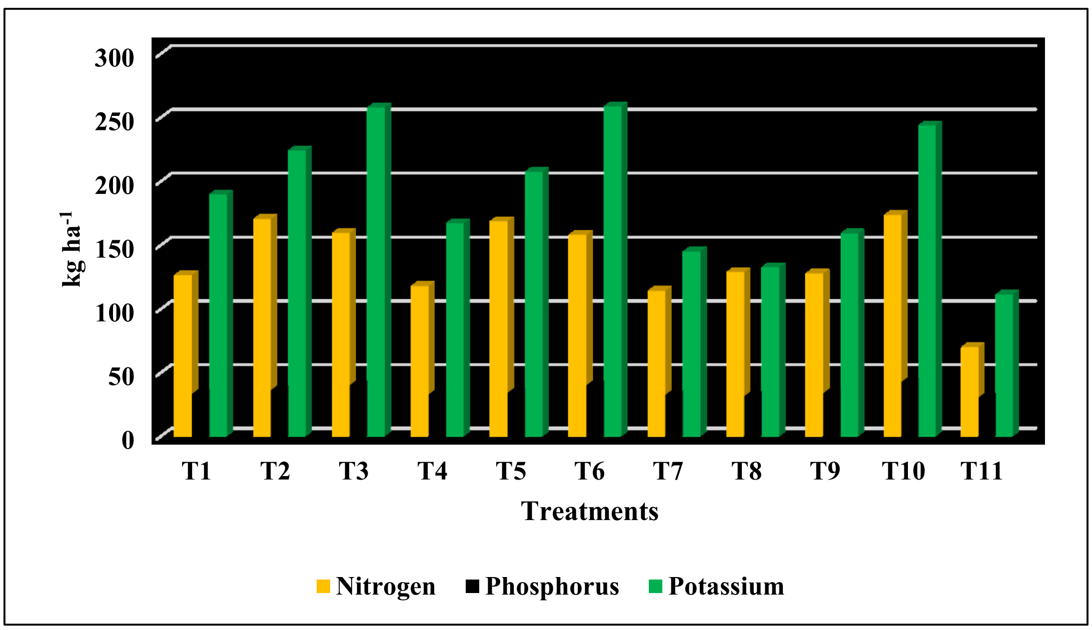


Fig 9: Effect of weed management practices on nutrient uptake by crop, kg ha

bensulfuron methyl + pretilachlor *fb* hand weeding, bensulfuron methyl + pretilachlor *fb* azimsulfuron, pyrazosulfuron ethyl *fb* hand weeding, and pyrazosulfuron ethyl *fb* azimsulfuron along with hand weeding twice which indicated its effectiveness in managing weeds (Fig: 10). Maximum depletion of nutrient was observed in weedy check plot which highlight the competitive nature of weeds. Weed infestation depleted the soil by 24.7 kg nitrogen, 5.8 kg phosphorus and 63.4 kg potassium ha^{-1} in one season (Sharma, 2007).

5.4 ECONOMICS OF WEED MANAGEMENT

Economics of weed management in semi dry rice revealed that the net returns was significantly influenced by the weed management practices followed. The net income and benefit cost ratio were significantly higher under all the herbicide treated plots compared to weedy check. Net income for bensulfuron methyl + pretilachlor *fb* azimsulfuron and pyrazosulfuron ethyl *fb* azimsulfuron was 49300.33 and 49462.00 Rs ha^{-1} respectively. But bensulfuron methyl + pretilachlor *fb* hand weeding and pyrazosulfuron ethyl *fb* hand weeding treatments recorded a net income of 42980.00 and 42444.67 Rs ha^{-1} respectively only, even though the yield recorded by these treatments were highest. The higher cost of labour involved in the hand weeding treatment may be the reason for this lower net income. One third of the total cost of cultivation was meant for meeting the labour charges of hand weeding. Hasanuzzaman *et al.* (2007) reported that weed control cost is maximum for hand weeding (2 hand weedings at 30 and 45 DAT) and the lowest for chemical weed management. The economics of the study in terms of B: C ratio favoured the use of new generation herbicides for weed management in semi dry rice. Yadav (2006) reported that pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} recorded higher net income and B: C ratio while Uma *et al.* (2014) reported bensulfuron methyl 0.6% + pretilachlor 6% fb hand weeding at 40 DAS recorded higher net income and B: C ratio in transplanted rice. It was obvious that hand weeding was effective in controlling the weeds but the cost of cultivation was much higher bringing down the net income and B: C ratio favouring new generation herbicide based weed management for economic control (Fig: 11). The results of the present study corroborate the observations made by Kathiresan (2001) that the use of low dose high efficiency herbicides will reduce the total volume of herbicide use and make weed management easier and economic.

5.5 ENZYME STUDIES

The evaluation of soil enzyme activities may provide useful information on microbial activity and be helpful in establishing the effects of soil specific environmental conditions (Andreoni *et al*., 2004). Herbicides not only affect the target organisms, but also microbial communities in soil. The dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils (Burns, 1978). However soil dehydrogenase was estimated in order to determine overall microbial activity (Baboo *et al*., 2013).

In general, from the data it was observed that the dehydrogenase enzyme followed an asymptotic behaviour. This pattern can be described as an increase at initial stages reaching a maximum at active growth stage followed by a decline. At 45 DAS it showed an increase and after that at 60 DAS again a declining trend was seen. The dehydrogenase activity was significantly higher at 45 DAS compared to other time of plant growth *viz*., 15, 30 and 60 DAS. This might be due to the spurt in microbial population with the addition of exudates or rhizodeposition during the growth stages *i.e*., up to 45 days. In a study to out find the effect of herbicides on dehydrogenase activity in flooded rice soil the dehydrogenase activity increased up to 40 days after transplanting (DAT), after which the activity decreased with no significant difference at 120 DAT. The sharp increase at 20 and 40 DAT represented the most active growth period of rice crop and could be due to the proliferation of anaerobic micro-flora in the rhizosphere. (Rao and Raman, 1998). In the present study, the highest activity of dehydrogenase recorded at 45 DAS irrespective of the treatment may be due to the fact

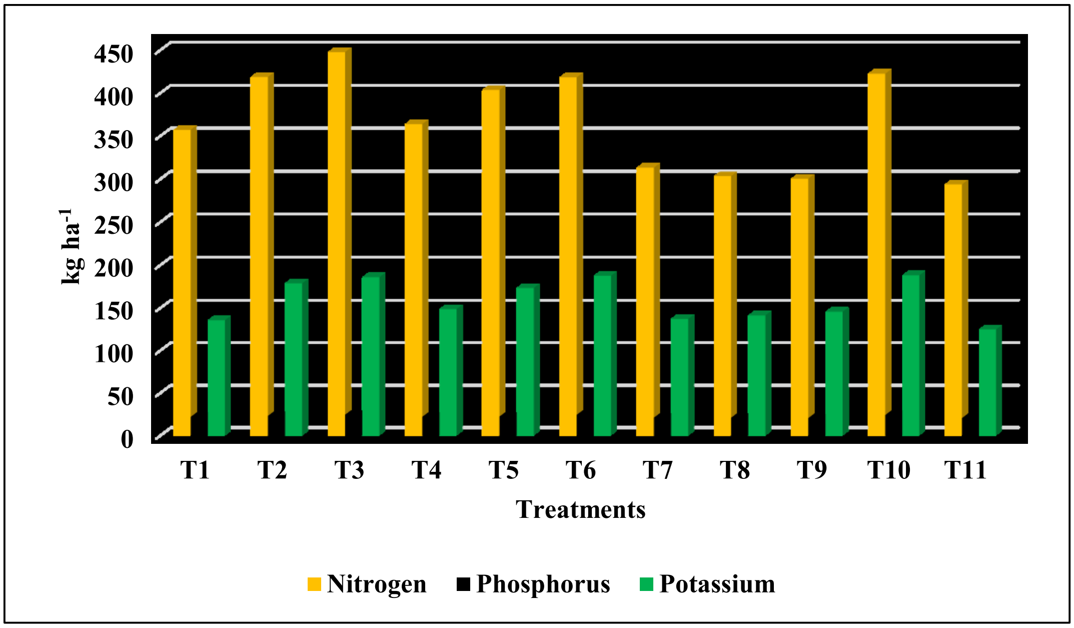


Fig 10: Effect of weed management practices on soil nutrient status after the experiment, kg ha^{-1}

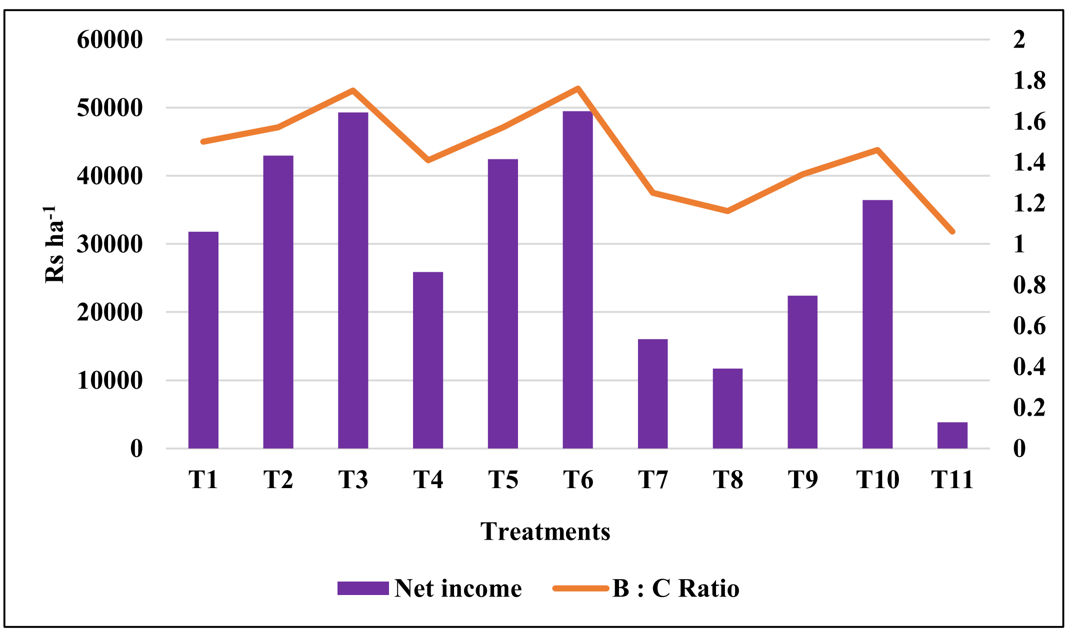
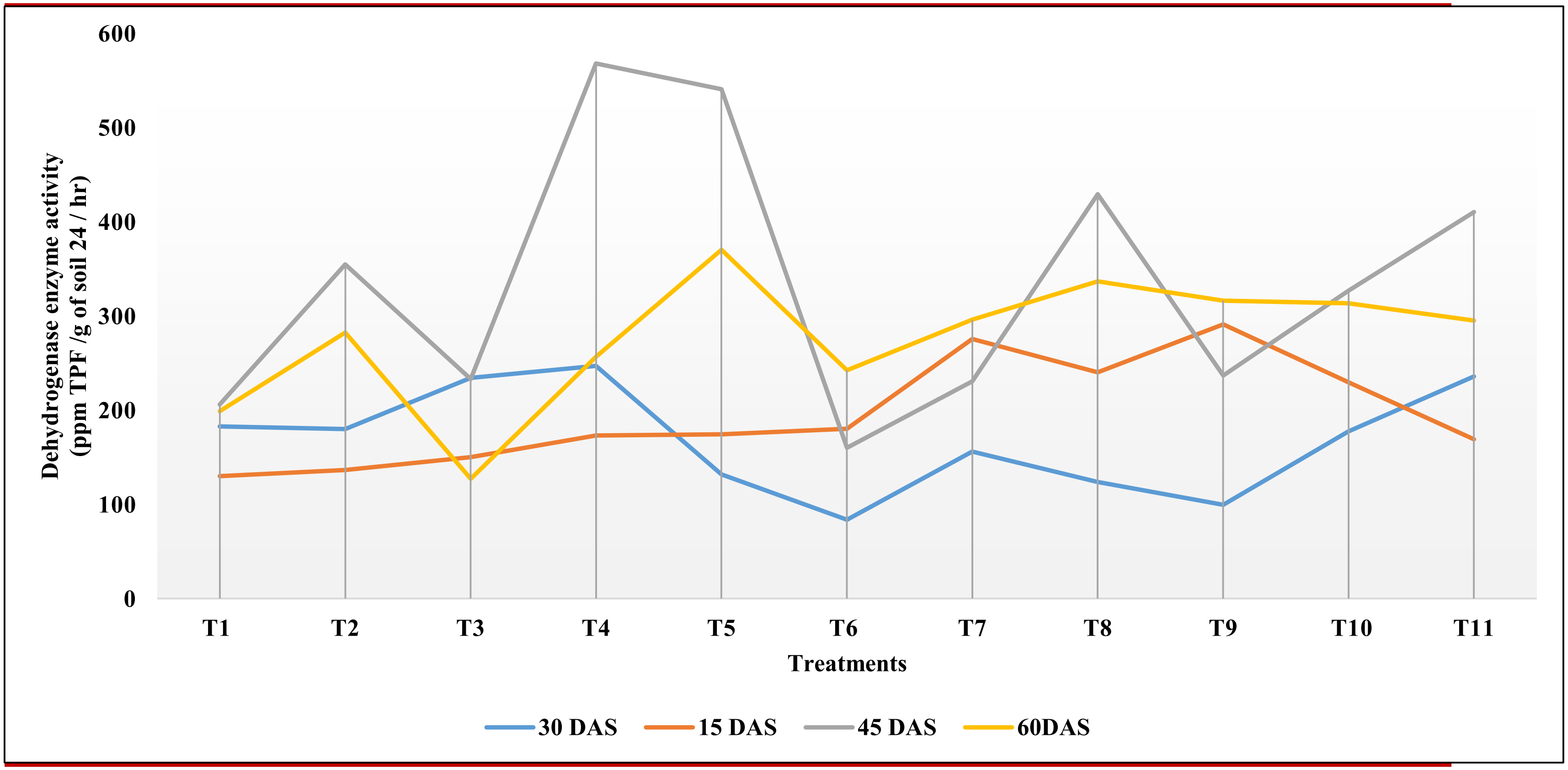


Fig 11: Effect of weed management practices on economics of weed management

that it corresponds to the active growth stage of the crop and there is enhanced rhizosphere activity coupled with higher moisture content of soil after commencement of flooding from 40 DAS in semi dry rice. Besides the herbicides used at recommended rate were non-inhibitory on dehydrogenase activity and hence found to be safe for soil microbial activity and soil ecosystem. Since dehydrogenase is an endo enzyme, its activity was found maximum at active growth stage (Fig: 12).

An increased dehydrogenase activity was observed in control plots. At 15 DAS the activity was seen higher for plots treated with oxyfluorfen as pre-emergent irrespective of the other weed control operations followed which was on par with enzyme activity recorded from hand weeded plot. But at 30 DAS this effect got reduced along with a general reduction in enzyme activity in all treatments except in weedy check which was on par with pyrazosulfuron ethyl treated plots. At 45 DAS plots treated with pyrazosulfuron ethyl showed maximum activity followed by weedy check which was significantly different from all other treatments. At 60 DAS also pyrazosulfuron ethyl treated plots recorded higher enzyme activity which was significantly different from all other herbicide treated plots including weedy check. Higher enzyme activity in pyrazosulfuron ethyl treated plots gave an indication that this herbicide was safe to microorganisms and non-inhibitory to dehydrogenase activity when used at recommended dose. Results are in conformity with the findings of Yadav (2006) who reported that pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} did not cause any long term lethal effect on soil microorganisms and soil environment. Bensulfuron methyl+ pretilachlor recorded comparatively lower values of dehydrogenase activity at all the stage of growth, which may be due to comparatively higher dose.

Fig: 12. Dehydrogenase enzyme activity (ppm TPF g^{-1} of soil 24 hr^{-1}) as influenced by herbicide treatments



The present study revealed that the adoption of an appropriate weed management strategy is critical in semi dry system of rice cultivation. The dry conditions in the early 45 DAS in semi dry rice promoted weed growth at critical period of crop growth which resulted in 52.22 per cent yield reduction in rice. Pre-emergence application of bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} on the next day of sowing followed by azimsulfuron @ 30 g a.i. ha^{-1} as post emergence application at 25 DAS or pre-emergence application of pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} on the next day of sowing followed by azimsulfuron @ 30 g a.i. ha^{-1} as post emergence application at 25 DAS was observed to be the best weed management practice for semi dry rice in terms of yield and economics.

Summary

6. SUMMARY

An investigation entitled “Herbicide based weed management for semi dry rice (*Oryza sativa* L.)” was undertaken in farmer’s field at Kanjirathadi padasekharam in Nemom Panchayath, Thiruvananthapuram district, Kerala state during May 2014 to September 2014. The main objective of the study was to evaluate the weed control efficiency and economics of new generation herbicides and to develop a herbicide based weed management strategy for semi dry rice.

The field experiment laid out in randomised block design, comprised of eleven weed management practices replicated thrice. The rice variety used for the study was Uma. The treatments were T_1: bensulfuronmethyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre - emergence), T_2: T_1 + hand weeding at 40 DAS, T_3: T_1 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence), T_4: pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre - emergence), T_5: T_4 + hand weeding at 40 DAS, T_6 : T_4 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence), T_7 : oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre - emergence), T_8 : T_7 + hand weeding at 40 DAS, T_9 : T_7 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence) and two controls: T_{10}: hand weeding at 20 and 40 DAS and T_{11}: weedy check.

The results of the study are summarized below:

- A substantial diversity of weed flora was observed in the experimental site with a variation in weed flora during dry and flooded condition.
- Broadleaved weeds were the most dominant group (five species) followed by sedges and grasses (four species each) throughout the crop growth period.
- The effect of pre-emergent herbicides lasted only up to 15-20 DAS.
- Bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} and pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} were promising broad spectrum herbicides for early season weed control in semi dry system of rice cultivation.

- The application of pre-emergent herbicides (except oxyfluorfen) followed by one hand weeding at 40 DAS was effective in controlling grasses, sedges and broad leaved weeds and resulted in reduced density of weeds.
- Weed management practices involving application of pre-emergent herbicides (except oxyfluorfen @ 0.15 kg a.i. ha^{-1}) followed by post emergent application of azimsulfuron @ 30 g a.i. ha^{-1} was found effective in reducing weed density and weed infestation at critical period of crop growth except for perennial grasses.
- Azimsulfuron @ 30 g a.i. ha^{-1} was not effective in controlling the grass species like *Echinochloa* and weedy rice which appeared later after flooding.
- The weed dry weight recorded by the weedy check remained high all throughout the crop growth and showed a steady increase with increase in crop age.
- The weed control efficiency revealed the superiority of hand weeding (twice) treatment which recorded higher weed control efficiency at all crop growth stages.
- Pre-emergence application of herbicides followed by post emergence application of azimsulfuron @ 30 g a.i. ha^{-1} effectively controlled weed growth during all crop growth stages especially at critical period (40 DAS).
- Treatments with hand weeding at 40 DAS in combination with pre-emergent herbicide application recorded higher weed control efficiency at 60 DAS and at harvest.
- Weed management practices involving combination of either hand weeding at 40 DAS or post emergence application of azimsulfuron @ 30 g a.i. ha^{-1} with pre-emergence application of either bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} or pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} recorded lower nutrient removal by weeds.

- Effective weed control especially during the critical period of crop weed competition significantly influenced the yield attributing characters and yield of rice.
- Highest growth parameters were recorded for bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* hand weeding at 40 DAS and pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb* hand weeding at 40 DAS and for the treatments involving post emergence application of azimsulfuron @ 30 g a.i. ha^{-1} with pre-emergent herbicides *viz*., bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} or pyrazosulfuron ethyl @ 25 g a.i. ha^{-1}.
- Yield parameters and yield (both grain and straw yield) were higher for bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* hand weeding at 40 DAS, and was statistically on par with bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1} and pyrazosulfuron ethyl @ 25 g a.i. ha^{-1}*fb* either hand weeding at 40 DAS or azimsulfuron @ 30 g a.i. ha^{-1}. Grain and straw yield were lowest under weedy check.
- The yield realized was maximum in treatments which could keep the field weed free during critical period which is specifically the reason attributable for the better performance of weed management practices involving pre *fb* post emergent herbicide application or pre *fb* hand weeding at 40 DAS.
- Higher nitrogen and potassium uptake by crop was reported by bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* hand weeding at 40 DAS, bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1}, pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb* hand weeding at 40 DAS and pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1} along with hand weeding twice (control-1).
- Phosphorus uptake by crop was significantly higher for treatments with pre and post emergent herbicides (bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1}, pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb*

azimsulfuron @ 30 g a.i. ha^{-1}) followed by pre-emergent herbicide with hand weeding at 40 DAS and hand weeding twice (control-1).

- None of the pre-emergent herbicide treatments showed any visual phytotoxic symptoms on the emerging rice seedlings. In oxyfluorfen treated plots, seed germination and crop density were lower at the initial stages compared to other weed management practices.
- Bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1}, pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} and azimsulfuron @ 30 g a.i. ha^{-1} did not produce any phytotoxic symptoms on rice and were found safe for rice crop.
- Soil nutrient status remained higher for bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* hand weeding, bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1}, pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb* hand weeding, and pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} *fb* azimsulfuron @ 30 g a.i. ha^{-1} along with hand weeding twice which indicated its effectiveness in managing weeds.
- The net income and benefit cost ratio were substantially higher under all the herbicide treated plots compared to hand weeded control. The treatments involving post emergence application of azimsulfuron @ 30 g a.i. ha^{-1} with pre-emergent herbicides *viz*., bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} or pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} recorded higher net income and B: C ratio.
- Dehydrogenase enzyme followed an asymptotic behaviour with the highest activity of dehydrogenase recorded at 45 DAS irrespective of the treatment. Pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} registered higher soil enzyme activity at 45 and 60 DAS which is a direct indication of soil microorganisms.
- Pre-emergence application of bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} on the next day of sowing followed by azimsulfuron @ 30 g a.i. ha^{-1} as post emergence application at 25 DAS or pre-emergence application of

pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} on the next day of sowing followed by azimsulfuron @ 30 g a.i. ha^{-1} as post emergence application at 25 DAS was observed as the best weed management practice for semi dry rice in terms of growth attributes, yield attributes, yield and economics.

Future lines of research

In the present study, the new generation chemicals selected as treatments were found to be less effective against perennial grasses in dry sown (semi dry) system of rice cultivation. More detailed studies can be done to find out other efficient new generation herbicides against perennial grasses in dry seeded system. The present study includes dehydrogenase enzyme analysis to find out the effect of herbicides on soil dehydrogenase enzyme which is direct indication of soil microorganisms. Studies can be done to find out the effect of such new generation herbicides on soil micro flora by observing the soil microbial population and to see whether beneficial or harmful microorganisms are affected.

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Herbicide Based Weed Management for Semi Dry Rice (*Oryza sativa* L.)

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ABSTRACT

An investigation entitled "Herbicide based weed management for semi dry rice (*Oryza sativa* L.)" was conducted during the period May to September 2014 at farmer's field in Nemom block, Thiruvanthapuram. The main objectives of the study were to evaluate the weed control efficiency of new generation herbicides in semi dry rice, to assess their selectivity and influence on growth and yield, to work out the economics and to develop a weed management strategy for semi dry rice.

The field experiment comprised of eleven treatments replicated thrice (Variety: Uma) was laid out in randomised block design. The treatments were T_1: bensulfuronmethyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} (pre - emergence), T_2: T_1 + hand weeding at 40 DAS, T_3: T_1 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence), T_4: pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} (pre - emergence), T_5: T_4 + hand weeding at 40 DAS, T_6 : T_4 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence), T_7 : oxyfluorfen @ 0.15 kg a.i. ha^{-1} (pre - emergence), T_8 : T_7 + hand weeding at 40 DAS, T_9 : T_7 + azimsulfuron @ 30 g a.i. ha^{-1} (post emergence) and two controls: T_{10}: hand weeding at 20 and 40 DAS and T_{11}: weedy check.

Result of the study revealed substantial reduction in weed population and biomass in all the herbicide treated plots compared to weedy check. Weed composition of the experimental field indicated the dominance of broad leaved weeds followed by sedges and grasses with considerable variation in weed flora during dry and flooded condition.

Hand weeding at 20 and 40 DAS (T_{10}) recorded lowest weed density, weed dry weight and highest weed control efficiency. Absolute frequency (Af) for all weed species throughout the crop growth stages was also lower under hand weeding while higher values of importance value (IV) and summed dominance ratio (SDR) for sedges and broad leaved weeds were recorded in weedy check (T_{11}).

Pre-emergent herbicide application followed by either hand weeding at 40 DAS (T_2 and T_5) or application of post emergent herbicides (T_3 and T_6) recorded higher weed control efficiency and lower nutrient removal in comparison with hand weeding twice (20 and 40 DAS). None of the herbicides produced any phytotoxic symptoms on rice plant. However, crop density and growth was lower at the initial stages in oxyfluorfen treated plots. This indicated that bensulfuron methyl + pretilachlor and pyrazosulfuron can be treated as safe pre-emergent herbicides for dry sown (semi dry) system of rice cultivation. Result of the study also indicated the safety of the herbicides on microbial activity as evidenced by the increase in soil dehydrogenase activity in herbicides applied plots.

The yield attributes of rice *viz*., number of productive tillers m^{-2} and filled grains $panicle^{-1}$ were significantly influenced by the weed management practices T_2, T_3, T_5, T_6 and T_{10}. Grain yield (4817.67 kg ha^{-1}) and straw yield (7969.33 kg ha^{-1}) were significantly higher in T_2 (bensulfuronmethyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} + hand weeding at 40 DAS) and remained on par with T_3, T_5, T_6 and T_{10}. Yield loss due to weeds was found to be 52.22 per cent.

The most economically viable weed management practice was T_6 (bensulfuronmethyl + pretilachlor fb azimsulfuron) with a B: C ratio of 1.76 which was on par with T_3 (1.75). Grain yield, net income and B: C ratio were significantly lower in weedy check.

It can be concluded that the most effective weed management practice for semi dry rice is pre-emergence application of either bensulfuron methyl + pretilachlor @ 60 + 600 g a.i. ha^{-1} or pyrazosulfuron ethyl @ 25 g a.i. ha^{-1} on the next day of sowing followed by post emergence application of azimsulfuron @ 30 g a.i. ha^{-1} at 25 DAS.

സംഗ്രഹം

'പൊടിവിത കൃഷിയിൽ കളനാശിനികൾ ഉപയോഗിച്ചുള്ള കളനിയന്ത്രണം' എന്ന ഗവേഷണ പദ്ധതി നേമം ബ്ലോക്കിലെ കാഞ്ഞിരത്തടി പാടശേഖരത്തിൽ 2014 മേയ്-സെപ്റ്റംബർ കാലത്ത് നടത്തുകയുണ്ടായി. പുതുതലമുറ കളനാശിനികളുടെ കാര്യക്ഷമത, വരണക്ഷമത, കളനിയന്ത്രണശേഷി എന്നിവ പരിശോധിച്ച് പൊടി വിതയിലേക്ക്യോജിച്ച ഒരു കളനിയന്ത്രണമാർഗ്ഗം കണ്ടെത്തുക എന്നതായിരുന്നു പദ്ധതിയുടെ ഉദ്ദേശം.

വിത്തിട്ട് പിറ്റേ ദിവസം മണ്ണിലേക്ക് തളിക്കുന്ന പൂർവ്വനിർഗ്ഗമന കളനാശിനികളായ ബെൻസൾഫൂറോൺ മീഥൈൽ + പ്രെറ്റിലാക്ലോർ, പൈറാസോസൾഫൂറോൺ ഈഥൈൽ, ഓക്സിഫ്ളൂർഫെൻ എന്നിവയും കളകൾ പ്രത്യക്ഷപ്പെട്ടതിനു ശേഷം ഇലകളിലേക്ക് തളിക്കുന്ന അസിംസൾഫൂറോൺ എന്ന കളനാശിനിയുമാണ് പരീക്ഷണത്തിൽ ഉൾപ്പെടുത്തിയത്. പൂർവ്വനിർഗ്ഗമന കളനാശിനികൾ തനിച്ചും, ഇവ കൈകൊണ്ടുള്ള കളപറിക്കൽ രീതിയുമായും ഇരുപത്തഞ്ചാം ദിവസം അസിംസൾഫൂറോൺ പ്രയോഗവുമായി യോജിപ്പിച്ചുമുള്ള 9 തരം വ്യത്യസ്ത കളനിയന്ത്രണ രീതികളാണ് പഠന വിധേയമാക്കിയത്. വിവിധ നിയന്ത്രണ രീതികളിൽ സംയോജിത നിയന്ത്രണ മാർഗ്ഗമായ പൂർവ്വനിർഗ്ഗമന കളനാശിനി (ബെൻസൾഫൂറോൺ മീഥൈൽ + പ്രെറ്റിലാക്ലോർ, പൈറാസോസൾഫൂറോൺ ഈഥൈൽ ഇവയിൽ ഏതെങ്കിലും) + അസിംസൾഫൂറോൺ പ്രയോഗവും പൂർവ്വനിർഗ്ഗമന കളനാശിനി + കൈകൊണ്ടുള്ള കള നീക്കം ചെയ്യൽ രീതിയും മികച്ച കളനിയന്ത്രണ ക്ഷമത രേഖപ്പെടുത്തി. ബെൻസൾഫൂറോൺ മീഥൈൽ + പ്രെറ്റിലാക്ലോർ, പൈറാസോസൾഫൂറോൺ ഈഥൈൽ എന്നീ പുത്തൻ തലമുറ പൂർവനിർഗ്ഗമന കളനാശിനികൾ നെൽച്ചെടിയുടെ വളർച്ചക്ക് ഒരു ദോഷവും സൃഷ്ടിക്കുന്നില്ല എന്നതിനാൽ അവ പൊടിവിതയിലെ പ്രയോഗത്തിന് സുരക്ഷിതമാണെന്നു തെളിഞ്ഞു.

നെൽച്ചെടിയുടെ വളർച്ചാ മാനദണ്ഡങ്ങൾ പരിശോധിച്ചതിൽ ഏറ്റവും ഉയർന്ന വിളവ് രേഖപ്പെടുത്തിയത് ബെൻസൾഫൂറോൺ മീഥൈൽ + പ്രെറ്റിലാക്ലോർ എന്ന പൂർവ്വനിർഗ്ഗമന കളനാശിനി പ്രയോഗിച്ച് 40 ദിവസം കഴിഞ്ഞ് കൈകൾ കൊണ്ട് കള പറിച്ചുമാറ്റുന്ന രീതിയിലാണ്. രണ്ടു പ്രാവശ്യം കൈകൾകൊണ്ടു കള പറിച്ചുമാറ്റുന്ന രീതിയും മറ്റു സംയോജിതരീതികളും മേൽപ്പറഞ്ഞ രീതിയോടൊപ്പം മികച്ചതാണെന്ന് ബോധ്യപ്പെട്ടു. ഏറ്റവും മികച്ച വരവു-ചെലവ് അനുപാതം രേഖപ്പെടുത്തിയത് പൂർവ്വനിർഗ്ഗമന കളനാശിനി + അസിംസൾഫൂറോൺ സംയോജിത നിയന്ത്രണ മാർഗ്ഗത്തിലാണ്.

കളനിയന്ത്രണക്ഷമത, ഉൽപാദനം എന്നിവ കണക്കിലെടുക്കുമ്പോൾ ബെൻസൾഫൂറോൺ മീഥൈൽ + പ്രെറ്റിലാക്ലോർ (60+600 ഗ്രാം/ഹെ), പൈറാസോസൾഫൂറോൺ ഈഥൈൽ (25 ഗ്രാം/ഹെ) ഇവയിൽ ഏതെങ്കിലും വിതച്ച് പിറ്റേ ദിവസം മണ്ണിൽ തളിച്ചതിനു ശേഷം അസിംസൾഫൂറോൺ (30 ഗ്രാം/ഹെ) ഇരുപത്തഞ്ചാം ദിവസം ഇലകളിൽ തളിക്കുക എന്ന സംയോജിത കളനിയന്ത്രണ രീതിയാണ് പൊടിവിതയിൽ ഏറ്റവും അനുയോജ്യമായ മാർഗ്ഗം.

Appendices

APPENDIX-I
Weather parameters during the experimental period
(April 2014 - October 2014)

Standard weeks	Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
	Maximum temperature	Minimum temperature	Maximum R.H.	Minimum R.H.		
14	32.4	24.5	89.9	75.3	8.4	9.5
15	32.0	24.2	91.0	69.6	9.4	16.0
16	32.0	25.0	90.7	73.3	9.9	6.0
17	32.8	24.4	94.0	76.6	8.9	11.4
18	32.2	23.8	93.1	83.3	6.6	18.7
19	30.7	24.3	92.0	84.4	7.3	33.1
20	32.5	25.1	88.3	72.6	10.0	0.0
21	32.4	25.5	86.3	75.6	9.9	8.3
22	31.8	25.6	92.5	75.2	9.3	1.8
23	30.1	24.5	94.3	83.3	8.2	4.9
24	30.7	25.1	90.9	77.4	9.0	3.3
25	31.1	25.7	92.3	77.7	9.3	2.8
26	30.5	25.0	92.7	79.1	9.5	4.8
27	30.4	24.7	90.9	79.0	9.2	2.5
28	29.7	24.2	92.9	80.4	8.7	4.8
29	30.1	24.2	90.4	76.7	9.3	6.5
30	29.9	24.2	91.6	73.6	9.3	3.7
31	29.2	23.5	95.3	85.9	8.6	15.7
32	29.4	23.5	88.6	77.3	8.7	22.2
33	29.7	24.0	89.7	79.6	8.9	2.0
34	29.8	24.0	94.0	80.9	8.1	73.0
35	29.9	23.9	87.6	84.1	8.7	34.4
36	29.2	23.9	96.1	79.3	8.8	16.0
37	30.1	24.5	89.3	74.1	9.7	1.5
38	30.5	24.6	85.0	75.6	9.8	0.0
39	31.1	24.1	93.3	84.9	7.5	18.6
40	30.7	23.9	95.4	73.6	8.6	3.0
41	30.7	24.2	73.6	85.7	8.9	6.9
42	30.3	23.7	82.4	92.4	7.0	23.3

APPENDIX- II

SES (Standard Evaluation System for Rice) SCORE CHART

a) Stem borer Infestation

Scale	Dead hearts (%)
0	No damage
1	1-10
3	11-20
5	21-30
7	31-60
9	61 and above

b) Rice bug infestation

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

c) Incidence of sheath blight

Scale	Relative lesion height (%)
0	No infection
1	Limited to lower 20% of the plant height
3	20-30
5	31-45
7	46-65
9	More than 65