HERBICIDE MIXTURES FOR WEED MANAGEMENT IN DIRECT SEEDED PUDDLED RICE (*Oryza sativa* L.)

by

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(2013-21-103)

THESIS

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

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LIST OF ABBREVIATIONS

ACCase	:	Acetyl coenzyme-A carboxylase
Ad	:	Absolute density
Af	:	Absolute frequency
ALS	:	Acetolactate synthase
ANOVA	:	Analysis of variance
B: C	:	Benefit cost
BLW	:	Broad leaf weeds
CD (0.05)	:	Critical difference at 5 % level
CFU	:	Colony forming units
cm	:	Centimetre
CRD	:	Completely randomized block design
DAHA	:	Days after herbicide application
DAI	:	Days after incubation
DAS	:	Days after sowing
DAT	:	Days after transplanting
DMP	:	Dry matter production
DRR	:	Directorate of Rice Research
DSR	:	Direct seeded rice
dS m^{-1}	:	Decisiemens per metre
day^{-1}	:	Per day
EC	:	Electrical conductivity
et al.	:	Co-workers/ Co-authors
FAO	:	Food and Agriculture Organization
FYM	:	Farm yard manure
Fig.	:	Figure
g	:	Gram
h^{-1}	:	Per hour
ha	:	Hectare
ha^{-1}	:	Per hectare

HWT	:	Hand weeding twice
IOBC	:	International Organization for Biological Control
i.e.	:	That is
IIRR	:	Indian Institute of Rice Research
IV	:	Importance value
JBHA	:	Just before herbicide application
K	:	Potassium
KAU	:	Kerala Agricultural University
kg^{-1}	:	Per kilogram
L	:	Litre
LD	:	Lethal dose
LAI	:	Leaf area index
m^2	:	Square metre
m^{-2}	:	Per square metre
mg	:	Milligram
mm	:	Millimetre
mL	:	Millilitre
M ha	:	Million hectare
M t	:	Million tonnes
MSL	:	Mean sea level
N	:	Nitrogen
NS	:	Non significant
No.	:	Number
OD	:	Oil dispersion
P	:	Phosphorus
pH	:	Potenz hydrogen
$Panicle^{-1}$	:	Per panicle
RBD	:	Randomized block design
Rd	:	Relative density
Rf	:	Relative frequency
RH	:	Relative humidity

SE	:	Suspo emulsion
SEm	:	Standard error of mean
SC	:	Suspension concentrate
Spp.	:	Species
TPF	:	Triphenyl formazon
t	:	Tonnes
USDA	:	United States Department of Agriculture
viz.,	:	Namely
WCE	:	Weed control efficiency
WDWC	:	Weed dry weight in control plot
WDWT	:	Weed dry weight in treated plot

LIST OF SYMBOLS

β	:	Beta
%	:	Per cent
@	:	at the rate of
°C	:	Degree Celsius
µ	:	Micro
₹	:	Rupee

Introduction

1. INTRODUCTION

Rice is "life" for more than sixty per cent of the world's population and plays a major role in the economic and social stability of the world (Chauhan *et al.*, 2014). It provides 27 per cent of dietary energy supply and 20 per cent of dietary protein intake in the developing world (FAO, 2004). According to the Asia Rice Foundation, between 2015 and 2020, 1.2 billion new rice consumers will be added in Asia. In order to feed these people, rice production has to be increased from the present production of 320 M t to 420 M t. But the major resources for rice production *viz.*, land, water and labour are becoming scarce day by day. Hence to meet the increased demand of rice for the growing population is a great challenge to agriculture in future.

In India rice is grown in an area of 44 M ha with a production of 104 M t (USDA, 2014). Transplanting of rice seedlings in puddled soil is the predominant crop establishment method adopted for rice cultivation in Kerala and other states of India. Singh *et al.* (1985) reported that transplanting requires 250 to 300 m h ha^{-1}, which is nearly 25 per cent of the total labour requirement for rice cultivation. Urbanization and industrialization resulted in labour scarcity and hike in wage rate has increased the cost of production resulting in reduced profit to the farmers. Hence, there is a shift in crop establishment method in recent years, from transplanting to direct seeding.

Direct seeding technology is a good alternative to transplanting, the major advantages being easiness in operation, less labour requirement, high water productivity and early maturity. The major yield limiting constraint in direct seeded rice (DSR) is the weed problem. Simultaneous emergence of crop and weed seeds, absence of adequate water to suppress the weeds at the time of seedling emergence, presence of morphologically similar weeds which are difficult to control and less competitive nature of the rice seedling are the major reasons for heavy weed infestation in DSR. Weeds compete with rice crop for water, nutrients and sunlight and also exhibit allelopathy, competition and

parasitism (Hussain and Khan, 1987). Crop weed competition is severe in DSR than in transplanted rice. Larger the duration of competition, higher the reduction in grain yield. The yield loss depends on several factors like weed species, degree of infestation, growing season, cultivar used, management practices followed, prevailing environmental condition, *etc.* Crop-weed competition in DSR occurs in two phases; *i.e.*, from 15 to 30 and from 45 to 60 days after sowing (DAS) (Mahajan *et al.*, 2012).

Weed management in DSR relies mostly on herbicides, because it is the most effective, viable and economic option for weed control and is more labour efficient than manual or mechanical methods (Chauhan *et al.*, 2014). Though herbicides are effective and economical, the continuous use of same herbicide or herbicides with similar mode of action will lead to the development of herbicide resistance and shift in weed flora. Single herbicide seldom provides satisfactory and season long weed control due to narrow spectrum of activity (Khaliq *et al.*, 2012a). Herbicide mixtures can overcome the problem of herbicide resistance, shift in weed flora and broaden the spectrum of weed control (Fischer *et al.*, 2004; Damalas, 2005).

An ideal herbicide is one that brings about selective control of weeds for sufficiently long period to get a competitive advantage to the crop and at the same time, dissipates from the soil before the crop season without leaving any residue. Residual problem may arise when these herbicides persist in soil in its original or closely related phytotoxic form for a long time. Hence, it is necessary to check the ill effect of herbicides in the main crop as well as the succeeding crop. Bioassay study using indicator plants is the accurate and simple method to detect the residual effect of applied herbicides in soil.

Soil is a dynamic system in which continuous interaction takes place between soil minerals, organic matter and organisms. These three major soil components influence the physicochemical and biological properties of terrestrial system. Herbicides, in spite of its useful effect in the enhancement of agricultural

production by controlling weeds, may contaminate the healthy soil ecosystem and may raise concerns relating to human health and environment. Soil enzymes are the potential indicators of soil quality and health as they react quickly to the changes in environmental conditions, microbial population and vegetation (Tejada, 2009). Excessive and continuous use of herbicides without the knowledge of its effect on soil enzymes may have adverse impact on biochemical functioning of soil including cycling of nutrients, xenobiotic and organic matter decomposition.

Sustainable agriculture depends on the use of herbicides, pesticides, fungicides and fertilizers in an economically viable and ecofriendly manner. Seed treatment with biocontrol agents *viz.*, *Pseudomonas fluorescens* and *Trichoderma viride* is the most widely used practice among the farmers to control the seed and soil borne pathogens in rice. So, for the successful adoption of integrated pest management programme in rice production, it is necessary to screen the compatibility of biocontrol agents with the herbicides. Similarly screening the compatibility of *Azospirillum* and *Azotobacter* with herbicides will pave the way for the combined use of herbicides and these N fixing organisms for weed management and for reducing the use of N fertilizers. Herbicides are known to influence disease incidence in plants directly by herbicide-pathogen interaction or indirectly by making the plant more or less resistant to pathogen. The non-target effect of herbicides on plant pathogens need to be exploited for the cost effective management of pest and diseases.

Weed seed bank is the main reason for the persistence of weeds in agricultural land (Konstantinovic and Blagojevic, 2014). The size and species composition of the weed seed bank in soil reflect the extent to which management practices have reduced the seed production by weeds. The main objective of any weed management programme should be to deplete the weed seed bank and enable the rice crop to be competitive either by delaying the weed emergence or suppressing the weed emergence and growth.

Keeping the above facts in view, the present investigation was carried out with the following objectives:

- To study the bio-efficacy of post emergence herbicide mixtures, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl for weed control in direct seeded rice.
- To evaluate the effect of herbicide mixtures on soil micro flora and macro fauna, enzyme activity in the soil and weed seed bank.
- To screen the most sensitive indicator plant for both bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl.
- To determine the residual effects of herbicide mixtures in soil using the most sensitive indicator plant.
- To assess the *in vitro* sensitivity of herbicide mixtures to soil borne pathogen *Rhizoctonia solani*, bio control agents (*Pseudomonas fluorescens* and *Trichoderma viride*) and bio fertilizer organisms (*Azospirillum lipoferum* and *Azotobacter chroococcum)*.

Review of Literature

2. REVIEW OF LITERATURE

Transplanting of rice seedlings in puddled soil is the main method of crop establishment in India, but direct seeded rice (DSR) is gaining popularity among the rice growers due to acute labour shortage, hike in wage rate and water scarcity. Heavy weed infestation is the major biological constraint in improving the productivity of DSR. The current state of knowledge on weed management in DSR, impact of herbicides on soil health *viz*., enzymes, microbial population, earthworm and organic carbon; *in vitro* sensitivity of herbicides to bio control agents, bio inoculants and plant pathogen and bioassay technique to determine the herbicide residue in soil are reviewed here.

2.1 DIRECT SEEDED RICE (DSR)

Transplanting is the main method of crop establishment in South East Asian countries including India. Puddling and transplanting consumes up to 30 per cent of the total water requirement of rice. In recent years there is increased concern about the availability of water for rice due to decrease in water table (Hugar *et al*., 2009), competition with urban areas (Chauhan, 2012) and increasing costs of diesel and electricity charges. Most of the South East Asian countries are facing the problem of water scarcity (both physical and economic). It has been reported that 2 M ha of fully irrigated and 13 M ha of partially irrigated lands in Asia during wet season experience physical water scarcity and 22 M ha of irrigated lands in the dry season would face economic water scarcity by 2025 (Ali *et al*., 2014).

In addition to water scarcity, the farmers are facing the problem of acute labour shortage and hike in wage rate. Transplanting takes about 250 to 300 man h ha^{-1}, which is approximately 25 per cent of the total labour requirement of the rice crop (Singh *et al*., 1985). Urbanization and migration of rural labour result in labour scarcity as well as hike in wage rate. This causes increased cost of production and reduced profits to farmers. Because of these reasons there has

been shift in crop establishment from transplanting to DSR in many Asian countries including India. In Kerala also, direct seeding has emerged as the major method of crop establishment.

Direct seeded rice refers to raising rice crop by sowing seeds directly in the field rather than by transplanting seedlings from the nursery. DSR crop can be cultivated by wet seeding, dry seeding or water seeding.

Direct seeding is a good alternative to transplanting as it is more economical and labour saving. Direct seeded rice matures 7 to 10 days earlier than transplanted rice due to absence of transplanting shock. Awan *et al.* (2006) reported that direct seeded rice was almost at par in yield with transplanted crop. DSR is the major opportunity to attain optimum plant density and high water productivity in water scarce areas (Ali *et al.*, 2014).

Though direct seeded rice has several advantages and it could be an effective alternative to traditional transplanting, poor germination, uneven crop stand and high weed infestation are the major constrains in direct seeded rice (Du and Tuong, 2002).

2.2 WEED FLORA UNDER DIRECT SEEDED RICE

The concurrent emergence of competitive weeds, absence of water to suppress the weeds at the time of seedling emergence and prevalence of difficult to control weeds are the major reasons for the severe infestation of weeds in DSR. Javier *et al.* (2005) reported a shift in weed flora by the change in the crop establishment method. Research reports revealed that with change in crop establishment from transplanting to direct seeding a marked change in weed flora has been observed in rice-wheat system in northern India. Singh *et al.* (2005) observed that in India, compared to *Cyperus iria*, *Echinochloa colona*, and *Caesulia axillaris* Roxb in transplanted rice, *Echinochloa crusgalli*, *Commelina diffusa* Burm. f., *Cyperus rotundus* L., and *Leptochloa chinensis* (L.) Nees, become dominant in direct seeded rice. Yaduraju and Mishra (2005) reported that

direct seeding also favours sedges such as *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus* and *Fimbristylis miliacea*.

Changes in crop establishment, from transplanting to direct seeding also resulted in marked changes in the composition of weed flora (Singh, *et al*., 2008). *Echinochloa spp*. was the most noxious weed in the rice fields of Philippines under transplanted situation; however when the system was changed to direct seeding *Leptochloa chinensis* became more dominant than *Echinochloa spp*. Direct seeding increased the population of annual grasses such as *Echinochloa crusgalli*, *Echinochloa colona* and *Leptochloa chinensis*, the perennial sedge *Cyperus rotundus* and broad leaf weeds such as *Commelina diffusa* and *Caesulia axillaris* (Singh *et al*., 2008). Adoption of direct seeding technology may result in weed flora shift towards more difficult to control and competitive grasses and sedges (Kumar and Ladha, 2011).

2.3 YIELD LOSS DUE TO WEEDS IN DSR

Weeds will adversely affect the yield, quality and cost of production. Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Raju and Reddy, 1992). Yield loss depends on several factors such as associated weed flora, degree of infestation, rice ecosystem, growing season, cultivar raised, cultural and management practices followed. Research evidences have shown that in the absence of effective weed control options, the yield loss are more in direct seeded rice than in transplanted rice. On an average, yield loss, due to weed competition ranges from 15 to 20 per cent, but in severe cases it may exceed 50 per cent (Hasanuzzaman *et al*., 2009) or even complete crop failure (Jayadeva *et al*., 2011). Based on studies conducted at Rice Research Station, Moncompu, Raj *et al*. (2013b) reported that, season long weed competition in wet seeded rice caused 69.71 and 67.40 per cent reduction in grain yield during *kharif* and *rabi* season, respectively.

2.4 CROP-WEED COMPETITION AND CRITICAL PERIOD FOR WEED CONTROL IN DSR

The weed competition affects crop growth and is complicated because various factors affect the extent to which it occurs. The rice crop and the associated weeds require almost same environmental conditions for the growth and development. The competition begins when crop and weeds are grown in close proximity to each other and supply of necessary growth factors falls below the demand of both (Mukherjee, 2006). Rao (2011) reported that for every unit of weed growth there will be one unit less of crop growth. When the available resources for crop growth become limiting the competition between crops and weeds is most severe.

Crop-weed competition is more in DSR than in transplanted rice. Because weeds and rice seedlings emerge simultaneously, the competitive advantage of the crop is reduced and also the alternate events of wetting and drying enhance the growth of weeds. When the competing plants have similar vegetative habits and demand on resources, then the competition becomes severe. The severity of competition depends not only on the competing species but also on its density, duration and the fertility status of the soil. According to Singh (2008), in DSR it is important to minimize the crop-weed competition during the early stages of the crop before it forms a closed leaf canopy. Yaduraju and Mishra (2008) reported that in DSR, grasses are usually most dominant during the early season, whereas sedges and broad leaf weeds dominate later in the season. They also reported that, *Cyperus difformis* created more serious problem in DSR and offered greatest competition at pre-tillering and tillering stage. .

The critical period for weed control is the period in the crop growth cycle during which weeds must be controlled to prevent substantial yield loss (Dogan *et al.*, 2004; Isik *et al.*, 2006). It is the time interval between two components of weed interference namely, the critical weed interference and critical weed-free periods. Critical weed interference period is the maximum length of time during

which weeds emerging soon after crop planting can coexist with the crop without causing substantial yield loss. On the contrary, the critical weed-free period is the minimum length of time required for the crop to be maintained weed-free before yield loss caused by late-emerging weeds is no longer a concern (Isik *et al.*, 2006). Weed control during the critical weed-free period is essential to reduce the weed competition and for effective utilization of available resources for enhanced productivity. In DSR, the critical period of weed competition has been reported to be 15-45 days after sowing. Azmi *et al.* (2007) reported that critical period for weed control under mixed weed infestation in DSR was from 12 to 60 DAS. The effective control of weeds at initial stages of rice growth (0 to 40 DAS) could help in improving the productivity of direct seeded rice (Maity and Mukherjee, 2008). Singh (2008) opined that a weed free situation for the first 60 or 75 days produced yield comparable with weed free conditions until harvesting. The competition in direct seeded rice beyond 15 days after seeding may cause significant reduction in grain yield.

2.4.1 Nutrient Depletion by Weeds Due to Weed Competition

Weeds usually have faster growth, compete severely for nutrients and remove large amount of plant nutrients from the soil. Hence weeds not only increase the cost of cultivation but also deplete the resource base. Malik and Moorthy (1996) reported that depending on the intensity of weed growth, weeds depleted 86.5 kg N, 12.4 kg P and 134.5 kg K ha^{-1}. According to Singh *et al.* (2002), weeds removed nutrients eight times higher under direct seeded rice compared to puddled transplanted rice. Reduction in weed density and weed dry weight resulted in significant increase in the uptake of nutrients by crop (Payman and Singh, 2008). Nutrient removal by weeds and nutrient uptake by crops are inversely related (Ramachandiran *et al.*, 2012).

Kumar *et al.* (2010) reported that application of herbicides effectively controlled the weeds and brought down the uptake of nutrients by weeds. Removal of nutrients by weeds was lower in pretilachlor + safener compared to

other weed control treatments (Sangeetha *et al.*, 2011). Application of almix + butachlor @ 0.004 + 0.938 kg ha^{-1} recorded the lowest removal of N (8.7 kg ha^{-1}), P (1.8 kg ha^{-1}) and K (8.5 kg ha^{-1}) compared to other treatments (Dubey *et al.*, 2013). Nath *et al.* (2014) reported that at 60 DAS in direct seeded puddled rice, weeds removed 41.63 kg N, 5.71 kg P and 5.73 kg K ha^{-1} from weedy check plots, whereas in penoxsulam applied plots weeds removed only 12.31 kg N, 1.77 kg P and 5.64 kg K ha^{-1} indicating the significance of weed control in reducing the nutrient depletion by weeds, which would otherwise be utilized by crop plants for better crop growth and productivity. Reshma (2014) stated that at all stages of observation *viz.*, 30 and 60 DAS and at harvest, removal of major nutrients by the weeds were the highest in weedy check.

2.5 CHEMICAL METHOD OF WEED CONTROL IN DSR

Under puddled sown rice culture, chemical method of weed control is the efficient method for controlling grasses, sedges and broad leaved weeds and for achieving higher grain yield (Mukherjee, 2006). Herbicide based weed management is the smartest and viable option of weed control in direct seeded rice due to labour scarcity at the critical time of weeding and high wage rate (Singh *et al.*, 2006). Herbicide based weed management reduces the total energy requirement for rice cultivation (Singh and Singh, 2010). According to Begum *et al.* (2011) chemical method of weed control becomes the popular and best alternative to hand weeding because of the high labour involvement in hand weeding (190 man days ha^{-1}) and also is tedious, time consuming and impractical under adverse weather conditions. Moreover, hand weeding becomes less effective on some occasions because of escape or regeneration of perennial weeds having many flushes. Herbicide use in DSR systems becomes even more important, as rice and weed seedlings emerge simultaneously and some weed seedlings (e.g., *Echinochloa spp.*) are morphologically similar to rice seedlings (Chauhan, 2012). Herbicides provide superior weed control and are more labour efficient than manual or mechanical methods of weed management (Chauhan *et al.*, 2014).

Chemical method of weed control should not be considered as a replacement for other weed control methods, however, should be integrated with them. Hill *et al.* (2001) reported that the success of herbicidal method of weed control is closely linked to water management to provide suitable condition for achieving specificity in weed control and minimizing the risk of phytotoxicity to rice seedlings. Judicious selection of herbicide, correct time of application, proper dose and method of application are important criteria for higher weed control efficiency and crop yield. Jacob *et al.* (2014) opined that the major advantage in going for herbicidal control of weeds in DSR is the reduction in the cost of cultivation.

De Datta (1981) opined that despite some adverse environmental effects, herbicides are considered to be the most effective, practical and economical means of weed management in DSR. At present, no viable alternatives are available to replace herbicides for weed management in rice.

2.5.1 Post Emergence Herbicides

Herbicides are very effective for controlling weeds in DSR, but pre-emergence application of herbicides is not possible always because of unfavorable climate and sowing pressure (Porwal, 1999). Limited application time window (0 to 5 DAS), toxicity to rice crop and critical water regime are the major challenges in the application of pre-emergence herbicides. Continuous use of pre-emergence herbicides in high dose causes shift in weed flora from grasses to non-grassy weeds (Singh *et al.*, 2009) and development of herbicide resistance in weed due to long persistence in soil. This necessitates the use of post emergence herbicides for weed control in DSR, which provides broad spectrum weed control and tackle the problem of herbicide resistance. Post emergence herbicides are applied after the emergence of crop and weed. It offers wide application time window from 4 to 25 DAS of rice. It should be used wisely at the correct stage of the weed and at appropriate dose. For example, bispyribac sodium should be applied at two to three leaf stage of the weed @ 25 to 30 g ha^{-1} for effective weed control in rice

(Yadav *et al.*, 2009; Khaliq *et al.*, 2011). Some of the post emergence herbicides found effective for weed control in wet seeded rice are bispyribac sodium, fenoxaprop-p-ethyl, penoxsulam, azimsulfuron, cyhalofop butyl, metsulfuron methyl, 2, 4-D sodium salt etc. The choice of herbicide depends on the system of rice culture, weed flora, stage of the weed species, climatic condition and farmer's economic situation (Khaliq *et al.*, 2012b).

2.5.1.1 Penoxsulam for Weed Management in Rice

Penoxsulam is a post emergence versatile herbicide developed by Dow Agro Sciences marketed under the trade name Granite 24 SC in India. Penoxsulam is a triazolopyrimidine sulfonamide group herbicide which acts by inhibiting acetolactate synthase (ALS) enzyme in susceptible species and reduces the transport of photosynthates from leaves to roots, resulting in root growth inhibition (Devine *et al.*, 1990; Shaner, 1991). According to Larelle *et al.* (2003), it is a systemic herbicide, absorbed mainly by leaves and secondarily by roots internally disrupts the growing weeds resulting in death. Penoxsulam provides broad spectrum control of annual grasses, sedges and broad leaf weeds (Jabusch and Tjeerdema, 2005).

Damalas *et al.* (2006) reported that single application of penoxsulam gave excellent control of *Echinochloa oryzoides* and *Echinochloa phyllopogon*. Yadav *et al.* (2008) pointed out that post emergence application of penoxsulam @ 20 to 22.5 g ha^{-1} resulted in 77 to 88 per cent grass weed control in transplanted rice. According to Pacanoski and Glatkova (2009), application of penoxsulam to wet seeded rice at tillering stage provided excellent control of *Echinochloa crusgalli*, *Cyperus rotundus* and *Heteranthera limosa*. Penoxsulam does not affect the rice yield or seed quality when applied between the two leaf and mid tillering stage of the rice @ 40 g ha^{-1} (Kogan *et al.*, 2011). Mathew *et al.* (2013) reported that post emergence application of penoxsulam @ 25 g ha^{-1} at 15 to 20 DAS was effective for the broad spectrum control of weeds and higher grain yield in wet seeded rice. It was also pointed out that penoxsulam @ 22.5 and 25 g ha^{-1} at 15 to 20 DAS was

significantly superior to pyrazosulfuron @ 20 g ha^{-1} at four to seven DAS, in controlling grassy weeds. According to Ganai *et al.* (2014), application of penoxsulam @ 22.5 g ha^{-1} being at par with weed free treatment can be recommended for effective and economical weed control in direct seeded rice. Sasna (2014) reported the superiority of both the doses of penoxsulam *i.e.* 22.5 and 25 g ha^{-1} based on the weed density, dry weight and WCE; but based on the benefit cost ratio, penoxsulam @ 22.5 g ha^{-1} was adjudged as the best treatment for effective and economic weed management in transplanted lowland rice.

2.5.1.2 Bispyribac Sodium for Weed Management in Rice

Bispyribac sodium is a product of Kumiai Chemical Industry Co. Ltd., Japan, marketed in India in the trade names of Nominee Gold, Adora, Taarak etc. It is a selective herbicide, mainly absorbed through the leaf surface and translocated throughout the plant. The herbicide is effective against annual and perennial grasses, sedges and broad leaf weeds in rice fields (Schmidt *et al.*, 1999; Yun *et al.*, 2005). It belongs to the chemical group pyrimidinylthiobenzoate, acts by inhibiting acetolactate synthase (ALS) enzyme in susceptible plants and the subsequent synthesis of branched amino acids, which in turn interferes with cell division and causes cessation of plant growth, leading to chlorosis, necrosis and death of sensitive plants (Darren and Stephen, 2006). The residue in the soil, grain and straw were below the detectable limit even when bispyribac sodium was applied at very high dose of 200 and 500 g ha^{-1} indicating that the herbicide will not pose any threat to the environment when applied at the recommended rates (Tamilselvan *et al.*, 2014).

Bispyribac sodium applied at mid tillering has been reported to reduce the barnyard grass population by 98 per cent, but when the application was delayed, the control was reduced to 70 per cent (Williams, 1999). The effectiveness of bispyribac sodium as a post emergence herbicide was also reported by Mahajan *et al.* (2009). Application of bispyribac sodium @ 25 g ha^{-1} at 15-25 days after transplanting (DAT) resulted in significant increase in grain yield over weedy

check and could be a suitable herbicide for the control of complex weed flora in transplanted rice (Yadav *et al.*, 2009). Bispyribac sodium was significantly superior in reducing the density and dry weight of weeds in dry direct seeded rice (Khaliq *et al.*, 2011). Bispyribac sodium was very effective against grasses particularly *Echinochloa spp*, but it did not provide effective control against *Leptochloa chinensis* and *Dactyloctenium aegyptium* (Chauhan, 2012; Chauhan and Abugho, 2012) and *Eleusine indica* (Rahman *et al.*, 2012). Raj *et al.* (2013b) opined that in wet seeded rice, bispyribac sodium was less effective against sedges than penoxsulam and pyrazosulfuron, but efficacy in controlling *Echinochloa* was better than penoxsulam and pyrazosulfuron.

2.5.2 Herbicide Resistance and Weed Shift

Though herbicides are considered to be effective and economical in controlling weeds in DSR, the continuous use of same herbicide or herbicides with similar mode of action will lead to the development of herbicide resistance and shift in weed flora either slowly or rapidly. Herbicide factors that contribute to resistance development in weeds include long residual activity, a single target site of action, a specific mode of action and a high effective kill rate for a wide range of weed species. Research reports have revealed that herbicide resistance problems are accelerating day by day and consequently management of weeds became more difficult and complex (Rao, 2011).

Intensive use of pre-emergence herbicides like butachlor, anilofos and pretilachlor for the control of early flush of grassy weeds in transplanted rice resulted in herbicide resistance problems (Budhar *et al.*, 1991). Valverde *et al.* (2000) reported that worldwide, 30 weed species associated with rice have developed resistance to propanil, 2, 4-D and some of the more recently introduced sulfonylureas. Due to the continuous use of butachlor, pretilachlor and anilofos weed shift from grasses to non-grasses and sedges in transplanted rice fields was noticed (Singh *et al.*, 2004b). Similar observations were also made by Rajkhowa *et al.* (2006).

One of the recent ways to overcome the shift in weed flora and to prevent the development or delay the development of herbicide resistance in weeds is the use of herbicide mixtures. Herbicide mixtures will help to prevent the resistance problem and shift in weed population, which is always a problem associated with the use of single herbicide (Wrubel and Gressel, 1994).

2.5.3 Herbicide Mixtures

Due to narrow spectrum of activity, use of single herbicides seldom furnishes satisfactory and season long weed control. The herbicide mixtures (both tank and proprietary mixture) broaden the spectrum of weed control in single application (Fischer *et al.*, 2004; Damalas, 2005). A grass effective herbicide in combination with a herbicide that kill broad leaf weeds, would take care of both types; similarly a grass effective herbicide in combination with herbicide that control both broad leaf weeds and sedges will provide a wider spectrum of weed control (Mukherjee, 2006). Paswan *et al.* (2012) opined that herbicides with different mode of action when mixed together, bind to different target sites in weeds and prevent the probability of target site resistance in susceptible species.

Avudaithai and Veerabadran (2000) reported that combined application of different herbicides even at lower doses proved more effective against a broad spectrum of weeds. Bensulfuron methyl is very effective against broad leaf weeds, but the combined application of bensulfuron methyl and 2, 4-D enhanced the spectrum of weed control (Kim and Im, 2002). Singh *et al.* (2004a) reported that a ready mix formulation of metsulfuron methyl + chlorimuron ethyl was very effective against diverse weed flora. Dixit and Varshney (2008) opined that post emergence application of chlorimuron ethyl + metsulfuron methyl was most promising for controlling broad leaf weeds and sedges in direct seeded drilled rice. Metsulfuron methyl + chlorimuron ethyl applied @ 4 g ha^{-1} on 21 DAS or applied @ 4 g ha^{-1} on seven DAS in integration with one hand weeding (40 DAS) effectively controlled weeds and brought about a marked increase in grain yield in

direct seeded rice (Gopinath and Kundu, 2008). Rahman *et al.* (2012) reported that tank mix application of cyhalofop butyl and bensulfuron methyl resulted in broad spectrum control of grass, sedges and broad leaf weeds. Based on studies conducted in dry seeded fine rice, Khaliq *et al.* (2012a) opined that application of tank mixture of bispyribac sodium + ethoxysulfuron resulted in greater weed suppression, higher grain yield and economic returns.

Herbicide mixtures also reduce the herbicide load in environment and reduce the cost of application in addition to broad spectrum weed control. Aurora and De Datta (1992) reported that herbicides used in combination reduced the usage rate compared to single herbicide use. Chauhan and Yadav (2013) opined that in future, the combination of two or more herbicides may become a part of an effective and integrated approach to achieve more satisfactory control of complex weed flora in DSR.

2.5.3.1 Penoxsulam + Cyhalofop Butyl for Weed Management in Rice

Penoxsulam + cyhalofop butyl is a unique premix oil dispersible formulation with adjuvant built in form. A combination of penoxsulam, a broad spectrum herbicide of chemical group triazolopyrimidine sulfonamide inhibiting ALS enzyme in susceptible species and cyhalofop butyl, a grass effective herbicide belonging to the chemical group aryloxyphenoxypropionate which inhibits the activity of acetyl coenzyme-A carboxylase - the enzyme is having a major role in fatty acid metabolism. Gressel and Segel (1990) reported that, a combination of two different herbicides with different mode of action will prevent or delay the evolution of target site resistance in weeds. Lap *et al.* (2013) revealed that combination products containing penoxsulam and cyhalofop butyl increased rice productivity in direct seeded, water seeded and transplanted rice production systems. Based on the results of on farm demonstration trials from 2003 to 2011, premix formulations of penoxsulam + cyhalofop butyl applied @ 10 g ha^{-1} + 50 g ha^{-1} to 12.5 g ha^{-1} + 62.5 g ha^{-1}, at 7 to 18 DAS or DAT provided more than 90 per cent control of common weeds in rice. Also post emergence application of

herbicide mixture at rates up to five times the labelled use rate (300 g ha^{-1}) did not produce any phytotoxic symptoms in rice plant. Since each herbicide has different mode of action, it is an effective means to manage *Echinochloa spp* resistance (Lap *et al.*, 2013). Field studies conducted at Thrissur, Kerala indicated that post emergence application of penoxsulam + cyhalofop butyl @ 135 and 150 g ha^{-1} resulted in very good control of all types of weeds in wet seeded rice (Abraham and Menon, 2015). According to Ramachandra *et al.* (2015), application of penoxsulam + cyhalofop butyl 6 % OD @ 135 g ha^{-1} at 15 DAT resulted in better weed control and higher grain yield (6640 kg ha^{-1}) compared to hand weeding twice (6266 kg ha^{-1}) in transplanted rice. Yadav *et al.* (2015) revealed that post emergence application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} in transplanted and wet seeded rice provided superior control of sedges as compared to bispyribac sodium alone (25 g ha^{-1}) and mixture of bispyribac sodium + fenoxaprop-p-ethyl (25 g ha^{-1}+ 60.4 g ha^{-1}), for broad leaf control it was equivalent to bispyribac sodium (25 g ha^{-1}) and azimsulfuron (37.5 g ha^{-1}).

2.5.3.2 Bispyribac Sodium + Metamifop for Weed Management in Rice

Bispyribac sodium + metamifop is a unique premix suspo-emulsion (SE) formulation. It is a combination product of broad spectrum bispyribac sodium (3.8 %) which belongs to the chemical group pyrimidinylthiobenzoate inhibiting the biosynthesis of amino acids in susceptible plants, and metamifop (9.5 %), a grass effective herbicide belonging to the chemical group aryloxyphenoxypropionate which inhibits the activity of acetyl coenzyme-A carboxylase (ACCase) leading to growth retardation of weeds.

Results of the study from six locations *viz.*, IIRR-Hyderabad, Moncompu, Jagdalpur, Gangavati, Malan and Kaul indicated that bispyribac sodium + metamifop @ 70 g ha^{-1} with PIW-III wetter was effective and gave higher yield than when applied alone (DRR, 2013). Based on field experiments conducted at Central Farm Unit, Coimbatore, TNAU, Priya and Chinnusamy (2013) concluded that the post emergence application of new herbicide mixture bispyribac sodium +

metamifop 14 % SE could keep the weed density and dry weight below the economic threshold level and increase the grain yield and net returns in wet seeded rice. Raj *et al.* (2013a) reported that the application of bispyribac sodium + metamifop 14 % SE @ 70 g ha^{-1} + PIW-III wetter, 10-15 DAS resulted in enhanced rice yield in wet seeded rice. It was also pointed out that even at higher concentration of 140 g ha^{-1}, the herbicide did not produce any phytotoxic symptoms in rice plant and the combined application of bispyribac sodium and metamifop was better than their individual application in reducing the weed density and weed dry matter.

2.6 WEED SEED BANK AND WEED MANAGEMENT

Weed seed bank is the reserve of viable weed seeds present in the soil surface and scattered in the soil profile. Weed seed bank is the main reason for the continued presence of weeds in the agricultural field (Cousens and Mortimer, 1995) and it is an indicator of weed population in soil (Dhawan, 2007). Annual fluctuations of climatic factors significantly influence the weed seed bank (Harbuck *et al.,* 2009).

Changes to the emerged weed population represent the immediate impact of changing farming practices, whereas changes to the seed bank may be more representative of long-term trends associated with changes in farming practices (Buhler, 1995; Vanasse and Leroux, 2000; Legere and Stevenson, 2002). Steinmann and Klingebiel (2004) opined that weed seed bank has impact on the distribution of annual and perennial weeds over the years and it affects the spread of weed community. Weed seed characteristics such as high output, efficient dispersal, longevity and seed dormancy, produce large seed banks in the soil (Pereira *et al.*, 2013).

Understanding the dynamics of soil seed bank can help in the development of integrated weed management programmes and also help to predict the degree to which the crop-weed competition affect the crop yield and quality

(Ambrosio *et al.*, 2004; Menalled, 2008). Accurate forecast of potential weed seedling density would allow the farmers to implement control measures more effectively thus avoiding inappropriate and over use of herbicides (Mobli and Hassannejad, 2013).

Weed seed bank can be manipulated by altering seedling recruitment, seedling mortality, seed viability and fecundity. Manual weeding and herbicidal use reduce the weed population by increasing seedling mortality (Pandey and Pingali, 1996). Barberi *et al.* (1998) reported that herbicides reduced the weed density and number of weed seeds entering the seedbank. Buhler *et al.* (2001) pointed out that when weeds were controlled by cultivation only, the seed bank was approximately 25 times greater than where herbicides in conjunction with cultivation practices were adopted for weed control. Jain *et al.* (2006) reported that continuous use of clodinafop fb 2, 4-D and isoproturon + 2, 4-D for control of weeds in wheat field significantly reduced the number of weed seeds in the seed bank over weedy check. Walia and Brar (2006) also reported that herbicide treatments significantly reduced the seed bank of *Phalaris minor* in wheat field. According to Islam (2012), herbicide application influenced the seed number and species composition of the seed bank. Differential seed density in weed seed bank was observed by herbicide application *i.e.*, seeds of some weed species will be less in the seed bank, whereas seeds of some other species dominate depending on the type of herbicide applied. Konstantinovic and Blagojevic (2014) opined that by the use of herbicides in the phase of weed emergence and growth, the seed bank size can be reduced.

2.7 EFFECT OF HERBICIDES ON SOIL ENZYME ACTIVITY

Soil enzyme activity can be used as a good indicator of soil biogeochemical processes because of its involvement in organic matter decomposition (Sinsabaugh *et al.*, 1991), organic matter formation, soil organic matter stabilization, catalyzing several reactions necessary for the life process of the microorganisms and recycling of nutrients (Dick *et al.*, 1994). They are easy

to measure and respond rapidly to changes in land management (Dick, 1997). Since they are sensitive to agrochemicals, they are the good markers for measuring the degree of pollution (Kuperman and Carreiro, 1997). Assay of soil enzymes can be used as good indicators of soil quality and health (Schloter *et al.*, 2003) and may provide useful information on microbial activity in the soil (Andreoni *et al.*, 2004). Due to greater microbial activity and release of root exudates and enzymes to the rhizosphere, enzyme activities are higher in the rhizosphere soil than in bulk soil (George *et al.*, 2005; Villanyi *et al.*, 2006). Research reports have revealed that herbicides can cause both qualitative and quantitative changes in soil enzyme activity (Sebiomo *et al.*, 2011; Xia *et al.*, 2012).

Dehydrogenase enzyme activity in soil is often used as the measure of any disruption caused by pesticides, trace elements or management practices to the soil (Reddy and Faza, 1989; Wilke, 1991; Frank and Malkomes, 1993). It is an indicator of overall microbial activity, because it is an intracellular enzyme in all living microbial cells and is linked with microbial oxido-reduction processes (Quilchano and Maranon, 2002; Stepniewska and Wolinska, 2005). It can also be used as a parameter for assessing the side effects of herbicide treatments on the soil microbial biomass (Sebiomo *et al.*, 2011).

The highest activity of dehydrogenase was observed at lower doses of pesticides, and the lowest activity at higher doses of pesticides (Baruah and Mishra, 1986). Hang *et al.* (2002) reported that the dehydrogenase enzyme activities were higher in soil samples treated with herbicides; the higher the concentration of butachlor, higher the dehydrogenase activity. Sebiomo *et al.* (2011) observed that application of atrazine, prime extra (a combination of atrazine and metolachlor) and glyphosate increased the dehydrogenase activity from 2nd to 6th week of application. Compared to control, dehydrogenase activity was significantly higher in field treated with butachlor and cyhalofop butyl each @ 1 kg ha^{-1} at 30, 45 and 60 DAT (Vandana *et al.*, 2012). Application of pendimethalin and oxyflourfen @ 1 kg ha^{-1} and 0.1 kg ha^{-1}, respectively along

with one inter cultivation at 30 DAS and one hand weeding at 45 DAS recorded higher dehydrogenase activity at 20 and 40 DAS in maize (Nadiger *et al.*, 2013). Based on the field experiments conducted at Thrissur, Kerala, Shitha *et al.* (2015) reported that dehydrogenase activity in soil was unaffected by the application of Round up and Glycel @ 6 and 12 mL L^{-1}.

Combined application of bromoxynil + prosulfuron @ 1 mg kg^{-1} caused 74 per cent inhibition in dehydrogenase activity as compared to control (Pampulha and Oliveira, 2006). Similarly, Stepniewska *et al.* (2007) reported that application of fonofos @ 1.0 mg kg^{-1} caused 5 to 21 per cent decrease in dehydrogenase activity; however, 10 times higher concentration of the herbicide resulted in 17 to 44 per cent decrease in dehydrogenase activity compared to control.

Urease, an extracellular enzyme plays a major role in the hydrolysis of urea to NH_3 and CO_2. Its activity in soil is correlated with soil organic matter content and mainly originated from microorganisms (Beri *et al.*, 1978). The amount of urease enzyme indicates the biological activity of soil (Reddy *et al.*, 2011). Pal *et al.* (2013) reported a positive correlation between urease activity and microbial population in the soil. Urease enzyme is highly sensitive and is a useful indicator to evaluate the soil pollution (Srinivasulu and Rangaswamy, 2014).

Wang *et al.* (2007) reported that butachlor at higher concentrations (50 mg kg^{-1} and 100 mg kg^{-1}) inhibited the urease activity in soil. Inhibitory effect of higher doses of herbicide on urease enzyme activity decreased with time due to irreversible adsorption of herbicides on to the soil colloids, their partial degradation and or stabilization of microbial population in soil with time (Rao *et al.*, 2012). Manual weeding and chemical control of weeds influence the urease activity in soil. Sole application of UPH-203 (Clodinofop propargyl) or in combination with Na-acifluorfen 10 % SL recorded better urease activity than control (Pal *et al.*, 2013). Urease activity in pyrazosulfuron treated soil showed an

increasing trend from 7th day to 28th day of incubation (Baboo *et al.*, 2013). Under unflooded condition, urease activity was consistently inhibited by pesticide treatments, whereas under flooded conditions all the treatments recorded higher urease activity (Rasool *et al.*, 2014). Up to 13.6 per cent increase in urease enzyme activity was noticed when the herbicide Successor T 550 SE (pethoxamid + terbuthylazine) was applied at optimal dose to 40 fold of the recommended dose (Tomkiel *et al.*, 2014).

The breakdown of proteinaceous compounds in soil to simpler nitrogenous compounds is brought about by the protease enzyme in soil. The amount of this extracellular enzyme is indicative of the biological capacity of soil (Burns, 1982). The protease enzyme plays a major role in N metabolism and regulates the amount of N available for plant growth (Stevenson, 1986). NH_4-N accumulation in soil organic matter (Sardans and Penuelas, 2005; Tischer, 2005), the presence of proteolytic bacteria and proteinaceous substrate availability influences the protease enzyme activity in soil (Sardans *et al.*, 2008; Anjaneyulu *et al.*, 2011; Subrahmanyam *et al.*, 2011).

Both biotic and abiotic factors affect the protease activity in soil (Makoi and Ndakidemi, 2008). Protease enzyme activity is significantly affected by the type of herbicide, concentration of the herbicide and incubation period. The lowest activity of protease was observed in butachlor treated plot compared to 2, 4-DEE, pretilachlor and pyrazosulfuron ethyl (Latha and Gopal, 2010). The protease activity in soil treated with butachlor, pyrazosulfuron and glyphosate showed an increasing trend from 7th to 28th day of incubation (Baboo *et al.*, 2013). Rasool *et al.* (2014) reported that, the protease activity was stimulated initially by butachlor application but decreased towards the end of the experiment under unflooded condition, but under flooded condition, the effect was stimulatory.

β glucosidase enzyme plays a major role in the transformation or decomposition of organic matter in soil. Both fungi and bacteria secrete this extracellular enzyme which constitutes an important part of the soil matrix as

abiotic enzyme (Sinsabaugh and Moorhead, 1994). β glucosidase enzymes releases low molecular sugars from organic matter, the important energy sources of microorganisms (Tabatabai, 1994; Bandick and Dick, 1999). It is a soil quality indicator and gives the reflection of past biological activity and the capacity of soil to stabilize the soil organic matter and can be used to detect the management effect on soil (Bandick and Dick, 1999; Ndiaye *et al.*, 2000). Depending on the nature and concentration of herbicide, incubation period and soil condition, application of herbicide influence the β glucosidase activity in soil (Hussain *et al.*, 2009).

Soil treated with butachlor and pretilachlor recorded higher levels of β glucosidase activity (Saha *et al.* 2012). Sofo *et al.* (2012) reported that application of triasulfuron at ten-fold the field rate increased the β glucosidase activity in soil. Significant increase in β glucosidase activity in soil (5.6 to 29.4 per cent) was observed at 7 to 14 days after treatment with two highest concentrations (3.0 and 30.0 mg) of nicosulfuron, a sulfonyl urea herbicide (Santric *et al.*, 2014). Application of carfentrazone ethyl at optimal dose increased the activity of β glucosidase in soil (Tomkiel *et al.*, 2014).

Latha and Gopal (2010) pointed out that, when pyrazosulfuron, butachlor and pretilachlor were applied at 100 times field rate the β glucosidase activity was inhibited by 16.21, 21.32 and 10.09 per cent, respectively over control, whereas when applied at field rate, inhibition of β glucosidase activity was only 5.64, 7.47 and 3.59 per cent, respectively over control.

Acid phosphatase is an extracellular enzyme produced by many soil microorganisms and it plays a major role in the hydrolysis of organic P to inorganic P. It can be a good indicator of organic phosphorus mineralization and biological activity of soil (Dick and Tabatabai, 1993). Phosphatase activity is highly correlated with organic matter content of the soil (Jordan and Kremer, 1994; Aon and Colaneri, 2001). Acid phosphatase enzyme plays a major role in the P cycling in the soil and P acquisition by plants and microorganisms

(Schneider *et al.*, 2001). Phosphatase enzyme is mainly concentrated in the surface soil layer and rhizosphere soil (Tarafdar *et al.*, 2001).

The factors that influence the rate of synthesis, release and stability of phosphatase enzymes in soil are soil pH (Tabatabai, 1994; Martinez and Tabatabai, 2000), management practices (Wright and Reddy, 2001; Ndakidemi, 2006), crop and species (Ndakidemi, 2006) and soil microbial community (Renella *et al.*, 2006; Renella *et al.*, 2007).

Manual weeding and chemical weed control significantly influence the acid phosphatase activity in soil. Bacmaga *et al.* (2012) reported that, the herbicide Aurora 40 WG (carfentrazone-ethyl) had no negative effect on acid phosphatase activity in soil. Rao *et al.* (2012) stated that, lowest concentration of oxadiargyl *i.e.*, 0.75 kg ha^{-1} recorded the highest phosphatase activity, whereas highest concentration of oxadiargyl (1.5 kg ha^{-1}) recorded the lowest phosphatase activity.

Reduction in acid phosphatase activity with herbicide application was reported by several workers (Sukul, 2006; Yu *et al.*, 2006; Jastrzebska and Kucharski, 2007). According to Majumdar *et al.* (2010), the weedy check and hand weeding treatments recorded significantly higher acid phosphatase activity than herbicide treatments. It was also pointed out that compared to initial status; herbicide application reduced the acid phosphatase activity by 16.7 to 27.7 per cent at 7 days after herbicide application.

2.8 EFFECT OF HERBICIDES ON MICROBIAL POPULATION IN SOIL

Soil microorganisms play an important link in the soil-plant-herbicide-fauna-man relationship as they take part in the degradation of herbicides (Milosevic and Govedarica, 2002). Schloter *et al.* (2003) reported that, soil microorganisms take part in various biochemical processes leading to the release of nutrients to the plants and are considered as the indicators of soil quality and health. These organisms have a vital role in maintaining the soil productivity;

their number, activity and diversity may serve as the biological indicators of soil fertility (Rezende *et al.*, 2004; Blagodatskaya and Kuzyakov, 2013).

Change in soil microflora has been considered as one of the possible reasons for the decline in rice cropping systems (Reichardt *et al.*, 1998). Herbicides can cause both qualitative and quantitative changes in the soil microbial population (Saeki and Toyota, 2004). Herbicides not only affect the target weed but also affect the soil microorganism by altering the metabolic activities (Singh and Walker, 2006) and physiological and biochemical behavior (Hussain *et al.*, 2009). The increased dependence of herbicides for weed control in rice has led to concern about their toxicological behavior in rice field environment (Latha and Gopal, 2010).

Sensitivity to a given herbicide varies greatly among the different microbial species and strains. Stimulatory or depressive effect of herbicides on the microbial population may depend on the toxicity of applied herbicide (Abdel-Mallek *et al.*, 1994), type, concentration and mode of applied herbicide, environmental conditions, group of microorganisms, bioavailability and persistence (Zain *et al.*, 2013).

Total microbial count in soil is indicative of qualitative changes due to herbicide application. Adverse to no effect or stimulatory effect of herbicides on soil micro flora was reported by several research workers. Consequent to herbicide application under field condition, an initial depressive effect in microbial population for a short period followed by an increase in total bacterial number is observed, implying that initial depression could be due to the adverse impact on susceptible strains and subsequent increase could be due to the increase in the growth rate of resistant strains (Barman and Varshney, 2008). 2, 4-D exerted a negative influence on soil bacteria up to 15 days after spraying, while the influence was positive on fungal colonies. With advancement of time, the bacterial population also increased, suggesting the dissipation of the herbicide (Devi *et al.*, 2008). Singh and Singh (2009) reported that on the day of herbicide

spray, the viable count of bacteria was highest in weedy check and hand weeding treatment compared to herbicide treated plots, but at 20 days after spray the bacterial population in the herbicide treatments were at par with hand weeding treatment.

Fungi and actinomycetes are able to metabolize the xenobiotic compounds and utilize these compounds as source of energy. In glyphosate treated soil, increase in actinomycetes population was observed with time (Araujo *et al.*, 2003). Application of Imazamox and benfluralin resulted in 25 to 64 per cent decline in actinomycetes population (Vischetti *et al.*, 2004). No change in the population of actinomycetes was observed by the application of metsulfuron-methyl herbicide (He *et al.*, 2006). Dayaram (2013) also made similar observation that actinomycetes population in the herbicide treated plots did not vary much compared to pre-treatment count. Long term application of buctril super (bromoxynil) herbicide in wheat field, decreased the actinomycetes population by 29 per cent (Abbas *et al.*, 2015).

Glyphosate, an organophosphorus compound is used a source of P, C and N by both gram positive and negative bacteria and fungi (Van Eerd *et al.*, 2003), resulting in an increase in fungal count (Ratcliff *et al.*, 2006) and bacterial abundance and biomass (Zabaloy and Gomez, 2008). Significant decline in fungal population was observed due to atrazine application (Sebiomo *et al.*, 2011). Actinomycetes and fungal count showed an increasing trend from 7^{th} to 28^{th} day of treatment of butachlor, pyrazosulfuron and glyphosate (Baboo *et al.*, 2013). In direct seeded rice, significantly higher microbial population was observed in the herbicide treatments compared to control, at all stages of observation indicating the utilization of herbicides as source of C during the degradation process (Kaur *et al.*, 2014).

2.9 EFFECT OF HERBICIDES ON EARTHWORMS

Earthworms play a major role in soil quality by shredding residues, stimulating microbial activity and decomposition, improving soil fertility and soil physical properties *viz*., improving soil aggregation and infiltration. Since they play a major role in the recycling of carbon and nitrogen in the ecosystem, they are used as bio indicators of soil fertility (Callahan, 1988; Goats and Edwards, 1988). Earthworms can also be used as biomarkers for toxicity and bioaccumulation assessment (Nusetti *et al*., 1999; Gobi *et al*., 2004).

Several workers reported that herbicides have adverse effect on the survival of earthworms, as well as its growth and reproduction (Ribidoux *et al*., 1999; Helling *et al*., 2000; Zhou *et al*., 2007; Correia and Moreira, 2010).

Some studies revealed that herbicides are harmless to earthworms. Mele and Carter (1999) reported that herbicide application had no influence on earthworm species richness. Yadav (2006) reported no significant reduction in the earthworm population as compared to the initial status in the pyrazosulfuron treated plots after harvest. Glyphosate application had no adverse impact on the growth, behavior and mortality of the earthworm, *Pheretima carnosus* (Kaneda *et al*., 2009). Correia and Moreira (2010) revealed that earthworms exposed to soil spiked with glyphosate were all alive throughout the study period. Oluah *et al*. (2010) reported that, the mortality of earthworm, *Nsukkadrilus mbae* ranged from 37.8 to 80. 5 per cent when exposed to atrazine. Singh and Singh (2015), pointed out that the toxicity of 2, 4-D on earthworm, *Eutyphoeus waltoni* was both time and dose dependent. Shitha *et al*. (2015) revealed that either round up or glycel had no negative effect on the multiplication of earthworms.

2.10 EFFECT OF HERBICIDES ON ORGANIC CARBON STATUS OF SOIL

Soil organic carbon constitute 58 per cent of the soil organic matter (Bianchi *et al*., 2008), and it is an indicator of soil quality (Adeboye and Bala, 2011). It is the important constituent of soil as it provides energy to the

microorganisms and release nutrients to the plants through mineralization process (Abbas *et al.*, 2015).

Fate of herbicide in the soil is greatly affected by the presence of organic matter by aiding their disappearance (Ali, 1990; Ayansina and Oso, 2006). Decline in organic carbon content in soil followed by herbicide application was reported by several workers. Decline in enzyme activity and organic carbon content in soil due to herbicide application was reported by Niemi *et al.* (2009). Baboo *et al.* (2013) reported significant reduction in organic carbon level in soil after the application of herbicide. Root exudates and hormones are liberated in to the rhizosphere which increases the organic carbon in the soil. So the death of weeds due to herbicide application results in decline in organic carbon in the soil (Bhatttacharya *et al.*, 2013). Mishra *et al.* (2013) revealed that significant quantity of organic matter accumulated in weedy check and hand weeded conditions compared to herbicides. Following the application of bromoxynil, a reduction of 28.57 and 21.56 per cent in total organic carbon content was observed in two different sites of study (Abbas *et al.*, 2015).

The herbicides, pendimethalin, oxyfluorfen and pretilachlor increased the organic carbon content in soil. Presence of herbicides in the rhizosphere of plant influenced the physiological activities of the host plant root system which led to the release of more quanta of exudates and indirectly resulted in higher level of organic carbon in the rhizosphere soil (Trimurtulu *et al.* 2015).

2.11 *IN VITRO* SENSITIVITY OF BIO CONTROL AGENTS TO HERBICIDES

To overcome the hazardous effect of pesticides, the concept of sustainable agriculture is gaining popularity now a day, which involves a set of production systems with few inputs and integrated pest and disease management. Integrated pest management is a strategy involving the use of biological, physical, mechanical and chemical measures in an integrated manner to manage the pest in a cost effective manner. *Pseudomonas fluorescens* and *Trichoderma viride* are

the major bio control agents used in rice. These antagonistic organisms occurring in nature are highly host specific, virulent, self-perpetuating and genetically stable. These bio control agents may influence the ecological factors in favour of crop by mitigating the effects of pathogen and stimulating the crop growth (Gangwar, 2013b). Screening for the compatibility of herbicides with *Trichoderma* and *Pseudomonas*, is very important for the successful bio control of diseases under conventional rice cultivation (Sirvi *et al.*, 2013).

Pseudomonas fluorescens is a gram negative rod shaped bacteria drawing wide attention because of the production of secondary metabolites such as siderophores, antibiotics, volatile compounds, hydrogen cyanide (HCN), enzymes and phytohormones (Weller *et al.*, 2002; Nagarajkumar *et al.*, 2004).

Pseudomonas fluorescens is effective against sheath rot caused by *Sarocladium oryzae* (Sakthivel and Gnanamanickam, 1987; Sakthivel and Gnanamanickam, 1989), sheath blight caused by *Rhizoctonia solani* (Thara, 1994; Kavitha, 2002), bacterial blight caused by *Xanthomonas oryzae pv oryzae* (Vasudevan, 2002; Velusamy and Gnanamanickam, 2003) and blast caused by *Pyricularia oryzae* (Valasubramanian, 2004).

Trichoderma viride is known for its mycoparasitic and antagonistic mechanism for the control of fungal disease in rice *viz.*, brown leaf spot caused by *Bipolaris oryzae* and sheath blight caused by *Rhizoctonia solani* (Biswas and Datta, 2013).

The combined use of bio control agents and pesticides results in synergistic or additive effects in the control of soil borne pathogens (Locke *et al.*, 1985). Several studies have been conducted *in vitro* to evaluate the negative effects of insecticides and fungicides on the growth and development of bio control agents (Hirose *et al.*, 2001; Neves *et al.*, 2001; Silva and Neves, 2005). However the studies regarding the side effects of different group of herbicides on

the growth and development of bio control agents are meagre (Santoro *et al.*, 2014).

The side effects of sulfonylurea and imidazolinone herbicides on plant-associated bacteria *Pseudomonas sp.* was investigated under pure culture conditions by Forlani *et al.* (1995) and it was found that sulfonyl urea herbicides *viz.*, chlorsulfuron and rimsulfuron inhibited the growth of one out of four strains of *Pseudomonas*. Goutam *et al.* (2004) reported that the tested herbicides *viz.*, trifluralin @ 1.0 and 1.25 kg ha^{-1}, thiazopyr @ 0.12, 0.18, 0.24 and 0.30 kg ha^{-1}, isoproturon @ 0.50 and 1.00 kg ha^{-1} and linuron at 0.75 kg ha^{-1} are compatible with *Pseudomonas sp.* Jeenie *et al.* (2011) opined that fluchloralin @ 20.25 x 10^4 µL L^{-1} and pendimethalin @ 9 x 10^4 and 15 x 10^4 µL L^{-1} had no adverse effect on the growth of *Pseudomonas striata*. According to Das *et al.* (2013), an increase in the concentration of herbicides, haloxyfop ethyl, fenoxaprop p-ethyl and quizalofop ethyl from 0.0 to 0.1, 0.2, 0.3, 0.4 and 0.5 per cent reduced the colony forming unit of *Pseudomonas striata* with different degree of sensitivity. Maximum number of *Pseudomonas striata* was recorded in the control and minimum at 0.5 per cent concentration. Gangwar, (2013b) reported that, *Pseudomonas fluorescens* was found to be compatible with butachlor and pendimethalin at lower doses (250 and 500 µL L^{-1}) as well as at higher doses (1000 and 2000 µL L^{-1}). However, anilophos was compatible with *Pseudomonas fluorescens* at lower concentrations of 250 and 500 µL L^{-1} only. Similarly, *in vitro* screening studies done by Prasad *et al.* (2013) indicated that the herbicide pendimethalin inhibited the growth of *Pseudomonas*.

Parakhia and Akbari (2001) pointed out that pendimethalin, fluchloralin, butachlor, paraquat, 2, 4-D and oxydiazon showed no adverse effect on the radial growth of *Trichoderma harzianum*. Sushir and Pandey (2001) reported that fluchloralin and oxadiazon affect the growth of *Trichoderma spp.* by 42.22 and 37.77 per cent even at 125 and 250 µ L mL^{-1}. According to Khalko *et al.* (2006), antagonist fungi *Trichoderma harzianum* showed high tolerance against

butachlor, whereas *Trichoderma viride* showed high tolerance against glyphosate. Alachlor at 500 µL L^{-1} was highly sensitive to *Trichoderma harzianum* and *Trichoderma viride* causing 80.7 and 75.9 per cent inhibition respectively, in radial mycelial growth. Robert *et al.* (2008) reported that, the herbicides differ in the chemical structure and functional group; they also differ in the effects on *Trichoderma sp.* Gangwar (2013a) opined that the herbicides *viz.*, butachlor, pendimethalin and pretilachlor showed compatibility with *Trichoderma harzianum* even at high concentration of 2000 µL L^{-1}. Saxena *et al.* (2014) reported that 2, 4-D ethyl ester, pretilachlor, alachlor, butachlor, fluchloralin and pendimethalin were found compatible with *Trichoderma harzianum* (PBT23) even at higher concentration (250 µL mL^{-1}). 2, 4-D, clomazone, and imazapyr herbicides showed the least toxicity to *Trichoderma atroviride.* However, carfentrazone ethyl and sulfentrazone at recommended dose and double the recommended dose inhibited the fungus germination by 56.6 and 71.2 per cent and 82.73 and 96.24 per cent, respectively over control (Santora *et al.*, 2014).

2.12 *IN VITRO* SENSITIVITY OF BIO INOCULANTS TO HERBICIDES

Herbicides not only have adverse effect on the plant growth, but also influence the plant growth by the additive and synergistic interaction between plant growth promoting bacteria (Brock, 1975). The use of herbicides has become an integral part of agriculture to control the weeds, which cause severe economic loss to the farmers. *Azospirillum lipoferum*, *Azotobacter chroococcum*, *Bacillus megaterium* var. *phosphaticum* and *Frateuria aurantia* are the commonly used bio fertilizers or bio inoculants in rice. These bio fertilizer organisms are exposed to herbicides either at the time of planting or later in the season (Jeenie *et al.*, 2011). Some herbicides used in agriculture may have negative effect on the growth of these organisms. The adverse effect may be due to the difference in the mode of action, concentration of the herbicide or chemical group. Evaluation of new herbicides for their toxicity on bio fertilizer organisms will enable the rice growers to select the compatible ones.

On exposure to 2, 4-D at 5 mg L^{-1} concentration, substantial stimulation in nitrogenase activity of *Azospirillum* was noticed (Patnaik and Rao, 1994). Sulfonyl ureas *viz.*, chlorsulfuron and rimsulfuron inhibited the growth of one of two isolates of *Azospirillum* and two out of five *Bacillus* isolates studied (Forlani *et al.*, 1995). Gahlot and Narula (1996) reported that *Azotobacter chroococcum* strains isolated from agricultural soil remain unaffected up to 50 mg L^{-1} concentration of 2, 4-D in liquid media. The growth of three tested strains of *Azotobacter chroococcum* was unaffected even in 10 times recommended dose of herbicides *viz.*, Ro-Neet (cycloate) and pyramin (chloridazon) (Mrkovacki *et al.*, 2002). *Azotobacter chroococcum* was found to be compatible with herbicides *viz.*, thiazopyr, trifluralin, isoproturon and linuron (Goutam *et al.*, 2004). Mohiuddin and Khan (2011) reported that metribuzin and 2, 4-D had no adverse effect on the growth of phosphorus solubilizing bacteria, but moderate influence on the growth of *Azospirillum* and *Azotobacter*. Lenart (2012) reported that the herbicide linuron did not inhibit the growth of tested strains of *Azotobacter chroococccum*. Metribuzin at field rate did not affect the phosphorus solubilization activity of *Klebsiella* sp. strain PS19 (Ahemad and Khan, 2011). Khalid and Khokhar (2013) reported that *Azospirillum* and *Azorhizobium* remain active in the presence of herbicides *viz.*, triasulfuron + terbutryn (Logran) or sulfosulfuron (Leader) and able to mitigate the carry over effect of these two herbicides. *In vitro* studies revealed that at field rate, herbicides isoproturon and clodinafop stimulated the growth of phosphorus solubilizing microbes (Lone *et al.*, 2014).

2.13 EFFECT OF HERBICIDES ON PLANT PATHOGENS

Herbicides are known to increase or decrease the plant diseases caused by soil borne pathogens (Katan and Eshel, 1973; Altman and Campbell, 1977). Herbicidal effect on plant diseases has been reported by several workers (Altman and Campbell, 1979; Altman, 1991; Levesque *et al.*, 1992). Herbicides not only control the target weeds but also have non target effect on plant pathogens present in the soil. It may have direct and indirect effect on plant pathogen.

Yu *et al.* (1988) reported that low rate of herbicides stimulate the growth of pathogen under *in vitro* condition. Hence, dose is important in the direct and indirect effect of herbicides on plant diseases. The herbicides influence the plant-pathogen interaction either through their effect on plant or pathogen or on the surrounding soil organisms. Herbicides affect the plant diseases either by altering the virulence of the pathogen or by altering the level of resistance in the host plant (Madhuri *et al.*, 2013).

Under *in vitro* condition, herbicides bentazone, benthiocarb, butachlor, nitrofen, pendimethalin, propanil and 2, 4-D sodium salt at 1000 mg L^{-1} completely inhibited the radial mycelial growth of *Rhizoctonia solani* (Das, 1986). Pathak *et al.* (1996) reported that 2, 4-D inhibited the growth of *Rhizoctonia solani* under *in vitro* condition. The mycelial growth of *Rhizoconia solani* was inhibited by the herbicides trifluralin and butralin @ 5, 50, 100, 500 and 1000 mg L^{-1} (Abdel, 2002). *In vitro* studies revealed that, the herbicides butachlor, cimmethyline, glyphosate, bensulfuron and pyrazosulfuron inhibited the mycelial growth of *Rhizoctonia solani* (Shen *et al.*, 2002). Zhu *et al.* (2002) reported that the mycelial growth of *Rhizoctonia solani* was inhibited by the herbicides, oxyfuorfen, butachlor, acetochlor, cinmethylin and oxadiazon and they also reported that the germination of sclerotia was inhibited by these herbicides @ 100 mg L^{-1}. The herbicide benthiocarb showed an inhibitory effect on the growth and sclerotia production of *Sclerotium oryzae* under *in vitro* condition (Gupta and Sharma, 2004). Yadav (2006) reported that mycelial growth and sclerotia production of *Rhizoctonia solani* decreased, as the concentration of pyrazosulfuron ethyl in the medium increased from 20 to 70 mg L^{-1}. Gopika *et al.* (2011) opined that butachlor @ 400 µL L^{-1} was superior in inhibiting the mycelial growth of *Sclerotium oryzae* causing stem rot in rice by 97.1 per cent as compared to oxadiargyl @ 150 µL L^{-1} (27.9 per cent). According to Madhuri and Reddy (2013), oxyfluorfen, alachlor, quizalofop-p-ethyl and 2, 4-D sodium salt were highly effective in inhibiting the growth of *Sclerotium rolfii* under *in vitro* condition. Pendimethalin, alachlor and quizalfop-p-ethyl recorded 100

per cent growth inhibition of *Rhizoctonia solani* and 2, 4-D sodium salt recorded 100 per cent inhibition in the radial growth of *Fusarium udum*. Rajan *et al.* (2013) reported that round up @ 12 mL L^{-1} and paraquat 4 mL L^{-1} inhibited the growth of *Fusarium oxysporum f. sp. ciceri* causing wilt in chickpea. Shrivastava (2015) pointed out that the herbicide fluchloralin inhibited the mycelial growth of *Sclerotium rolfii* causing root rot and collar rot diseases in legumes, crucifers and cucurbits at recommended and double the recommended dose, whereas pendimethalin at recommended and double the recommended dose stimulated the radial growth of *Sclerotium rolfii*.

2.14 BIOASSAY FOR THE DETERMINATION OF HERBICIDE RESIDUES IN SOIL

Bioassay is a useful tool that complements the analytical methods and provides information regarding the herbicide residue and its possible phytotoxicity (Stork and Hannah, 1996). A bioassay can be able to detect the herbicide or herbicide residue present in the soil at concentrations high enough to affect the crop growth, yield and quality (Alberta Research Council, 2001). It is a major tool for the quantitative and qualitative determination of herbicide residues (Ramani and Khanpara, 2010). Bioassay is used to measure the biological response of a living plant to herbicide and to quantify its concentration in a substrate (Rao, 2011). A plant bioassay is the simple, accurate, inexpensive and direct method for determining the herbicide residue in soil. Biological test requires an indicator organism or species, which are sensitive to a specific herbicide or a class of herbicide. Selecting suitable plant species for bioassay is critical and the plant parameter measured in the bioassay should correlate well with herbicide concentration (Szmigielski *et al.*, 2012).

For detecting the ALS herbicides residues, maize (Hsiao and Smith, 1983; Mersie and Foy, 1985), red beet (Jourdan *et al.*, 1998), sunflower (Hernandez-Sevillano *et al.*, 2001) and oriental mustard (Eliason *et al.*, 2004; Szmigielski *et al.*, 2008) have been used as indicator plants.

Cotton (Main *et al.*, 2004; Grey *et al.*, 2007) and sugar beet (Szmigielski *et al.*, 2009) have been reported as the suitable indicator plants for the detection of protox inhibiting herbicides in soil.

Gowda *et al.* (2003) pointed out setaria as the best indicator plant for detecting the residues of fluazifop-p-butyl. Cucumber and sorghum were used as indicator plants for the detection of residues and persistence of oxyfluorfen, oxadiargyl, quizalfop and fenoxaprop-p-ethyl (Ramani and Khanpara, 2010). Szmigielski *et al.* (2012) reported sugar beet as the best indicator plant for the detection of flucarbazone and sulfentrazone herbicides in soil. Yadav *et al.* (2013) reported cucumber as the best indicator plant for the residue studies of pyrazosulfuron ethyl in soil.

Sunflower root dry weight was used as the sensitive biological parameter to study the persistence and phytotoxicity of several sulfonylureas in three different soils (Kotoula-Syka *et al.*, 1993). Several research reports revealed that plant height and dry or fresh weight has been found to be the sensitive parameters for the detection of sulfonyl urea herbicide residue in soil (Vicari *et al.*, 1994; Stork and Hannah, 1996). Hernandez-Sevillano *et al.* (2001) reported that the most sensitive parameter used in bioassay with sulfosulfuron was root length. Root length was better than root dry weight to find the response of maize cultivars to soil applied chlorsulfuron in field condition. Eliason *et al.* (2002) indicated that root length was the sensitive parameter for the detection of the herbicide flucarbazone in the soil. Gowda *et al.* (2003) reported that, fresh weight of setaria seedlings was the most sensitive parameter for detecting the fluazifop-p-butyl residue in soil. Shoot length of cucumber was identified as the best parameter for detecting the residue of pyrazosulfuron ethyl in soil (Yadav *et al.*, 2013).

Metsulfuron methyl was applied to wheat crop on 28 DAS, at different rates (4, 8 and 12 g ha^{-1}) as post emergence herbicide, and the bioassay technique could detect the residue up to 30 days in surface soil, while with HPLC, residues were not detectable on the 15^{th} day indicating the sensitivity of bioassay technique

(Paul *et al.*, 2009). Bioassay test conducted to evaluate the sensitivity of indicator plants *viz.*, maize, sunflower and barley to clomazone residues in sandy loam soil revealed that even the lowest concentration of clomazone (0.12 mg kg^{-1} of soil) caused significant reduction in the measured parameters of sunflower and barley, indicating its residual phytotoxic effects (Umiljendic *et al.*, 2013).

Application of pyrazosulfuron @ 15 to 30 g ha^{-1} did not cause any significant difference in measured parameters *viz.*, plant height, root length and fresh biomass of the indicator plant, cucumber revealing that pyrazosulfuron ethyl did not leave any phytotoxic residue in soil to cause growth inhibition in cucumber (Yadav, 2006). The post emergence herbicides *viz.*, oxadiargyl @ 90 g ha^{-1}, quizalofop-ethyl @ 40 g ha^{-1} and fenoxaprop-p-ethyl @ 75 g ha^{-1} when applied at 60 DAS showed no reduction in germination percentage, plant height and dry weight of indicator plants, sorghum and cucumber indicating no residual phytotoxic effect (Ramani and Khanpara, 2010). Poddar *et al.* (2014) reported that application of oxyfluorfen at different concentrations (150 to 300 g ha^{-1}) for the control of weeds in DSR did not hamper the population of succeeding crops of lentil, linseed and coriander after the rice in two years of study, indicating that oxyfluorfen did not leave any phytotoxic residue in soil.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation comprised of a field experiment and a series of laboratory experiments. Field experiment was conducted in farmer's field in Kalliyoor Panchayat, Thiruvananthapuram district, Kerala from May 2014 to March 2015 for two consecutive seasons. Bioassay and weed seed bank assay were carried out at the Department of Agronomy, College of Agriculture, Vellayani. Microbiological studies *viz.*, *in vitro* sensitivity to *Pseudomonas fluorescens*, *Azospirillum lipoferum*, *Azotobacter chroococcum* and *Trichoderma viride* and microbial count were taken up in the Department of Agricultural Microbiology, College of Agriculture, Vellayani. Study on *in vitro s*ensitivity to soil borne pathogen was done at the Department of Plant Pathology, College of Agriculture, Vellayani. The details of the materials used and methodology adopted during the course of investigation are presented below.

3.1 PART I - BIO-EFFICACY OF POST EMERGENCE HERBICIDE MIXTURES IN DIRECT SEEEDED RICE

3.1.1 Experimental Site

3.1.1.1 Location

The experiment was conducted in farmers field in Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India, situated at 8° 26.762' N latitude and 77° 0.136' E longitude and 29 m above mean sea level (MSL).

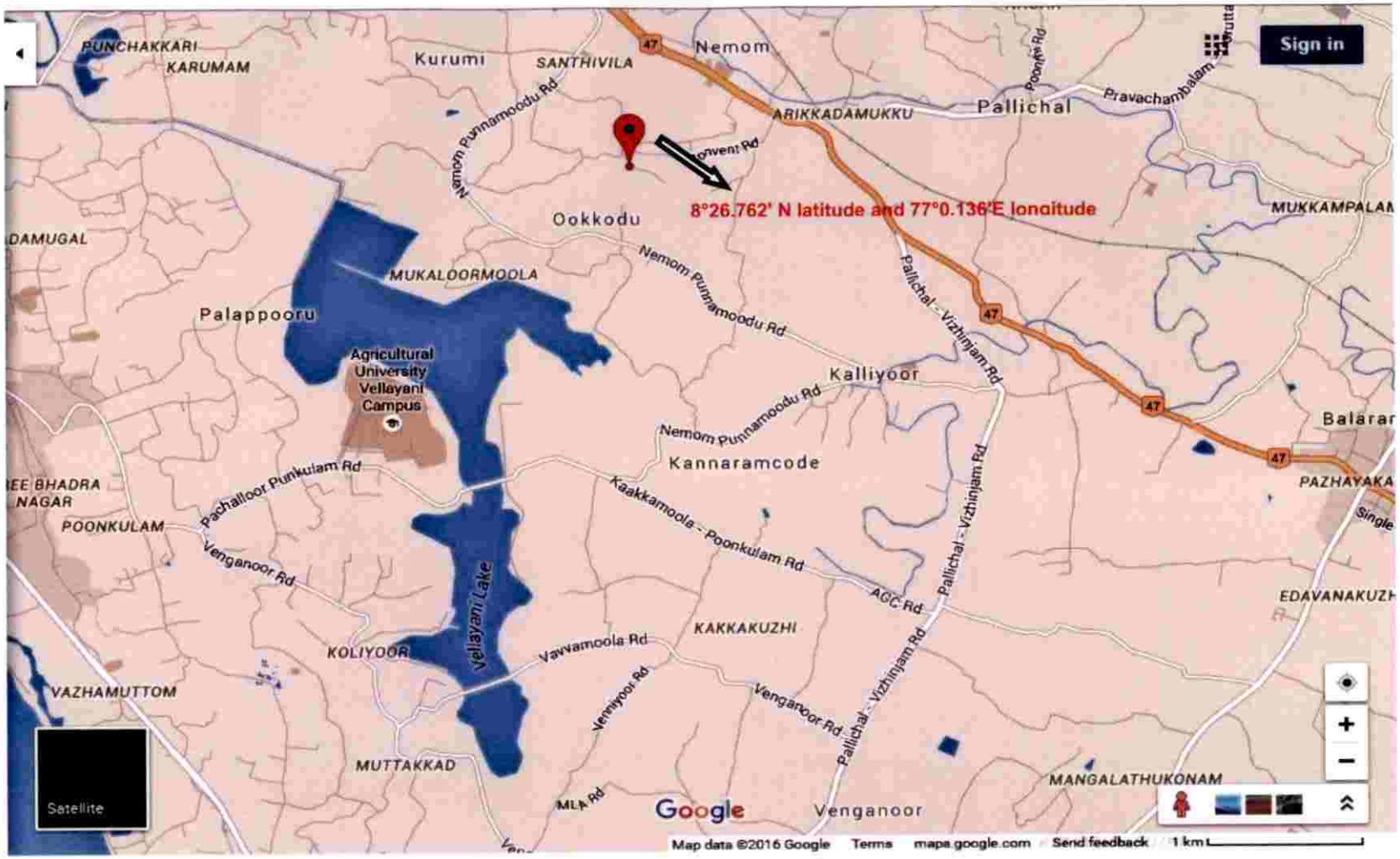

Plate 1: Location of the experimental field

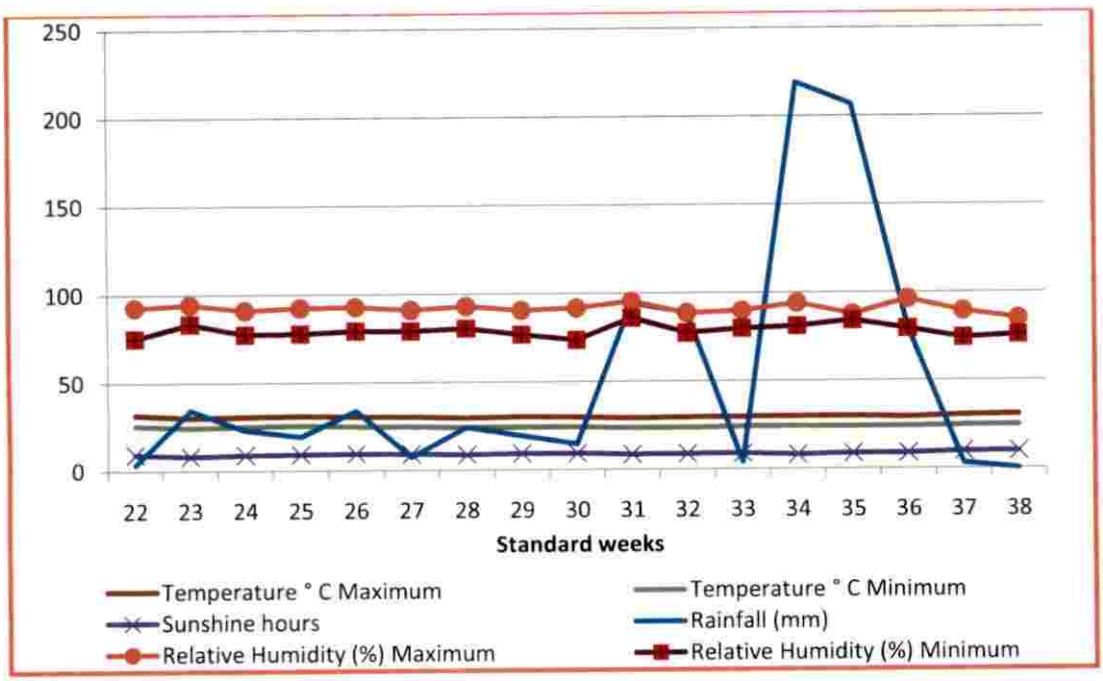

Fig.1a. Weather data during the first crop season (May 2014 to September 2014)

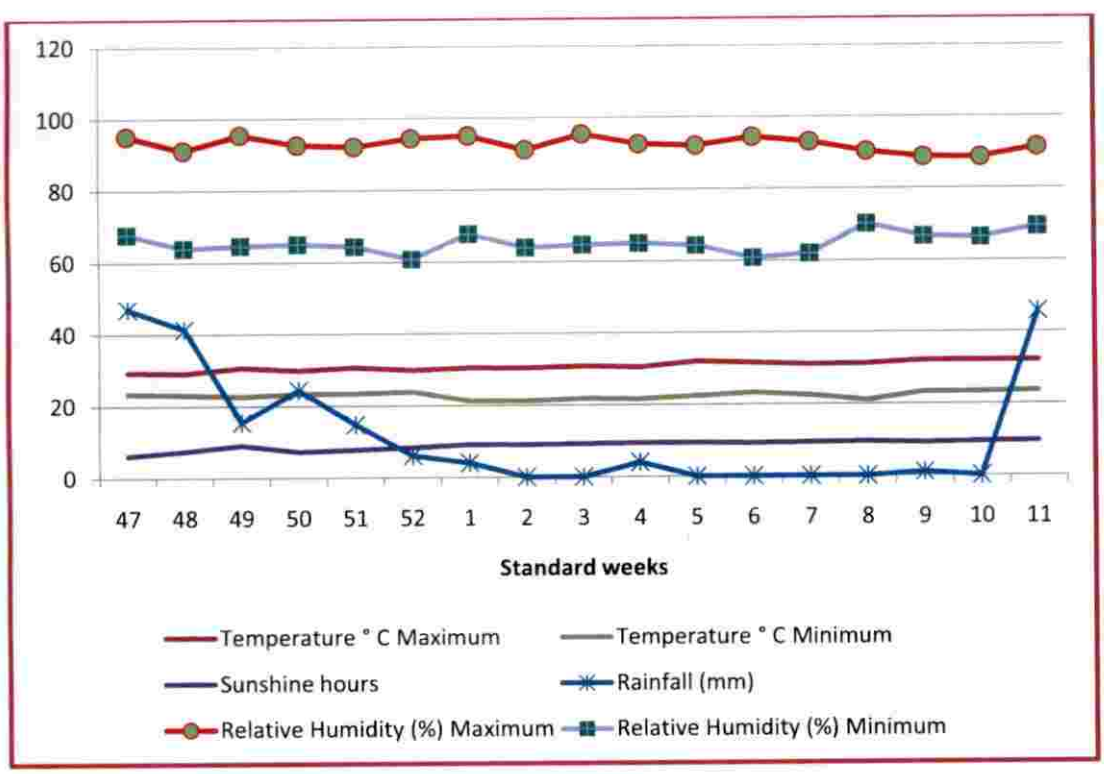

Fig.1b.Weather data during the second crop season (November 2014 to March 2015)

3.1.1.2 Climate

The experimental site has humid tropical climate. The average annual rainfall received during the period of experimentation was 875.5 mm during first crop season and 203.4 mm during second crop season. The mean maximum and minimum temperature recorded during first and second crop seasons were 30.1 °C and 24.4 ° C and 30.8 ° C and 22.6° C, respectively. The total number of rainy days during first and second crop seasons was 46 and 21, respectively. The mean weekly weather data prevailed during the cropping periods is presented in Appendix I and II and Figure 1a and 1b.

3.1.1.3 Cropping Season

The experiment was conducted for two consecutive seasons during *kharif* season (first crop) from May 2014 to September 2014 and *rabi* season (second crop) from November 2014 to March 2015.

3.1.1.4 Soil

The soil of the experimental field was well drained sandy clay loam. Soil was acidic in reaction, high in organic carbon and medium in available N, P and K. The important physicochemical properties of the soil are presented in Table1.

3.1.1.5 Cropping History of the Field

The experimental field was under continuous cultivation of rice for more than 10 years.

Table 1. Soil characteristics of the experimental field

A. Mechanical composition of the soil in the experimental area

Sl. No.	Fractions	Content in soil, %	Method
1	Coarse sand	47.52	Bouyoucos Hydrometer Method (Bouyoucos, 1962)
2	Fine sand	12.10	
3	Silt	7.93	
4	Clay	32.40	

B. Initial chemical properties of the soil of the experimental area

Sl. No.	Fractions	Content		Method adopted
		First crop	Second crop	
1	Soil reaction	4.6	5.5	pH meter (1: 2.5 soil water ratio) (Jackson, 1973)
2	EC, dS m^{-1}	0.2	0.2	Conductivity meter (1: 2.5 soil water ratio) (Jackson,1973)
3	Organic carbon, %	1.6	1.93	Walkley and Black rapid titration method (Walkley and Black, 1934)
4	Available N, kg ha^{-1}	286.71	284.42	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P, kg ha^{-1}	14.64	12.09	Bray colorimetric method (Jackson, 1973)
6	Available K, kg ha^{-1}	167.33	173.38	Ammonium acetate method (Jackson, 1973)

Table 2. Technical information of the herbicides used in the study

Common name	Bispyribac sodium + metamifop	Penoxsulam + cyhalofop butyl	Penoxsulam	Bispyribac sodium
Chemical name	1.Sodium 2, 6-bis [(4,6-dimethoxypyrimidin -2-yl)oxy]benzoate 2. (R)-2-[4-[(6-chloro-2-benzoxazoyl) oxy]phenoxy]-N-(2-fluorophenyl-N-methyl propanamide	1.2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy [1,2,4] triazolo[1,5-c]pyrimidin-2-yl)-6(trifluoromethyl) benzenesulfonamide 2.(R)-2-[4-(4-cyano-2-fluorophenoxy) phenoxy] propionate	2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy [1,2,4]triazolo[1,5-c]pyrimidin-2-yl)-6 (trifluoromethyl) benzenesulfonamide	Sodium 2, 6-bis[(4,6-dimethoxypyrimidin-2-yl) oxy]benzoate
Trade name	Nominee® M	Vivaya™	Granite	Nominee Gold
Formulation	3.8 + 9.5 % SE	5.15 + 1.03 % OD	24 % SC	10 % SC
Physical state, colour and odour	Off white viscous suspension concentrate, aromatic odour	Pale yellow liquid with an aromatic odour	Off white liquid, musty odour	Odourless white powder
Acute oral toxicity LD 50 (rats)	>2000 mg kg^{-1}	>5000 mg kg^{-1}	>5000 mg kg^{-1}	>2000 mg kg^{-1}
Manufacturer	PI Industries, Gujarat	Dow Agro Chemicals	Dow Agro Chemicals	PI Industries, Gujarat

3.1.2 Materials

3.1.2.1 Crop Variety

PTB 50 (Kanchana), a short duration (100-105 days), red long bold grain variety suitable for all seasons, resistant to blight, blast, stem borer and gall midge, released from Regional Agricultural Research Station, Pattambi, Kerala, India was used for the study. Varietal characters are given in Appendix V.

3.1.2.2 Source of Seed

The paddy seed was obtained from Regional Agricultural Research Station, Pattambi, Kerala. The seeds of maize and sunflower for bioassay were obtained from Tamil Nadu Agricultural University, Coimbatore and cucumber from Department of Olericulture, College of Agriculture, Vellayani.

3.1.2.3 Manures and Fertilizers

Well decomposed farm yard manure (FYM) analyzing 0.49 per cent N, 0.2 per cent P_2O_5 and 0.46 per cent K_2O was used as organic source. Fertilizers were applied in the form of urea (46 per cent N), factomphos (20 per cent N, 20 per cent P_2O_5, 15 per cent S) and muriate of potash (60 per cent K_2O).

3.1.2.4 Herbicides

The technical information, toxicity data and other available information of herbicides, penoxsulam, bispyribac sodium, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl are presented in Table 2.

3.1.3 Methods

3.1.3.1 Design and Lay Out

The experimental design, lay out, field culture and observations were same for both seasons (first and second crop). The detailed lay out plan of the experiment is depicted in Fig. 2.

Experimental design	:	Randomized block design (RBD)
Number of treatments	:	12
Number of replication	:	3
Gross plot size	:	5 m x 4 m
Net plot size	:	4 m x 3 m
Total number of plots	:	36

3.1.3.2 Treatment Details

T_1- Bispyribac sodium + metamifop 14 % SE @ ^{60} g ha^{-1} at 15 DAS

T_2- Bispyribac sodium + metamifop 14 % SE @ 70 g ha^{-1} at 15 DAS

T_3- Bispyribac sodium + metamifop 14 % SE @ 80 g ha^{-1} at 15 DAS

T_4- Bispyribac sodium + metamifop 14 % SE @ 90 g ha^{-1} at 15 DAS

T_5- Penoxsulam + cyhalofop buytl 6 % OD @ 120 g ha^{1} at 15 DAS

T_6- Penoxsulam + cyhalofop buytl 6 % OD @ 125 g ha^{-1} at 15 DAS

T_7- Penoxsulam + cyhalofop buytl 6 % OD @ 130 g ha^{1} at 15 DAS

T_8- Penoxsulam + cyhalofop buytl 6 % OD @ 135 g ha^{-1} at 15 DAS

T_9- Bispyribac sodium 10 % SC @ 25 g ha^{1} at 15 DAS

T_{10}-Penoxsulam 24 % SC @ 22.5 g ha^{-1} at 15 DAS

T_{11}-Hand weeding twice at 20 and 40 DAS (HWT)

T_{12}-Weedy check

3.1.3.3 Field Preparation and Lay Out

The field was thoroughly ploughed with power tiller and was uniformly levelled. After land preparation, the experiment was laid out as per the technical programme. Raised bunds of 20 cm height and channels of 30 cm width were taken around each plot and 60 cm wide channels were taken along the length of each block between the replications.

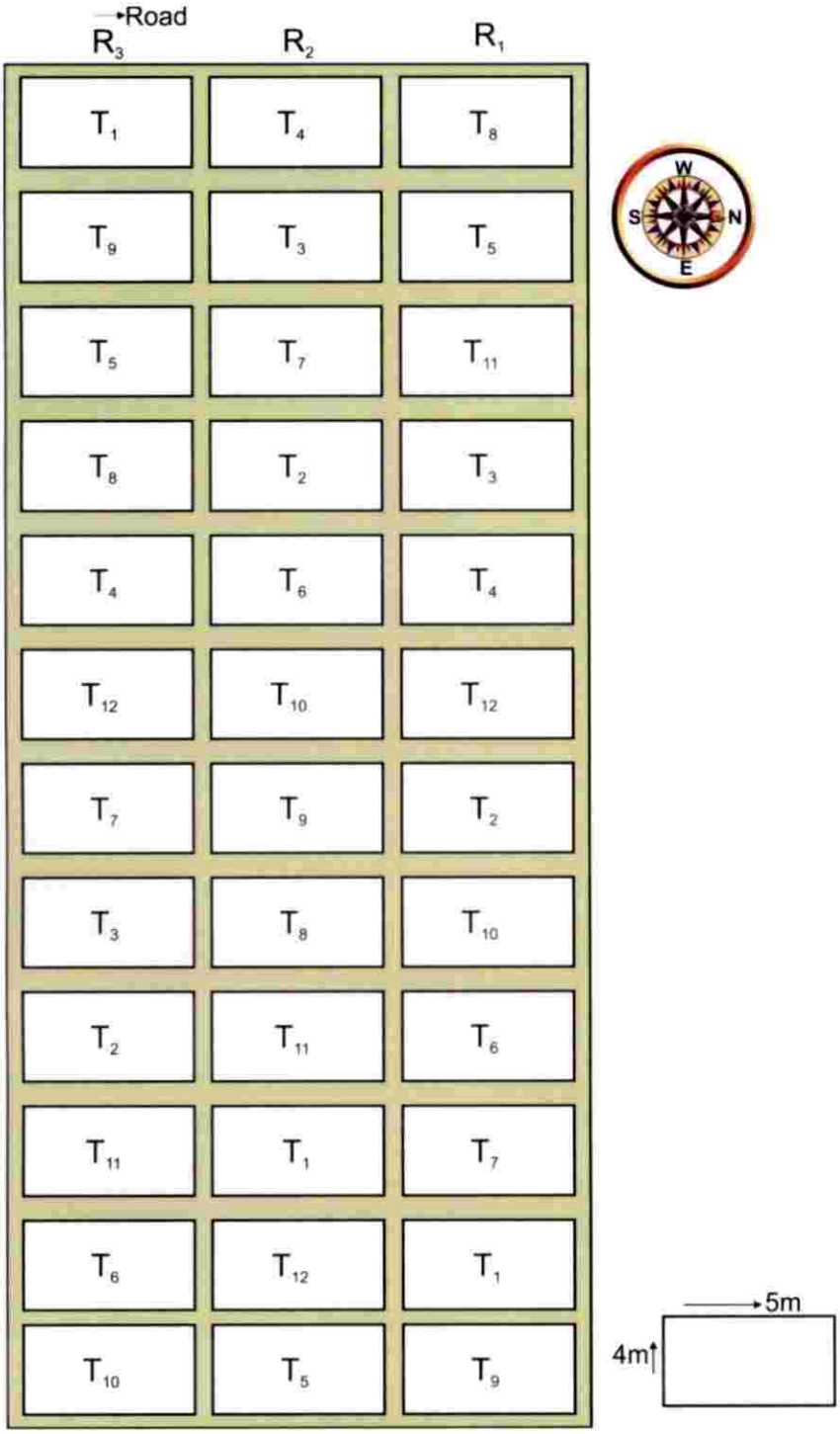

Fig.2. Lay out plan of the experiment (first and second crop seasons)

(A) Layout of the experiment during first crop season

(B) Layout of experiment during second crop season

Plate 2. Lay out of the experimental field

(A) General view of the experiment during first crop season

(B) General view of the experiment during second crop season

Plate 3. General view of the experimental field

3.1.3.4 Seeds and Sowing

Healthy seeds were soaked in water for 24 h. After, the seed were taken out and incubated in gunny bags for sprouting. The sprouted seeds were broadcasted in individual plot @ 100 kg ha^{-1} on 31/05/2014 during first crop and on 25/11/2014 during second crop.

3.1.3.5 Application of Manures and Fertilizers

The crop was uniformly fertilized with recommended dose of FYM (5 t ha^{-1}) and chemical fertilizers (70: 35: 35 kg N: P_2O_5: K_2O ha^{-1}). The entire dose of FYM was incorporated at the time of last ploughing. The fertilizers were applied in three splits; one third N and K and half P at 15 days after sowing (DAS), one third N and K and half P at 35 DAS and remaining one third N and K at 55 DAS.

3.1.3.6 Water Management

Water management was carried out as per *Package of Practices Recommendations*: *Crops* (KAU, 2011).

3.1.3.7 Weed Management

The herbicides were applied at 15 DAS as per the treatment schedule. The spray volume used in the study was 500 L ha^{-1} and herbicides were sprayed with hand operated knapsack sprayer fitted with a flat fan nozzle. In hand weeding treatment, weeding was done twice manually at 20 and 40 DAS.

3.1.3.8 Plant Protection

One spray of acephate (750 g ha^{-1}) was given against rice folder attack at the seedling stage of the crop and two sprays of malathion (750 mL ha^{-1}) were given against rice bug at flowering and milky stage of the crop. No serious incidence of diseases was noticed during the growth of the crop. A prophylactic spray of *Pseudomonas fluorescens* @ 20 g L^{-1} was given at 45 DAS against sheath blight and bacterial leaf blight.

3.1.3.9 Harvest

The crop was harvested on 17/09/2014 during first crop and on 18/03/2015 during second crop. The net plot area were harvested separately, threshed and winnowed. The weight of grain and straw from individual plots were recorded and expressed in kg ha^{-1} on dry weight basis.

3.1.4 Observations on Crop

3.1.4.1 Growth Components

3.1.4.1.1 Phytotoxicity Rating

The treated plots were observed closely and the visual symptoms of herbicide toxicity on plants were recorded, seven days after herbicide application.

3.1.4.1.2 Plant Height

Ten plants from the net plot area of each treatment were selected at random. The plant height was recorded from ground level to the tip of the top most leaf at 30 and 60 DAS and from the base of the plant to the tip of the ear head at harvest and expressed in cm.

3.1.4.1.3 Tillers m^{-2}

In each treatment plot, tiller count was taken from two spots of 0.25 m^2 from the net plot area each at random by using a quadrate and was expressed in number m^{-2} at 30 and 60 DAS and at harvest.

3.1.4.1.4 Leaf Area Index

Ten primary tillers were randomly selected from the net plot area of each treatment. The length and breadth of the fourth leaf from top were measured at 30 and 60 DAS. Leaf area was then worked out by the method suggested by Palanisamy and Gomez (1974).

Leaf area	=	K (Lx B)
K	=	0.75 (Yoshida *et al.*, 1976)
L	=	leaf length (cm)
B	=	Maximum breadth of the leaf (cm)

LAI was calculated as follows

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

3.1.4.1.5 Dry Matter Production (DMP)

Five hills were randomly selected outside the net plot area of each treatment leaving two border rows, at 30 and 60 DAS and at harvest. The uprooted plant samples were initially air dried and later oven dried at 60 °C till the attainment of a constant weight. The total DMP was computed at each growth stage of the crop and was expressed in kg ha^{-1}.

3.1.4.2 Yield Components

3.1.4.2.1 Productive Tillers

From the net plot area of each treatment, number of productive tillers was recorded from two spots of 0.25 m^2 each at random and the mean value was arrived at. From this mean value, the number of productive tillers m^{-2} was computed.

3.1.4.2.2 Panicle Weight

From the primary tillers, ten panicles were collected randomly from the net plot area of each treatment. They were sun dried till a constant weight was attained and was expressed as g $panicle^{-1}$.

3.1.4.2.3 Filled Grains $Panicle^{-1}$

The total number of filled grains was counted from the ten sample panicles and the mean number $panicle^{-1}$ was worked out.

3.1.4.2.4 Sterility Percentage

From the selected panicles, the number of unfilled grains was recorded and sterility percentage was worked out. The values were transformed by arcsine transformation.

3.1.4.2.5 Thousand Grain Weight

Thousand grains from each net plot area were drawn at random, dried and weighed at 14 per cent moisture content and was expressed in g.

3.1.4.2.6 Grain Yield

The grain from the net plot area of each treatment was dried in sun to a moisture content of 14 per cent and its weight was recorded and expressed in kg ha^{-1}.

3.1.4.2.7 Straw Yield

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

3.1.4.2.8 Harvest Index

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

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

3.1.4.2.9 Weed Index (WI)

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

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

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

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

3.1.5 Observations on Weeds

3.1.5.1 Floristic Composition of Weeds

Weeds from the experimental area were identified and recorded.

3.1.5.2 Weed Dry Matter Production

Weed dry weight was recorded at 15, 30, 45 and 60 DAS by placing a quadrate of size 0.5 m x 0.5 m randomly at two sites in each treatment plot. The weeds in the quadrate were uprooted and categorized into sedges, broad leaf weeds (BLW) and grasses. The uprooted weeds were sundried for one day and then oven dried at 60 °C until constant weight was attained and dry weight was recorded as g m^{-2}.

3.1.5.3 Weed Control Efficiency (WCE)

Weed control efficiency was calculated by adopting the formula suggested by Mani and Gautham (1973).

$$WCE = \frac{WDWC - WDWT}{WDWC} x\ 100$$

Where

WCE - weed control efficiency

WDWC - weed dry weight in unweeded (control) plot

WDWT - weed dry weight in treated plot

3.1.5.4 Absolute Density (Ad)

Number of weeds was recorded from the randomly selected quadrate (0.5 m x 0.5 m) at two sites in each treatment plot and the mean value was

recorded. The weeds were categorized into sedges, broad leaf weeds and grasses. The absolute density of sedges, broad leaf weeds, grasses and total absolute density were calculated at 15, 30, 45 and 60 DAS using the formula suggested by Philips (1959).

Ad= Total number of weeds of a given species in m^2

3.1.5.5 Relative Density (Rd)

Relative density of sedges, broad leaf weeds and grasses were calculated at 15, 30, 45 and 60 DAS using the formula suggested by Philips (1959).

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

3.1.5.6 Absolute Frequency (Af)

Absolute frequency of sedges, broad leaf weeds, grasses and total frequency of weeds were worked out at 15, 30, 45 and 60 DAS using the formula suggested by Phlilips (1959).

$$Af = \frac{\text{Number of quadrates in which a given species occured}}{\text{Total number of quadrates}} \times 100$$

3.1.5.7 Relative Frequency (Rf)

Relative frequency was computed at 15, 30, 45 and 60 DAS, separately for sedges, broad leaf weeds and grasses using the formula developed by Philips (1959).

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

3.1.5.8 Importance Value (IV)

Importance value of sedges, broad leaf weeds and grasses were worked out at 15, 30, 45 and 60 DAS by adding the relative density (Rd) and relative frequency (Rf) of a given species (Kent and Coker, 1992).

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

3.1.5.9 Summed Dominance Ratio (SDR)

Summed dominance ratio of sedges, broad leaf weeds and grasses were worked out at 15, 30, 45 and 60 DAS, according to the formula developed by Sen (1981). Summed dominance ratio of sedges, broad leaf weeds and grasses were worked out separately.

$$\text{SDR} = \frac{\text{Relative density} + \text{Relative frequency}}{2}$$

3.1.6 Soil Analysis

3.1.6.1 Organic Carbon

Composite soil samples were collected from each treatment plot just prior to herbicide spraying, 15 days after herbicide spraying (*i.e.*, 30 DAS) and 45 days after herbicide spraying (*i.e.*, 60 DAS). Samples were shade dried, sieved through a 0.2 mm sieve and analysed for organic carbon content by rapid titration method (Walkley and Black, 1934).

3.1.6.2 Available Nitrogen

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

3.1.6.3 Available Phosphorus

Available phosphorus content of the soil was determined by Dickman and Brays molybdenum blue method using spectrophotometer (Jackson, 1973).

3.1.6.4 Available Potassium

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

3.1.7 Plant Analysis

3.1.7.1 Nutrient Content in Plants

The plant samples at 30 and 60 DAS and at harvest stage and weed samples at 30 and 60 DAS were analysed for the total N, P and K content. The grains were analysed separately. The samples were dried in a hot air oven 60 °C to constant weight, ground and sieved through 0.5 mm sieve. The required quantities of samples were weighed out accurately and were subjected to acid extraction and N, P and K content was determined.

3.1.7.1.1 Total Nitrogen Content

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

3.1.7.1.2 Total Phosphorus Content

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

3.1.7.1.3 Total Potassium Content

Total potassium content was determined using flame photometer (Jackson, 1973).

3.1.7.2 Uptake of Nutrients

The N, P and K uptake of weeds at 30 and 60 DAS and the crop at 30 and 60 DAS and at harvest stage were worked out by multiplying the nutrient content with DMP and expressed in kg ha^{-1}.

3.1.8 Microbial Count in Soil

Soil samples for the enumeration of total count of bacteria, fungi and actinomycetes were collected with soil auger just before herbicide application (15 DAS), 15 days after herbicide application (30 DAS) and 45 days after herbicide application (60 DAS). Four samples were collected from each treatment plot to a depth of 15 cm, mixed thoroughly to form a composite sample. The total count of bacteria, fungi and actinomycetes were assessed by serial dilution plate technique (Johnson and Curl, 1972). The media and dilution used for isolation of different groups of microorganisms are given in Appendix III and compositions of the media are given in Appendix IV.

3.1.9 Quantitative Estimation of Earthworms

Estimation of earthworms was carried out before the experiment and after the harvest of first and second crop.

Two representative samples from each plot were collected and earthworm population was estimated. Sampling area was plotted with one metre square wooden frame. Soil samples were drawn up to 10 cm depth (Bano and Kale, 1991). The soil lumps were broken and the soil was passed through the fingers to sort out the worms. The smaller worms were collected by passing through a sieve of 3-4 mm size. The worms were then counted.

3.1.10 Soil Enzyme Assay

Soil samples for enzyme assay were collected with soil auger just before herbicide application (15 DAS), 15 days after herbicide application (30 DAS), 45 days after herbicide application (60 DAS) and at harvest stage. Four samples were collected from each plot to a depth of 15 cm, mixed thoroughly to form a composite sample and stored in polythene bag at 4 °C. The enzyme assay was completed within a week.

3.1.10.1 Dehydrogenase Activity

The dehydrogenase activity was determined by the method described by Casida *et al.* (1964) and expressed as µg triphenyl formazon (TPF) g^{-1} soil h^{-1}.

3.1.10.2 β Glucosidase Activity

Soil was incubated with buffered (pH 6.0) para nitrophenyl β glucopyranoside and para nitrophenol released was determined and expressed as µg para nitro phenol g^{-1} soil h^{-1} (Eivasi and Tabatabai, 1988).

3.1.10.3 Protease Activity

Soil was incubated with casein and tyrosine released was determined and expressed as mg tyrosine g^{-1}soil h^{-1} (Ladd and Butler, 1972).

3.1.10.4 Acid Phosphatase Activity

Soil was incubated with buffered (pH 6.5) para nitrophenyl phosphate tetrahydrate and para nitrophenol released was determined and expressed as µg para nitro phenol g^{-1} soil h^{-1} (Evasi and Tabatabai, 1977).

3.1.10.5 Urease Activity

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

3.1.11 Economic Analysis

The economics of cultivation was worked out based on the cost of cultivation and the prevailing price of the produce.

3.1.11.1 Net Income

Net income was computed using the formula

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

3.1.11.2 Benefit Cost Ratio (B: C ratio)

Benefit cost ratio was computed using the formula

$$\text{B: C ratio} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.2 PART II - SCREENING OF INDICATOR PLANTS AND DETER MINATION OF HERBICIDE RESIDUE IN POST EXPERIMENT SOIL

3.2.1 Screening of Indicator Plants

3.2.1.1 Screening of Indicator Plants for the Herbicide Mixtures Bispyribac Sodium + Metamifop

Test crops	:	Maize, cucumber and sunflower
Design	:	CRD
Replication	:	3
Treatments	:	8 (7 different concentrations of bispyribac sodium + metamifop *viz.*, 0.01, 0.05, 0.1, 0.5, 1, 10, 100 µL L^{-1} and control)

Soil was collected from herbicide free area, washed thoroughly and air dried. Then it was fortified with different concentrations of bispyribac sodium + metamifop (as per the treatments) and mixed thoroughly and 300 g soil was taken in small plastic pots of 500 mL capacity separately. Ten seeds of each test species were dibbled in each pot at uniform depth of 2 cm. Separate experiment was taken for each test crop. Germination count was taken at 4 DAS and then the plants were thinned to three per pot to avoid competition. At 14 DAS, the plants were uprooted from each pot without causing any damage to the roots. Shoot length and root length were recorded. The root system was removed using a sharp knife and the fresh shoot weight was recorded. Then the plants were dried in hot air oven at 60 °C to constant weight and the shoot dry weight was recorded.

Data on shoot length, root length, shoot fresh and dry weight of indicator plants raised in different concentrations of bispyribac sodium + metamifop was statistically analyzed and regression equations were developed. The test crop which showed the highest R^2 value for all the tested parameters was selected as the best indicator plant and the parameter which showed the highest R^2 value was selected as the best parameter for the bioassay of herbicide mixture, bispyribac sodium + metamifop. The response curve was also developed for the tested parameters of the best indicator plant.

3.2.1.2 Screening of Indicator Plants for the Herbicide Mixtures Penoxsulam + Cyhalofop Butyl

Test crops	:	Maize, cucumber and sunflower
Design	:	CRD
Replication	:	3
Treatments	:	8 (7 different concentrations of penoxsulam + cyhalofop butyl *viz*., 0.01, 0.05, 0.1, 0.5, 1, 10, 100 µL L^{-1} and control)

The experiment was conducted and observations were recorded as described in 3.2.1.1.

3.2.2 Determination of Herbicide Residue in Post Experiment Soil

3.2.2.1 Determination of Bispyribac Sodium + Metamifop Residue in Post Experiment Soil

Design	:	CRD
Replication	:	3
Treatments	:	7
T_1	:	Bispyribac sodium + metamifop 14 % SE @ 60 g ha^{-1}
T_2	:	Bispyribac sodium + metamifop 14 % SE @ 70 g ha^{-1}
T_3	:	Bispyribac sodium + metamifop 14 % SE @ 80 g ha^{-1}

T_4 : Bispyribac sodium + metamifop 14 % SE @ 90 g ha^{-1}

T_5 : Bispyribac sodium 10 % SC @ 25 g ha^{-1}

T_6 : Hand weeding twice at 20 and 40 DAS

T_7 : Weedy check

Composite soil sample was collected from each treatment plot at a depth of 15 cm after the harvest of the crop. From this sample, 300 g soil was weighed and transferred into plastic containers of 500 mL capacity and 10 seeds of the most sensitive indicator plant, *i.e.*, maize was dibbled. Observations on shoot and root length and shoot fresh and dry weight were recorded as described in 3.2.1.1. Data were statistically analyzed to determine the residual toxicity of bispyribac sodium + metamifop.

3.2.2.2 Determination of Penoxsulam + Cyhalofop Butyl Residue in Post Experiment Soil

Design : CRD

Replication : 3

Treatments : 7

T_1 : Penoxsulam + cyhalofop butyl 6 % OD @ 120 g ha^{-1}

T_2 : Penoxsulam + cyhalofop butyl 6 % OD @ 125 g ha^{-1}

T_3 : Penoxsulam + cyhalofop butyl 6 % OD @ 130 g ha^{-1}

T_4 : Penoxsulam + cyhalofop butyl 6 % OD @ 135 g ha^{-1}

T_5 : Penoxsulam 24 % SC @ 22.5 g ha^{-1}

T_6 : Hand weeding twice at 20 and 40 DAS

T_7 : Weedy check

The experiment was conducted with the best indicator plant *viz.*, maize and observations were recorded as described in 3.2.1.1. Data on shoot and root length

and shoot fresh and dry weight of maize plant were statistically analyzed to determine the residual toxicity of penoxsulam + cyhalofop butyl.

3.3 PART III - *IN VITRO* SENSITIVITY TO SOIL BORNE PATHOGEN *Rhizoctonia solani*

3.3.1 *In Vitro* Sensitivity of Bispyribac Sodium + Metamifop to *Rhizoctonia solani*

The *in vitro* sensitivity of soil borne pathogen, *Rhizoctonia solani* to bispyribac sodium + metamifop was determined by poisoned food technique (Zentmeyer, 1955).

Design	:	CRD
Replication	:	3
Treatments	:	8 (seven different concentrations of bispyribac sodium + metamifop *viz.*, 100, 120, 140, 160, 180, 200, 220 µL L^{-1} and control).

Stock solution of bispyribac sodium + metamifop (1000 µL L^{-1}) was prepared by dissolving the required quantity of herbicide mixture in sterile water. Fifty mL of 200, 220, 280, 320, 360, 400 and 440 µL L^{-1}, bispyribac sodium + metamifop (double concentration of tested treatments) were prepared in 100 mL conical flask with sterilized water. Fifty mL double strength potato dextrose agar (PDA) media (composition of the media are given in Appendix IV) was prepared in 250 mL conical flask and sterilized. Fifty mL double concentration of herbicide was mixed with 50 mL molten double strength PDA media to get the required concentrations of 100, 120, 140, 160, 180, 200 and 220 µL L^{-1} of the herbicide mixture. After solidification, the plates were inoculated at the centre with 5 mm disc of four day culture of *Rhizoctonia solani*. The control plate was maintained without herbicide. The petri plates were incubated at room temperature. The observations on radial colony diameter in cm were recorded on the day when the full growth of mycelia was observed in control plate *i.e.*, six

days after inoculation. Inhibition of radial mycelial growth was measured by the method suggested by Sunder *et al.* (1995).

$$\text{Per cent inhibition} = \frac{(X - Y)}{X} \times 100$$

Where X is the radial growth of mycelia in control plate

Y is the radial growth of mycelia in treated plot.

The experiment was repeated for confirmation.

3.3.2 *In Vitro* Sensitivity of Penoxsulam + Cyhalofop Butyl to *Rhizoctonia solani*

The *in vitro* sensitivity of *Rhizoctonia solani* to penoxsulam + cyhalofop butyl were determined by the procedure as described in 3.3.1.

Design	:	CRD
Replication	:	3
Treatments	:	8 (Seven different concentrations of penoxsulam + cyhalofop butyl *viz.*, 230, 240, 250, 260, 270, 280, 290 $\mu L\ L^{-1}$ and control).

3.4 PART IV - *IN VIITRO* SENSITIVITY OF HERBICIDE MIXTURES TO BENEFICIAL ORGANISMS

3.4.1 *In Vitro* Sensitivity of Herbicide Mixtures to Bio Control Agents

3.4.1.1 In Vitro Sensitivity of Herbicide Mixtures to Trichoderma viride

3.4.1.1.1 In Vitro Sensitivity of Bispyribac sodium + Metamifop to Trichoderma viride

The *in vitro* sensitivity of *Trichoderma viride* to bispyribac sodium + metamifop was determined by poisoned food technique (Zentmeyer, 1955).

Design : CRD

Replication : 3

Treatments : 8 (seven different concentrations of bispyribac + sodium + metamifop *viz.*, 100, 120, 140, 160, 180, 200, 220 µL L^{-1} and control).

The required concentrations were prepared as per the procedure explained in 3.3.1. After solidification, the plates were inoculated at the centre with 5 mm disc of four day culture of *Trichoderma viride*. The control plate was maintained without herbicide. The petri plates were incubated at room temperature. The observations on radial colony diameter were recorded on the day when the full growth of mycelia was observed in control plate *i.e.*, six days after inoculation. Inhibition of radial mycelial growth was measured by the method suggested by Sunder *et al.* (1995).

$$\text{Per cent inhibition} = \frac{(X - Y)}{X} x100$$

Where X is the radial growth of mycelia in control plate

Y is the radial growth of mycelia in treated plot.

The experiment was repeated for confirmation.

3.4.1.1.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Trichoderma viride

Trichoderma viride was tested *in vitro* for sensitivity to different concentrations of penoxsulam + cyhalofop butyl by the procedure as described in 3.4.1.1.1.

Design : CRD

Replication : 3

Treatments : 8 (Seven concentrations of penoxsulam + cyhalofop butyl *viz.*, 230, 240, 250, 260, 270, 280, 290 µL L^{-1} and control).

3.4.1.2 In Vitro Sensitivity of Herbicide Mixtures to Pseudomonas fluorescens

3.4.1.2.1 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Pseudomonas fluorescens

Pseudomonas fluorescens was tested *in vitro* for sensitivity to different concentrations of bispyribac sodium + metamifop by disc diffusion method suggested by Bauer *et al.* (1966).

Design : CRD

Replication : 3

Treatments : 8 (seven concentrations of bispyribac sodium + metamifop *viz.*, 100, 120, 140,160, 180, 200, 220 µL L^{-1} and control).

Twenty mL of sterilized King's B medium was poured into 90 mm sterile petri plates, after solidification and stored for 24 h to ensure the sterility (composition of the media are given in Appendix IV). The petri plates containing King's B medium were swabbed with four day old broth of *Pseudomonas fluorescens*. Sterile filter paper disc of 6 mm dipped in respective concentrations of herbicide were placed at the centre of the petri plate. Sterile filter paper disc dipped in sterile water served as the control. The petri plates were sealed and kept for three days incubation at room temperature. The observations on inhibition zone in mm were recorded at three days after incubation (DAI) and the growth was visually categorized as positive culture growth (+) around the disc and inhibited culture growth (-) around the disc. The experiment was repeated for confirmation.

3.4.1.2.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to *Pseudomonas fluorescens*

Pseudomonas fluorescens was tested *in vitro* for sensitivity to different concentrations of penoxsulam + cyhalofop butyl by the procedure as described in 3.4.1.2.1.

Design : CRD

Replication : 3

Treatments : 8 (Seven concentrations of penoxsulam + cyhalofop butyl *viz.*, 230, 240, 250, 260, 270, 280, 290 μL L^{-1} and control).

3.4.2 *In vitro* Sensitivity of Herbicide Mixtures to Bio Fertilizer Organisms

3.4.2.1 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Azospirillum lipoferum and Azotobacter chroococcum

Azospirillum lipoferum and *Azotobacter chroococcum* were tested *in vitro* for sensitivity to different concentrations of bispyribac sodium + metamifop by disc diffusion method suggested by Bauer *et al.* (1966).

Design : CRD

Replication : 3

Treatments : 8 (seven concentrations of bispyribac sodium + metamifop *viz.*, 100, 120, 140, 160, 180, 200, 220 μL L^{-1} and control).

Twenty mL of NFb (Nitrogen free bromothymol blue) medium and Jensen medium were poured into 90 mm sterile petri plates, after solidification and stored for 24 h to ensure the sterility (composition of the media are given in

Appendix IV). The petri plates containing NFb medium were swabbed with four day old broth suspension of *Azospirillum lipoferum* and Jensen medium with four day old broth of *Azotobacter chroococcum*. Sterile filter paper disc of 6 mm dipped in respective concentrations of herbicide were placed at the centre of the petri plate. Sterile filter paper disc dipped in sterile water served as the control. The petri plates were sealed and kept for three days incubation at room temperature. The observations on inhibition zone in mm were recorded at three days after incubation (DAI) and the growth was visually categorized as positive culture growth (+) around the disc and inhibited culture growth (-) around the disc. The experiment was repeated for confirmation.

3.4.2.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Azospirillum lipoferum and Azotobacter chroococcum

Azospirillum lipoferum and *Azotobacter chroococcum* were tested *in vitro* for sensitivity to different concentrations of penoxsulam + cyhalofop butyl by the procedure as described in 3.4.2.1.

Design	:	CRD
Replication	:	3
Treatments	:	8 (Seven concentrations of penoxsulam + cyhalofop butyl *viz*., 230, 240, 250, 260, 270, 280, 290 $\mu L\ L^{-1}$ and control).

3.5 PART V - WEED SEED BANK ASSAY

Weed seed bank in the soil was estimated before and after the experiment of both first and second crop by the seedling emergence method suggested by Luschei (2003).

The experiment was conducted in CRD with twelve treatments and three replications. The treatments were:

T_1- Bispyribac sodium + metamifop 14% SE @ 60 g ha^{-1} at 15 DAS

T_2- Bispyribac sodium + metamifop 14% SE @ 70 g ha^{-1} at 15 DAS

T_3- Bispyribac sodium + metamifop 14% SE @ 80 g ha^{-1} at 15 DAS

T_4- Bispyribac sodium + metamifop 14% SE @ 90 g ha^{-1} at 15 DAS

T_5- Penoxsulam + cyhalofop buytl 6% OD @ 120 g ha^{1} at 15 DAS

T_6- Penoxsulam + cyhalofopbuytl 6 % OD @ 125 g ha^{-1} at 15 DAS

T_7- Penoxsulam + cyhalofopbuytl 6 % OD @ 130 g ha^{1} at 15 DAS

T_8- Penoxsulam + cyhalofopbuytl 6 % OD @ 135 g ha^{-1} at 15 DAS

T_9- Bispyribac sodium 10 % SC @ 25 g ha^{1} at 15 DAS

T_{10}-Penoxsulam 24 % SC @ 22.5 g ha^{-1} at 15 DAS

T_{11}-Hand weeding twice at 20 and 40 DAS (HWT)

T_{12}-Weedy check

Composite soil sample was collected from each treatment using a soil auger at a depth of 15 cm. One kg soil was weighed and transferred and evenly spread in a plastic tray under net house condition. The soil was kept at adequate moisture level. The emerging weeds were counted up to 70 days at fortnightly interval and categorized into sedges, broad leaf weeds and grasses.

3.6 STATISTICAL ANALYSIS

The data generated from the experiments were statistically analysed using analysis of variance technique (ANOVA) of Randomized Block Design described by Cochran and Cox (1965). The data which required transformation were appropriately transformed. The pooled analysis was carried out for grain yield, straw yield, weed index, net returns and B: C ratio by taking the season as source of variance in addition to replication and treatment.

Results

4. RESULTS

Investigation entitled "Herbicide mixtures for weed management in direct seeded puddled rice (*Oryza sativa* L.)" was conducted at Upaniyoor padashekaram, Vellayani, Thiruvananthapuram during the first and second crop seasons of 2014-15. The main aim of the study was to assess the bio-efficacy of the herbicide mixtures bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl for weed control in direct seeded rice and also to assess the residual effect of these herbicide mixtures in soil using the indicator plant. It was also intended to study the impact of these herbicide mixtures on soil microorganisms, earth worm and enzyme activity in soil and weed seed bank. The *in vitro* sensitivity of these herbicide mixtures to soil borne pathogen *Rhizoctonia solani*, beneficial microorganisms *viz.*, *Pseudomonas fluorescens*, *Trichoderma viride* and N fixing organisms *Azospirillum lipoferum* and *Azotobacter chroococcum* was also studied. The results of the experiments are presented in this chapter.

4.1 PART I - BIO-EFFICACY OF POST EMERGENCE HERBICIDE MIXTURES IN DIRECT SEEDED RICE

4.1.1 Crop Growth Characters

The data on growth characters are presented in Tables 3 and 4.

4.1.1.1 Phytotoxicity Rating (Seedling) (Table 3)

Phytotoxicity observations on rice crop were recorded at 7 DAHA (days after herbicide application) to assess whether the applied herbicides had any toxicity in rice plant. Phytotoxicity was rated on a visual scale of 1-10, where 1 indicates no phytotoxicity and 10 indicates total crop damage. The data on phytotoxicity ratings during first and second crop seasons revealed that none of the treated herbicides produced any phytotoxic symptoms in rice plants.

Table 3. Effect of weed management treatments on phytotoxicity, plant height and leaf area index (first and second crop seasons)

Treatments	Phytotoxicity ratings		Plant height (cm)						Leaf area index			
	First crop	Second crop	First crop	Second Crop	First crop	Second Crop	First crop	Second crop	First crop	Second crop	First crop	Second Crop
			30 DAS	30 DAS	60 DAS	60 DAS	Harvest	Harvest	30 DAS	30 DAS	60 DAS	60 DAS
T_1	1	1	42.70	40.10	74.10	64.30	94.3	91.57	3.53	2.74	7.79	7.02
T_2	1	1	38.80	37.13	74.17	64.17	92.00	93.33	3.18	2.85	7.96	7.15
T_3	1	1	40.43	38.70	71.87	63.97	91.50	91.43	3.61	2.62	7.65	7.25
T_4	1	1	38.20	36.53	71.83	66.23	91.30	90.27	3.78	2.83	7.85	7.73
T_5	1	1	43.70	38.90	74.50	65.13	98.00	91.87	3.28	2.77	7.33	7.94
T_6	1	1	37.10	37.27	72.17	64.77	95.17	91.93	3.44	2.76	7.91	8.10
T_7	1	1	42.50	38.10	69.60	63.41	95.20	92.73	4.00	2.67	8.54	8.21
T_8	1	1	44.50	38.57	72.37	65.17	98.50	94.27	3.92	3.02	8.09	7.71
T_9	1	1	41.97	37.00	73.00	62.33	94.87	93.60	3.63	2.60	7.15	6.75
T_{10}	1	1	40.60	37.10	73.07	61.51	101.90	90.07	3.49	2.89	7.55	7.02
T_{11}	1	1	38.87	36.70	67.10	62.23	93.43	92.03	2.69	2.76	7.89	6.91
T_{12}	1	1	38.37	34.10	66.33	61.48	91.00	86.23	2.34	2.21	5.82	5.05
SEm (±)	#	#	1.025	0.549	`1.545	0.597	0.781	0.739	0.284	0.266	0.169	0.206
CD (0.05)			3.006	1.609	4.532	1.745	2.291	2.167	0.402	0.376	0.495	0.604

- mean value, 1- no phytotoxicity; DAS - days after sowing

4.1.1.2 Plant Height (Table 3)

Appreciable difference in plant height was observed due to weed management treatments at different stages of crop growth during both the seasons. All the treatments recorded higher plant height in first crop season compared to second crop season. Average plant height observed at 30 and 60 DAS (days after sowing) and at harvest stage were 40.65, 71.68 and 94.76 cm and 37.52, 63.73 and 91.61 cm, respectively during first and second crop season.

Perusal of data at 30 DAS indicated that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the maximum plant height which was statistically on par with its lower dose of 120 (T_5) and 130 g ha^{-1} (T_7), bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1), and bispyribac sodium applied alone @ 25 g ha^{-1} (T_9). Bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) registered minimum plant height and it was on par with weedy check (T_{12}), bispyribac sodium + metamifop @ 70 and 80 g ha^{-1} (T_2 and T_3), hand weeding twice (T_{11}) and penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}). During second crop season T_1 recorded plants with maximum height which was statistically comparable with T_5, T_3 and T_8. Weedy check (T_{12}) recorded significantly shorter plants compared to other treatments.

Critical appraisal of data at 60 DAS pointed out that maximum plant height was recorded in T_5 which was on par with T_2, T_1, T_{10}, T_9, T_8, T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}), T_3 and T_4. Weedy check recorded minimum plant height, but it was on par with T_{11} and T_7. During second crop season T_4 recorded maximum plant height and it was statistically on par with T_8, T_5 and T_6. As in the first crop season weedy check recorded minimum height and it was on par with T_{10}, T_{11} and T_9.

At harvest stage during first crop season, T_{10} resulted in maximum height and it was significantly superior to all other treatments. Similar to 30 and 60 DAS, weedy check recorded the lowest plant height but it was statistically comparable with T_4, T_3 and T_2. During second crop season, T_8 recorded

maximum plant height which was statistically on par with T_9, T_2 and T_7. Weedy check registered the lowest value and it was significantly inferior to all other treatments.

4.1.1.3 Leaf Area Index (LAI) (Table 3)

Total leaf area of rice is a factor closely related to grain production because higher leaf area intercepts more incident solar radiation and pave the way for increased photosynthesis and grain yield.

Leaf area index (LAI) was significantly influenced by weed management treatments at 30 and 60 DAS during both the seasons. The LAI increased rapidly from seedling to booting stage. During both the seasons, the maximum leaf area index was registered at booting stage. At all stages of observation (30 and 60 DAS) during both the seasons, weedy check recorded the lowest leaf area index among all the treatments.

Observations at 30 DAS during first crop season indicated that penoxsulam + cyhalofop butyl @ 130 g ha^{-1} (T_7) recorded the highest LAI (4.00) which was statistically on par with its higher dose of 135 g ha^{-1} (T_8), bispyribac sodium + metamifop @ 90 and 80 g ha^{-1} (T_4 and T_3) and bispyribac sodium applied alone @ 25 g ha^{-1} (T_9). During second crop season, T_8 recorded the highest LAI (3.02) which was on par with other weed management treatments except T_3 and T_9.

Perusal of data at 60 DAS during first crop season revealed that T_7 recorded the highest LAI which was on par with T_8. During second crop season, T_7 recorded the highest leaf area index which was on par with T_6, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), T_3 and T_8.

Table 4. Effect of weed management treatments on tiller and dry matter production (first crop and second crop seasons)

Treatments	Tillers (No. m^{-2})						Dry matter production (kg ha^{-1})					
	30 DAS		60 DAS		Harvest		30 DAS		60 DAS		Harvest	
	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop	Second crop
T_1	573	575	711	741	576	636	3311	2760	7856	7084	14730	14248
T_2	624	598	719	745	636	665	3478	3116	7694	7776	14931	14871
T_3	621	614	685	794	629	684	3320	2986	7415	7783	15028	15198
T_4	632	638	748	777	663	695	4423	3393	9024	7497	15104	15220
T_5	555	587	710	785	643	699	3272	3009	8597	7333	15189	15234
T_6	637	605	709	793	663	713	3137	3217	7626	7380	15246	15313
T_7	673	641	697	805	696	731	3522	3293	7628	7961	15702	15657
T_8	645	679	781	777	694	729	5006	3636	8596	7542	15281	16029
T_9	638	575	699	737	665	639	3316	3055	7685	7014	14152	14482
T_{10}	616	633	789	753	715	713	4466	3289	8448	7185	15187	15121
T_{11}	649	616	749	799	708	737	4268	3234	8683	7358	15426	14546
T_{12}	524	484	609	656	511	509	2140	2324	5329	5418	12685	10467
SEm (±)	15.39	15.40	14.14	8.71	10.90	12.17	155.70	80.17	154.00	110.70	164.80	200.08
CD (0.05)	45.14	45.18	41.46	25.54	31.97	35.7 1	456.69	235.14	451.70	324.69	483.38	587.67

DAS - Days after sowing

4.1.1.4 Tillers m^{-2} (Table 4)

Tillering capacity reflects the ability of the rice plant to make use of space, light and nutrition effectively and it finally contributes to yield.

Weed management treatments significantly influenced the tiller production at all growth stages of the crop. There was an increase in tiller production from seedling to booting stage (60 DAS) and the maximum number of tillers per square meter was observed at 60 DAS. The average number of tillers observed at 30 and 60 DAS and harvest stages was 616, 717 and 650, respectively during the first crop season and 604, 764 and 679, respectively during the second crop season. Among the treatments, weedy check (T_{12}) recorded the lowest number of tillers m^{-2} at all the stages of crop growth during both the seasons.

Critical appraisal of data at 30 DAS during first crop season indicated that penoxsulam + cyhalofop butyl @ 130 g ha^{-1} (T_7) recorded the highest number of tillers m^{-2} which was statistically comparable with its other doses of 135 and 125 g ha^{-1}(T_8 and T_6), hand weeding twice (T_{11}), bispyribac sodium applied alone @ 25 g ha^{-1} (T_9) and bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4). During second crop season, T_8 recorded the highest number of tillers which was on par with T_7 and T_4.

Perusal of data at 60 DAS during first crop season revealed that penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}) recorded the highest number of tillers which was on par with T_8, T_{11} and T_4. During second crop season, T_7 recorded the highest number of tillers which was statistically on par with T_{11}, T_3 (bispyribac sodium + metamifop @ 80 g ha^{-1}), T_6 and T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}).

At harvest stage during both the seasons, reduction in number of tillers was observed in all the treatments compared to that at booting stage (60 DAS). During first crop season, T_{10} (penoxsulam applied alone @ 22.5 g ha^{-1}) recorded the highest number of tillers which was statistically on par with T_{11}, T_7 and T_8.

However, during second crop season, T_{11} recorded the highest number of tillers m^{-2} which was statistically on par with T_7, T_8, T_6 and T_{10}.

4.1.1.5 Dry Matter Production (DMP) (Table 4)

Significant difference in dry matter production was observed due to weed management treatments. In general DMP increased gradually from maximum tillering stage (30 DAS) to harvest stage. The rate of increase was almost two times or more. The maximum DMP was observed at harvest stage. The average DMP observed at 30 and 60 DAS and at harvest stage were 3638, 7882 and 14888 and 3109, 7277 and 14699 kg ha^{-1}, respectively during first and second crop seasons. At all stages of crop growth, weedy check recorded the lowest dry matter production and it was significantly inferior to all the weed management treatments.

Analysis of data at 30 DAS during first and second crop seasons revealed that penoxsulam + cyhalofop butyl @135 g ha^{-1} (T_8) recorded the highest DMP (5006 and 3636 kg ha^{-1} respectively) and it was significantly superior to all other treatments.

At 60 DAS during first crop season T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) registered the highest DMP (9024 kg ha^{-1}) which was on par with T_{11} (hand weeding twice), T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) and T_8. During second crop season, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the highest DMP and it was on par with T_3 and T_2 (bispyribac sodium + metamifop @ 80 and 90 g ha^{-1}) and these two treatments were on par with T_8 and T_4.

At harvest stage of first crop season, T_7 recorded the highest DMP (15702 kg ha^{-1}) which was on par with T_{11}, T_8 and T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}). During second crop season, T_8 recorded the highest DMP (16029 kg ha^{-1}) which was statistically comparable with T_7.

Table 5. Effect of weed management treatments on yield components (first and second crop seasons)

Treatments	Yield components										
	First crop season						Second crop season					
	Panicles ($No.m^{-2}$)	Panicle weight (g)	Filled grains $panicle^{-1}$	Sterility percentage		1000 grain Weight (g)	Panicles ($No.m^{-2}$)	Panicle weight (g)	Filled grains $panicle^{-1}$	Sterility percentage		1000 grain Weight (g)
T_1	518.7	2.43	75.9	14.46	(22.33)	31.27	588.0	2.47	82.1	12.67	(20.75)	29.10
T_2	592.0	2.79	85.2	8.74	(17.20)	31.57	632.0	2.32	83.4	16.41	(23.88)	30.77
T_3	577.3	2.58	80.0	9.36	(17.74)	31.30	641.3	2.41	82.2	14.09	(22.04)	30.97
T_4	613.3	2.58	81.6	8.55	(17.30)	31.23	660.0	2.61	86.4	11.76	(19.86)	31.23
T_5	592.0	2.58	82.1	10.88	(19.25)	31.13	664.0	2.53	84.4	12.29	(20.50)	30.77
T_6	616.0	2.67	82.1	9.28	(17.73)	31.70	700.0	2.58	89.8	13.03	(21.12)	30.67
T_7	658.7	3.10	96.9	8.03	(16.46)	31.67	686.0	2.61	88.0	12.16	(20.26)	30.97
T_8	625.3	2.84	87.8	9.66	(18.11)	31.83	709.3	3.06	98.9	11.68	(19.87)	30.87
T_9	609.3	2.60	86.9	16.03	(23.60)	31.07	607.7	2.51	71.6	12.17	(20.42)	29.40
T_{10}	668.0	2.62	88.3	9.16	(17.61)	31.33	690.7	2.61	81.4	15.90	(23.44)	30.47
T_{11}	614.7	2.57	80.9	11.56	(19.86)	31.33	700.0	2.55	79.5	17.49	(24.69)	30.30
T_{12}	414.7	1.34	62.7	19.48	(26.18)	30.60	441.3	1.11	48.3	24.88	(29.92)	29.50
SEm (±)	18.03	0.126	2.61		0.544	0.225	14.07	0.151	3.73		1.297	0.477
CD (0.05)	52.87	0.369	7.65		1.595	NS	41.25	0.444	10.95		3.805	NS

Values in parentheses are transformed values – data are subjected to arcsine transformation, NS - non significant

4.1.2 Yield Attributes, Yield and Harvest Index

4.1.2.1 Yield Attributes (Table 5)

Data on productive tillers m^{-2}, panicle weight, filled grains $panicle^{-1}$, sterility percentage and thousand grain weight of first and second crop are presented in Table 5.

Panicles m^{-2} was significantly influenced by weed management treatments during both the seasons. Critical appraisal of data during both the seasons indicated that, panicles m^{-2} was more in second crop season. During first crop season, penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}) recorded the highest number of panicles m^{-2} which was on par with penoxsulam + cyhalofop butyl @ 130, 135 and 125 g ha^{-1} (T_7, T_8 and T_6). During second crop season, T_8 recorded the highest number of panicles m^{-2} which was statistically on par with hand weeding twice (T_{11}), T_6, T_{10} and T_7. During both the seasons, weedy check (T_{12}) recorded significantly lower number of panicles m^{-2}.

Panicle weight was also significantly influenced by the weed management treatments. During first crop season, the treatment T_7 recorded the maximum panicle weight (3.10 g) which was statistically on par with T_8 and T_2. During second crop season, T_8 recorded the maximum panicle weight and it was significantly superior to other treatments. During both the seasons, weedy check recorded significantly lower panicle weight (1.34 g and 1.11 g respectively).

Similar to panicles m^{-2}, filled grains $panicle^{-1}$ was also significantly influenced by weed management treatments during both the seasons. During first crop season, T_7 recorded the highest number of filled grains $panicle^{-1}$ (96.9), which was significantly superior to other treatments. During second crop season, T_8 recorded the highest number of filled grains $panicle^{-1}$ (98.9) which was on par with T_6 and T_7. However, weedy check (T_{12}) recorded the lowest number of filled grains $panicle^{-1}$ during both the seasons.

Sterility percentage was also significantly influenced by weed management treatments during both the seasons. Weedy check recorded the highest sterility percentage during both the seasons (19.48 and 24.88 per cent respectively) and it was statistically inferior to all other treatments. Perusal of data during first crop season revealed that, T_7 recorded the lowest sterility percentage of 8.03 per cent which was statistically comparable with bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1} (T_4, T_3 and T_2), T_{10} and T_6. However, during second crop season, T_8 recorded the lowest sterility per cent (11.68) which was on par with T_4, T_7, T_9, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), T_1 (bispyribac sodium + metamifop @ 60 g ha^{-1}), T_6, T_3 and T_{10}.

Thousand grain weight was not significantly influenced by the weed management treatments during both the seasons.

4.1.2.2 Yield and Harvest Index (Table 6)

Data on grain and straw yield and harvest index of two seasons are furnished in Table 6.

Grain yield was significantly influenced by weed management treatments during both the seasons. All the tested herbicides applied for the control of weeds enhanced the grain yield compared to weedy check during both the seasons and yield enhancement ranged from 4285 to 8295 kg ha^{-1} during first crop season and from 4240 to 8889 kg ha^{-1} during second crop season. Season long weed competition caused 40.33 to 48.34 per cent reduction in yield during first crop season and the magnitude of yield reduction in second crop season ranged from 42.59 to 52.30 per cent.

During first crop season, penoxsulam + cyhalofop buyl @ 130 g ha^{-1} (T_7) recorded the highest grain yield which was statistically on par with penoxsulam + cyhalofop butyl @ 135 and 125 g ha^{-1} (T_8 and T_6). During second crop season, treatment T_8 recorded the highest grain yield which was significantly superior to

Table 6. Effect of weed management treatments on grain yield, straw yield, harvest index and weed index (first and second crop seasons) and pooled grain and straw yield and weed index

Treatments	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index		Weed index				Pooled grain yield (kg ha^{-1})	Pooled straw yield (kg ha^{-1})	Pooled weed index	
	First crop	Second crop	First crop	Second crop	First crop	Second crop	First crop		Second crop					
T_1	7441	7385	7526	6862	0.50	0.52	10.29	(3.27)	16.89	(4.17)	7413	7194	13.59	(3.72)
T_2	7643	8273	7289	6925	0.51	0.54	7.86	(2.89)	6.90	(2.72)	7958	7107	7.38	(2.78)
T_3	7620	8373	7408	6847	0.51	0.55	8.12	(2.90)	5.79	(2.44)	7997	7127	6.96	(2.67)
T_4	7659	8442	7444	6429	0.51	0.57	7.67	(2.85)	5.01	(2.33)	8051	6937	6.34	(2.59)
T_5	7441	8273	7748	6994	0.49	0.54	10.29	(3.27)	6.96	(2.73)	7857	7371	8.63	(3.01)
T_6	8017	8473	7230	6871	0.52	0.55	3.35	(1.96)	4.66	(2.27)	8245	7051	4.01	(2.11)
T_7	8295	8547	7407	6805	0.52	0.56	0.0	(0.71)	3.82	(2.07)	8421	7106	1.91	(1.39)
T_8	8037	8889	7244	7126	0.53	0.56	3.11	(1.90)	0.0	(0.71)	8463	7185	1.56	(1.30)
T_9	7181	7724	7733	6758	0.48	0.54	13.41	(3.72)	13.10	(3.68)	7453	7246	13.26	(3.70)
T_{10}	7629	7997	7541	6731	0.50	0.54	8.02	(2.92)	10.03	(3.24)	7813	7136	9.03	(3.08)
T_{11}	7698	8171	7361	6376	0.51	0.56	7.20	(2.76)	8.09	(2.92)	7935	6868	7.65	(2.84)
T_{12}	4285	4240	7289	6227	0.37	0.41	48.46	(7.00)	52.30	(7.27)	4263	6758	50.38	(7.13)
SEm (±)	133.1	115.7	325.25	259.12	0.013	0.008		0.148		0.137	88.2	207.9		0.116
CD (0.05)	390.2	339.3	NS	NS	0.037	0.027		0.434		0.403	252.0	NS		0.332

Values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

all other treatments. During both the seasons, weedy check (T_{12}) recorded the lowest grain yield and it was significantly inferior to all other treatments.

Contrary to grain yield, straw yield was not significantly influenced by weed management treatments during both the seasons. Though no significant difference among the treatments was observed, during first crop season T_5 recorded the highest straw yield (7748 kg ha^{-1}) and T_6 recorded the lowest straw yield (7230 kg ha^{-1}); while during second crop season T_8 recorded the highest straw yield (7126 kg ha^{-1}) and T_{12} recorded the lowest straw yield (6227 kg ha^{-1}).

Harvest index was also significantly influenced by weed management treatments. During first crop season, the treatment T_8 recorded the highest harvest index (0.53) which was on par with T_7, T_6, T_{11} (hand weeding twice), T_{10} (penoxsulam @ 22.5 g ha^{-1}) and all tested doses of bispyribac sodium + metamifop (T_1, T_2, T_3 and T_4). During second crop season, T_4 recorded the highest harvest index (0.57) which was on par with T_8, T_7, T_{11}, T_6 and T_3. During both the seasons, weedy check recorded the lowest harvest index and was significantly inferior to all other treatments.

4.1.2.3 Pooled Grain and Straw Yield (Table 6)

Pooled data of grain yield are presented in Table 6. Pooled grain yield was significantly influenced by the weed management treatments. Weedy check (T_{12}) recorded the lowest grain yield. Among the treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the highest grain yield which was statistically on par with its lower doses @ 130 and 125 g ha^{-1} (T_7 and T_6). However, T_6 was also on par with bispyribac sodium + metamifop @ 90 and 80 g ha^{-1} (T_4 and T_3). Bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1) recorded the lowest grain yield, among the herbicide treatments and it was statistically on par with bispyribac sodium applied alone @ 25 g ha^{-1} (T_9).

Pooled data of first and second crop season revealed that, straw yield was not significantly influenced by the weed management treatments. However, the highest straw yield was observed in penoxsulam + cyhalofop butyl @ 120 g ha^{-1} (T_5) and the lowest in weedy check (T_{12}).

4.1.2.4 Weed Index (Table 6)

Weed management treatments exerted significant influence on weed index.

During first crop season, penoxsulam + cyhalofop buty @ 130 g ha^{-1} (T_7) was considered as the weed free plot for calculating the weed index, since it recorded the minimum weeds and highest grain yield among the treatments. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest weed index (3.11) which was on par with penoxsulam + cyhalofop @ 125 g ha^{-1} (T_6). Compared to other treatments, bispyribac sodium @ 25 g ha^{-1} (T_9) and weedy check (T_{12}) recorded significantly higher weed index values of 13.41 and 48.46, respectively.

For calculating the weed index during second crop season, T_8 was considered as the weed free plot, since it recorded the minimum weed infestation and highest grain yield among the treatments. Among the treatments, T_7 recorded the lowest weed index (3.82) which was on par with T_6 and bispyribac sodium + metamifop @ 90 and 80 g ha^{-1} (T_4 and T_3). The treatments T_9, T_1 (bispyribac sodium + metamifop @ 60 g ha^{-1}) and T_{12} were significantly inferior among other treatments and recorded higher weed index of 13.10, 16.89 and 52.30, respectively.

Pooled data indicated that T_8 recorded the lowest weed index (1.56) which was on par with T_7. Among the herbicide treatments, T_1 recorded the highest weed index (13.59) and it was on par with T_9 (13.26). Weedy check was significantly inferior among all the treatments and recorded the highest weed index of 50.38.

Table 7. Major weed flora present in the experimental field

COMMON NAME	SCIENTIFIC NAME	FAMILY	MALAYALAM NAME
SEDGES			
Umbrella sedge	*Cyperus difformis* L.	Cyperaceae	Thalekkettan
Rice flat sedge	*Cyperus iria* L.	Cyperaceae	Manjakora
Bulrush	*Schoenoplectus juncoides* (Roxb.) Palla.	Cyperaceae	Soochipullu
Globe fingerush	*Fimbristylis miliacea* (L.) Vahl.	Cyperaceae	Mung
BROAD LEAF WEEDS			
Yellow burr head/ Yellow velvet leaf	*Limnocharis flava* (L.) Buchenau.	Limnocharitaceae	Nagapola, Malamkoovalam
Water primrose	*Ludwigia perennis* L.	Onagraceae	Neergramboo
Goose weed	*Sphenoclea zeylanica* Gaertn.	Sphenocleaceae	Pongolan, Pongati
Pickerel weed	*Monochoria vaginalis* (Burm.f.) C.Presl ex Kunth	Pontederiaceae	Karimkoovalam, Neelolpalam
Water clove	*Marsilea quadrifolia* L.	Marsileaceae	Neeraral
Birdbill day flower/ Creeping day flower	*Commelina diffussa* Burm.f.	Commelinaceae	Vazhappadathi
Bergia	*Bergia capensis* L.	Elantinaceae	-
GRASS			
Isachne/Blood grass	*Isachne miliacea* Roth ex Roem. et Schult	Poaceae	Changalipullu

4.1.3 Observations on Weeds

4.1.3.1 Floristic Composition of Weeds (Table 7)

Weed species present in the experimental field, collected during first and second crop seasons of 2014-15 were identified and categorized into sedges, BLW and grasses. *Schoenoplectus juncoides*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* were the major sedges; *Isachne miliacea* was the major grass weed; *Ludwigia perennis*, *Limnocharis flava*, *Sphenoclea zeylanica*, *Marsilea quadrifolia*, *Bergia capensis*, *Commelina diffussa* and *Monochoria vaginalis* were the major broad leaf weeds present in the experimental field.

4.1.3.2 Dry Weight (Dry Matter Production) of Weeds

4.1.3.2.1 Dry Weight of Sedges (Table 8)

Dry weight of sedges was not significantly influenced by the weed management treatments at 15 DAS (just before herbicide application). However at 30 DAS (15 days after herbicide application), 45 DAS (30 days after herbicide application) and 60 DAS (45 days after herbicide application), dry weight of sedges varied significantly due to weed management treatments. Weedy check (T_{12}) registered the highest dry weight of sedges at 30, 45 and 60 DAS with mean values of 26.29, 228.83 and 195.99 g m^{-2}, respectively during first crop season and 9.61, 45.00 and 167.74 g m^{-2}, respectively during second crop season.

Observations at 30 DAS (15 days after herbicide application) during first crop season indicated that among the weed management treatments, the lowest dry weight of sedges was recorded in penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6), however it was on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8), penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}), bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4), bispyribac sodium applied alone @ 25 g ha^{-1} (T_9) and penoxsulam + cyhalofop butyl @ 120 g ha^{-1} (T_5). During second crop season also, the lowest

dry weight of sedges was recorded in T_8; however it was on par with T_6, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_{10} and T_5.

Perusal of data at 45 DAS during first crop season indicated that among the treatments, T_8 registered the lowest dry weight of sedges which was statistically comparable with T_5, T_{10}, T_6 and T_7. During second crop season also, T_8 recorded the lowest dry weight of sedges among the treatments and it was on par with T_7, T_5, T_6, T_{10} and T_{11}.

Critical appraisal of data at 60 DAS revealed that, similar to 45 DAS, the lowest dry weight of sedges was observed in T_8 which was statistically comparable with T_7, T_6, T_{10} and T_5. A similar trend was observed during second crop season also.

4.1.3.2.2 Dry Weight of Broad Leaf Weeds (BLW) (Table 9)

The dry weight of BLW was not significantly influenced by weed management treatments at 15 DAS (just before herbicide application). However at 30 DAS (15 days after herbicide application), 45 DAS (30 days after herbicide application) and 60 DAS (45 days after herbicide application), dry weight of BLW was significantly influenced by weed management treatments. At 30, 45 and 60 DAS, weedy check (T_{12}) registered the highest dry weight of BLW and was significantly inferior to all the treatments.

At 30 DAS during first crop season, the lowest dry weight of BLW was recorded in penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8); however it was on par with penoxsulam + cyhalfop butyl @ 125 g ha^{-1} (T_6), all tested doses of bispyribac sodium + metamifop (T_1, T_2, T_3 and T_4), bispyribac sodium @ 25 g ha^{-1} (T_9) and penoxsulam @ 22.5 g ha^{-1} (T_{10}). During second crop season also, T_8 registered the lowest dry weight and it was on par with T_7, T_6, T_{10}, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) and T_2.

Table 8. Effect of weed management treatments on dry weight of sedges (first and second crop seasons)

Treatments	Dry weight of sedges (g m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	1.51	(1.36)	2.77	(1.77)	26.75	(5.21)	22.78	(4.82)	0.86	(1.15)	2.71	(1.79)	12.90	(3.64)	15.49	(3.97)
T_2	1.18	(1.29)	7.95	(2.91)	14.24	(3.79)	5.62	(2.47)	0.94	(1.19)	1.35	(1.33)	7.59	(2.81)	10.17	(3.23)
T_3	2.16	(1.63)	2.99	(1.87)	13.40	(3.70)	3.52	(2.00)	1.67	(1.45)	1.09	(1.23)	7.12	(2.71)	8.29	(2.96)
T_4	0.75	(1.11)	0.84	(1.15)	6.88	(2.69)	2.19	(1.58)	0.85	(1.16)	0.77	(1.11)	4.68	(2.27)	5.37	(2.42)
T_5	1.17	(1.29)	1.18	(1.29)	0.04	(0.73)	1.15	(1.26)	0.59	(1.03)	0.25	(0.85)	0.49	(0.99)	2.28	(1.63)
T_6	2.56	(1.70)	0.47	(0.97)	0.28	(0.87)	0.64	(1.06)	1.16	(1.28)	0.06	(0.75)	0.62	(1.06)	0.59	(1.37)
T_7	2.13	(1.61)	1.85	(1.50)	0.58	(0.98)	0.41	(0.95)	0.39	(0.94)	0.10	(0.77)	0.41	(0.94)	1.00	(1.19)
T_8	1.32	(1.30)	0.52	(1.01)	0.01	(0.72)	0.16	(0.80)	0.36	(0.92)	0.04	(0.73)	0.18	(0.82)	0.33	(0.88)
T_9	2.67	(1.77)	0.97	(1.2)	10.6	(3.30)	10.20	(3.27)	0.61	(1.04)	0.92	(1.16)	8.62	(3.02)	10.82	(3.36)
T_{10}	2.56	(1.74)	0.63	(1.06)	0.25	(0.85)	0.86	(1.14)	0.71	(1.10)	0.17	(0.81)	1.11	(1.22)	2.70	(1.66)
T_{11}	2.24	(1.63)	4.02	(2.11)	10.80	(3.33)	7.03	(2.74)	1.43	(1.36)	2.85	(1.81)	1.52	(1.42)	6.40	(2.54)
T_{12}	1.60	(1.43)	26.29	(5.17)	228.83	(15.14)	195.99	(14.01)	1.09	(1.25)	9.61	(3.17)	45.0	(6.73)	167.74	(13.05)
SEm (±)		0.176		0.131		0.274		0.162		0.121		0.129		0.209		0.305
CD (0.05)		NS		0.385		0.805		0.474		NS		0.380		0.614		0.893

Values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, NS - non significant

Table 9. Effect of weed management treatments on dry weight of broad leaf weeds (first crop and second seasons)

Treatments	Dry weight of broad leaf weeds (g m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	1.80	(1.45)	0.22	(0.85)	5.17	(2.37)	2.82	(1.82)	0.38	(0.92)	0.81	(1.14)	7.32	(2.79)	14.33	(3.85)
T_2	0.82	(1.11)	0.44	(0.95)	2.01	(1.58)	2.30	(1.67)	0.36	(0.92)	0.37	(0.93)	2.07	(1.59)	7.51	(2.80)
T_3	0.90	(1.14)	0.64	(1.07)	0.54	(1.01)	1.29	(1.34)	0.46	(0.98)	0.45	(0.97)	2.23	(1.62)	5.89	(2.50)
T_4	1.19	(1.27)	0.58	(1.00)	2.68	(1.78)	0.95	(1.20)	0.46	(0.97)	0.43	(0.96)	2.02	(1.57)	5.72	(2.47)
T_5	1.53	(1.42)	1.08	(1.25)	3.00	(1.87)	1.75	(1.50)	0.82	(1.14)	0.25	(0.86)	1.36	(1.34)	2.91	(1.82)
T_6	0.51	(1.00)	0.21	(0.84)	1.10	(1.27)	1.31	(1.32)	0.53	(1.00)	0.16	(0.81)	0.62	(1.06)	3.16	(1.89)
T_7	0.65	(1.05)	0.99	(1.22)	3.16	(1.88)	1.09	(1.26)	0.31	(0.90)	0.13	(0.79)	0.41	(0.95)	2.63	(1.75)
T_8	0.92	(1.17)	0.22	(0.84)	1.46	(1.31)	1.06	(1.25)	0.48	(0.99)	0.07	(0.76)	0.83	(1.09)	1.30	(1.33)
T_9	1.58	(1.39)	0.62	(1.05)	0.19	(0.82)	1.26	(1.33)	0.60	(1.03)	0.75	(1.10)	3.18	(1.92)	7.27	(2.76)
T_{10}	1.05	(1.23)	0.66	(1.06)	4.45	(2.16)	2.64	(1.77)	0.29	(0.89)	0.18	(0.82)	1.25	(1.32)	3.31	(1.95)
T_{11}	0.71	(1.08)	2.42	(1.68)	1.84	(1.53)	2.90	(1.84)	0.38	(0.93)	1.41	(1.38)	0.47	(0.97)	3.88	(2.07)
T_{12}	0.33	(0.89)	5.67	(2.48)	20.23	(4.54)	35.36	(5.95)	0.56	(1.03)	2.36	(1.69)	26.72	(5.22)	50.81	(7.20)
SEm (±)		0.187		0.122		0.187		0.147		0.084		0.071		0.148		0.251
CD (0.05)		NS		0.356		0.548		0.432		NS		0.208		0.433		0.735

Values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, NS - non significant

Critical appraisal of data at 45 DAS, during first crop season indicated that the lowest dry weight of BLW was registered in T_9; however it was on par with T_3, T_6 and T_8. During second crop season, the lowest dry weight of BLW was recorded in T_7, which was on par with T_{11} (hand weeding twice), T_6, T_8, T_{10} and T_5.

Perusal of data at 60 DAS during first crop season revealed that the lowest dry weight of BLW was recorded in T_4 which was statistically comparable with T_8, T_7, T_6, T_9, T_3 and T_5. During second crop season, T_8 registered the lowest dry weight of BLW and it was statistically comparable with T_7, T_5 and T_6.

4.1.3.2.3 Dry Weight of Grasses (Table 10)

Dry weight of grasses was not significantly influenced by weed management treatments at 15 DAS during both the seasons. During both the seasons at all stages of observations (30, 45 and 60 DAS), weedy check (T_{12}) recorded the highest dry weight of grasses and was significantly inferior to all the treatments

Observations at 30 DAS during first crop season indicated that dry weight of grasses was not significantly influenced by the weed management treatments. But during second crop season, weed management treatments significantly influenced the dry weight of grasses. Grasses were absent in bispyribac sodium + metamifop @ 60, 70 and 80 g ha^{-1} (T_1, T_2 and T_3), penoxsulam + cyhalofop butyl @ 120 and 125 g ha^{-1} (T_5 and T_6) and recorded zero dry weight and these treatments were on par with all other treatments, except weedy check.

Critical appraisal of data at 45 DAS during first crop season revealed that the lowest dry weight of grasses was observed in T_6, but it was statistically comparable with T_{11} (hand weeding twice), T_7 and T_8 (penoxsulam + cyhalofop butyl @ 130 and 135 g ha^{-1}), T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}), T_1 and T_2. During second crop season, T_2 recorded zero dry weight and it was statistically comparable with rest of the treatments, except T_5 and T_{12}.

Table 10. Effect of weed management treatments on dry weight of grasses (first and second crop seasons)

Treatments	Dry weight of grasses (g m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0.00	(0.71)	0.05	(0.74)	0.55	(1.02)	4.03	(2.11)	0.18	(0.82)	0.00	(0.71)	0.19	(0.82)	0.51	(0.98)
T_2	0.00	(0.71)	0.02	(0.72)	0.75	(1.08)	3.62	(2.02)	0.07	(0.76)	0.00	(0.71)	0.00	(0.71)	0.41	(0.94)
T_3	0.09	(0.77)	0.23	(0.84)	1.09	(1.24)	1.80	(1.52)	0.04	(0.73)	0.00	(0.71)	0.04	(0.73)	0.37	(0.93)
T_4	0.28	(0.87)	0.00	(0.71)	0.39	(0.91)	1.20	(1.30)	0.77	(0.76)	0.01	(0.72)	0.11	(0.78)	0.36	(0.92)
T_5	0.02	(0.72)	1.30	(1.18)	1.02	(1.23)	2.26	(1.45)	0.26	(0.87)	0.00	(0.71)	0.83	(1.11)	0.50	(1.00)
T_6	0.00	(0.71)	0.00	(0.71)	0.14	(0.79)	0.70	(1.10)	0.14	(0.80)	0.00	(0.71)	0.03	(0.73)	0.14	(0.80)
T_7	0.14	(0.79)	0.00	(0.71)	0.34	(0.90)	0.63	(1.06)	0.06	(0.75)	0.01	(0.72)	0.11	(0.78)	0.28	(0.87)
T_8	0.05	(0.74)	0.06	(0.75)	0.34	(0.91)	0.69	(1.09)	0.07	(0.76)	0.01	(0.72)	0.02	(0.72)	0.21	(0.83)
T_9	0.24	(0.84)	0.89	(1.08)	1.77	(1.50)	2.84	(1.83)	0.13	(0.79)	0.25	(0.86)	0.44	(0.95)	1.82	(1.48)
T_{10}	0.00	(0.71)	0.15	(0.80)	1.34	(1.35)	3.46	(1.99)	0.15	(0.80)	0.05	(0.74)	0.14	(0.80)	1.55	(1.41)
T_{11}	0.00	(0.71)	0.26	(0.73)	0.16	(0.81)	0.88	(1.16)	0.19	(0.83)	0.07	(0.76)	0.01	(0.72)	0.79	(1.14)
T_{12}	0.00	(0.71)	0.77	(1.10)	4.16	(2.16)	8.65	(3.03)	0.05	(0.74)	0.96	(1.15)	1.63	(1.45)	8.85	(3.01)
SEm (±)		0.055		0.176		0.117		0.182		0.040		0.074		0.085		0.165
CD (0.05)		NS		NS		0.343		0.534		NS		0.219		0.250		0.486

Values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, NS - non significant

Table 11. Effect of weed management treatments on total dry weight of weeds (first and second crop seasons)

Treatments	Total dry weight of weeds (g m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	3.31	(1.94)	3.05	(1.85)	32.47	(5.73)	29.63	(5.48)	1.42	(1.38)	3.52	(2.00)	20.41	(4.57)	30.33	(5.54)
T_2	2.00	(1.57)	8.41	(2.98)	17.00	(4.15)	11.54	(3.47)	1.37	(1.37)	1.72	(1.46)	9.65	(3.15)	18.10	(4.27)
T_3	3.15	(1.91)	3.86	(2.08)	15.04	(3.92)	6.61	(2.67)	2.17	(1.61)	1.54	(1.39)	9.39	(3.11)	14.55	(3.86)
T_4	2.22	(1.64)	1.42	(1.38)	9.95	(3.21)	4.33	(2.18)	1.39	(1.38)	1.21	(1.30)	6.81	(2.70)	11.44	(3.44)
T_5	2.72	(1.79)	3.56	(1.96)	4.06	(2.13)	5.15	(2.33)	1.67	(1.46)	0.50	(0.98)	2.68	(1.75)	5.69	(2.45)
T_6	3.07	(1.86)	0.68	(1.08)	1.52	(1.42)	2.65	(1.75)	1.84	(1.51)	0.22	(0.85)	1.27	(1.33)	4.90	(2.32)
T_7	2.92	(1.83)	2.84	(1.81)	4.08	(2.09)	2.13	(1.62)	0.77	(1.12)	0.24	(0.86)	0.93	(1.18)	3.91	(2.07)
T_8	2.28	(1.66)	0.80	(1.14)	1.82	(1.47)	1.91	(1.55)	0.92	(1.19)	0.12	(0.79)	1.04	(1.17)	1.83	(1.53)
T_9	4.50	(2.23)	2.48	(1.71)	12.56	(3.59)	14.30	(3.84)	1.34	(1.33)	1.92	(1.51)	12.24	(3.57)	19.91	(4.50)
T_{10}	3.61	(2.01)	1.44	(1.36)	6.04	(2.52)	6.96	(2.73)	1.16	(1.29)	0.40	(0.94)	2.49	(1.71)	7.56	(2.77)
T_{11}	2.96	(1.86)	6.70	(2.67)	12.80	(3.63)	10.81	(3.36)	2.00	(1.56)	4.33	(2.18)	2.00	(1.58)	11.07	(3.33)
T_{12}	1.93	(1.52)	32.73	(5.76)	253.22	(15.92)	240.01	(15.51)	1.70	(1.47)	12.93	(3.66)	73.35	(8.59)	227.40	(15.07)
SEm (±)		0.165		0.177		0.288		0.144		0.112		0.136		0.207		0.331
CD (0.05)		NS		0.519		0.846		0.421		NS		0.398		0.608		0.971

Values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, NS - non significant

At 60 DAS, during first crop season, the lowest dry weight of grasses was observed in T_7, however it was on par with T_8, T_6, T_{11}, T_4, T_5 and T_3. During second crop season, the lowest dry weight of grasses was recorded in T_6 and it was on par with T_8, T_7, T_4, T_3, T_2, T_1, T_5 and T_{11}.

4.1.3.2.4 Total Dry Weight of Weeds (Table 11)

Perusal of data at 15 DAS (just before herbicide application) during both the seasons indicated that, treatments had no significant effect on total weed dry weight, but had a significant effect at 30 DAS (15 days after herbicide application), 45 DAS (30 days after herbicide application) and 60 DAS (45 days after herbicide application). Weedy check registered the highest total dry weight of weeds at 30, 45 and 60 DAS, with a mean value of 32.73, 253.22 and 240.01 g m^{-2}, respectively during first crop season and 12.93, 75.35 and 227.40 g m^{-2}, respectively during second crop season.

Observations at 30 DAS during first crop season indicated that the lowest weed dry weight was recorded in penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) which was statistically on par with its highest dose of 135 g ha^{-1} (T_8), penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}) and bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4). During second crop season, the lowest total weed dry weight was observed in T_8 which was on par with T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_6, T_{10} and T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}).

Critical appraisal of data at 45 DAS during first crop season indicated that the lowest weed dry weight was registered in treatment T_6 (1.52 g m^{-2}) which was statistically comparable with T_8, T_7 and T_5. During second crop season the lowest weed dry weight (1.04 g m^{-2}) was observed in T_8 and it was statistically comparable with T_7, T_6, T_{11} (hand weeding twice), T_{10} and T_5.

At 60 DAS, during first crop season, the lowest weed dry weight (1.91 g m^{-2}) was observed in T_8 and it was on par with T_7 and T_6. During second crop

season also, the lowest weed dry weight (1.83 g m^{-2}) was observed in T_8 and it was on par with T_7, T_6 and T_5.

4.1.3.3 Weed Control Efficiency (WCE) (Table 12)

Weed control efficiency was significantly influenced by the weed management treatments at 30, 45 and 60 DAS during both the seasons.

Perusal of data at 30 DAS during first crop season indicated that the lowest WCE was observed in bispyribac sodium + metamifop @ 70 g ha^{-1} (T_2) which was on par with hand weeding twice (T_{11}). The highest WCE was recorded in penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) and was statistically comparable with its other doses of 135 and 130 g ha^{-1} (T_8 and T_7), penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}), bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) and bispyribac sodium applied alone @ 25 g ha^{-1} (T_9). During second crop season T_{11} recorded the lowest WCE which was on par with bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1). The highest WCE was recorded in T_8 which was on par with T_6, T_7, T_{10} and T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}).

Critical appraisal of data at 45 DAS during both the seasons indicated that the treatment T_1 registered the lowest WCE and was statistically inferior among the other weed management treatments. During first crop season, the highest WCE was registered in T_6 and T_8 which were statistically on par with T_7, T_5 and T_{10}. However during second crop season, highest weed control efficiency was registered in T_7 and it was on par with T_8, T_6, T_{11}, T_{10} and T_5.

The data at 60 DAS during first and second crop season indicated that T_1 registered the lowest WCE (87.48 and 86.51 per cent, respectively) and was inferior among all the other weed management treatments. During first crop season, the highest WCE (99.20 per cent) was registered in T_8 and it was statistically comparable with T_7, T_6 and T_4. During second crop season also, the highest WCE (99.19 per cent) was registered in T_8 which was statistically on par with T_7, T_6, T_5 and T_{10}.

Table 12. Effect of weed management treatments on weed control efficiency (first and second crop seasons)

Treatments	WCE (%)											
	First crop season						Second crop season					
	30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	90.92	(9.53)	87.07	(9.33)	87.48	(9.36)	72.42	(8.52)	71.88	(8.47)	86.51	(9.30)
T_2	74.14	(8.61)	93.18	(9.65)	95.19	(9.76)	86.03	(9.28)	87.01	(9.33)	91.88	(9.58)
T_3	88.14	(9.39)	94.11	(9.70)	97.24	(9.87)	87.32	(9.33)	87.20	(9.34)	93.43	(9.67)
T_4	95.68	(9.78)	96.10	(9.80)	98.19	(9.91)	90.19	(9.49)	90.64	(9.52)	94.83	(9.74)
T_5	88.58	(9.40)	93.40	(9.92)	97.87	(9.89)	95.73	(9.78)	96.38	(9.82)	97.55	(9.88)
T_6	97.90	(9.89)	99.40	(9.97)	98.73	(9.94)	98.34	(9.92)	98.24	(9.91)	97.82	(9.89)
T_7	91.46	(9.56)	98.34	(9.92)	99.11	(9.95)	98.11	(9.90)	98.71	(9.94)	98.34	(9.91)
T_8	97.46	(9.87)	99.30	(9.97)	99.20	(9.96)	99.11	(9.96)	98.47	(9.93)	99.19	(9.96)
T_9	92.17	(9.60)	95.05	(9.75)	94.05	(9.70)	84.13	(9.17)	83.25	(9.12)	90.05	(9.54)
T_{10}	95.45	(9.84)	97.63	(9.88)	97.10	(9.85)	96.94	(9.85)	96.52	(9.82)	96.80	(9.84)
T_{11}	79.72	(8.93)	94.95	(9.74)	95.49	(9.77)	66.96	(8.18)	97.26	(9.86)	95.22	(9.76)
T_{12}		0		0		0		0		0		0
SEm (±)		0.116		0.047		0.018		0.129		0.084		0.059
CD (0.05)		0.342		0.138		0.052		0.380		0.248		0.175

DAS-days after sowing, DAHA - days after herbicide application, WCE - weed control efficiency, values in parentheses are transformed values - Data are subjected to square root transformation - $\sqrt{(x)}$

4.1.3.4 Absolute Density of Weeds (Tables 13 to 16)

Absolute density of sedges, BLW, grasses and total density of weeds are presented in Tables 13 to 16.

4.1.3.4.1 Absolute Density of Sedges (Table 13)

Absolute density of sedges at different growth stages of crop growth was statistically analysed and presented in Table 13. Perusal of data at 15 DAS (just before herbicide application) during both the seasons revealed that absolute density of sedges was not significantly influenced by weed management treatments.

Weedy check (T_{12}) registered the highest population of sedges at 30, 45 and 60 DAS and was significantly inferior to all other treatments. During both the seasons, all the tested herbicides significantly reduced the absolute density of sedges compared to weedy check at different growth periods.

Critical appraisal of data at 30 DAS indicated that the lowest absolute density of sedges was recorded in penoxsulam + cyhalofop buty @ 135 g ha^{-1} (T_8), which was on par with its lower doses of 125 and 130 g ha^{-1} (T_6 and T_7), bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) and penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}). During second crop season, the treatment T_6 recorded the lowest sedges population and it was on par with penoxsulam @ 22.5 g ha^{-1} (T_{10}), T_8 and T_7.

Perusal of data at 45 DAS during first crop season revealed that, the treatment T_8 registered the lowest absolute density of sedges which was on par with the treatment T_7 and T_6. During second crop season also, the treatment T_8 recorded the lowest absolute density of sedges which was on par with T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}).

Table 13. Effect of weed management treatments on absolute density of sedges (first and second crop seasons)

Treatments	Absolute density of sedges (No. m^{-2})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	402.7 (17.99)	160.0 (12.64)	208.0 (14.36)	293.3 (17.10)	384.0 (19.50)	305.0 (17.43)	281.7 (16.72)	349.3 (18.68)
T_2	332.0 (17.93)	112.0 (10.59)	147.3 (12.13)	90.7 (9.55)	384.0 (19.20)	152.3 (12.31)	187.3 (13.58)	88.3 (8.80)
T_3	436.0 (20.46)	100.0 (9.84)	127.0 (11.27)	77.3 (8.78)	366.7 (18.45)	136.0 (11.67)	189.3 (13.77)	154.7 (12.36)
T_4	198.7 (13.93)	64.3 (8.04)	56.0 (7.34)	33.3 (5.61)	468.0 (20.74)	194.7 (13.95)	113.3 (10.55)	101.3 (9.96)
T_5	372.0 (19.10)	94.7 (9.72)	46.7 (6.85)	21.3 (4.45)	393.3 (19.83)	54.7 (7.40)	33.0 (5.77)	53.3 (7.30)
T_6	518.7 (22.04)	38.7 (6.24)	21.3 (3.91)	21.3 (4.61)	404.0 (20.00)	26.7 (5.19)	45.3 (6.77)	54.7 (7.42)
T_7	536.0 (22.46)	68.3 (8.28)	25.3 (3.78)	12.0 (2.99)	294.7 (17.18)	41.0 (6.45)	42.7 (6.44)	46.7 (6.51)
T_8	329.3 (16.84)	33.3 (5.78)	8.0 (2.12)	2.7 (1.45)	234.7 (15.33)	39.3 (6.29)	18.7 (3.76)	6.7 (2.30)
T_9	545.3 (23.00)	114.7 (10.71)	142.7 (11.95)	269.3 (16.42)	261.3 (15.37)	184.3 (13.59)	210.0 (14.50)	336.0 (18.34)
T_{10}	534.7 (22.90)	71.7 (8.49)	40.0 (6.14)	60.0 (7.75)	269.3 (16.42)	36.0 (5.96)	64.0 (8.02)	93.3 (9.68)
T_{11}	585.3 (23.29)	151.7 (12.34)	50.7 (7.10)	62.3 (7.92)	500.0 (21.78)	201.3 (14.20)	52.3 (7.27)	157.3 (12.49)
T_{12}	554.7 (20.93)	551.7 (23.19)	744.7 (27.28)	645.3 (25.36)	350.7 (18.41)	611.7 (24.70)	656.0 (25.58)	610.3 (24.68)
SEm (±)	4.316	0.933	1.115	0.795	2.348	0.559	0.872	1.015
CD (0.05)	NS	2.737	3.271	2.331	NS	1.639	2.558	2.977

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

Table 14. Effect of weed management treatments on absolute density of broad leaf weeds (first and second crop seasons)

Treatments	Absolute density of broad leaf weeds (No. m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	394.67	(19.39)	31.7	(5.67)	133.0	(11.43)	104.0	(10.05)	168.0	(12.49)	174.3	(13.15)	149.3	(11.52)	159.0	(12.63)
T_2	257.3	(13.20)	32.0	(5.67)	139.0	(11.76)	69.3	(8.23)	155.7	(12.29)	64.0	(8.02)	121.3	(10.82)	174.7	(13.20)
T_3	241.3	(12.93)	38.3	(6.20)	51.3	(7.14)	58.7	(7.65)	188.0	(13.34)	105.3	(10.01)	70.7	(8.17)	101.3	(9.97)
T_4	389.3	(19.02)	56.0	(7.45)	103.0	(10.11)	64.0	(7.86)	218.7	(14.58)	111.3	(10.58)	89.3	(9.23)	145.7	(12.04)
T_5	374.7	(19.27)	91.3	(9.55)	113.0	(10.42)	105.3	(10.18)	294.7	(16.79)	47.0	(6.88)	65.3	(8.05)	100.0	(9.93)
T_6	117.3	(10.53)	29.3	(5.35)	73.3	(8.58)	59.0	(7.68)	164.0	(12.31)	42.7	(6.56)	50.7	(7.15)	87.3	(9.35)
T_7	142.7	(11.73)	75.0	(8.67)	142.7	(11.91)	58.7	(7.63)	124.0	(10.93)	66.0	(8.15)	37.3	(6.06)	62.7	(7.83)
T_8	216.0	(14.04)	12.0	(3.43)	71.0	(8.34)	51.7	(7.23)	269.3	(15.56)	29.3	(5.45)	41.3	(6.44)	12.7	(3.64)
T_9	350.7	(17.44)	109.3	(10.41)	19.7	(4.48)	72.3	(8.51)	246.7	(14.65)	166.7	(12.92)	92.0	(9.55)	140.0	(11.77)
T_{10}	169.3	(12.94)	85.3	(9.19)	59.0	(7.57)	46.0	(6.81)	110.7	(10.39)	48.0	(6.90)	81.3	(9.02)	77.3	(8.79)
T_{11}	173.3	(12.77)	302.7	(17.39)	225.3	(14.63)	144.0	(11.85)	165.3	(12.52)	166.7	(12.66)	34.3	(5.89)	78.7	(8.87)
T_{12}	110.7	(8.45)	425.0	(20.59)	656.7	(25.63)	424.7	(20.53)	173.3	(12.90)	382.7	(19.58)	762.3	(27.58)	398.0	(19.90)
SEm(±)		3.632		0.598		1.023		0.969		2.314		0.861		1.194		0.719
CD (0.05)		NS		1.754		3.001		2.842		NS		2.526		3.503		2.109

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

Observation at 60 DAS during first crop season revealed that similar to that at 30 and 45 DAS, T_8 registered the lowest absolute density of sedges and it was on par with T_7. During second crop season also, T_8 registered the lowest absolute density of sedges and it was significantly superior to all other treatments in reducing the density of sedges.

4.1.3.4.2 Absolute Density of Broad Leaf Weeds (Tables 14)

Data on absolute density of broad leaved weeds (BLW) at 15 DAS (just before herbicide application), 30 DAS (15 days after herbicide application), 45 DAS (30 days after herbicide application) and 60 DAS (45 days after herbicide application) were statistically analysed and presented in Table 14.

Absolute density of BLW was not significantly influenced by weed management treatments at 15 DAS during both the seasons. However, at 30, 45 and 60 DAS, weed management treatments had a significant effect on the absolute density of BLW.

BLW population was the highest in weedy check (T_{12}) and was significantly inferior to all other treatments at 30, 45 and 60 DAS.

At 30 DAS, the lowest absolute density of BLW was observed in penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) and was significantly superior to other treatments in reducing the density of BLW. During second crop season also, the lowest absolute density of BLW was observed in T_8, however it was statistically comparable with lower doses of 120 and 125 g ha^{-1} (T_5 and T_6), and penoxsulam @ 22.5 g ha^{-1} (T_{10}).

Observations at 45 DAS during first crop season indicated that, the treatment bispyribac sodium @ 25 g ha^{-1} (T_9) recorded the lowest density of BLW however it was statistically comparable with bispyribac sodium + metamifop @ 80 g ha^{-1} (T_3). During second crop season, hand weeding twice (T_{11}) recorded the

lowest absolute density of BLW, however, it was statistically comparable with T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_8, T_6, T_5, T_3, T_{10} and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}).

Observations at 60 DAS revealed that T_{10} recorded the lowest absolute density of BLW, however it was on par with T_8, T_7, T_3, T_6, T_4, T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}) and T_9. During second crop season, the lowest absolute density of BLW was recorded in T_8 which was significantly superior to other treatments in reducing the density of BLW.

4.1.3.4.3 Absolute Density of Grasses (Table 15)

Observations at 15 DAS were taken just before herbicide application, and the magnitude of variation did not touch the level of statistical significance. The results revealed that at 30, 45 and 60 DAS, the absolute density of grasses varied significantly among the treatments and weedy check registered the highest density of grasses and was significantly inferior to all the treatments.

During first crop season at 30 DAS, the lowest density of grasses was recorded in bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) which was on par with penoxsulam + cyhalofop butyl @ 130 and 125 g ha^{-1} (T_7 and T_6) and hand weeding twice (T_{11}). During second crop season, the treatments penoxsulam + cyhalofop butyl @ 120 and 125 g ha^{-1} (T_5 and T_6) and bispyribac sodium + metamifop @ 60, 70 and 80 g ha^{-1} (T_1, T_2 and T_3) recorded no grasses and these treatments were significantly superior to all other weed management treatments in reducing the density of grasses.

At 45 DAS during first crop season, the lowest density of grasses was recorded in T_{11} and it was statistically on par with T_4, T_6, T_5 and T_8 (penoxsualm + cyhalofop butyl @ 135 g ha^{-1}). During second crop season, the lowest density of grasses was recorded in T_2 and it was on par with T_3.

Table 15. Effect of weed management treatments on absolute density of grasses (first and second crop seasons)

Treatments	Absolute density of grasses (No. m^{-2})															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0.0	(0.71)	17.7	(4.19)	20.7	(4.60)	71.7	(8.48)	54.7	(5.75)	0.0	(0.71)	18.0	(4.27)	21.7	(4.62)
T_2	0.0	(0.71)	11.0	(3.26)	21.3	(4.68)	42.3	(6.53)	41.3	(6.05)	0.0	(0.71)	0.0	(0.71)	12.0	(3.49)
T_3	28.0	(4.92)	6.3	(2.59)	28.0	(5.32)	40.7	(6.41)	32.0	(5.68)	0.0	(0.71)	2.7	(1.65)	24.0	(4.88)
T_4	17.3	(3.65)	0.0	(0.71)	11.0	(3.26)	18.7	(4.37)	54.7	(7.37)	2.7	(1.45)	6.0	(2.49)	24.7	(4.94)
T_5	8.0	(2.86)	34.3	(5.88)	16.7	(4.11)	66.3	(8.16)	68.0	(8.26)	0.0	(0.71)	18.7	(4.26)	21.3	(4.67)
T_6	1.3	(1.18)	0 .0	(0.71)	10.7	(3.30)	19.0	(4.40)	44.0	(6.56)	1.3	(1.18)	5.7	(2.45)	5.0	(2.25)
T_7	17.3	(3.43)	0.0	(0.71)	21.3	(4.64)	29.0	(5.41)	30.7	(5.37)	3.3	(1.98)	7.3	(2.71)	15.7	(3.90)
T_8	8.0	(2.45)	12.0	(3.53)	16.0	(4.04)	30.7	(5.55)	42.7	(5.98)	5.0	(2.30)	6.7	(2.49)	10.7	(3.26)
T_9	50.7	(5.37)	32.7	(5.72)	63.7	(7.84)	99.3	(10.00)	68 .0	(8.19)	30.7	(5.58)	61.3	(7.85)	68.0	(8.25)
T_{10}	0.0	(0.71)	14.7	(3.71)	81.7	(9.03)	62.7	(7.91)	5.3	(2.12)	20.7	(4.57)	31.3	(5.62)	58.7	(7.67)
T_{11}	2.7	(1.45)	5.3	(1.83)	7.7	(2.86)	21.3	(4.64)	38.7	(6.23)	5.3	(2.12)	11.7	(3.40)	68.0	(8.25)
T_{12}	0.0	(0.71)	98.7	(9.95)	168.7	(12.99)	166.7	(12.84)	30.7	(5.53)	76.7	(8.79)	129.3	(11.29)	124.0	(11.15)
SEm (±)		1.370		0.497		0.436		0.443		1.278		0.373		0.541		0.480
CD (0.05)		NS		1.457		1.278		1.298		NS		1.094		1.586		1.408

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

Table 16. Effect of weed management treatments on total density of weeds (first and second crop seasons)

Treatments	Total density of weeds (No. m^{-2})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	797.3 (28.09)	209.3 (14.47)	361.7 (19.00)	469.0 (21.61)	606.7 (24.59)	479.3 (21.82)	449.0 (21.03)	530.0 (23.01)
T_2	589.3 (24.19)	155.0 (12.43)	306.7 (17.52)	202.3 (14.23)	580.0 (23.97)	216.3 (14.70)	308.7 (17.45)	275.0 (16.54)
T_3	705.3 (26.56)	144.7 (11.92)	206.3 (14.35)	176.7 (13.28)	586.7 (23.92)	241.3 (15.42)	262.7 (16.20)	280.0 (16.65)
T_4	605.3 (24.36)	120.3 (10.98)	170.0 (12.96)	116.0 (10.77)	741.3 (26.96)	308.7 (17.57)	208.7 (14.26)	271.7 (16.44)
T_5	757.3 (27.39)	220.3 (14.83)	176.3 (13.29)	193.0 (13.79)	756.0 (25.72)	101.7 (10.10)	117.0 (10.83)	174.7 (13.20)
T_6	637.3 (24.77)	68.0 (8.26)	105.3 (10.27)	99.3 (9.99)	612.0 (24.55)	70.7 (8.43)	101.7 (10.19)	147.0 (12.12)
T_7	696.0 (25.94)	143.3 (11.98)	189.3 (13.67)	99.7 (9.97)	449.3 (21.17)	110.3 (10.52)	87.3 (9.34)	125.0 (11.06)
T_8	553.3 (23.40)	57.3 (7.58)	95.0 (9.63)	85.0 (9.24)	546.7 (23.08)	73.7 (8.59)	66.7 (8.11)	30.0 (5.52)
T_9	946.7 (30.54)	256.7 (16.02)	226.0 (15.01)	441.0 (21.00)	576.0 (23.16)	381.7 (19.55)	363.3 (19.07)	544.0 (23.33)
T_{10}	704.0 (26.37)	171.7 (13.09)	180.7 (13.37)	168.7 (13.01)	385.3 (19.61)	104.7 (10.20)	176.7 (13.21)	229.3 (15.14)
T_{11}	761.3 (27.28)	459.7 (21.43)	283.7 (16.64)	227.7 (14.97)	704.0 (25.94)	373.3 (19.28)	98.3 (9.93)	304.0 (17.44)
T_{12}	665.3 (23.13)	1075.3 (32.67)	1570.0 (39.62)	1236.7 (35.17)	554.7 (23.16)	1071.0 (32.72)	1547.7 (39.30)	1132.3 (33.62)
SEm (±)	3.331	0.780	0.954	0.762	2.571	0.741	1.020	0.781
CD (0.05)	NS	2.287	2.799	2.233	NS	2.173	2.992	2.290

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

Critical appraisal of data at 60 DAS, during first crop season, revealed that the lowest absolute density of grasses was observed in T_4 which was on par with T_6, T_{11}, T_7 and T_8. However, during second crop season, T_6 registered the lowest absolute density of grasses which was on par with T_8 and T_2.

4.1.3.4.4 Total Density of Weeds (Table 16)

The total density of weeds was not significantly influenced by treatments at 15 DAS (just before herbicide application). However, at 30 DAS (15 days after herbicide application), 45 DAS (30 days after herbicide application) and 60 DAS (45 days after herbicide application), weed management treatments had a significant impact on total density of weeds. At 30, 45 and 60 DAS, weedy check registered the highest total density of weeds and it was significantly inferior to all other treatments with an average total density of 1075.3, 1570.0 and 1236.7 No. m^{-2}, respectively, during first crop season and 1071.0, 1547.7 and 1132.3 No. m^{-2}, respectively, during second crop season.

Critical appraisal of data at 30 DAS, during first crop season revealed that, the lowest total density of weeds was recorded in penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) and it was statistically comparable with lower dose of 125 g ha^{-1} (T_6) and these two treatments were significantly superior to other weed management treatments. During second crop season, the lowest total density of weeds was observed in T_6; however it was on par with its other three doses of 135, 130 and 120 g ha^{-1} (T_8, T_7 and T_5) and penoxsulam @ 22.5 g ha^{-1} (T_{10}).

Perusal of data at 45 DAS, during first crop season indicated that, the lowest total density of weeds was recorded in T_8; however, it was on par with T_6. During second crop season also, T_8 registered the lowest total density and it was statistically comparable with T_7, T_{11} (hand weeding twice), T_6 and T_5.

Table 17. Effect of weed management treatments on relative density of sedges (first and second crop seasons)

Treatments	Relative density of sedges (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	47.08	(6.24)	76.47	(8.75)	57.56	(7.59)	62.79	(7.95)	65.77	(8.01)	63.90	(7.99)	65.36	(8.06)	65.86	(8.14)
T_2	39.82	(6.29)	72.83	(8.53)	48.11	(6.95)	45.33	(6.76)	63.51	(7.92)	69.81	(8.27)	57.82	(7.93)	30.06	(5.25)
T_3	45.15	(6.71)	67.23	(8.18)	61.69	(7.89)	43.50	(6.63)	59.69	(7.60)	52.02	(7.21)	66.45	(8.18)	54.83	(7.43)
T_4	37.31	(5.91)	54.04	(7.32)	32.26	(5.66)	40.72	(6.40)	58.98	(7.54)	62.86	(7.93)	49.12	(7.04)	36.65	(6.06)
T_5	48.43	(6.94)	42.83	(6.53)	26.38	(5.17)	10.12	(3.19)	53.48	(7.29)	53.57	(7.30)	28.51	(5.37)	31.20	(5.59)
T_6	77.40	(8.76)	58.31	(7.58)	24.96	(4.96)	21.55	(4.63)	66.85	(8.17)	37.65	(6.12)	44.61	(6.72)	37.35	(6.15)
T_7	74.30	(8.58)	47.87	(6.91)	13.99	(3.51)	10.70	(2.90)	66.37	(8.15)	37.28	(6.10)	44.13	(6.68)	35.62	(5.81)
T_8	63.55	(7.91)	58.47	(7.64)	2.51	(1.41)	3.33	(1.55)	49.05	(6.87)	53.16	(7.29)	21.39	(4.68)	14.17	(3.79)
T_9	59.03	(7.56)	44.68	(6.68)	63.61	(8.00)	61.07	(7.84)	45.40	(6.61)	48.33	(6.95)	57.88	(7.64)	62.00	(7.90)
T_{10}	75.18	(8.66)	42.21	(6.49)	20.70	(4.55)	35.71	(5.99)	70.66	(8.02)	37.49	(6.10)	36.15	(6.05)	40.76	(6.42)
T_{11}	71.16	(8.34)	33.16	(5.75)	21.02	(4.48)	28.23	(5.35)	70.34	(8.38)	48.91	(6.99)	53.52	(7.34)	51.24	(7.17)
T_{12}	73.72	(8.56)	50.11	(7.05)	47.37	(6.92)	52.09	(7.24)	63.16	(7.95)	56.94	(7.55)	42.36	(6.54)	53.96	(7.38)
SEm (±)		0.881		0.323		0.553		0.506		0.721		0.220		0.258		0.549
CD (0.05)		NS		0.948		1.622		1.483		NS		0.645		0.757		1.611

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation - 15 and 30 DAS - $\sqrt{(x)}$, 45 and 60 DAS - $\sqrt{(x+0.5)}$, NS - non significant

The data pertaining to total density of weeds at 60 DAS, during first crop season indicated that, the lowest total density of weeds was observed in T_8; however, it was statistically comparable with T_7, T_6 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) and these treatments were statistically superior among all other weed management treatments in reducing the density of weeds. During second crop season also, the lowest total density of weeds was recorded in T_8 and it was significantly superior to all other weed management treatments.

4.1.3.5 Relative Density of Weeds (Tables 17 to 19)

Relative density of sedges, BLW and grasses during first and second crop seasons are presented in Tables 17 to 19.

4.1.3.5.1 Relative Density of Sedges (Table 17)

The weed management treatments significantly influenced the relative density of sedges at 30, 45 and 60 DAS and at 15 DAS no significant difference was observed among the treatments during both the seasons.

Perusal of data at 30 DAS during first crop season indicated that hand weeding twice (T_{11}) recorded the lowest relative density of sedges which was statistically comparable with penoxsulam @ 22.5 g ha^{-1} (T_{10}), penoxulam + cyhalofop butyl @ 120 g ha^{-1} (T_5) and bispyribac sodium @ 22.5 g ha^{-1} (T_9). During second crop season, T_{10} and T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the lowest relative density, which was statistically on par with T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}).

Data at 45 and 60 DAS during first and second crop season indicated that T_8 recorded the lowest relative density of sedges.

Table 18. Effect of weed management treatments on relative density of broad leaf weeds (first and second crop seasons)

Treatments	Relative density of broad leaf weeds (%)							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	52.91 (7.01)	15.33 (3.91)	36.58 (6.00)	21.67 (4.61)	26.37 (5.01)	36.10 (6.01)	30.12 (5.31)	30.13 (5.49)
T_2	60.17 (7.75)	20.50 (4.53)	45.26 (6.71)	33.48 (5.74)	29.96 (5.27)	30.19 (5.47)	42.18 (6.48)	65.58 (8.04)
T_3	50.95 (7.14)	27.83 (5.23)	24.59 (4.94)	32.85 (5.73)	34.10 (5.49)	41.32 (6.93)	32.58 (5.70)	35.44 (5.94)
T_4	60.05 (7.67)	45.96 (6.74)	61.08 (7.81)	43.33 (6.56)	33.41 (5.57)	36.34 (6.02)	48.16 (6.94)	53.68 (7.31)
T_5	49.81 (7.05)	41.46 (6.44)	64.31 (8.01)	54.22 (7.35)	37.33 (6.06)	46.43 (6.80)	55.20 (7.40)	56.33 (7.49)
T_6	22.44 (4.48)	41.69 (6.36)	64.47 (8.40)	59.30 (7.66)	24.80 (4.90)	60.57 (7.77)	49.85 (7.06)	59.40 (7.71)
T_7	22.32 (4.60)	52.13 (7.21)	73.37 (8.56)	58.31 (7.63)	26.85 (5.12)	59.70 (7.72)	47.68 (6.30)	50.42 (7.08)
T_8	45.22 (5.64)	20.02 (4.40)	75.38 (8.68)	60.95 (7.80)	44.23 (6.52)	40.17 (6.33)	73.35 (8.56)	49.38 (7.01)
T_9	34.21 (5.59)	42.21 (6.48)	9.24 (2.98)	16.34 (4.04)	41.17 (6.23)	43.63 (6.60)	25.12 (4.99)	25.52 (5.03)
T_{10}	24.82 (4.94)	49.05 (6.99)	31.63 (5.61)	27.28 (5.22)	27.99 (5.25)	46.08 (6.75)	45.81 (6.76)	33.50 (5.78)
T_{11}	28.56 (4.99)	65.72 (8.10)	76.04 (8.69)	61.99 (7.87)	23.36 (4.80)	49.74 (7.05)	34.80 (5.90)	26.36 (5.10)
T_{12}	26.28 (5.02)	40.47 (6.34)	41.88 (6.47)	34.45 (5.84)	30.74 (5.54)	35.89 (5.98)	49.23 (7.02)	35.04 (5.91)
SEm (±)	0.938	0.404	0.364	0.338	0.803	0.265	0.407	0.365
CD (0.05)	NS	1.186	1.068	0.991	NS	0.778	1.195	1.074

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation, 15, 30, 45 and 60 DAS - $\sqrt{(x)}$, NS - non significant

4.1.3.5.2 Relative Density of Broad Leaf Weeds (BLW) (Table 18)

Relative density of BLW was significantly influenced by the treatments at 30, 45 and 60 DAS and at 15 DAS no significant difference was observed during both the seasons.

Perusal of data at 30 DAS during first crop season indicated that the treatment bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1) recorded the lowest relative density of BLW, which was on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) and bispyribac sodium + metamifop @ 70 g ha^{-1} (T_2). During second crop season, T_2 recorded the lowest relative density which was on par with T_{12} (weedy check), T_1 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}).

Data at 45 and 60 DAS during first and second crop season revealed that, bispyribac sodium applied alone @ 25 g ha^{-1} (T_9) recorded the lowest relative density of BLW among all the treatments.

4.1.3.5.3 Relative Density of Grasses (Table 19)

Relative density of grasses was not significantly influenced by the treatments at 15 DAS, but at 30, 45 and 60 DAS, weed management treatments exerted significant influence on this vegetation analysis parameter during both the seasons.

At 30 DAS during first crop season, penoxsulam + cyhalofop butyl @ 125 and 130 g ha^{-1} (T_6 and T_7) and bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) recorded zero relative density of grasses and these treatments were on par with hand weeding twice (T_{11}). During second crop season, T_1, T_2, T_3 (bispyribac sodium + metamifop @ 60, 70 and 80 g ha^{-1}) and T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) recorded zero relative density, which were on par with T_4, T_6 and T_{11}.

Table 19. Effect of weed management treatments on relative density of grasses (first and second crop seasons)

Treatments	Relative density of grasses (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0 .00	(0.71)	8.21	(2.93)	5.86	(2.41)	15.54	(3.93)	7.86	(2.42)	0.00	(0.71)	4.51	(2.20)	4.01	(1.99)
T_2	0.00	(0.71)	6.67	(2.50)	6.96	(2.63)	21.19	(4.58)	6.53	(2.54)	0.00	(0.71)	0.00	(0.71)	4.36	(2.06)
T_3	3.90	(1.97)	4.94	(2.29)	13.72	(3.69)	23.65	(4.86)	6.21	(2.54)	0.00	(0.71)	0.97	(1.17)	9.73	(2.99)
T_4	2.64	(1.64)	0.00	(0.71)	6.66	(2.51)	15.92	(4.01)	7.61	(2.83)	0.79	(1.04)	2.73	(1.78)	9.67	(3.05)
T_5	1.76	(1.37)	15.72	(4.03)	9.32	(3.01)	35.66	(5.97)	9.20	(3.11)	0.00	(0.71)	16.29	(3.97)	12.47	(3.52)
T_6	0.16	(0.80)	0.00	(0.71)	10.58	(3.18)	19.15	(4.37)	8.34	(2.86)	1.65	(1.25)	5.54	(2.45)	3.25	(1.67)
T_7	3.38	(1.72)	0.00	(0.71)	12.64	(3.46)	30.99	(5.49)	6.79	(2.62)	3.01	(1.83)	8.19	(2.83)	13.95	(3.57)
T_8	1.23	(1.24)	21.51	(4.68)	22.11	(4.31)	35.72	(5.97)	6.72	(2.54)	6.67	(2.67)	5.27	(2.36)	33.12	(5.57)
T_9	6.76	(2.12)	13.11	(3.65)	27.15	(5.17)	22.59	(4.76)	13.43	(3.71)	8.04	(2.92)	17.00	(4.17)	12.48	(3.52)
T_{10}	0.00	(0.71)	8.74	(2.89)	47.67	(6.84)	37.00	(6.08)	1.35	(1.28)	16.17	(4.02)	18.04	(4.27)	25.73	(5.06)
T_{11}	0.28	(0.86)	1.11	(1.13)	3.00	(1.71)	9.79	(3.13)	6.31	(2.58)	1.35	(1.28)	11.68	(3.41)	22.39	(4.72)
T_{12}	0.00	(0.71)	9.42	(3.14)	10.75	(3.28)	13.46	(3.67)	6.10	(2.53)	7.17	(2.77)	8.41	(2.96)	11.00	(3.32)
SEm (±)		0.467		0.360		0.366		0.339		0.519		0.272		0.369		0.449
CD (0.05)		NS		1.056		1.073		0.993		NS		0.796		1.083		1.317

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation, 15, 30, 45 and 60 DAS - $\sqrt{(x)}$, NS - non significant

Perusal of data at 45 DAS during first crop season revealed that, T_{11} recorded the lowest relative density of grasses which was on par with T_1, T_4 and T_2. However, during second crop season, T_2 recorded zero relative density which was on par with T_3 and T_4.

Critical appraisal of data at 60 DAS during first crop season indicated that T_{11} recorded the lowest relative density of grasses which was on par with T_{12} (weedy check), T_1 and T_4. During second crop season, T_6 recorded the lowest relative density which was on par with T_1 and T_2.

4.1.3.6 Absolute Frequency (Tables 20 to 23)

Absolute frequency of sedges, BLW and grasses and total frequency of weeds of both first and second crop seasons are presented in Tables 20 to 23.

4.1.3.6.1 Absolute Frequency of Sedges (Table 20)

Absolute frequency of sedges was significantly influenced by the treatments at 30, 45 and 60 DAS and at 15 DAS the treatments had no significant effect on this parameter.

Perusal of data at 30, 45 and 60 DAS during first and second crop season indicated that penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest absolute frequency of sedges among the treatments.

4.1.3.6.2 Absolute Frequency of Broad Leaf Weeds (BLW) (Table 21)

Absolute frequency of BLW was not significantly influenced by the weed management treatments at 15 DAS, but at 30, 45 and 60 DAS, it was significantly influenced by the treatments during both the seasons

Table 20. Effect of weed management treatments on absolute frequency of sedges (first and second crop seasons)

Treatments	Absolute frequency of sedges (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	55.56	(7.37)	100.00	(10.02)	88.89	(9.41)	88.89	(9.41)	88.89	(9.39)	100.00	(10.02)	88.89	(9.41)	100.00	(10.02)
T_2	77.78	(8.78)	77.78	(8.81)	77.78	(8.84)	66.67	(8.20)	77.78	(8.78)	77.78	(8.81)	55.56	(7.41)	88.89	(9.42)
T_3	66.67	(8.17)	66.67	(8.20)	55.56	(7.41)	55.56	(7.41)	66.66	(7.98)	55.56	(7.41)	66.67	(8.19)	66.67	(8.20)
T_4	55.56	(7.37)	55.56	(7.41)	33.33	(5.82)	44.44	(6.61)	77.78	(8.59)	44.44	(6.61)	44.44	(6.61)	55.56	(7.41)
T_5	66.67	(8.17)	55.56	(7.41)	22.22	(4.76)	66.67	(8.01)	55.56	(7.37)	44.44	(6.61)	66.67	(8.19)	55.56	(7.41)
T_6	88.89	(9.39)	22.22	(4.12)	22.22	(4.76)	44.44	(6.61)	77.78	(8.78)	33.33	(5.82)	44.44	(6.61)	44.44	(6.61)
T_7	88.89	(9.39)	33.33	(5.82)	22.22	(4.76)	33.33	(5.82)	77.78	(8.78)	33.33	(5.82)	33.33	(5.82)	33.33	(5.82)
T_8	66.66	(7.98)	11.11	(3.40)	11.11	(2.41)	11.11	(2.41)	55.56	(7.18)	22.22	(4.76)	22.21	(4.76)	22.22	(4.76)
T_9	77.78	(8.78)	88.89	(9.41)	88.89	(9.41)	100.00	(10.02)	55.56	(7.37)	88.89	(9.41)	88.89	(9.41)	88.89	(9.41)
T_{10}	88.89	(9.39)	77.78	(8.81)	33.33	(5.81)	55.56	(7.41)	88.89	(9.39)	55.56	(7.41)	66.67	(8.20)	77.78	(8.81)
T_{11}	88.89	(9.39)	100.00	(10.02)	88.89	(9.41)	100.00	(10.02)	77.78	(8.78)	77.78	(8.81)	100.00	(10.02)	88.89	(9.41)
T_{12}	88.89	(9.39)	100.00	(10.02)	100.00	(10.02)	100.00	(10.02)	66.67	(8.17)	100.00	(10.02)	100.00	(10.02)	100.00	(10.02)
SEm (±)		0.687		0.678		0.585		0.735		0.899		0.552		0.469		0.518
CD (0.05)		NS		1.990		1.717		2.156		NS		1.619		1.376		1.520

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation, 15 DAS - $\sqrt{(x)}$, 30, 45 and 60 DAS - $\sqrt{(x+0.5)}$, NS - non significant

Table 21. Effect of weed management treatments on absolute frequency of broad leaf weeds (first and second crop seasons)

Treatments	Absolute frequency of broad leaf weeds (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	77.78	(8.78)	66.67	(8.01)	100.00	(10.00)	100.00	(10.00)	44.44	(6.57)	100.00	(10.02)	100.00	(10.00)	88.89	(9.39)
T_2	66.67	(8.17)	66.67	(8.20)	66.67	(8.17)	88.89	(9.39)	44.44	(6.57)	66.67	(8.20)	77.78	(8.78)	77.78	(8.78)
T_3	66.67	(8.17)	55.56	(7.41)	44.44	(6.57)	66.67	(8.17)	44.44	(6.57)	44.44	(6.61)	55.56	(7.37)	55.56	(7.37)
T_4	77.78	(8.78)	44.44	(6.61)	55.56	(7.37)	44.44	(6.57)	44.44	(6.57)	33.33	(5.82)	55.56	(7.37)	44.44	(6.66)
T_5	66.67	(8.17)	66.67	(8.20)	77.78	(8.78)	88.89	(9.39)	44.44	(6.57)	55.56	(7.41)	44.44	(6.57)	66.67	(8.16)
T_6	44.44	(6.57)	33.33	(5.82)	55.56	(7.37)	55.56	(7.37)	33.33	(5.77)	44.44	(6.61)	44.44	(6.57)	55.56	(7.45)
T_7	44.44	(6.57)	33.33	(5.82)	55.56	(7.37)	55.56	(7.37)	33.33	(5.77)	33.33	(5.82)	33.33	(5.77)	44.44	(6.66)
T_8	66.67	(7.98)	11.11	(3.40)	33.33	(5.77)	44.44	(6.57)	55.56	(7.37)	33.33	(5.82)	33.33	(5.77)	44.44	(6.66)
T_9	55.56	(7.37)	88.89	(9.41)	55.56	(7.41)	88.89	(9.39)	55.56	(7.37)	88.89	(9.41)	77.78	(8.78)	88.89	(9.39)
T_{10}	55.56	(7.37)	55.56	(7.41)	88.89	(9.39)	66.67	(8.17)	33.33	(5.77)	66.67	(8.20)	88.89	(9.39)	77.78	(8.78)
T_{11}	44.44	(6.57)	77.78	(8.81)	88.89	(9.39)	88.89	(9.39)	33.33	(5.77)	88.89	(9.41)	77.78	(8.59)	88.89	(9.39)
T_{12}	44.44	(6.57)	100.0	(10.02)	100.00	(10.00)	100.00	(10.00)	33.33	(5.77)	100.00	(10.02)	100.00	(10.00)	100.00	(10.00)
SEm (±)		0.742		0.609		0.588		0.566		0.627		0.464		0.633		0.474
CD (0.05)		NS		1.786		1.723		1.659		NS		1.361		1.856		1.391

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation, 15, 45 and 60 DAS - $\sqrt{(x)}$, 30 DAS$\sqrt{(x+0.5)}$, NS - non significant

Table 22. Effect of weed management treatments on absolute frequency of grasses (first and second crop seasons)

Treatments	Absolute frequency of grasses (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0.00	(0.71)	33.33	(5.80)	66.67	(8.16)	77.78	(8.78)	22.22	(4.12)	0.00	(0.71)	33.33	(5.81)	77.78	(8.78)
T_2	0.71	0.71)	44.44	(6.70)	55.56	(7.41)	66.67	(8.17)	33.33	(5.82)	0.71	(0.71)	0.00	(0.71)	33.33	(5.77)
T_3	33.33	(5.82)	33.33	(5.80)	55.56	(7.37)	55.56	(7.37)	33.33	(5.82)	0.71	(0.71)	22.22	(4.76)	44.44	(6.57)
T_4	22.22	(4.12)	0.00	(0.71)	11.11	(3.32)	44.44	(6.57)	33.33	(5.82)	11.11	(3.40)	11.11	(3.40)	33.33	(5.77)
T_5	22.22	(4.12)	44.44	(6.70)	55.56	(7.37)	66.67	(7.98)	33.33	(5.82)	0.00	(0.71)	77.78	(8.78)	55.56	(7.37)
T_6	11.11	(3.40)	0.00	(0.71)	33.33	(5.77)	55.56	(7.37)	33.33	(5.82)	11.11	(3.40)	33.33	(5.81)	33.33	(5.77)
T_7	22.22	(4.12)	0.00	(0.71)	33.33	(5.77)	66.67	(8.17)	33.33	(5.82)	11.11	(3.40)	11.11	(3.40)	22.22	(4.71)
T_8	22.22	(4.12)	11.11	(3.40)	33.33	(5.77)	44.44	(6.57)	33.33	(5.82)	22.22	(4.76)	11.11	(2.41)	22.22	(4.71)
T_9	22.22	(4.12)	66.67	(8.16)	88.89	(9.39)	88.89	(9.39)	33.33	(5.82)	77.78	(8.81)	88.89	(9.41)	66.67	(8.17)
T_{10}	0.00	(0.71)	55.56	(7.41)	66.67	(8.16)	100.00	(10.00)	22.22	(4.12)	77.78	(8.81)	88.89	(9.41)	100.00	(10.00)
T_{11}	11.11	(2.41)	66.67	(8.16)	55.56	(7.41)	88.89	(9.39)	33.33	(5.82)	44.44	(6.70)	44.44	(6.70)	88.89	(9.39)
T_{12}	0.00	(0.71)	100.00	(10.02)	100.00	(10.00)	100.00	(10.00)	33.33	(5.82)	77.78	(8.81)	100.00	(10.02)	10.00	(10.00)
SEm (±)		1.252		0.346		0.429		0.637		0.663		0.330		0.582		0.393
CD (0.05)		NS		1.014		1.256		1.869		NS		0.968		1.707		1.154

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation, first crop- 15 and 30- $\sqrt{(x+0.5)}$,45 and 60 DAS - $\sqrt{(x)}$, second crop-15, 30 and 45 DAS- $\sqrt{(x+0.5)}$, 60 DAS - $\sqrt{(x)}$, NS - non significant

Table 23. Effect of weed management treatments on total frequency of weeds (first and second crop seasons)

Treatments	Total frequency of weeds (%)							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	155.55 (12.46)	200.00 (14.12)	255.56 (15.98)	266.67 (16.31)	133.34 (11.42)	200.00 (14.14)	222.23 (14.89)	266.67 (16.31)
T_2	155.56 (12.46)	188.90 (13.73)	200.01 (14.14)	222.23 (14.90)	144.45 (11.74)	144.44 (12.00)	133.34 (11.49)	200.00 (14.11)
T_3	144.44 (12.00)	155.56 (12.45)	155.56 (12.35)	177.78 (13.28)	166.67 (12.91)	100.00 (10.00)	144.44 (12.00)	166.67 (12.87)
T_4	155.55 (12.46)	100.00 (9.90)	100.00 (9.97)	133.33 (11.48)	155.56 (12.32)	88.83 (9.40)	111.11 (10.47)	133.33 (11.52)
T_5	133.33 (11.55)	166.67 (12.90)	155.56 (12.41)	222.22 (14.84)	155.56 (12.08)	100.00 (10.00)	188.89 (13.71)	177.78 (13.32)
T_6	144.44 (12.00)	55.55 (7.36)	111.11 (10.52)	155.56 (12.41)	144.44 (12.00)	88.83 (9.39)	122.22 (11.02)	133.33 (11.52)
T_7	133.33 (11.28)	66.66 (8.16)	111.11 (10.03)	155.56 (12.46)	155,55 (12.46)	77.77 (8.82)	77.77 (8.82)	99.99 (10.00)
T_8	144.44 (11.87)	33.33 (5.77)	77.77 (8.76)	100.00 (9.90)	144.44 (12.00)	77.77 (8.82)	66.66 (8.10)	88.88 (9.43)
T_9	144.44 (12.00)	244.45 (15.65)	233.34 (15.21)	277.78 (16.66)	155.56 (12.46)	255.56 (15.98)	255.56 (15.96)	244.45 (15.63)
T_{10}	144.44 (12.00)	188.89 (13.73)	188.89 (13.73)	222.23 (14.90)	144.44 (12.00)	200.01 (14.11)	244.45 (15.63)	255.56 (15.98)
T_{11}	144.44 (12.00)	244.45 (15.64)	233.34 (15.26)	277.78 (16.69)	144.44 (12.00)	211.12 (14.50)	222.23 (13.67)	266.67 (16.31)
T_{12}	133.33 (11.55)	300.00 (17.32)	300.00 (17.32)	300.00 (17.32)	133.33 (11.55)	277.78 (16.66)	300.00 (17.32)	300.00 (17.32)
SEm (±)	0.380	0.512	0.622	0.616	0.446	0.390	0.607	0.445
CD (0.05)	NS	1.501	1.823	1.823	NS	1.146	1.782	1.307

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x)}$, NS - non significant

Perusal of data at 30, 45 and 60 DAS during first crop season indicated that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest absolute frequency of BLW among all the treatments. However during second crop season, the treatments T_8 and T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the lowest absolute frequency of BLW.

4.1.3.6.3 Absolute Frequency of Grasses (Table 22)

Absolute frequency of grasses was not significantly influenced by the treatments at 15 DAS, but at 30, 45 and 60 DAS the effect was significant and did not follow any specific trend. However, during both the seasons, weedy check (T_{12}), penoxsulam @ 22.5 ha^{-1} (T_{10}) and bispyribac sodium @ 25 g ha^{-1} (T_9) recorded higher absolute frequency of grasses compared to other treatments.

4.1.3.6.4 Total Frequency (Table 23)

Total frequency of weeds was not significantly influenced by the weed management treatments at 15 DAS, but at 30, 45 and 60 DAS, this parameter was significantly influenced by the weed management treatments.

Perusal of data at 30, 45 and 60 DAS during both the seasons indicated that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest total frequency of weeds.

4.1.3.7 Relative Frequency (Tables 24 to 26)

Relative frequency of sedges, BLW and grasses of both seasons were presented in Tables 24 to 26.

4.1.3.7.1 Relative Frequency of Sedges (Table 24)

Relative frequency of sedges was significantly influenced by the treatments at 30, 45 and 60 DAS during both the seasons and at 15 DAS, no significant difference was observed among the treatments during both the seasons.

Table 24. Effect of weed management treatments on relative frequency of sedges (first and second crop seasons)

Treatments	Relative frequency of sedges (%)															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	41.67	(6.38)	50.95	(7.16)	34.52	(5.90)	33.13	(5.79)	58.33	(7.58)	50.00	(7.11)	40.12	(6.35)	37.90	(6.19)
T_2	41.67	(6.38)	42.06	(6.50)	40.48	(6.36)	30.16	(5.53)	50.00	(7.05)	53.33	(7.33)	41.11	(6.43)	45.24	(6.76)
T_3	40.00	(6.32)	48.41	(6.90)	35.55	(6.00)	30.55	(5.56)	45.00	(6.61)	55.56	(7.41)	45.00	(6.74)	41.11	(6.45)
T_4	36.67	(5.95)	55.56	(7.47)	36.11	(5.99)	34.44	(5.82)	48.33	(6.83)	44.44	(6.70)	38.89	(6.25)	41.11	(6.45)
T_5	43.33	(6.57)	34.44	(5.82)	9.52	(3.16)	30.59	(5.45)	41.67	(6.38)	44.44	(6.70)	34.17	(5.77)	31.11	(5.62)
T_6	61.67	(7.83)	33.33	(5.80)	19.44	(4.45)	27.78	(5.31)	53.33	(7.30)	41.67	(6.42)	40.00	(6.36)	36.67	(6.00)
T_7	58.33	(7.58)	50.00	(7.11)	19.44	(4.39)	21.67	(4.70)	53.33	(7.30)	44.44	(6.68)	44.44	(6.68)	36.11	(5.99)
T_8	43.33	(6.45)	11.11	(3.40)	8.33	(2.16)	8.33	(2.16)	36.67	(5.92)	22.22	(4.76)	27.38	(5.28)	19.44	(4.39)
T_9	51.67	(7.10)	36.94	(6.11)	40.28	(6.36)	36.11	(6.05)	38.33	(6.13)	35.12	(5.97)	34.92	(5.93)	36.31	(6.06)
T_{10}	61.67	(7.58)	41.11	(6.43)	16.19	(4.05)	24.60	(4.97)	61.67	(7.83)	27.30	(5.25)	27.38	(5.28)	30.36	(5.55)
T_{11}	61.67	(7.83)	41.67	(6.48)	38.73	(6.25)	36.11	(5.79)	53.33	(7.30)	36.94	(6.11)	45.83	(6.79)	33.13	(5.79)
T_{12}	66.67	(8.13)	33.33	(5.82)	33.33	(5.82)	33.33	(5.82)	50.00	(7.07)	36.11	(6.05)	33.33	(5.82)	33.33	(5.82)
SEm (±)		0.656		0.420		0.533		0.550		0.610		0.361		0.300		0.336
CD (0.05)		NS		1.240		1.564		1.614		NS		1.057		0.879		0.985

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation, 15 DAS - $\sqrt{(x)}$, 30, 45 and 60 DAS - $\sqrt{(x+0.5)}$, NS - non significant

Table 25. Effect of weed management treatments on relative frequency of broad leaf weeds (first and second crop seasons)

Treatments	Relative frequency of broad leaf weeds (%)							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	58.33 (7.60)	34.76 (5.90)	39.29 (6.30)	37.89 (6.15)	28.33 (5.26)	50.00 (7.07)	46.79 (6.81)	33.13 (5.63)
T_2	58.33 (7.60)	37.30 (6.11)	35.71 (5.96)	39.68 (6.29)	28.33 (5.26)	46.67 (6.82)	58.89 (7.66)	40.48 (6.32)
T_3	40.00 (6.32)	37.30 (6.11)	28.89 (5.39)	38.88 (6.20)	31.67 (5.51)	44.44 (6.57)	38.33 (6.13)	32.78 (5.70)
T_4	50.00 (7.05)	44.44 (6.68)	55.56 (7.47)	32.78 (5.70)	30.00 (5.34)	44.44 (6.57)	50.00 (7.00)	32.78 (5.70)
T_5	43.33 (6.57)	41.11 (6.43)	53.18 (7.30)	40.12 (6.33)	33.33 (5.69)	55.56 (7.37)	23.33 (4.82)	36.67 (5.95)
T_6	31.67 (5.51)	66.67 (8.08)	50.00 (7.04)	36.11 (5.95)	23.33 (4.82)	50.00 (7.07)	38.33 (6.13)	43.33 (6.57)
T_7	28.33 (5.28)	50.00 (7.11)	50.00 (7.04)	28.33 (5.26)	23.33 (4.82)	44.44 (6.64)	44.44 (6.64)	44.44 (6.64)
T_8	43.33 (6.43)	11.11 (3.40)	33.33 (5.75)	47.22 (6.75)	40.00 (6.20)	55.55 (7.45)	61.11 (7.61)	61.11 (7.61)
T_9	35.00 (5.88)	39.44 (6.31)	19.44 (3.86)	31.94 (5.63)	38.33 (6.13)	34.52 (5.86)	30.16 (5.49)	36.31 (6.01)
T_{10}	38.33 (6.13)	28.89 (5.39)	47.62 (6.91)	30.16 (5.49)	23.33 (4.82)	33.97 (5.81)	36.31 (6.01)	30.36 (5.49)
T_{11}	31.67 (5.51)	33.33 (5.74)	40.63 (6.33)	31.94 (5.63)	23.33 (4.82)	43.61 (6.55)	34.72 (5.76)	33.13 (5.75)
T_{12}	33.33 (5.69)	33.33 (5.82)	33.33 (5.82)	33.33 (5.77)	25.00 (5.00)	36.11 (6.00)	33.33 (5.77)	33.33 (5.77)
SEm (±)	0.627	0.476	0.692	0.448	0.576	0.476	0.600	0.544
CD (0.05)	NS	1.396	NS	NS	NS	NS	NS	NS

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation; first crop-30 and 45 - $\sqrt{(x+0.5)}$, 15 and 60 DAS - $\sqrt{(x)}$, second crop- 15, 30, 45 and 60 DAS - $\sqrt{(x)}$, NS - non significant

Table 26. Effect of weed management treatments on relative frequency of grasses (first and second crop seasons)

Treatments	Relative frequency of grasses (%)							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	0.00 (0.71)	14.29 (3.85)	26.19 (5.16)	28.97 (5.37)	13.33 (3.26)	0.00 (0.71)	13.09 (3.67)	28.97 (5.42)
T_2	0.00 (0.71)	20.63 (4.59)	23.81 (4.92)	30.16 (5.49)	21.67 (4.70)	0.00 (0.71)	0.00 (0.71)	14.28 (3.31)
T_3	20.00 (4.53)	14.29 (3.77)	35.55 (6.00)	30.55 (5.51)	21.67 (4.88)	0.00 (0.71)	16.67 (4.14)	26.11 (5.13)
T_4	13.33 (3.61)	0.00 (0.71)	8.33 (2.63)	32.78 (5.70)	21.67 (4.70)	11.11 (3.40)	11.11 (3.40)	26.11 (5.13)
T_5	13.33 (3.26)	24.44 (4.96)	37.3 (6.11)	29.28 (5.34)	25.00 (5.05)	0.00 (0.71)	42.50 (6.54)	32.22 (5.62)
T_6	6.67 (2.33)	0.00 (0.71)	30.56 (5.56)	36.11 (5.95)	23.33 (4.88)	8.33 (2.63)	21.67 (4.70)	20.00 (4.53)
T_7	13.33 (3.26)	0.00 (0.71)	30.55 (5.56)	43.33 (6.57)	23.33 (4.88)	11.11 (3.40)	11.11 (3.40)	19.44 (4.39)
T_8	13.33 (3.26)	11.11 (2.33)	58.33 (7.67)	44.44 (6.64)	23.33 (4.88)	22.22 (4.76)	11.11 (3.40)	19.44 (4.39)
T_9	13.33 (3.26)	23.60 (4.90)	40.28 (6.36)	31.94 (5.63)	23.33 (4.88)	30.36 (5.53)	34.92 (5.93)	27.38 (5.28)
T_{10}	0.00 (0.71)	30.00 (5.52)	36.19 (6.04)	45.23 (6.72)	15.00 (3.43)	38.73 (6.25)	36.31 (6.04)	39.29 (6.30)
T_{11}	6.67 (1.98)	25.00 (5.04)	20.63 (4.37)	31.94 (5.63)	23.33 (4.88)	19.44 (4.45)	19.44 (4.39)	33.73 (5.82)
T_{12}	0.00 (0.71)	33.33 (5.82)	33.33 (5.82)	33.33 (5.77)	25.00 (5.05)	27.78 (5.31)	33.33 (5.82)	33.33 (5.82)
SEm (±)	0.924	0.368	0.491	0.363	0.547	0.342	0.272	0.552
CD (0.05)	NS	1.081	1.441	NS	NS	1.001	0.796	NS

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation, first crop - 15, 30 and 45 DAS - $\sqrt{(x+0.5)}$,60 DAS - $\sqrt{(x)}$, second crop - 15 and 30 DAS - $\sqrt{(x+0.5)}$, 45 and 60 DAS - $(\sqrt{x})$, NS - non significant

Critical appraisal of data at 30, 45 and 60 DAS during both the seasons revealed that penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest relative frequency of sedges among the treatments.

4.1.3.7.2 Relative Frequency of BLW (Table 25)

During first crop season, relative frequency of BLW was significantly influenced by the treatments only at 30 DAS and at 15, 45 and 60 DAS no significant difference was observed. However, during second crop season, no significant difference was observed among the treatments at all the four stages of observation.

Critical appraisal of data at 30 DAS during first crop season indicated that among the treatments, penoxsulam + cyhalofop buty @ 135 g ha^{-1} (T_8) recorded significantly lower relative frequency of BLW. During second crop no significant difference was observed among the treatments.

4.1.3.7.3 Relative Frequency of Grasses (Table 26)

Relative frequency of grasses was not significantly influenced by the treatments at 15 and 60 DAS during both the seasons, but at 30 and 45 DAS, weed management treatments exerted significant effect on this parameter.

Critical appraisal of data at 30 DAS during first crop season revealed that, grasses were absent in bispyribac sodium + metamifop applied @ 90 g ha^{-1} (T_4) and penoxsulam + cyhalofop butyl @ 125 and 130 g ha^{-1} (T_6 and T_7) and registered zero relative frequency. During second crop season, the treatments bispyribac sodium + metamifop @ 60, 70 and 80 g ha^{-1} (T_1, T_2 and T_3) and penoxsulam + cyhalofop butyl @ 120 g ha^{-1} (T_5) recorded zero grass population and thus registered zero relative frequency.

At 45 DAS during first crop season, T_4 recorded significantly lowest relative frequency of grasses among the treatments and during second crop

season, T_2 recorded zero grass population and hence the relative frequency was zero and lowest among the treatments.

4.1.3.8 Summed Dominance Ratio (SDR) (Tables 27 to 29)

The data on summed dominance ratio of sedges, grasses and broad leaf weeds of both seasons are presented in Tables 27 to 29.

4.1.3.8.1 Summed Dominance Ratio of Sedges (Table 27)

The data on summed ratio of sedges indicated that weed management treatments significantly influenced the SDR values at 30, 45 and 60 DAS during both the seasons.

Appraisal of data at both seasons revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest SDR values at all stages of observation except at 30 DAS during second crop season, where penoxsulam @ 22.5 g ha^{-1} (T_{10}) recorded the lowest SDR value; however, it was on par with T_8.

4.1.3.8.2 Summed Dominance Ratio of BLW (Table 28)

The data on summed dominance ratio of broad leaf weeds at 15, 30, 45 and 60 DAS are presented in the Table 28.

At 30, 45 and 60 DAS, the weed management treatments did exert significant effect on this parameter but did not follow any specific pattern.

4.1.3.8.3 Summed Dominance Ratio of Grasses (Table 29)

The data on summed dominance ratio of sedges at 15, 30, 45 and 60 DAS are presented in Table 29.

At 30, 45 and 60 DAS, the weed management treatments exerted significant effect on this parameter but did not follow any specific pattern.

Table 27. Effect of weed management treatments on summed dominance ratio of sedges (first and second crop seasons)

Treatments	Summed dominance ratio of sedges							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	44.38 (6.46)	6..72 (7.98)	46.04 (6.81)	47.97 (6.96)	62.05 (7.80)	50.75 (7.09)	57.74 (7.60)	51.88 (7.23)
T_2	40.75 (6.40)	57.45 (7.58)	44.30 (6.68)	37.75 (6.18)	56.76 (7.50)	61.58 (7.85)	49.47 (7.03)	37.65 (6.16)
T_3	42.58 (6.56)	57.82 (7.59)	48.62 (7.01)	37.03 (6.12)	52.35 (7.12)	53.79 (7.31)	55.73 (7.45)	47.97 (6.96)
T_4	36.99 (5.98)	54.80 (7.39)	34.19 (5.83)	37.58 (6.13)	53.66 (7.20)	53.66 (7.30)	44.00 (6.63)	38.88 (6.26)
T_5	45.88 (6.81)	38.64 (6.20)	17.95 (4.20)	20.36 (4.50)	47.57 (6.86)	50.91 (7.11)	31.34 (5.58)	31.16 (5.60)
T_6	69.53 (8.34)	45.82 (6.75)	22.20 (4.76)	24.67 (4.97)	60.09 (7.75)	39.73 (6.28)	42.31 (6.48)	37.01 (6.10)
T_7	66.32 (8.13)	48.94 (6.99)	16.72 (4.13)	16.18 (4.03)	59.85 (7.73)	40.87 (6.39)	44.29 (6.65)	35.87 (5.92)
T_8	48.44 (6.76)	34.79 (5.88)	13.06 (3.66)	5.83 (2.51)	42.86 (6.41)	40.47 (6.28)	24.58 (4.94)	21.81 (4.69)
T_9	55.35 (7.37)	40.80 (6.38)	51.94 (7.24)	48.59 (7.00)	41.87 (6.38)	41.73 (6.45)	46.40 (6.82)	49.16 (7.04)
T_{10}	68.43 (8.29)	41.66 (6.46)	18.45 (4.23)	30.16 (5.53)	66.17 (8.12)	32.40 (5.67)	31.77 (5.63)	35.56 (6.00)
T_{11}	66.42 (8.13)	37.42 (6.11)	29.88 (5.50)	32.17 (5.71)	61.84 (7.86)	42.93 (6.55)	49.68 (7.04)	42.19 (6.52)
T_{12}	70.20 (8.38)	41.72 (6.45)	40.35 (6.39)	42.72 (6.57)	56.58 (7.52)	46.53 (6.82)	37.85 (6.15)	43.65 (6.64)
SEm (±)	0.751	0.251	0.374	0.297	0.643	0.353	0.200	0.362
CD (0.05)	NS	0.735	1.097	0.871	NS	1.036	0.587	1.062

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation, first crop - 15 and 30 DAS - $\sqrt{(x)}$, 45 and 60 DAS - $\sqrt{(x+0.5)}$, second crop-15, 30 and 45 DAS -$\sqrt{(x)}$, 60 DAS -$\sqrt{(x+0.5)}$, NS - non significant

Table 28. Effect of weed management treatments on summed dominance ratio of broad leaf weeds (first and second crop seasons)

Treatments	Summed dominance ratio of broad leaf weeds							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	51.04 (6.94)	25.04 (5.00)	37.94 (6.19)	29.78 (5.45)	27.36 (5.15)	43.05 (6.56)	33.46 (5.78)	31.63 (5.62)
T_2	59.26 (7.69)	28.87 (5.36)	40.49 (6.40)	36.58 (6.03)	29.19 (5.28)	38.43 (6.20)	50.54 (7.11)	53.03 (7.24)
T_3	45.47 (6.74)	32.56 (5.69)	26.74 (5.22)	35.87 (5.97)	32.89 (5.58)	46.21 (6.77)	35.46 (5.94)	34.11 (5.84)
T_4	55.03 (7.38)	45.20 (6.70)	58.32 (7.66)	38.06 (6.15)	31.71 (5.46)	40.40 (6.33)	44.83 (6.60)	43.23 (6.56)
T_5	46.58 (6.82)	41.29 (6.42)	58.75 (7.69)	47.17 (6.87)	35.33 (5.88)	50.99 (7.13)	39.27 (6.25)	46.50 (6.78)
T_6	28.06 (5.19)	45.85 (6.75)	57.24 (7.59)	47.70 (6.86)	24.41 (4.92)	55.29 (7.43)	44.09 (6.63)	51.37 (7.16)
T_7	25.33 (4.95)	50.73 (7.12)	61.69 (7.86)	43.32 (6.56)	25.09 (4.98)	52.08 (7.21)	46.07 (6.77)	47.44 (6.87)
T_8	44.28 (6.37)	23.90 (4.88)	54.36 (7.36)	54.09 (7.33)	42.12 (6.37)	42.31 (6.49)	67.23 (8.15)	51.91 (7.12)
T_9	34.61 (5.78)	40.83 (6.36)	14.34 (3.60)	24.15 (4.91)	39.75 (6.19)	39.08 (6.25)	27.64 (5.25)	30.92 (5.55)
T_{10}	31.58 (5.57)	38.97 (6.22)	39.63 (6.33)	28.72 (5.36)	25.67 (5.05)	36.69 (6.05)	41.06 (6.40)	31.93 (5.64)
T_{11}	30.12 (5.28)	49.53 (7.02)	58.34 (7.64)	46.97 (6.84)	23.35 (4.82)	49.51 (7.02)	34.76 (5.87)	29.75 (5.44)
T_{12}	29.81 (5.37)	36.90 (6.07)	37.61 (6.17)	33.89 (5.81)	27.88 (5.78)	36.00 (5.99)	41.28 (6.42)	34.18 (5.85)
SEm (±)	1.120	0.423	0.611	0.448	0.963	0.374	0.465	0.552
CD (0.05)	NS	0.878	1.267	0.929	NS	0.775	0.964	1.146

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x)}$, NS - non significant

Table 29. Effect of weed management treatments on summed dominance ratio of grasses (first and second crop seasons)

Treatments	Summed dominance ratio of grasses															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0.00	(0.71)	11.25	(3.41)	16.03	(4.06)	22.25	(4.71)	10.60	(2.92)	7.14	(2.72)	8.81	(2.97)	16.49	(4.05)
T_2	0.00	(0.71)	13.65	(3.74)	15.39	(3.98)	25.68	(5.06)	14.10	(3.81)	10.32	(3.29)	0.71	(0.71)	9.32	(3.04)
T_3	11.95	(3.52)	9.62	(3.18)	24.64	(5.01)	27.10	(5.19)	14.77	(3.90)	7.14	(2.03)	8.82	(3.03)	17.92	(4.19)
T_4	7.99	(2.59)	0.00	(0.71)	7.50	(2.53)	24.37	(4.92)	14.64	(3.88)	0.40	(0.91)	6.92	(2.71)	17.89	(4.20)
T_5	7.55	(2.53)	20.08	(4.53)	23.31	(4.86)	32.47	(5.69)	17.10	(4.19)	12.22	(3.56)	29.40	(5.46)	22.35	(4.69)
T_6	3.43	(1.56)	0.00	(0.71)	20.55	(4.58)	27.63	(5.22)	15.84	(4.03)	0.71	(0.71)	13.61	(3.75)	11.63	(3.40)
T_7	8.36	(2.64)	0.00	(0.71)	21.59	(4.70)	34.39	(5.83)	18.83	(4.37)	0.82	(1.05)	9.65	(3.16)	16.70	(4.07)
T_8	7.28	(2.49)	16.31	(4.09)	40.23	(6.25)	40.08	(6.33)	15.03	(3.92)	5.84	(2.51)	8.19	(2.93)	26.28	(5.12)
T_9	10.05	(2.84)	18.36	(4.17)	33.72	(5.82)	27.27	(5.22)	18.38	(4.33)	15.14	(3.77)	25.96	(5.13)	19.93	(4.46)
T_{10}	0.00	(0.71)	30.49	(5.55)	41.93	(6.50)	41.12	(6.41)	8.17	(2.61)	31.42	(5.60)	27.18	(5.24)	32.51	(5.70)
T_{11}	3.47	(1.55)	13.06	(3.64)	11.82	(3.24)	20.87	(4.55)	14.82	(3.91)	13.18	(3.40)	15.56	(4.01)	28.06	(5.27)
T_{12}	0.00	(0.71)	21.38	(4.68)	22.04	(4.75)	23.40	(4.83)	15.55	(4.00)	20.25	(4.56)	20.87	(4.62)	22.17	(4.71)
SEm (±)		0.748		0.313		1.062		0.244		0.484		0.588		0.240		0.260
CD (0.05)		NS		0.917		1.502		0.715		NS		1.723		0.705		0.763

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation, 15, 30 and 45 - $\sqrt{(x+0.5)}$, 60 DAS -$\sqrt{(x)}$, NS - non significant

4.1.3.9 Importance Value (IV) (Tables 30 to 32)

Importance value of sedges, BLW and grasses exerted during both the seasons are presented in Tables 30 to 32.

4.1.3.9.1 Importance Value of Sedges (Table 30)

The data on importance value of sedges indicated that weed management treatments significantly influenced the SDR values at 30, 45 and 60 DAS during both the seasons.

Critical appraisal of data at both seasons revealed that, among the treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the lowest importance value of sedges at all stages of observation except at 30 DAS during second crop season, where T_{10} recorded the lowest importance value; however, it was on par with T_8.

4.1.3.9.2 Importance Value of BLW (Table 31)

The data on importance value of broad leaved weeds at 15, 30, 45 and 60 DAS are presented in the Table 31.

At 30, 45 and 60 DAS, the weed management treatments had significant effect on this parameter but did not follow any specific pattern similar to summed dominance ratio of BLW.

4.1.3.9.3 Importance Value of Grasses (Table 32)

The data on summed dominance ratio of sedges at 15, 30, 45 and 60 DAS are presented in the Table 32.

At 30, 45 and 60 DAS, the weed management treatments had significant effect on this parameter but did not follow any specific pattern.

Table 30. Effect of weed management treatments on importance value of sedges (first and second crop seasons)

Treatments	Importance value of sedges															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	88.75	(9.10)	127.43	(11.28)	92.08	(9.61)	95.92	(9.81)	124.10	(11.06)	113.90	(10.77)	115.49	(10.77)	103.76	(10.21)
T_2	81.49	(9.03)	114.90	(10.71)	88.58	(9.42)	75.49	(8.71)	113.51	(10.62)	123.15	(11.12)	98.93	(9.97)	75.30	(8.67)
T_3	85.15	(9.25)	115.64	(10.74)	97.24	(9.89)	74.05	(8.63)	104.69	(10.10)	107.57	(10.37)	111.45	(10.56)	95.94	(9.81)
T_4	73.98	(8.43)	109.96	(10.44)	68.37	(8.22)	75.16	(8.64)	107.31	(10.20)	107.31	(10.35)	88.00	(9.40)	77.76	(8.82)
T_5	91.76	(9.60)	77.27	(8.77)	35.90	(5.89)	40.72	(6.32)	95.14	(9.72)	101.81	(10.08)	62.67	(7.92)	62.30	(7.89)
T_6	139.06	(11.77)	91.64	(9.55)	44.40	(6.50)	49.33	(7.04)	120.18	(10.98)	79.45	(8.91)	84.61	(9.20)	74.02	(8.60)
T_7	132.63	(11.47)	97.87	(9.75)	33.43	(5.50)	32.37	(5.65)	119.70	(10.95)	81.73	(9.06)	88.57	(9.43)	71.73	(8.34)
T_8	106.88	(10.24)	69.58	(8.09)	26.12	(5.01)	11.67	(2.46)	85.71	(9.10)	75.38	(8.91)	49.16	(6.84)	43.61	(6.25)
T_9	110.70	(10.40)	81.61	(9.03)	103.89	(10.21)	97.18	(9.88)	83.73	(9.05)	83.45	(9.15)	92.80	(9.65)	98.31	(9.93)
T_{10}	136.85	(11.70)	83.32	(9.13)	36.89	(5.94)	60.32	(7.79)	132.33	(11.51)	64.79	(8.06)	63.53	(8.00)	71.12	(8.46)
T_{11}	132.83	(11.48)	74.83	(8.65)	59.75	(7.75)	64.34	(8.05)	123.67	(11.14)	85.85	(9.29)	99.35	(9.99)	84.38	(9.20)
T_{12}	140.39	(11.83)	83.44	(9.12)	80.70	(9.01)	85.42	(9.27)	113.16	(10.66)	93.05	(9.67)	75.69	(8.73)	87.22	(9.37)
SEm (±)		0.989		0.337		0.704		0.640		0.905		0.472		0.412		0.662
CD (0.05)		NS		0.989		2.063		1.877		NS		1.385		1.207		1.941

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application, values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

Table 31. Effect of weed management treatments on importance value of broad leaf weeds (first and second crop seasons)

Treatments	Importance value of broad leaf weeds							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)	15 DAS (JBHA)	30 DAS (15 DAHA)	45 DAS (30 DAHA)	60 DAS (45 DAHA)
T_1	111.25 (10.38)	50.09 (7.01)	75.87 (8.69)	59.56 (7.71)	54.71 (7.28)	86.10 (9.29)	66.91 (8.18)	63.26 (7.95)
T_2	118.51 (10.87)	57.73 (7.58)	80.98 (8.99)	73.15 (8.53)	58.37 (7.47)	76.85 (8.76)	101.07 (10.05)	106.05 (10.29)
T_3	90.95 (9.54)	65.23 (8.06)	53.47 (7.31)	71.74 (8.45)	65.77 (7.90)	92.42 (9.58)	70.92 (8.41)	68.22 (8.25)
T_4	110.05 (10.44)	90.40 (9.48)	116.64 (10.79)	76.11 (8.70)	63.40 (7.72)	79.79 (8.95)	98.16 (9.91)	86.45 (9.29)
T_5	93.15 (9.64)	82.57 (9.08)	117.48 (10.82)	94.34 (9.71)	70.66 (8.31)	101.99 (10.08)	78.53 (8.84)	93.00 (9.58)
T_6	56.11 (7.33)	91.69 (9.55)	114.47 (10.68)	95.41 (9.71)	48.80 (6.96)	110.57 (10.51)	88.18 (9.37)	102.74 (10.13)
T_7	50.66 (7.00)	102.13 (10.10)	123.37 (11.07)	86.64 (9.28)	50.18 (7.05)	104.15 (10.19)	92.12 (9.58)	94.87 (9.74)
T_8	88.55 (9.40)	47.80 (6.91)	108.71 (10.37)	108.17 (10.40)	84.23 (9.00)	84.61 (9.18)	134.46 (11.58)	80.49 (10.19)
T_9	69.21 (8.17)	81.66 (8.99)	28.68 (5.34)	48.29 (6.94)	79.50 (8.76)	78.15 (8.83)	55.28 (7.42)	61.83 (7.85)
T_{10}	63.15 (7.87)	77.93 (8.79)	79.25 (8.89)	57.44 (7.58)	51.33 (7.16)	73.38 (8.56)	82.12 (9.05)	63.86 (7.98)
T_{11}	60.23 (7.47)	99.06 (9.93)	116.67 (10.77)	93.93 (9.68)	46.69 (6.83)	96.68 (9.82)	69.52 (8.30)	59.50 (7.69)
T_{12}	59.61 (7.59)	73.80 (8.58)	75.21 (8.67)	67.78 (8.22)	55.74 (7.46)	72.00 (8.48)	82.56 (9.09)	68.37 (8.27)
SEm (±)	0.937	0.466	0.654	0.462	0.964	0.363	0.321	0.327
CD (0.05)	NS	1.365	1.357	1.231	NS	1.067	0.942	0.962

DAS - days after sowing, JBHA - just before herbicide application, DAHA- days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x)}$, NS - non significant

Table 32. Effect of weed management treatments on importance value of grasses (first and second crop seasons)

Treatments	Importance value of grasses															
	First crop season								Second crop season							
	15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)		15 DAS (JBHA)		30 DAS (15 DAHA)		45 DAS (30 DAHA)		60 DAS (45 DAHA)	
T_1	0.00	(0.71)	22.49	(4.78)	32.05	(5.66)	44.51	(6.67)	21.19	(4.56)	14.29	(3.85)	17.60	(4.25)	32.98	(5.74)
T_2	0.00	(0.71)	27.3	(5.27)	30.77	(5.54)	51.35	(7.15)	28.20	(5.33)	20.63	(4.50)	0.00	(0.71)	18.64	(4.28)
T_3	23.90	(4.93)	19.23	(4.41)	49.28	(7.02)	54.20	(7.34)	29.54	(5.47)	14.29	(3.85)	17.64	(3.70)	35.84	(5.98)
T_4	15.97	(3.53)	0.00	(0.71)	14.99	(3.87)	48.73	(6.96)	29.27	(5.45)	0.79	(1.04)	13.84	(3.78)	35.78	(5.97)
T_5	15.09	(3.44)	40.16	(6.37)	46.62	(6.82)	64.94	(8.06)	34.20	(5.89)	24.44	(4.98)	58.79	(7.69)	44.70	(6.68)
T_6	6.83	(2.00)	0.00	(0.71)	41.10	(6.37)	55.26	(7.38)	31.68	(5.65)	0.00	(0.71)	27.21	(5.26)	23.25	(4.81)
T_7	16.71	(3.60)	0.00	(0.71)	43.19	(6.57)	68.77	(8.26)	30.12	(5.52)	1.65	(1.25)	19.3	(4.45)	33.40	(5.75)
T_8	14.57	(3.39)	32.62	(5.74)	80.45	(8.97)	80.16	(8.96)	30.05	(5.50)	11.68	(3.47)	16.38	(4.09)	52.57	(7.22)
T_9	20.09	(3.88)	36.72	(6.03)	67.43	(8.17)	54.53	(7.38)	36.77	(6.09)	30.28	(5.28)	51.92	(7.22)	39.86	(6.31)
T_{10}	0.00	(0.71)	60.97	(7.82)	83.86	(9.14)	82.23	(9.06)	16.35	(3.56)	62.84	(7.90)	54.35	(7.38)	65.02	(8.06)
T_{11}	6.95	(2.01)	26.11	(5.14)	23.63	(4.85)	41.73	(6.43)	29.64	(5.49)	26.35	(5.18)	31.12	(5.62)	56.12	(7.49)
T_{12}	0.00	(0.71)	42.75	(6.58)	44.08	(6.64)	46.79	(6.84)	31.10	(5.62)	40.50	(6.40)	41.74	(6.50)	44.33	(6.66)
SEm (±)		1.025		0.303		0.274		0.344		0.538		0.503		0.508		0.265
CD (0.05)		NS		0.887		0.805		1.01		NS		1.476		1.489		0.778

DAS - days after sowing, JBHA - just before herbicide application, DAHA - days after herbicide application , values in parentheses are transformed values - data are subjected to square root transformation - $\sqrt{(x)}$, NS - non significant

Table 33. Effect of weed management treatments on organic carbon content of soil (first and second crop seasons)

Treatments	Organic carbon (%)							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	1.19	1.21	1.47	1.13	1.12	1.26	1.70	1.60
T_2	1.20	1.23	1.46	1.19	1.05	1.29	1.67	1.62
T_3	1.20	1.27	1.48	1.20	1.04	1.32	1.70	1.79
T_4	1.20	1.22	1.55	1.26	1.15	1.28	1.89	1.64
T_5	1.21	1.35	1.55	1.27	1.18	1.32	1.99	1.81
T_6	1.23	1.37	1.56	1.23	1.20	1.56	1.97	1.63
T_7	1.12	1.23	1.58	1.20	1.13	1.36	1.98	1.60
T_8	1.22	1.29	1.55	1.20	1.13	1.31	1.93	1.84
T_9	1.18	1.23	1.46	1.09	1.15	1.28	1.75	1.48
T_{10}	1.21	1.23	1.45	1.11	1.13	1.32	1.76	1.64
T_{11}	1.18	1.26	1.51	1.10	1.16	1.37	1.82	1.54
T_{12}	1.16	1.24	1.40	1.10	1.14	1.26	1.67	1.47
SEm (±)	0.025	0.023	0.028	0.042	0.044	0.042	0.024	0.040
CD (0.05)	NS	0.066	0.083	0.122	NS	0.121	0.069	0.117

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

4.1.4 Soil and Plant Analysis

The data on organic carbon content, soil nutrient status, nutrient uptake both by the crop and weeds are presented in Tables 33 to 38.

4.1.4.1 Organic Carbon Content of Soil (Table 33)

Statistical analysis of data recorded during first and second crop season indicated an increase in soil organic carbon content from 15 to 60 DAS and a decline at harvest stage. The highest soil organic carbon content was at 60 DAS which corresponds to booting stage of the crop. At 15 DAS (just before herbicide application), there was no significant difference in organic carbon status of the soil during both the seasons.

Data on organic carbon content in soil at 30 DAS (15 days after herbicide application) during both the seasons indicated that, it was significantly influenced by the treatments. During first crop season, the highest organic carbon content was observed in penoxulam + cyhalofop butyl @ 125 g ha^{-1} (T_6), which was statistically on par with its lowest dose of 120 g ha^{-1} (T_5). During second crop season T_6 recorded significantly higher organic carbon content in the soil.

Critical appraisal of data at 60 DAS (45 DAHA) indicated that during first crop season, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the highest organic carbon content and it was on par with other doses of 120, 125 and 135 g ha^{1} (T_5, T_6 and T_8) and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}). During second crop season, T_5 recorded the highest organic carbon content which was statistically on par with T_7, T_6 and T_8.

During harvest stage also organic carbon content was significantly influenced by various weed management treatments. During first crop season T_5 recorded higher organic carbon content which was statistically on par with T_4, T_6, T_7, T_8, T_{10} (penoxsulam @ 22.5 g ha^{-1}), T_3 and T_2 (bispyribac sodium +

metamifop @ 80 and 70 g ha^{-1}). During second crop season T_8 recorded higher organic carbon content which was on par with T_5 and T_3.

4.1.4.2 Available N, P and K Status of Soil (Tables 34 and 35)

Data on nitrogen, phosphorus and potassium content in soil are presented in Tables 34 and 35.

4.1.4.2.1 Available Nitrogen Status of Soil (Tables 34 and 35)

Weed management treatments significantly influenced the available nitrogen content of soil at all growth stages during both the seasons. In general, the availability of nitrogen in soil was lowest at harvest stage during both the seasons. At all the stages of observation (30 and 60 DAS and at harvest stage), weedy check recorded the lowest N content and it was significantly inferior to all the treatments.

Statistical analysis of data at 30 DAS during first crop season indicated that the N availability in soil was highest in penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8), which was significantly superior to all other treatments. During second crop season, the N availability was found to be the highest in T_{11} (hand weeding twice) which was significantly superior to other treatments. It was followed by T_8, which was statistically on par with its lower doses of 130, 125 and 120 g ha^{-1} (T_7, T_6 and T_5) and with T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}).

Perusal of data at 60 DAS during first crop season indicated that, the N availability was highest in T_{10} (penoxsulam @ 22.5 g ha^{-1}) which was followed by T_{11} and the same was on par with T_4. During second crop season, T_8 recorded the highest availability of N in the soil which was statistically comparable with T_7, which in turn was on par with T_4.

The observations at harvest stage of first crop season revealed that, the highest N availability in soil was in T_{10}, which in turn was on par with T_6, T_7 and T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}). During second crop season, T_8 recorded highest N availability, which in turn was statistically comparable with T_7, T_6, T_{11} and T_5.

4.1.4.2.2 Available Phosphorus Status of Soil (Tables 34 and 35)

Weed management treatments significantly influenced the availability of phosphorus in the soil at 30 and 60 DAS and at harvest stage of the crop. An increase in the availability of phosphorus was observed from 30 DAS to harvest stage during both the seasons. The average availability of phosphorus observed at 30 and 60 DAS and at harvest stages were 13.94, 19.12 and 19.33 kg ha^{-1}, respectively during first crop season and 10.51, 13.93 and 23.51 kg ha^{-1}, respectively during second crop season.

During first crop season at 30 DAS, penoxsulam + cyhalofop butyl @ 130 and 135 g ha^{-1} (T_7 and T_8) recorded the highest available phosphorus in the soil which was statistically on par with their lower dose of 125 g ha^{-1} (T_6) and bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} (T_3 and T_4). During second crop season, T_7 recorded the highest available phosphorus in the soil which was statistically on par with T_8, T_6, T_3, T_4 and T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}).

Available phosphorus at 60 DAS during first crop season indicated that among the treatments, T_8 recorded the highest availability (21. 54 kg ha^{-1}) which was statistically comparable with T_6, T_7, T_{11} (hand weeding twice), T_2, T_4, T_3 and T_{10} (penoxsulam @ 22.5 g ha^{-1}). During second crop season T_6 recorded the highest available phosphorus in soil which was statistically comparable with T_3, T_8, T_2, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), T_7 and T_9. During both the seasons, the lowest availability of phosphorus was registered by T_{12} (weedy check).

Critical appraisal of data at harvest stage during first crop season indicated that, T_7 recorded the highest available phosphorus in soil (23.01 kg ha^{-1}) which was statistically on par with T_6, T_5 and T_8. During second crop season, T_5 recorded significantly higher available phosphorus in soil. Weedy check recorded the lowest available phosphorus among the treatments, during both the seasons.

4.1.4.2.3 Available Potassium Status of Soil (Tables 34 and 35)

Weed management treatments significantly influenced the availability of potassium in soil at 30 and 60 DAS and at harvest stage of the direct seeded rice. The average availability of potassium observed at 30 and 60 DAS and at harvest stage were 154.20, 162.85 and 199.21 kg ha^{-1}, respectively during first crop season and 188.30, 174.38 and 209.88 kg ha^{-1}, respectively during second crop season. The highest potassium availability was noticed in the harvest stage of the crop during both the seasons.

Perusal of data at 30 DAS during first crop season indicated that, the highest availability of K was recorded in bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) which was statistically on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8). However during the second crop season, T_{10} (penoxsualm @ 22.5 g ha^{-1}) recorded the highest availability of K which was on par with T_3 (bispyribac sodium + metamifop @ 80 g ha^{-1}), T_4 and T_8.

At 60 DAS during first crop season, the highest availability of K was recorded in penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) and it was on par with other doses of 120, 130 and 135 g ha^{-1} (T_5, T_7 and T_8) and also with bispyribac sodium + metamifop @ 70, 80 and 90 g ha^{-1} (T_2, T_3 and T_4), hand weeding twice (T_{11}) and bispyribac sodium @ 25 g ha^{-1} (T_9). During second crop season also, T_6 recorded the highest K availability which was significantly superior to all the other treatments. During both the seasons, weedy check (T_{12}) recorded the lowest K availability among the treatments.

Table 34. Effect of weed management treatments on available N, P and K status of soil, kg ha^{-1} (first crop season)

Treatments	Available Nitrogen			Available Phosphorus			Available Potassium		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T_1	282.16	301.06	238.34	10.87	17.40	17.32	125.44	154.00	189.54
T_2	313.60	337.02	282.24	13.21	19.56	19.75	146.84	164.42	206.19
T_3	326.14	334.51	269.70	14.33	19.28	18.37	152.66	171.25	195.47
T_4	344.96	359.60	269.70	16.77	19.48	18.80	186.82	167.22	198.02
T_5	288.51	321.96	244.61	12.56	18.06	21.87	156.69	163.75	196.90
T_6	319.87	326.14	288.51	18.55	21.28	22.68	159.15	172.15	202.83
T_7	332.42	338.69	282.24	19.02	21.09	23.01	169.46	171.59	219.56
T_8	376.32	338.69	271.79	19.02	21.55	20.83	175.40	166.43	218.74
T_9	319.87	334.51	269.70	11.24	17.08	17.16	149.97	157.25	184.02
T_{10}	324.05	384.68	305.17	12.65	18.43	18.06	152.21	165.65	223.03
T_{11}	344.96	363.77	280.15	10.50	20.59	18.77	148.62	158.14	190.40
T_{12}	244.61	259.24	227.86	8.55	15.71	15.34	127.12	142.36	165.87
SEm (±)	5.911	5.088	5.262	1.626	1.141	0.779	5.323	5.347	2.899
CD (0.05)	17.338	15.435	22.985	4.769	3.347	2.283	15.615	15.683	8.504

DAS - Days after sowing

Table 35. Effect of weed management treatments on available N, P and K status of soil, kg ha^{-1} (second crop season)

Treatments	Available Nitrogen			Available Phosphorus			Available Potassium		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T_1	238.34	234.16	221.61	9.00	9.56	19.04	141.79	144.88	191.75
T_2	242.52	246.70	234.16	11.53	16.73	27.56	191.60	183.68	215.06
T_3	246.70	247.55	238.34	11.95	17.01	19.54	215.38	182.56	208.55
T_4	263.42	263.42	242.52	10.97	11.70	22.07	214.14	189.28	233.86
T_5	259.24	259.24	250.88	7.31	16.17	34.30	201.82	159.04	197.34
T_6	259.24	250.13	255.10	10.40	17.29	24.60	196.56	206.08	218.18
T_7	265.13	271.79	259.24	14.06	15.18	23.19	193.20	183.68	215.72
T_8	271.79	276.00	271.79	13.63	16.73	25.87	213.92	185.92	260.96
T_9	238.34	238.34	221.61	9.42	15.18	18.55	176.94	169.12	195.67
T_{10}	238.34	255.06	234.15	9.42	11.16	28.11	215.52	179.20	212.28
T_{11}	288.52	259.24	255.06	9.98	11.22	23.57	163.97	176.96	195.22
T_{12}	209.06	217.43	200.70	8.44	9.28	15.67	134.74	132.16	173.94
SEm (±)	5.088	3.857	7.995	1.249	1.737	1.986	4.298	2.947	3.357
CD (0.05)	14.925	11.311	23.450	3.662	5.093	5.824	12.606	8.643	9.846

DAS - Days after sowing

Statistical analysis of data at harvest stage during first crop season revealed that among the treatments, T_{10} recorded the highest K availability and it was on par with T_8 and T_7. However, during second crop season, T_8 recorded the highest available K in soil, which was significantly superior to all other treatments. During both the seasons, weedy check registered the lowest K availability and it was significantly inferior to all other treatments.

4.1.4.3 Nutrient Uptake by Crop (Tables 36 and 37)

Nitrogen, phosphorus and potassium uptake by crop are presented in Tables 36 and 37.

4.1.4.3.1 Nitrogen Uptake by Crop (Tables 36 and 37)

Weed management treatments did have a significant influence on the N uptake by crop at 30 and 60 DAS and at harvest stage. Nitrogen uptake showed an increasing trend from seedling to harvest stage. The maximum uptake was noticed at the harvest stage during both first and second crop season. At all the crop growth, weedy check (T_{12}) recorded the lowest N uptake and it was significantly inferior to all the treatments during both the seasons.

Critical appraisal of data at 30 DAS during first crop season revealed that highest N uptake (100.73 kg ha^{-1}) was registered in bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) which was on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8). During second crop season also, T_4 recorded the highest uptake (95.61 kg ha^{-1}) of nitrogen, which was on par with penoxsulam @ 135, 130 and 125 g ha^{-1} (T_8, T_6 and T_7), hand weeding twice (T_{11}) and penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}).

Perusal of data at 60 DAS during first crop season indicated that T_6 recorded the highest N uptake (213.90 kg ha^{-1}) which was on par with T_4, T_{10}, T_{11}, T_8 and T_1 (bispyribac sodium + metamifop @ 60 g ha^{-1}). During second crop season, T_7 recorded the highest N uptake (219.25 kg ha^{-1}) which in turn was

statistically on par with bispyribac sodium + metamifop @ 80 and 70 g ha^{-1} (T_3 and T_2), T_{11}, T_8, T_6, and T_{10}.

Nitrogen uptake at harvest stage indicated that, the treatment T_6 recorded the highest uptake (248.34 kg ha^{-1}) which was on par with T_7 and T_3. During second crop season, T_8 recorded the highest N uptake (254.11 kg ha^{-1}) which was on par with T_7, T_6, T_4 and T_3.

4.1.4.3.2. Phosphorus Uptake by Crop (Tables 36 and 37)

Weed management treatments significantly enhanced the phosphorus uptake of the crop at 30 and 60 DAS and at harvest stage during both the seasons. Uptake of phosphorus showed an increasing trend from seedling to harvest stage similar to that of N. The maximum uptake was noticed at harvest stage during both the seasons. Weedy check recorded the lowest P uptake by crop, at all stages of crop growth during both the seasons.

Critical appraisal of data at 30 DAS during first crop season revealed that the maximum P uptake was in bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4) which was found to be on par with penoxsulam + cyhalofop butyl @135 g ha^{-1} (T_8). During second crop season, penoxsulam + cyhalofop butyl @125 g ha^{-1} (T_6) recorded the highest uptake of phosphorus which was on par with T_8 and T_9 (bispyribac sodium applied alone @ 25 g ha^{-1}).

Perusal of the data at 60 DAS, during first and second crop season indicated that, the treatment T_8 recorded the highest uptake of phosphorus.

Data pertaining to P uptake at harvest stage of first crop revealed that treatment T_7 recorded the highest P uptake which was statistically comparable with T_8, T_6, hand weeding twice (T_{11}), bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1} (T_4, T_3 and T_2), T_{10} (penoxsulam @ 22.5 g ha^{-1}) and T_5 (penosxulam + cyhalofop butyl @ 120 g ha^{-1}). During second crop season, T_{10} recorded the highest P uptake and it was statistically on par with T_8, T_5, T_2, T_6 and T_{11}.

4.1.4.3.3 Potassium Uptake by Crop (Tables 36 and 37)

Potassium uptake was significantly influenced by weed management treatments at 30 and 60 DAS and at harvest stage during first and second crop seasons. During both the seasons, weedy check recorded the lowest K uptake by the crop, at all the stages of of crop growth.

Perusal of data at 30 DAS during first crop season indicated that T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}) recorded the highest K uptake among the treatments and it was on par with T_{11} (hand weeding twice). Similar to first crop season, during second crop season also, the highest K uptake was recorded in T_8, which was statistically on par with T_3 (bispyribac sodium + metamifop @ 80 g ha^{-1}).

Critical appraisal of the data at 60 DAS during first crop revealed that the highest K uptake was in T_8, which was on par with T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}), T_{10} (penoxsulam @ 22.5 g ha^{-1}) and T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}). During second crop season, the treatment T_6 recorded the highest K uptake and it was significantly superior to other treatments.

During harvest stage of first crop the highest K uptake was recorded in T_7 which was on par with T_8, T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}), T_3, T_4, T_9 (bispyribac sodium @ 25 g ha^{-1}) and T_2. For the second crop, the highest K uptake was recorded in T_3 which was on par with all tested doses of penoxsulam + cyhalofop butyl (T_5, T_6, T_5 and T_8) and bispyribac sodium + metamifop @ 90, 70 and 60 g ha^{-1} (T_4, T_2 and T_1).

Table 36. Effect of weed management treatments on nutrient uptake by crop, kg ha^{-1} (first crop season)

Treatments	Nitrogen uptake			Phosphorus uptake			Potassium uptake		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T_1	77.82	205.95	203.98	10.20	16.72	15.89	86.56	143.74	150.00
T_2	80.40	201.75	236.06	8.69	17.85	17.95	88.20	154.94	156.65
T_3	78.50	199.09	241.09	7.98	15.20	17.59	91.69	147.82	157.61
T_4	100.73	212.26	232.48	13.73	18.56	18.11	101.12	155.55	157.14
T_5	80.76	198.63	231.98	8.56	17.64	17.48	91.35	147.66	152.63
T_6	89.18	213.90	248.34	8.50	18.67	18.73	91.90	141.77	158.05
T_7	85.76	202.78	242.92	8.43	18.70	19.10	90.66	150.04	163.24
T_8	96.14	210.13	233.19	13.37	18.98	19.09	128.18	163.98	162.55
T_9	81.67	193.18	208.95	9.98	16.40	16.18	88.04	147.74	157.02
T_{10}	82.80	210.71	234.81	12.17	17.38	17.73	103.52	155.34	156.47
T_{11}	81.74	210.38	235.91	9.97	17.05	18.52	122.10	141.57	152.64
T_{12}	65.33	141.65	152.07	5.83	11.01	12.03	77.99	99.18	104.94
SEm (±)	3.869	3.768	2.886	0.464	0.704	0.800	5.383	3.521	2.851
CD (0.05)	11.347	11.052	8.463	1.360	2.066	2.347	15.790	10.327	8.361

DAS - Days after sowing

Table 37. Effect of weed management treatments on nutrient uptake by crop, kg ha^{-1} (second crop season)

Treatments	Nitrogen uptake			Phosphorus uptake			Potassium uptake		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
T_1	68.43	181.18	199.80	4.20	8.49	16.38	56.29	135.12	156.91
T_2	82.92	212.22	222.94	5.70	8.44	24.08	57.00	173.86	153.47
T_3	87.85	214.82	239.05	5.80	10.64	18.55	71.31	163.64	174.35
T_4	95.61	206.30	243.97	5.96	10.57	16.60	55.99	174.27	164.38
T_5	82.83	196.87	235.07	5.84	12.13	24.19	58.72	135.69	169.32
T_6	90.71	213.81	246.53	10.27	11.17	23.96	65.58	193.88	171.27
T_7	89.18	219.25	249.53	6.51	11.45	18.97	68.26	164.17	169.51
T_8	92.32	214.33	254.11	8.11	13.18	25.40	88.67	174.67	166.05
T_9	78.77	206.07	205.81	7.95	8.13	17.78	53.04	165.65	144.77
T_{10}	88.67	210.18	228.53	5.17	10.63	26.26	65.66	160.63	146.59
T_{11}	89.77	215.31	224.63	3.67	10.46	23.44	62.52	136.14	151.11
T_{12}	58.17	145.62	138.60	3.06	6.88	13.08	46.22	95.16	121.11
SEm (±)	2.644	4.062	5.677	1.180	0.831	1.459	6.534	3.904	7.512
CD (0.05)	7.755	11.913	16.651	3.461	2.437	4.281	19.163	11.450	22.031

DAS - Days after sowing

4.1.4.4 Nutrient Uptake by Weeds (Tables 38a amd 38b)

Nutrient uptake by weeds, at 30 and 60 DAS, was significantly influenced by the weed management treatments. The data were statistically analysed and presented in the Tables38a and 38b.

4.1.4.4.1 Nitrogen Uptake by Weeds (Tables 38a and 38b)

Nitrogen uptake by weeds was significantly influenced by the weed management treatments during both the seasons. During both the seasons, weedy check (T_{12}) recorded the highest uptake of nitrogen by weeds and was significantly higher than that in all other treatments at all stages of crop grwoth.

Perusal of data at 30 DAS during first crop season indicated that, penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) recorded the lowest N uptake by weeds and it was statistically on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) and bispyribac sodium + metamifop @ 90 g ha^{-1} (T_4). During second crop season, T_8 recorded the lowest uptake by weeds and was statistically on par with its other doses of 130, 125 and 120 g ha^{-1} (T_7, T_6 and T_5), and T_{10} (penoxsulan @ 22.5 g ha^{-1}).

Critical appraisal of data at 60 DAS during first crop revealed that the lowest uptake of nitrogen by the weeds was in T_8 and it was statistically on par with T_6 and T_7. During second crop, T_8 recorded the lowest N uptake by weeds and it was on par with T_7, T_5 and T_6.

4.1.4.4.2 Phosphorus Uptake by Weeds (Tables 38a and 38b)

Phosphorus uptake by weeds at 30 and 60 DAS during first and second crop seasons was significantly influenced by the weed management treatments. During both the seasons at 30 and 60 DAS, the uptake of phosphorus by weeds was significantly higher in weedy check (T_{12}) than that in all the other treatments.

Perusal of data at 30 DAS during first crop season revealed that, the treatment penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) recorded the lowest uptake of phosphorus by weeds and was statistically on par with its other doses of 135, 130 and 120 g ha^{-1} (T_8, T_7 and T_5), bispyribac sodium + metamifop @ 90 and 80 g ha^{-1} (T_4 and T_3), penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}) and bispyribac sodium @ 25 g ha^{-1} (T_9). During second crop, T_8 recorded the lowest uptake and it was statistically on par with T_6, T_7, T_{10}, T_5, T_4, T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}) and T_3.

Critical appraisal of data at 60 DAS during both the seasons revealed that T_8 recorded the lowest uptake of P by weeds and it was statistically on par with T_7 and T_6.

4.1.4.4.3 Potassium Uptake by Weeds (Tables 38a and 38b)

Potassium uptake by weeds was also significantly influenced by the weed management treatments. The uptake of potassium by weeds was significantly higher in weedy check than that in other treatments.

Perusal of data at 30 DAS during first crop season revealed that penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) recorded the lowest K uptake and it was statistically on par with penoxsulam + cyhalofop butyl @ 135 and 130 g ha^{-1} (T_8 and T_7), penoxsulam @ 22.5 g ha^{-1} (T_{10}) and bispyribac sodium + metamifop @ 90 and 60 g ha^{-1} (T_4 and T_1). During second crop season, the treatment T_8 recorded the lowest K uptake and was statistically on par with T_6, T_7, and T_{10}.

Critical appraisal of data at 60 DAS during first crop season indicated that, T_8 recorded the lowest uptake and was statistically on par with T_7, T_6 and T_5. During second crop season also, T_8 recorded the lowest K uptake and was statistically on par with T_7.

Table 38a. Effect of weed management treatments on nutrient uptake by weeds, kg ha^{-1} (first crop season)

Treatments	Nitrogen uptake				Phosphorus uptake			Potassium uptake			
	30 DAS		60 DAS		30 DAS	60 DAS		30 DAS		60 DAS	
T_1	1.32	(1.35)	7.72	(2.87)	0.16	0.86	(1.17)	0.53	(1.01)	5.62	(2.46)
T_2	2.81	(1.82)	3.78	(2.07)	0.32	0.31	(0.90)	0.88	(1.17)	2.38	(1.70)
T_3	1.43	(1.38)	1.85	(1.53)	0.15	0.19	(0.83)	0.61	(1.05)	1.07	(1.25)
T_4	0.54	(1.02)	1.15	(1.28)	0.06	0.10	(0.78)	0.30	(0.89)	0.97	(1.20)
T_5	1.39	(1.35)	1.57	(1.42)	0.13	0.15	(0.80)	0.72	(1.09)	0.76	(1.12)
T_6	0.20	(0.82)	0.77	(1.12)	0.02	0.07	(0.76)	0.12	(0.79)	0.61	(1.05)
T_7	1.08	(1.26)	0.91	(1.19)	0.10	0.06	(0.75)	0.51	(1.00)	0.57	(1.03)
T_8	0.47	(0.98)	0.55	(1.02)	0.04	0.04	(0.73)	0.19	(0.83)	0.36	(0.93)
T_9	0.98	(1.24)	4.19	(2.16)	0.14	0.43	(0.96)	0.70	(1.07)	2.07	(1.61)
T_{10}	0.63	(1.05)	2.33	(1.68)	0.06	0.20	(0.83)	0.29	(0.89)	1.40	(1.38)
T_{11}	1.66	(1.47)	2.76	(1.80)	0.23	0.31	(0.90)	1.79	(1.50)	1.89	(1.55)
T_{12}	6.96	(2.73)	70.47	(8.42)	0.86	7.82	(2.88)	5.52	(2.46)	36.27	(6.06)
SEm (±)		0.081		0.074	0.045		0.011		0.079		0.079
CD (0.05)		0.238		0.218	0.131		0.033		0.232		0.233

DAS - Days after sowing, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$

Table 38b. Effect of weed management treatments on nutrient uptake by weeds, kg ha^{-1} (second crop season)

Treatments	Nitrogen uptake				Phosphorus uptake			Potassium uptake			
	30 DAS		60 DAS		30 DAS	60 DAS		30 DAS		60 DAS	
T_1	2.35	(2.02)	6.28	(2.59)	0.15	0.79	(1.14)	1.06	(1.25)	4.27	(2.18)
T_2	3.01	(1.87)	3.99	(2.09)	0.06	0.53	(1.01)	0.54	(1.02)	3.89	(2.10)
T_3	1.52	(1.42)	3.89	(2.09)	0.06	0.33	(0.91)	0.34	(0.92)	2.49	(1.73)
T_4	1.82	(1.52)	2.84	(1.81)	0.05	0.35	(0.92)	0.34	(0.92)	1.22	(1.30)
T_5	0.56	(1.01)	1.68	(1.45)	0.02	0.14	(0.80)	0.32	(0.90)	0.92	(1.18)
T_6	0.29	(0.89)	1.70	(1.48)	0.01	0.14	(0.80)	0.17	(0.82)	0.94	(1.20)
T_7	0.23	(0.85)	1.63	(1.44)	0.01	0.11	(0.78)	0.17	(0.82)	0.58	(1.03)
T_8	0.14	(0.80)	0.39	(0.94)	0.01	0.04	(0.74)	0.15	(0.80)	0.18	(0.83)
T_9	1.98	(1.54)	6.01	(2.55)	0.08	0.62	(1.05)	0.55	(1.03)	3.47	(1.97)
T_{10}	0.54	(1.01)	2.28	(1.64)	0.02	0.21	(0.84)	0.19	(0.83)	1.06	(1.23)
T_{11}	2.93	(1.85)	3.01	(1.85)	0.17	0.32	(0.90)	1.09	(1.26)	1.39	(1.36)
T_{12}	7.57	(2.84)	60.77	(7.80)	0.51	7.55	(2.84)	4.58	(2.25)	30.98	(5.61)
SEm (±)		0.164		0.206	0.019		0.029		0.019		0.099
CD (0.05)		0.416		0.605	0.057		0.084		0.055		0.292

DAS - Days after sowing, values in parentheses are transformed values - $\sqrt{(x+0.5)}$

4.1.5 Microbial Population in Soil (Tables 39a and 39b)

Data on the population of bacteria, fungi and actinomycetes in the soil are presented in Tables 39a and 39b.

4.1.5.1 Bacterial Population in Soil (Tables 39a and 39b)

Perusal of the data of first and second crop seasons indicated that there was no significant variation in bacterial population at 15 DAS (just before herbicide application) with an average population of 2.9 and 6.18 x 10^6 CFU g^{-1} wet soi, respectively. But the treatments had a significant impact on soil bacterial population at 30 and 60 DAS *i.e.*, at 15 and 45 days after herbicide application (DAHA). During both the seasons, there was a gradual increase in bacterial population from 15 DAS (just before herbicide application) to 60 DAS (45 DAHA), with the highest bacterial population at 60 DAS.

Data at 30 DAS during first crop season revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded significantly higher bacterial population in soil followed by penoxsulam applied alone (T_{10}) which was statistically on par with bispyribac sodium + metamifop @ 90 and 60 g ha^{-1} (T_4 and T_1) and penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6). The lowest bacterial population was observed in hand weeding twice (T_{11}). During second crop season also, T_8 recorded the highest bacterial population which was followed by T_6, T_7 and T_4. Weedy check (T_{12}) and bispyribac sodium + metamifiop @ 60 and 70 g ha^{-1} (T_1 and T_2) recorded significantly lower bacterial population (4.8 x 10^6 CFU g^{-1} wet soil) compared to other treatments.

Critical appraisal of the data at 60 DAS during the first crop season revealed that, T_5 recorded the highest bacterial population in the soil which was statistically comparable with T_4. Bispyribac sodium @ 25 g ha^{-1} (T_9) recorded the lowest bacterial population in soil, but it was statistically on par with T_{12}, T_{10} (penoxsulam @ 22.5 g ha^{-1}) and T_{11}. During second crop season, T_7 recorded significantly higher bacterial population in soil compared to other treatments.

The non herbicide treatments *viz.*, T_{11} and T_{12} recorded significantly lower population of bacteria compared to herbicide treatments.

4.1.5.2 Fungal Population in Soil (Tables 39a and 39b)

Data on fungal population at 15 DAS (just before herbicide application), during first and second crop seasons, indicated that there was no significant variation in fungal population and the average population was 1.03 and 2.19 x 10^4 CFU g^{-1} wet soil, respectively. But fungal population in soil was significantly influenced by weed management treatments at 30 DAS (15 DAHA) and 60 DAS (45 DAHA).

During first crop crop season, at 30 DAS (15 DAHA), penoxsulam + cyhalofop butyl @ 130 and 125 g ha^{-1} (T_7 and T_6) recorded significantly higher fungal population. The treatment bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1) recorded the lowest fungal population and was statistically on par with its higher dose of 70 g ha^{-1} (T_2). During second crop season, T_8 (penoxsulam + cyhalfop butyl @ 135 g ha^{-1}) recorded the highest fungal population and it was on par with T_7 and T_6. Hand weeding (T_{11}), recorded significantly lower fungal population (1.0 x 10^4 CFU g^{-1} wet soil) compared to other treatments.

Data at 60 DAS (45 DAHA) during first crop season revealed that, T_8 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) recorded higher soil fungal population which were on par with T_{12} (weedy check). Penoxsulam @ 22.5 g ha^{-1} (T_{10}) recorded the lowest fungal population among the treatments. During second crop season, almost a similar trend was observed T_8 recorded significantly higher fungal population in the soil which was followed by T_4. Though T_9 (bispyribac sodium @ 25 g ha^{-1}) recorded lower soil fungal population among the treatments, it was statistically on par with T_7, T_2, T_{10}, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), T_{12}, T_1 and T_{11}.

4.1.5.3 Actinomycetes Population in Soil (Tables 39a and 39b)

Critical appraisal of the data at 15 DAS (JBHA) during both the seasons revealed that soil actinomycetes population was not significantly influenced by the treatments. But at 30 and 60 DAS (15 and 45 days after herbicide application) weed management treatments exerted significant effect on this parameter. During first crop season, there was a slight decline in population at 30 DAS; however the population was reverted to original level by 60 DAS. But during second crop season this restitution to normality was not observed at 60 DAS.

Observations at 30 DAS during first crop season revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) and penoxsulam applied alone (T_{10}) recorded significantly higher actinomycetes population in soil compared to other treatments. Significantly lower population of actinomycetes was observed in bispyribac sodium + metamifop butyl @ 60 g ha^{-1} (T_1). During second crop season T_6 recorded significantly higher population of actionomycetes, which was followed by T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) and it was on par with T_{11} (hand weeding twice), T_2 (bispyribac sodium + metamifop butyl @ 70 g ha^{-1}) and T_8. Bispyribac sodium applied @ 25 g ha^{-1} (T_9) recorded significantly lower actinomycetes population in soil compared to other treatments.

Perusal of the data of first crop season at 60 DAS indicated that weedy check (T_{12}) recorded the highest population of actinomycetes in soil (3.1×10^5 CFU g^{-1} wet soil) which was on par with T_{11}, penoxsulam + cyhalofop butyl @ 120, 130 and 135 g ha^{-1} (T_5, T_7 and T_8) and T_9. The treatments, T_1 and T_6 recorded the lowest population of actinomycetes in soil. During second crop season, T_6 recorded significantly higher population of actinomycetes in soil. The lowest actinomycetes population in soil was registered by weedy check (T_{12}) and T_5.

Table 39a. Effect of weed management treatments on the population of soil bacteria, fungi and actinomycetes (first crop season)

Treatments	Population of soil bacteria (x 10^6 CFU g^{-1} wet soil)			Population of soil fungi (x 10^4 CFU g^{-1} wet soil)			Population of soil actinomycetes (x10^5 CFUg^{-1} wet soil)		
	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)
T_1	2.8	4.8	5.2	0.8	1.0	2.1	2.5	1.5	2.3
T_2	2.5	4.6	4.9	1.1	1.2	2.4	2.6	1.9	2.6
T_3	2.8	4.4	5.7	1.1	1.3	2.8	2.8	1.8	2.5
T_4	3.1	5.3	6.9	1.0	1.7	3.3	2.6	2.4	2.6
T_5	3.0	4.2	7.2	1.0	2.3	1.8	2.5	2.3	2.9
T_6	2.9	4.9	5.5	1.1	2.7	1.7	2.6	2.7	2.3
T_7	2.9	4.5	6.1	1.2	2.7	1.5	2.6	2.6	2.7
T_8	3.1	8.5	5.7	1.3	2.0	3.3	2.6	3.4	2.9
T_9	3.1	4.4	4.1	1.1	1.3	2.7	2.9	2.4	2.9
T_{10}	2.9	5.4	4.3	0.8	2.0	1.0	2.8	3.4	2.5
T_{11}	2.9	3.8	4.5	1.0	1.8	1.9	3.0	2.9	3.0
T_{12}	2.8	4.2	4.3	0.8	1.7	3.2	2.8	2.2.	3.1
SEm (±)	0.088	0.186	0.148	1.58	0.101	0.153	0.136	0.079	0.140
CD (0.05)	NS	0.772	0.432	NS	0.297	0.448	NS	0.234	0.411

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

Table 39b. Effect of weed management treatments on the population of soil bacteria, fungi and actinomycetes (second crop season)

Treatments	Population of soil bacteria (x 10^6 CFU g^{-1} wet soil)			Population of soil fungi (x 10^4 CFU g^{-1} wet soil)			Population of soil actinomycetes (x 10^5 CFU g^{-1} wet soil)		
	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)	JBHA (15 DAS)	15 DAHA (30 DAS)	45 DAHA (60 DAS)
T_1	6.0	4.8	16.4	2.0	1.8	0.3	4.2	2.2	2.1
T_2	6.9	4.8	14.4	2.2	2.6	0.2	4..4	2.8	2.3
T_3	5.9	6.4	19.2	2.0	2.8	0.6	4.3	2.6	2.0
T_4	6.2	7.6	19.6	2.3	1.5	0.8	4.0	3.0	2.3
T_5	5.9	7.2	14.4	2.3	1.4	0.2	4.7	2.4	1.8
T_6	6.0	9.9	16.0	2.6	3.0	0.8	4.7	3.5	2.7
T_7	6.2	9.2	20.0	2.3	3.1	0.1	4.4	2.6	2.3
T_8	6.1	11.3	18.4	2.3	3.2	1.2	4.4	2.8	2.5
T_9	6.2	5.6	13.7	2.1	2.1	0.1	4.2	1.8	2.2
T_{10}	6.3	6.8	14.4	2.2	1.8	0.2	4.4	2.2	2.0
T_{11}	6.4	6.0	12.0	2.1	1.0	0.3	4.9	2.8	2.5
T_{12}	6.1	4.8	12.4	1.9	1.5	0.2	4.6	2.5	1.8
SEm (±)	0.185	0.167	0.153	0.135	0.111	0.091	0.171	0.099	0.105
CD (0.05)	NS	0.489	0.447	NS	0.327	0.265	NS	0.293	3.08

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

Table 40. Effect of weed management treatments on earth worm population in soil, No. m^{-2}

Treatments	Before the experiment				After the experiment			
	First crop		Second crop		First crop		Second crop	
T_1	2.7	(1.65)	4.0	(2.12)	2.7	(1.65)	6.7	(2.65)
T_2	4.0	(2.12)	2.7	(1.65)	4.0	(2.12)	6.7	(2.65)
T_3	4.0	(1.92)	4.0	(2.12)	2.7	(1.65)	5.3	(2.39)
T_4	4.0	(2.12)	2.7	(1.65)	5.3	(2.39)	8.0	(2.86)
T_5	4.0	(2.12)	2.7	(1.65)	4.0	(2.12)	8.0	(2.86)
T_6	4.0	(1.92)	5.3	(2.39)	5.3	(2.39)	10.7	(3.24)
T_7	5.3	(2.39)	4.0	(2.12)	5.3	(2.39)	9.3	(3.07)
T_8	4.0	(2.12)	2.7	(1.65)	5.3	(2.39)	9.3	(3.07)
T_9	2.7	(1.65)	4.0	(2.12)	2.7	(1.65)	6.7	(2.59)
T_{10}	2.7	(1.65)	1.3	(1.18)	2.7	(1.65)	6.7	(2.59)
T_{11}	4.0	(2.12)	2.7	(1.65)	2.7	(1.65)	5.3	(2.39)
T_{12}	4.0	(2.12)	2.7	(1.65)	4.0	(2.12)	5.3	(2.39)
SE (±)		0.49		0.54		0.48		0.57
CD (0.05)		NS		NS		NS		NS

Values in parentheses are transformed values, Data are subjected to square root transformation - $\sqrt{(x+0.5)}$, NS - non significant

4.1.6 Quantitative Estimation of Earthworms (Table 40)

Before herbicide spraying, the average number of earthworms present in the experimental field was 3.8 m^{-2} and 3.2 m^{-2} for the first and second crop seasons, respectively and no significant difference was observed among the treatments (Table 40). After the experiment, during both the seasons, an increase in earthworm population was observed. The average number of earthworms present after the first and second crop was 3.9 and 7.3 m^{-2}, respectively and no significant variation could be observed among the treatments (Table 40). Compared to weedy check, all the herbicide treated plots registered the same number or more of earthworms per square metre.

4.1.7 Soil Enzyme Activity (Tables 41 to 45)

Effect of herbicides on dehydrogenase, β glucosidase, protease, acid phosphatase and urease activity in soil are presented in Tables 41 to 45.

4.1.7.1 Dehydrogenase Activity (Table 41)

Dehydrogenase activity in soil is considered as a valuable parameter for assessing the impact of herbicide treatments on the soil microbial biomass and can be used as an indicator of microbiological redox system.

Regarding the data on dehydrogenase activity at 15 DAS (just before herbicide application), it was not significantly influenced by the treatments. An average dehydrogenase activity of 180.63 and 195.86 µg TPF g^{-1} soil h^{-1}, respectively was observed during first and second crop seasons. An increase in activity was observed from seedling to booting stage and decline in activity at harvest stage was noticed during both the seasons. The maximum dehydrogenase activity was observed at booting stage (45 DAHA).

Table 41. Effect of weed management treatments on dehydrogenase activity in soil (first and second crop seasons)

Treatments	Dehydrogenase activity (µg TPF g^{-1}soil h^{-1})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	178.81	188.57	212.15	121.32	174.09	176.41	232.56	142.34
T_2	169.46	216.58	217.58	126.46	211.64	212.64	217.43	147.22
T_3	178.81	202.63	219.03	137.20	183.56	214.76	251.38	175.66
T_4	175.37	229.81	223.02	138.51	197.53	223.61	257.79	174.64
T_5	177.39	180.71	212.97	132.61	203.43	211.93	204.96	177.21
T_6	188.38	217.22	258.71	134.02	214.32	248.97	250.35	164.91
T_7	193.37	210.76	257.07	141.33	188.08	238.02	257.70	181.33
T_8	186.79	254.56	282.52	138.77	187.77	252.91	265.65	186.44
T_9	178.63	186.06	183.53	127.74	224.81	201.44	173.99	161.95
T_{10}	186.76	203.04	182.34	127.55	185.50	213.92	217.06	140.05
T_{11}	184.17	102.08	189.41	124.40	173.74	165.98	160.32	142.36
T_{12}	169.57	113.60	197.49	105.43	205.83	157.32	136.63	92.65
SEm (±)	5.109	7.063	5.013	3.057	12.733	7.517	11.214	10.191
CD (0.05)	NS	20.717	14.698	8.966	NS	22.047	32.892	29.891

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

At 15 DAHA (30 DAS), all herbicide treatments showed an enhanced dehydrogenase activity compared to weedy check (T_{12}) and hand weeding twice (T_{11}) during both the seasons. During first crop season, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8) recorded the highest dehydrogenase activity which was significantly superior to other treatments. During second crop season also, T_8 recorded the highest dehydrogenase activity which was statistically on par with T_6 and T_7 (penoxsulam + cyhalofop butyl @ 125 and 130 g ha^{-1}). During both the seasons non herbicide treatments *viz.*, T_{11} (hand weeding twice) and T_{12} (weedy check) recorded lesser dehydrogenase activity compared to the herbicide treatments.

At 45 DAHA (60 DAS), T_8 recorded the highest dehydrogenase activity. The lowest activity was observed in T_{10} (penoxsulam @ 22.5 g ha^{-1}), which was on par with T_9 (bispyribac sodium @ 25 g ha^{-1}) and T_{11}. During second crop season also T_8 recorded the highest dehydrogenase activity. The lowest dehydrogenase activity was observed in T_{12} and it was found to be on par with T_{11}.

Critical appraisal of data at harvest stage revealed that, during first crop season T_7 recorded the highest dehydrogenase activity. However, during second crop season, T_8 recorded the highest dehydrogenase activity. During both the seasons, T_{12} recorded the lowest dehydrogenase activity and was significantly inferior to all other treatments.

4.1.7.2 β Glucosidase Activity (Table 42)

β glucosidase enzyme plays an important role in the hydrolysis and biodegradation of various β glucosidases present in plant debris causing its decomposiion in the ecosystem. β glucosidase activity as a soil quality indicator gives a reflection of past biological activity, the capacity of the soil to stabilize the soil organic matter and can be used to detect the management effect on soils.

Table 42. Effect of weed management treatments on β glucosidase activity in soil (first and second crop seasons)

Treatments	β glucosidase activity (µg para nitro phenol g^{-1} soil h^{-1})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	34.71	20.10	37.16	54.71	51.57	34.41	58.82	57.35
T_2	34.71	27.31	35.88	56.27	48.76	40.59	50.88	59.80
T_3	40.78	30.20	39.31	56.27	44.90	40.59	57.24	69.21
T_4	36.86	27.03	39.12	62.25	51.31	39.22	59.31	68.14
T_5	38.63	35.26	39.31	59.41	52.94	43.83	66.89	73.45
T_6	40.78	40.42	41.86	57.06	54.12	46.27	65.29	59.61
T_7	38.63	27.48	39.51	57.16	49.41	39.51	68.72	63.53
T_8	40.98	31.28	38.73	58.24	44.44	42.75	64.12	75.03
T_9	39.90	22.74	32.85	52.55	46.07	32.22	51.08	63.61
T_{10}	39.51	23.33	36.27	53.82	45.49	39.41	52.45	64.51
T_{11}	37.85	33.43	38.24	55.68	44.83	42.06	56.47	59.31
T_{12}	37.55	27.16	35.40	54.02	44.98	32.16	49.12	55.28
SEm (±)	1.459	1.172	1.182	1.715	2.650	1.025	1.703	1.853
CD (0.05)	NS	3.436	3.465	5.030	NS	3.007	4.995	5.434

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

Critical appraisal of the data on β glucosidase enzyme activity in soil at different growth stages indicated that at 15 DAHA (30 DAS), a decline in activity was observed in all treatments, however, after that an increase in activity was observed up to harvest stage. The maximum glucosidase activity was observed at the harvest stage during both the seasons.

Data on β glucosidase enzyme activity in soil at 15 DAS (just before herbicide application) during the first and second crop seasons indicated that, β glucosidase activity in the soil was not significantly influenced by the treatments. But at 30 and 60 DAS (15 and 45 DAHA) and at harvest stage, weed management treatments exerted significant effect on β glucosidase activity in soil.

During first crop season at 30 DAS (15 DAHA), penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) recorded significantly higher β glucosidase enzyme activity. Among the treatments, the lowest activity was recorded in bispyribac sodium + metamifop @ 60 g ha^{-1} (T_1) which was statistically comparable with bispyribac sodium @ 25 g ha^{-1} (T_9) and penoxsulam @ 22.5 g ha^{-1} (T_{10}). During second crop season also, T_6 recorded significantly higher glucosidase activity compared to other treatments. Among the treatments, T_{12} (weedy check) recorded the lowest β glucosidase activity which was on par with T_1 and T_9.

Critical appraisal of the data at 60 DAS indicated that during first crop season, the highest β glucosidase activity was observed in T_6 and the lowest activity in T_9, which was on par with T_{12} and T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}). During second crop season, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the highest glucosidase activity which was on par with T_5, T_6 and T_8 (penoxsulam + cyhalofop butyl @ 120, 125 and 135 g ha^{-1}). Among the treatments, T_{12} recorded the lower values of β glucosidase activity, but it was on par with T_2, T_9 and T_{10} (penoxsulam @ 22.5 g ha^{-1}).

Harvest stage data also revealed that during first crop season, the highest activity was observed in T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) which was statistically on par with T_5 and T_8. The lowest activity was observed in T_9. During second crop season, T_8 recorded the highest glucosidase activity and it was on par with T_5. The lowest activity was observed in weedy check.

4.1.7.3 Protease Activity (Table 43)

Protease enzymes contribute to the breakdown of proteinaceous substances in soil to simpler nitrogen compounds that are available for plant nutrition.

Statistical analysis of the two season's data revealed that higher protease activity was at the seedling stage of the crop (15 DAS) with an average value of 193.25 and 194.89 mg tyrosine g^{-1}soil h^{-1}, respectively, during first and second crop seasons. A reduction in protease activity was observed at 30 DAS (15 DAHA), but by 60 DAS (45 DAHA) enzyme activity increased and then declined at harvest stage during both the crop seasons.

Just before herbicide application (15 DAS), during both the seasons, protease activity was not significantly influenced by the weed management treatments. But at 30 and 60 DAS (15 and 45 DAHA) and at harvest stage, weed management treatments showed significant effect on protease activity in soil.

At 15 DAHA, during first crop season, penoxsulam + cyhalofop butyl 135 g ha^{-1} (T_8) recorded the highest protease activity which was statistically on par with bispyribac sodium + metamifop @ 80 g ha^{-1} (T_3) and penoxsulam + cyhalofop butyl 130 g ha^{-1} (T_7). During second crop season also, T_8 recorded significantly higher protease activity which was on par with T_7. During both the seasons, the lower value of protease activity was observed in bispyribac sodium @ 25 g ha^{-1} (T_9).

Table 43. Effect of weed management treatments on protease activity in soil (first and second crop seasons)

Treatments	Protease activity (mg tyrosine g^{-1} soil h^{-1})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	188.73	111.63	159.95	105.32	192.26	134.20	136.14	101.74
T_2	221.43	103.41	146.54	150.53	194.10	151.65	163.59	108.48
T_3	204.77	118.38	161.44	150.52	190.22	210.22	198.29	115.22
T_4	201.70	106.54	148.31	168.38	185.73	147.98	169.00	117.66
T_5	202.67	102.87	190.15	131.24	198.60	133.69	200.22	111.85
T_6	201.87	116.81	200.63	183.28	195.32	130.52	206.76	125.73
T_7	191.57	124.09	151.78	147.05	186.34	206.86	191.22	117.26
T_8	178.80	131.64	153.08	152.36	200.83	217.67	183.08	115.73
T_9	176.90	84.91	155.59	88.99	196.14	128.89	146.24	104.50
T_{10}	186.90	109.6	140.72	136.14	184.51	131.75	171.96	117.26
T_{11}	200.84	114.70	134.43	85.11	199.81	161.96	132.46	101.03
T_{12}	182.53	109.81	117.63	58.47	195.12	155.83	118.07	92.56
SEm (±)	10.117	2.989	2.980	4.291	3.992	4.166	3.136	2.392
CD (0.05)	NS	8.767	8.740	12.585	NS	12.222	9.198	7.015

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

Observation at 45 DAHA (60 DAS) of first crop season revealed that penoxsulam + cyhalofop butyl @ 125 g ha^{-1} (T_6) recorded the highest protease activity which was statistically on par with its lowest dose of 120 g ha^{-1} (T_5) and T_3. During second crop season also, T_6 recorded significantly higher protease activity which was followed by T_5 and T_3. During both the seasons, T_{12} (weedy check) recorded the lowest protease activity (118.07 and 117. 63 mg tyrosine g^{-1} soil h^{-1}, respectively) and it was significantly inferior to all other treatments

At harvest stage, a decline in protease activity was observed. During both the seasons, penoxsulam + cyhalofop butyl @ 120 g ha^{-1} (T_6) recorded significantly higher protease activity and weedy check recorded the lowest activity (58.47 and 92.56 mg tyrosine g^{-1} soil h^{-1}, respectively) among all the treatments.

4.*1.7.4 Acid Phosphatase Activity (Table 44)*

Phosphatase is an exocellular enzyme produced by many soil microorganisms that are responsible for the hydrolytic cleavage of a variety of ester phosphate bonds of organic phosphates and anhydrides of orthophosphoric acid (H_3PO_4) into inorganic phosphate.

Observations on acid phosphatase activity at different stages revealed that first crop season recorded higher values of phosphatase activity compared to second crop season.

Data on acid phosphatase activity at 15 DAS (just before herbicide application) during both the seasons revealed that acid phosphatase activity in the soil was not significantly influenced by the treatments. Average phosphatase activity observed during first and second crop seasons were 49.49 and 46.19 µg para nitrophenol g^{-1} soil h^{-1}, respectively.

However, at 30 and 60 DAS (15 and 45 DAHA) weed management treatments exerted significant effect on acid phosphatase activity in soil.

Table 44. Effect of weed management treatments on acid phosphatase activity in soil (first and second crop seasons)

Treatments	Acid phosphatase activity (µg para nitro phenol g^{-1} soil h^{-1})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	48.60	28.62	29.76	58.95	45.37	24.62	16.84	29.14
T_2	50.73	34.07	34.44	67.03	48.22	27.34	20.54	32.01
T_3	51.08	30.63	41.25	58.31	47.16	28.48	22.58	27.87
T_4	50.85	34.82	38.73	55.98	47.09	27.32	23.05	28.95
T_5	49.09	30.96	33.77	65.63	50.47	22.56	20.70	34.83
T_6	49.05	31.39	41.41	64.13	44.48	26.93	25.26	30.03
T_7	48.39	35.19	37.70	62.49	44.27	34.06	31.80	30.63
T_8	47.37	36.39	45.43	59.57	45.43	28.64	29.82	31.68
T_9	49.70	30.56	37.71	54.17	44.06	25.36	22.86	28.45
T_{10}	47.03	32.32	40.15	64.45	45.31	24.77	22.85	31.99
T_{11}	52.54	40.09	33.05	55.51	47.05	26.36	22.44	29.36
T_{12}	49.46	34.91	43.80	48.22	45.38	23.31	23.19	23.70
SEm (±)	1.869	1.054	1.744	2.000	1.592	1.078	1.853	1.733
CD (0.05)	NS	3.091	5.114	5.867	NS	3.163	5.435	5.083

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

During both the seasons, at 30 DAS (15 DAHA) a reduction in phosphatase activity was observed in all treatments including weedy check and hand weeding. Significantly higher phosphatase activity was observed in hand weeding (T_{11}) during first crop season and it was followed by penoxsulam + cyhalofop butyl @ 135 g ha^{-1} (T_8). The lower dose of bispyribac sodium + metamifop, *i.e.*, @ 60 g ha^{-1} (T_1) recorded the lowest acid phosphatase activity but it was on par with bispyribac sodium @ 25 g ha^{-1} (T_9), bispyribac sodium + metamifop @ 80 g ha^{-1} (T_3) and penoxsulam + cyhalofop butyl @ 120 g ha^{-1} (T_5). During second crop season the treatment T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the highest activity which was followed by T_8. Among the treatments, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) recorded the lowest activity but it was statistically on par with T_{12} (weedy check), T_1, T_{10} (penoxsulam @ 22.5 g ha^{-1}) and T_9.

An increase in phosphatase activity was observed at 45 DAHA (60 DAS) during first crop season. The highest activity was observed in treatment T_8, which was statistically on par with T_{12}, T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}) and T_3. During second crop season T_7 recorded the highest activity which was statistically on par with T_8. During both the seasons, T_1 recorded the lowest activity among all the treatments.

Observations at harvest stage revealed an increase in acid phosphatase activity during both the seasons. During first crop season, T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}) recorded the highest activity which was statistically on par with T_5, T_{10}, T_6 and T_7. During second crop season, the treatment T_5 recorded the highest phosphatase activity which was statistically on par with T_2, T_{10}, T_8, T_7 and T_6. During both the seasons, weedy check recorded the lowest acid phosphatase activity in soil.

Table 45. Effect of weed management treatments on urease activity in soil (first and second crop seasons)

Treatments	Urease activity (µg urea hydrolyzed g^{-1} soil h^{-1})							
	First crop season				Second crop season			
	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest	15 DAS (JBHA)	30 DAS (15 DAHA)	60 DAS (45 DAHA)	Harvest
T_1	233.91	123.71	177.33	136.80	157.83	106.40	129.67	103.36
T_2	233.77	143.13	239.40	160.36	160.11	119.20	133.76	123.88
T_3	233.07	156.23	247.84	153.90	139.59	118.31	144.15	117.80
T_4	227.02	136.80	230.11	144.02	170.23	122.36	128.95	111.72
T_5	235.47	125.40	251.64	149.72	165.43	117.80	145.92	115.52
T_6	238.92	127.09	252.91	163.40	166.95	119.83	146.42	126.92
T_7	227.87	130.89	242.78	150.10	153.85	127.78	136.04	118.94
T_8	230.79	141.03	236.45	156.94	155.04	125.40	144.91	115.14
T_9	233.06	116.11	250.80	161.12	141.87	111.47	134.90	125.02
T_{10}	238.33	128.36	228.00	150.48	145.16	116.28	135.03	118.18
T_{11}	235.73	129.62	178.18	136.04	151.75	117.04	139.84	98.80
T_{12}	233.20	134.27	182.82	133.00	153.51	107.92	117.29	97.66
SEm (±)	3.391	4.707	7.810	2.489	8.738	3.178	4.713	4.113
CD (0.05)	NS	13.805	22.907	7.301	NS	9.322	13.824	12.065

DAS - Days after sowing, JBHA - Just before herbicide application, DAHA - Days after herbicide application, NS - non significant

4.1.7.5 Urease Activity (Table 45)

Urease activity is a useful indicator to evaluate soil health. Urease enzyme catalyzes the hydrolysis of urea to ammonium and carbon dioxide. Ammonium formed represents a bioavailable form of nitrogen for plant uptake; this ubiquitous activity has a primary role in the cycling of nitrogen.

Perusal of the data on urease activity in soil during the first and second crop seasons showed that it was significantly influenced by the treatments at 30 DAS (15 DAHA) and 60 DAS (45DAHA) and at harvest stage of the crop. Urease activity in the soil varied widely in both the seasons. Compared to second crop, first crop recorded higher values of urease activity at all the growth stages of the crop. Among the growth stages, seedling stage (15 DAS), recorded the highest urease activity in both the seasons. At 30 DAS (15 DAHA), a reduction in activity was observed as compared to 15 DAS, but at 60 DAS (45 DAHA) urease activity was found to be increased and at harvest stage again a decline in activity was observed during both the seasons.

Just before herbicide application (15 DAS) urease activity was not significantly influenced by the treatments during both the seasons.

Critical appraisal of the data on urease activity in soil at different time intervals revealed that though some herbicide treatments recorded lower urease activity than non-herbicide treated plots (T_{12} and T_{11}), the magnitude of variation did not touch the level of statistical significance.

During the first crop season at 30 DAS (15 DAHA), the highest urease activity was observed in bispyribac sodium + metamifop @ 80 g ha^{-1} (T_3) which was statistically on par with bispyribac sodium + metamifop @ 70 g ha^{-1} (T_2). The lowest urease activity was recorded in bispyribac sodium @ 25 g ha^{-1} (T_9). During second crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} (T_7) recorded the highest urease activity which was statistically on par with penoxsulam + cyhalofop butyl @ 135 and 125 g ha^{-1} (T_8 and T_6), bispyribac

sodium + metamifop @ 90 g ha^{-1} (T_4) and T_2. The lowest urease activity was observed in T_1, however this was on par with T_{12} (weedy check) and T_9.

At 60 DAS (45 DAHA) during first and second crop season, T_6 recorded the highest urease activity among the treatments. During first crop season, T_1 recorded the lowest urease activity which was on par with hand weeding (T_{11}) and T_{12}. However, during second crop, T_{12} (weedy check) recorded the lowest urease activity which was on par with T_4 and T_1.

The observations at harvest stage during both the seasons revealed that, T_6 recorded the highest urease activity in soil. The non-herbicide treatments *viz.*, T_{11} and T_{12} recorded lower urease activity compared to herbicide treatments.

4.1.8. Economics of Cultivation (Table 46)

The data on net returns and B: C ratios of two seasons are presented in Table 46.

Critical appraisal of data of first crop season pointed out that maximum net return (91, 056 ₹ ha^{-1}) was obtained for penoxsulam + cyhalofop butyl @ 130 g ha^{-1} (T_7) which was statistically on par with penoxsulam + cyhalofop butyl @ 135 and 125 g ha^{-1} (T_8 and T_6). Benefit cost ratio also follow the same trend, the highest B: C ratio (2.39) being recorded in the treatment T_7 which was on par with T_8 (2.31) and T_6 (2.31). Weedy check (T_{12}) was significantly inferior to all the treatments and recorded the lowest net returns of ` 23, 019 ha^{-1} and B: C ratio (1.37).

During second crop season, T_8 recorded the maximum net returns (1, 01,353 ₹ ha^{-1}), which was significantly superior to all the treatments. Similar to first crop season, weedy check recorded significantly lower net returns of ₹ 21,147 ha^{-1}. B: C ratio also followed a similar trend, and the highest value (2.54) was observed for treatment T_8, which was on par with T_7. Weedy check

Table 46. Effect of weed control treatments on net returns and B: C ratio (first and second crop seasons)

Treatments	Net returns (₹ ha^{-1})			B: C ratio		
	First crop	Second crop	Pooled mean	First crop	Second crop	Pooled mean
T_1	76916	75244	76080	2.19	2.17	2.18
T_2	79957	90945	85451	2.23	2.40	2.32
T_3	79317	92304	85810	2.22	2.41	2.32
T_4	79698	92777	86238	2.22	2.41	2.32
T_5	76280	90514	83397	2.17	2.38	2.28
T_6	86005	93866	89936	2.31	2.43	2.37
T_7	91056	94990	93023	2.39	2.45	2.42
T_8	86135	101353	93744	2.31	2.54	2.43
T_9	72659	81458	77059	2.13	2.27	2.20
T_{10}	80288	86102	83195	2.24	2.33	2.29
T_{11}	69525	77054	73289	1.91	2.01	1.96
T_{12}	23019	21147	22083	1.37	1.34	1.36
SEm(±)	1797.3	1745.2	1252.6	0.029	0.032	0.032
CD (p=0.05)	5271.7	5118.7	3580.10	0.085	0.093	0.090

and hand weeding twice recorded the B: C ratio of 1.34 and 2.01 respectively and these treatments were significantly inferior to other treatments.

Pooled data revealed that the maximum net returns was observed in T_8 (93, 744 ₹ ha^{-1}) which was on par with T_7; in turn T_7 was on par with T_6 and T_6 was on par with T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}). Weedy check was significantly inferior to all the treatments and resulted in lowest net returns of ₹ 22,083 ha^{-1}. Pooled B: C ratio also follows a very similar trend as that of pooled net returns, with maximum B: C ratio of 2.43 for T_8 and minimum of 1.36 in weedy check.

4.2 PART II - SCREENING OF INDICATOR PLANTS

4.2.1 Screening Indicator Plants for Bioassay to Detect the Herbicide Residue of Bispyribac Sodium + Metamifop in Soil (Tables 47 and 49)

Three indicator plants *viz*., cucumber, sunflower and maize were screened for identifying the most sensitive indicator plant for the herbicide mixture, bispyribac sodium + metamifop. For selecting the most sensitive indicator plant, regression models both quadratic, $Y= a + bX + C X^2$ and logarithmic linear regression equation, $Y= a + b \ln (X)$ were fitted and the best was found to be the logarithmic linear regression model. The same was used for identifying the best indicator plant.

4.2.1.1 Cucumber

The effect of different concentrations of bispyribac sodium + metamifop on on germination percentage, shoot length, root length, shoot fresh and dry weight of cucumber are presented in Table 47.

Data on germination percentage was not statistically analysed, since graded variation in this parameter was not observed among different concentrations of bispyribac sodium + metamifop.

Table 47. Effect of different concentrations of bispyribac sodium + metamifop on the growth parameters of tested indicator plants

Treatments	Growth parameters of indicator plants														
	Cucumber					Sunflower					Maize				
	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
T_1	30.0	0.56	0.49	0.09	0.011	76.7	2.16	0.65	0.28	0.036	80.00	0.37	0.74	0.08	0.001
T_2	40.0	0.80	0.79	0.11	0.012	80.0	3.22	0.81	0.30	0.037	86.67	3.94	1.50	0.13	0.026
T_3	60.0	3.22	1.60	0.18	0.015	80.0	5.42	0.87	0.38	0.039	83.33	17.65	3.74	0.64	0.082
T_4	66.0	4.36	1.48	0.21	0.018	76.7	5.67	1.05	0.44	0.047	86.67	29.48	7.57	1.08	0.133
T_5	63.0	5.53	3.30	0.32	0.023	80.0	7.73	1.53	0.49	0.048	90.00	30.95	13.47	1.35	0.157
T_6	74.07	7.82	4.50	0.60	0.042	80.0	8.02	2.23	0.55	0.049	90.00	32.80	18.45	1.40	0.181
T_7	90.0	9.00	6.99	0.61	0.049	86.7	14.08	4.08	0.80	0.056	100.00	37.30	26.76	1.60	0.188
T_8 (control)	90.0	9.54	7.03	0.76	0.057	93.3	16.15	4.61	0.87	0.057	100.00	37.69	27.93	1.64	0.192
SEm (±)	#	0.528	0.573	0.043	0.004	#	0.651	0.173	0.052	0.0028	#	1.486	1.334	0.082	0.0067
CD (0.05)		1.584	1.720	0.129	0.011		1.950	0.520	0.156	0.0083		4.455	4.000	0.246	0.0200

- mean values

The different concentrations of bispyribac sodium + metamifop significantly influenced the shoot fresh weight of cucumber. In general, shoot fresh weight of cucumber increased as the concentration of herbicide mixture decreased. The lowest shoot fresh weight was observed in T_1 (100 µL L^{-1}) which was statistically on par with T_2 (10 µL L^{-1}), T_3 (1 µL L^{-1}) and T_4 (0.5 µL L^{-1}). The maximum fresh weight was observed in control (T_8) (0.76 g). The reduction in shoot fresh weight at 0.01 to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 19.74 to 88.16 per cent compared to control. Logarithmic linear regression equation developed for shoot fresh weight of cucumber was Y= 0.2714-0.06155 ln (X).

Similar to shoot fresh weight, shoot dry weight of cucumber was also significantly influenced by the tested concentrations of bispyribac sodium + metamifop. In general, shoot dry weight of cucumber decreased as the concentration of the herbicide mixture increased. The lowest shoot dry weight was observed in T_1 and it was statistically comparable with T_2, T_3 and T_4. Maximum dry weight was observed in control treatment (T_8), which was on par with T_7 (0.01 µL L^{-1}). The reduction in shoot dry weight at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 14.04 to 80.70 per cent compared to that in control. Logarithmic linear regression equation developed for shoot dry weight of cucumber was Y= 0.0223 - 0.00414 ln (X).

Shoot length of cucumber was also significantly influenced by the tested concentrations of bispyribac sodium + metamifop. As the concentration of the herbicide mixture increased, a decrease in shoot length was observed. The highest concentration of the herbicide mixture (T_1) recorded the lowest shoot length (0.56 cm), which was on par with T_2. The control (T_8) recorded the maximum shoot length (9.54 cm) which was statistically comparable with T_7. The reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 5.66 per cent to 94.13 per cent compared to control. Logarithmic linear regression equation developed for shoot length of cucumber was Y= 3.950 - 0.9871 ln (X).

The root length was also significantly influenced by the tested concentrations of herbicide. The lowest value of root length (0.49 cm) was observed in the treatment T_1 which was on par with T_2, T_4 and T_3. The control (T_8) recorded the maximum root length and it was on par with T_7. The percentage reduction in root length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 0.57 to 93.03 compared to control. Logarithmic linear regression equation developed for root length of cucumber was Y= 2.385 - 0.6645 ln (X).

4.2.1.2 Sunflower

The effect of different concentrations of bispyribac sodium + metamifop on germination percentage, shoot length, root length, shoot fresh and dry weight of sunflower are presented in Table 47.

The data on germination percentage of sunflower was not statistically analyzed, since among the treatments graded variation was not observed.

Different concentrations of bispyribac sodium + metamifop significantly influenced the shoot fresh weight. As the concentration of the herbicide mixture increased, the shoot fresh weight decreased. The highest concentration (100 µL L^{-1}) of the herbicide mixture (T_1) recorded the lowest shoot fresh weight which was on par with T_2 (10 µL L^{-1}) and T_3 (1 µL L^{-1}). The control (T_8) recorded the maximum shoot fresh weight which was on par with T_7 (0.01 µL L^{-1}). The percentage reduction in shoot fresh weight at 0.01 µL L^{-1} to 100 µL L^{-1} concentations of bispyribac sodium + metamifop ranged from 8.05 to 67.82 compared to control. Logarithmic linear regession equation developed for the shoot fresh weight of sunflower was Y= 0.4349 -0.0513 ln (X).

The tested concentrations of the herbicide mixture significantly influenced the shoot dry weight. Reduction in shoot dry weight was observed with increase in concentration of the herbicide mixture. The lowest shoot dry weight was observed in T_1 and the highest shoot dry weight in control treatment (T_8). The per

cent reduction in shoot dry weight at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 1.75 to 36.84 compared to control. Logarithmic linaer regression equation developed for the shoot dry weight of sunflower was Y= 0.0434 -0.0022 ln (X).

The shoot length was also significantly influenced by the tested concentrations of the herbicide mixture. The shoot length decreased as the concentration of the herbicide mixture increased. The lowest shoot length was recorded in T_1 which was statistically comparable with T_2. The treatments, T_7 and T_8 recorded the shoot length of 14.08 and 16.15 cm respectively, which was significantly superior to other treatments. The percentage reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of herbicide mixture ranged from 12.82 to 86.63 compared to control. Logarithmic linear regression equation developed for the shoot length of sun flower was Y= 6.0154 -1.1373 ln (X).

The root length was also significantly influenced by tested concentrations of herbicide. Reduction in root length was noticed, as the concentration of tested herbicide mixture increased. The lowest root length (0.65 cm) was observed in T_1 which was statistically on par with T_2, T_3 and T_4 (0.5 µL L^{-1}). The control treatment (T_8) recorded the highest root length (4.61 cm). The percentage reduction in root length at 0.01 µL L^{-1} to 100 µL L^{-1} concemtrations of bispyribac sodium + metamifop ranged from 11.50 to 85.90 compared to control. Logarithmic linear regression equation developed for the root length of sunflower was Y= 1.4383 - 0.3132 ln (X).

4.2.1.3 Maize

The effect of different concentrations of bispyribac sodium + metamifop on germination percentage, shoot length, root length, shoot fresh and dry weight of maize are presented in Table 47.

The data on germination of maize was not statistically analysed, since no graded variation in this parameter was observed among the treatments.

The shoot fresh weight of maize was significantly influenced by the treatments. The highest tested concentration of the herbicide mixture (T_1) recorded the lowest shoot fresh weight (0.08 g) and it was statistically on par with T_2 (10 µL L^{-1}). The control treatment (T_8) recorded the maximum shoot fresh weight (1.64 g) and it was on par with T_7 (0.01 µL L^{-1}) and T_6 (0.05 µL L^{-1}). The percentage reduction in shoot fresh weight at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of bispyribac sodium + metamifop ranged from 2.44 to 95.12 compared to control. Logarithmic linear regression equation developed for the shoot fresh weight of maize was Y= 0.7980 - 0.1890 ln (X).

The shoot dry weight was also significantly influenced by the treatments. Among the treatments T_1 recorded the lowest dry weight of 0.001g. Significant difference in shoot dry weight was observed among the treatments from T_1 (100 µL L^{-1}) to T_5 (0.1 µL L^{-1}). The treatment T_5 was followed by T_6 which was on par with T_7 and T_8. The control treatment (T_8) recorded the maximum shoot dry weight (0.192 g). The percentage reduction in shoot dry weight at 0.01 to 100 µL L^{-1} concentrations of herbicide mixture ranged from 2.08 to 99.48 compared to control. Logarithmic linear regression equation developed for the shoot dry weight of maize was Y= 0.0977-0.0230 ln (X).

The shoot length was significantly influenced by different concentrations of the herbicide mixture. The highest tested concentration (T_1) recorded the lowest shoot length (0.37 cm) which was on par with T_2. The control (T_8) recorded the highest values of shoot length (37.69 cm) and it was on par with T_7. The percentage reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of the herbicide mixture ranged from 1.03 to 99.02 compared to control. Logarithmic linear regression equation developed for the shoot length of maize was Y= 19.4270-4.4705 ln (X).

The root length was also significantly influenced by the tested concentrations of the herbicide mixture. T_1 recorded the lowest root length (0.74), which was on par with T_2 and T_3. The treatment T_3 was on par with T_4 and it was

followed by T_5. The treatment T_5 was statistically comparable with T_6 and it was followed by T_7 and the same was on par with control which recorded the maximum root length (27.93 cm). Logarithmic linear regression equation developed for the root length of maize was Y= 8.8401-2.8056 ln (X).

4.2.1.4 R^2 values of Different Parameters of Tested Indicator Plants to Identify the Most Sensitive Indicator Plant for the Herbicide Mixture, Bispyribac Sodium + Metamifop (Table 49)

The different parameters tested *viz.*, shoot fresh weight, dry weight, shoot length and root length of tested indicator plants *viz.*, cucumber, sunflower and maize were significantly influenced by different concentrations of bispyribac sodium + metamifop. Regression equations were developed for these parameters by plotting the values against the herbicide concentrations in logarithmic scale. Among the indicator plants, maize plant showed the highest R^2 value for shoot length, root length, fresh and dry weight of shoot. Hence maize was selected as the best indicator plant for the herbicide mixture, bispyribac sodium + metamifop. The best parameter for the detection of residue in the soil was maize shoot dry weight, since it recorded the highest R^2 value (0. 9548).

4.2.2 Screening Indicator Plants for Bioassay to Detect the Herbicide Residue of Penoxsulam + Cyhalofop Butyl in Soil (Table 48 and 50)

Cucumber, sunflower and maize plants were screened for indentifying the most sensitive indicator plant for the herbicide mixture, penoxsulam + cyhalofop butyl. For selecting the most sensitive indicator plant for the herbicide mixture, regression models both quadratic, $Y= a + bX + C X^2$ and logarithmic linear regression equation, Y= a + b ln (X) were fitted and the best was found to be the log linear regression model. The same was used for identifying the best indicator plant.

Table 48. Effect of different concentrations of penoxsulam + cyhalofop butyl on the growth parameters of tested indicator plants

Treatments	Growth parameters of indicator plants														
	Cucumber					Sunflower					Maize				
	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Germination (%)	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)
T_1	33.33	0.83	0.62	0.07	0.002	96.67	1.74	0.15	0.207	0.019	86.67	2.50	1.04	0.106	0.014
T_2	33.33	1.18	1.10	0.10	0.004	100.00	2.19	0.36	0.327	0.026	100.00	10.91	2.70	0.543	0.047
T_3	50.00	4.68	1.44	0.17	0.012	100.00	3.10	0.53	0.373	0.027	90.00	27.23	5.81	1.060	0.064
T_4	53.33	7.20	1.73	0.24	0.014	93.33	3.99	0.77	0.398	0.027	100.00	34.17	13.10	1.270	0.077
T_5	56.67	9.66	3.24	0.43	0.022	93.33	8.09	1.50	0.520	0.029	100.00	38.47	14.67	1.613	0.113
T_6	56.67	11.41	4.96	0.46	0.024	100.00	10.61	2.59	0.577	0.036	93.33	42.61	21.51	1.730	0.114
T_7	56.67	12.33	5.80	0.53	0.028	100.00	19.33	7.12	1.037	0.040	93.33	44.98	22.44	1.860	0.125
T_8 (control)	46.67	14.57	9.03	0.72	0.035	100.00	19.87	8.14	1.22	0.044	100.00	51.73	27.11	1.880	0.149
SEm (±)	#	0.655	0.438	0.040	0.002	#	0.303	0.445	0.0767	0.0042	#	2.261	1.675	0.168	0.008
CD (0.05)		2.775	1.857	0.119	0.0063		0.909	1.336	0.2300	0.0127		6.777	5.023	0.5027	0.0247

- mean values

4.2.2.1 Cucumber

The effect of different concentrations of herbicide mixture, penoxsulam + cyhalofop butyl on shoot length, root length, shoot fresh and dry weight of cucumber are presented in Table 48.

The data on germination percentage of cucumber was not statistically analyzed, since no graded variation was observed among the treatments.

The shoot fresh weight of cucumber was significantly influenced by the treatments. In general, as the concentration of herbicide mixture increased, a decrease in fresh weight was observed. Concentration of 100 $\mu L\ L^{-1}$ penoxsulam + cyhalofop butyl (T_1) recorded the lowest shoot fresh weight (0.07 g), which was statistically on par with T_2 (10 $\mu L\ L^{-1}$) and T_3 (1 $\mu L\ L^{-1}$). The control treatment (T_8) recorded the highest shoot fresh weight (0.72 g) and it was significantly different from other treatments. The percentage reduction in shoot fresh weight at 0.01 $\mu L\ L^{-1}$ to 100 $\mu L\ L^{-1}$ concentrations of penoxsulam + cyhalofop butyl ranged from 26.39 to 90.28 compared to control. Logarithmic linear regression equation developed for the shoot fresh weight of cucumber was Y= 0.2582-0.0554 ln (X).

The shoot dry weight of cucumber was also significantly influenced by the treatments. As the concentration of herbicide mixture increased, the shoot dry weight decreased. The highest concentration of the herbicide mixture (T_1) recorded the lowest shoot dry weight (0.002 g) which was statistically on par with T_2 and T_2 was followed by T_3. The control (T_8) recorded the highest shoot dry weight (0.035 g) and was significantly different from other treatments. The percentage reduction in shoot dry weight at 0.01 $\mu L\ L^{-1}$ to 100 $\mu L\ L^{-1}$ concentrations of penoxsulam + cyhalofop butyl were 20 to 94.29 compared to control. Logarithmic linear regression equation developed for the shoot dry weight of cucumber was Y= 0.0135-0.0031 ln (X).

The shoot length was significantly influenced by the tested concentrations of herbicide mixture, penoxsulam + cyhalofop butyl. The highest concentration

of the herbicide (T_1) recorded the lowest shoot length (0.83 cm) and the highest shoot length was in control (14.57 cm). The control was on par with T_7 (0.01 µL L^{-1}). The percentage reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of penoxsulam + cyhalofop butyl ranged from 15.37 to 94.30 compared to control. Logarithmic linear regression quation developed for the shoot length of cucumber was Y= 6.0011 - 1.4327 ln (X).

Similar to shoot fresh weight, shoot dry weight and shoot length, the root length of cucumber was also significantly influenced by different concentrations of the herbicide mixture, penoxsulam + cyhalofop butyl. The root length decreased as the concentrations of the herbicide mixture increased. The treatment T_1 recorded the lowest root length (0.62 cm) which was on par with T_2, T_3 and T_4 (0.5 µL L^{-1} penoxsulam + cyhalofop butyl). The control (T_8) recorded the highest root length (9.03 cm) and was significantly different from other treatments. The percentage reduction in root length at 0.01 µl L^{-1} to 100 µL L^{-1} concentrations of herbicide mixture were 35.77 to 93.13 compared to control. Logarithmic linear regression equation developed for the root length of cucumber was Y= 2.3952-0.5766 ln (X).

4.2.2.2 Sunflower

The data on germination percentage was not statistically analyzed, since no graded variation in this parameter was observed among the treatments.

Different tested concentrations of herbicide mixture penoxsulam + cyhalofop butyl significantly influenced the shoot fresh weight of sunflower. The highest concentration (T_1) (100 µL L^{-1}) recorded the lowest shoot fresh weight (0.207 g) which was statistically on par with T_2 (10 µL L^{-1}), T_3 (1 µL L^{-1}) and T_4 (0.5 µL L^{-1}). The control (T_8) recorded the highest shoot fresh weight (1.223 g) among the treatments and it was on par with T_7 (0.01 µL L^{-1}). The percentage reduction in shoot fresh weight at 0.01 to 100 µL L^{-1} concentrations of penoxsulam + cyhalofop butyl were 15.21 to 83.07 compared to control.

Logarithmic linear regression equation developed for the shoot fresh weight of sunflower was Y= 0.4537- 0.0711 ln (X).

Similar to shoot fresh weight, shoot dry weight was also significantly influenced by the treatments. The shoot dry weight decreased as the concentrations of the herbicide increased. The highest concentration of the herbicide mixture (T_1) recorded the lowest dry weight (0.019 g) which was on par with T_2, T_3, T_4 and T_5 (0.1 µL L^{-1}). The control treatment recorded the highest shoot dry weight (0.044 g) which was on par with T_7 and T_6 (0.5 µL L^{-1}). The percentage reduction in shoot dry weight at 0.01 to 100 µL L^{-1} concentrations of herbicide mixture were 9.09 to 56.82 compared to control. Logarithmic linear regression equations developed for the shoot dry weight of sunflower was Y=02809- 0.0021 ln (X).

The shoot length of sunflower was significantly influenced by the tested concentrations of herbicide mixture, penoxsulam + cyhalofop butyl. The shoot length of sunflower decreased as the concentration of herbicide mixture increased. The highest concentration of the herbicide mixture (T_1) recorded the lowest shoot length (1.74 cm) which was on par with T_2. The control treatment (T_8) recorded the highest shoot length (19.87 cm) which was statistically comparable with T_7. The percentage reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of penoxsulam + cyhalofop butyl were 2.72 to 91.24, compared to control. Logarithmic linear regression equation developed for the shoot length of sunflower was Y= 6.1079-1.7063 ln (X).

The root length was also significantly influenced by the tested concentrations of herbicide mixture, penoxsulam + cyhalofop butyl. The lowest root length (0.15 cm) was observed in treatment T_1 which was statistically comparable with T_2, T_3 and T_4. The control treatment (T_8) recorded the highest root length (8.14 cm) which was on par with T_7. The percentage reduction in root length at 0.01 to 100 µL L^{-1} concentrations of herbicide mixture were 12.53 to

98.16 compared to control. Logarithmic linear regression equation developed for the root length of sunflower was Y= 1.5453- 0.5972 ln (X).

4.2.2.3 Maize

The effect of different concentrations of herbicide mixture, penoxsulam + cyhalofop butyl on germination percentage, shoot length, root length, shoot fresh and dry weight of maize are presented in Table 48.

The data on germination of maize was not statistically analyzed, since graded variation in this parameter was not observed among different concentrations of herbicide mixture, penoxsulam + cyhalofop butyl.

Different tested concentrations of herbicide mixture significantly influenced the shoot fresh weight of maize. The lowest shoot fresh weight (0.106 g) was observed in T_1 (100 µL L^{-1}) which was statistically on par with T_2 (10 µL L^{-1}). The control (T_8) recorded the highest shoot fresh weight (1.880 g) which was on par with T_7 (0.01 µL L^{-1}), T_6 (0.05 µL L^{-1}) and T_5 (0.01 µL L^{-1}). The percentage reduction in shoot fresh weight at 0.01 to 100 µL L^{-1} concentrations of penoxsulam + cyhalofop butyl ranged from 1.06 to 94.36 compared to control. Logarithmic linear regression equation developed for the shoot fresh weight of maize was Y= 1.0621- 0.2030 ln (X).

Shoot dry weight was also significantly influenced by different tested concentrations of herbicide mixture, penoxsulam + cyhalofop butyl. It was observed that, as the concentration of the herbicide mixture increased, the shoot dry weight of maize decreased. The lowest shoot dry weight (0.014 g) was observed in T_1, which was significantly inferior to other treatments and T_8 recorded the highest shoot dry weight and it was on par with T_7. The percentage reduction in shoot dry weight at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of herbicide mixture were 16.11 to 90.60 compared to control. Logarithmic linear regression equation developed for the shoot dry weight of maize was Y= 0.0726 - 0.0126 ln (X).

Table 49. R^2 values of different parameters of tested indicator plants, Y= a + b ln (X) to identify the most sensitive indicator plant for the herbicide mixture, bispyribac sodium + metamifop

Parameters	Cucumber	Sunflower	Maize
	R^2 values	R^2 values	R^2 values
Shoot fresh weight	0.7861	0.8245	0.9379
Shoot dry weight	0.7501	0.8772	0.9548
Shoot length	0.9325	0.8454	0.9310
Root length	0.8039	0.6670	0.8408

Table 50. R^2 values of different parameters of tested indicator plants, Y= a + b ln (X) to identify the most sensitive indicator plant for the herbicide mixture penoxsulam + cyhalofop butyl

Parameters	Cucumber	Sunflower	Maize
	R^2 values	R^2 values	R^2 values
Shoot fresh weight	0.9042	0.7007	0.9854
Shoot dry weight	0.9625	0.8787	0.9725
Shoot length	0.9424	0.7301	0.9644
Root length	0.8243	0.5917	0.8993

Similar to shoot dry weight, shoot length of maize was also significantly influenced by tested concentrations of penoxsulam + cyhalofop butyl. Shoot length of maize decreased as the concentration of the herbicide increased. The lowest shoot length was observed in T_1, which was followed by T_2 and T_3 and these treatments were significantly inferior to other treatments. The control (T_8) recorded the highest shoot length among the treatments and it was on par with T_7. The percentage reduction in shoot length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of penoxsulam + cyhalofop butyl ranged from 13.05 to 95.17 compared to control. Logarithmic linear regression equation developed for the shoot length of maize was Y= 26.0430 - 5.0312 ln (X).

Root length of maize was also significantly influenced by different concentrations of penoxsulam + cyhalofop butyl. The root length of maize decreased with increase in the concentration of herbicide mixture. The treatment T_1 recorded the minimum root length (1.04 cm) and control recorded the maximum (27.11 cm) root length. The percentage reduction in root length at 0.01 µL L^{-1} to 100 µL L^{-1} concentrations of herbicide mixture were 17.23 to 96.16 compared to control. Logarithmic linear regression equation developed for the root length of maize was Y= 10.2452 -2.5908 ln (X).

4.2.2.4 R^2 values for the Various Growth Parameters of Tested Indicator Plants to Identify the Most Sensitive Indicator Plant for the Herbicide Mixture, Penoxsulam + Cyhalofop Butyl (Table 50)

Different tested concentrations of the herbicide mixture, penoxsulam + cyhalofop butyl significantly influenced the shoot dry and fresh weight, shoot length and root length of tested indicator plants *viz*., cucumber, sunflower and maize. Logarithmic linear regression equations were developed for these parameters for each indicator plant by plotting the values against the herbicide concentrations. Among the indicator plants, maize plant showed the highest R^2 values for shoot dry and fresh weight, shoot length and root length. Hence maize was selected as the best indicator plant for the herbicide mixture, bispyribac

sodium + metamifop. The best parameter for the detection of residue in the soil was maize shoot fresh weight, since it recorded the highest R^2 value (0.9854).

4.2.2 Determination of Herbicide Residue in Post Experiment Soil (Table 51and 52)

4.2.2.1 Determination of Bispyribac Sodium + Metamifop Residue in Soil (Table 51)

The most sensitive indicator plant selected based on the screening trial was maize and it was used for assessing the residual effect of bispyribac sodium + metamifop.

Soil was collected from the experimental field after the harvest of rice during both the seasons and maize seeds were sown in the collected soil. Data on germination percentage, shoot length, shoot fresh and dry weight and root length of maize plant were statistically analysed to find out the residual effect in the soil consequent to the application of bispyribac sodium + metamifop at different doses *viz*., 60, 70, 80 and 90 g ha^{-1}. Bispyribac sodium @ 25 g ha^{-1} and weedy check were the controls. The results are presented in Table 51.

Results revealed that there was no significant difference among the treatments *viz*., bispyrbac sodium + metamifop @ 60, 70, 80 and 90 g ha^{-1}, hand weeding twice and weedy check, in the parameters studied during both the seasons. Hence it can be assumed that, the tested doses of bispyribac sodium + metamifop had no residual effect.

4.2.2.2 Determination of Penoxsulam + Cyhalofop Butyl Residue in Post Experiment Soil (Table 52)

Perusal of data on germination percentage, shoot length, shoot fresh and dry weight and root length of maize grown in the soil taken after the harvest of the

Table 51. Residual effect of bispyribac sodium + metamifop on the growth parameters of maize (first and second crop seasons)

Treatments	First crop						Second crop					
	Growth parameters of maize						Growth parameters of maize					
	Germination (%)		Shoot length (cm)	Root length (cm)	Fresh weight (g)	Dry weight (g)	Germination (%)		Shoot length (cm)	Root Length (cm)	Fresh weight (g)	Dry weight (g)
Bispyribac sodium + metamifop @ 60 g ha^{-1}	66.67	(54.78)	26.30	26.27	2.03	0.257	70.00	(56.99)	27.73	24.47	2.23	0.274
Bispyribac sodium + metamifop @ 70 g ha^{-1}	73.33	(59.21)	25.50	26.33	2.28	0.256	70.00	(57.29)	25.63	25.27	1.92	0.264
Bispyribac sodium + metamifop @ 80 g ha^{-1}	73.33	(59.21)	25.90	25.10	2.14	0.261	63.33	(52.86)	27.13	25.47	2.16	0.287
Bispyribac sodium + metamifop @ 90 g ha^{-1}	70.00	(57.79)	30.23	27.27	2.37	0.256	70.00	(56.99)	27.01	25.13	2.75	0.273
Bispyribac sodium @ 25 g ha^{-1}	66.67	(55.08)	26.80	27.17	2.34	0.244	70.00	(56.99)	26.67	25.00	1.93	0.246
Hand weeding twice at 20 and 40 DAS	66.67	(55.08)	28.37	24.93	2.09	0.263	63.33	(52.78)	25.53	25.30	2.42	0.293
Weedy check	60.00	(50.85)	28.07	26.00	2.06	0.267	70.00	(56.99)	26.03	24.17	2.14	0.263
SEm (±)		4.905	1.235	2.430	0.168	0.013		3.978	0.588	0.496	0.186	0.027
CD (0.05)		NS	NS	NS	NS	NS		NS	NS	NS	NS	NS

NS - Non significant, values in parentheses are transformed values - arcsine transformation

Table 52. Residual effect of penoxsulam + cyhalofop butyl on the growth parameters of maize (first and second crop seasons)

Treatments	First crop					Second crop				
	Growth parameters of maize					Growth parameters of maize				
	Germination (%)	Shoot length (cm)	Root length (cm)	Fresh weight (g)	Dry weight (g)	Germination (%)	Shoot length (cm)	Root Length (cm)	Fresh weight (g)	Dry weight (g)
Penoxsulam + cyhalofop butyl @ 120 g ha^{-1}	73.33 (59.71)	28.00	24.20	2.14	0.244	66.67 (55.08)	27.03	24.73	2.36	0.284
Penoxsulam + cyhalofop butyl @ 125 g ha^{-1}	70.00 (57.00)	25.07	25.00	2.17	0.270	80.00 (63.93)	26.77	25.00	2.11	0.270
Penoxsulam + cyhalofop butyl @ 130 g ha^{-1}	80.00 (63.44)	30.37	31.77	1.98	0.264	66.67 (55.78)	26.90	23.93	1.94	0.282
Penoxsulam + cyhalofop butyl @ 135 g ha^{-1}	73.33 (59.71)	27.50	29.23	2.10	0.306	70.00 (57.29)	27.07	24.93	2.37	0.281
Penoxsulam @ 22.5 g ha^{-1}	73.33 (59.21)	29.17	26.33	2.27	0.266	66.67 (54.78)	26.13	25.47	2.67	0.246
Hand weeding twice at 20 and 40 DAS	66.67 (55.08)	28.37	24.93	2.09	0.263	63.33 (52.78)	25.53	25.30	2.42	0.293
Weedy c heck	60.00 (50.85)	28.07	26.00	2.06	0.257	70.00 (56.99)	26.03	24.17	2.14	0.263
SEm (±)	4.600	2.149	2.430	0.086	0.017	4.951	0.426	0.462	0.243	0.027
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS - Non significant, values in parentheses are transformed values - arcsine transformation

rice of both the crop, from the treatment plots, penoxsulam + cyhalofopbutyl @ 120, 125, 130 and 135 g ha^{-1} and control treatments *viz.*, penoxsulam @ 22.5 g ha^{-1}, hand weeding twice and weedy check were statistically analyzed. It was observed that there was no significant difference in the parameters studied, among the tested doses of penoxsulam + cyhalofop butyl and the control treatments. Hence it can be inferred that the herbicide mixture, penoxsulam + cyhalofop butyl at the tested concentrations would not leave any phytotoxic residue in the soil which can cause growth inhibition in maize plant.

4.3 PART III - *IN VITRO* SENSITIVITY TO SOIL BORNE PATHOGEN

4.3.1 *In Vitro* Sensitivity of Bispyribac Sodium + Metamifop to Soil Borne Pathogen *Rhizoctonia solani* (Table 53)

In vitro sensitivity of bispyribac sodium + metamifop to soil borne pathogen, *Rhizoctonia solani* was studied. The observations were recorded on sixth day of incubation, when full radial growth of mycelia was observed in the control plate. The data were statistically analyzed and presented in Table 53.

Perusal of data revealed that, with an increase in the concentration of the herbicide, a significant reduction in the mycelial growth of *Rhizoctonia solani* was observed. All the tested concentrations of herbicide mixture, bispyribac sodium + metamifop significantly reduced the mycelial growth of the pathogen. The lowest concentration of 100 µL L^{-1} recorded the maximum colony diameter (5.27 cm) with a growth inhibition of 41.48 per cent, which was followed by 120 µL L^{-1} concentrations and the same was statistically on par with 140 µL L^{-1} in reducing the colony diameter. The percentage inhibitions in mycelial growth in these treatments were 56.30 and 57.41, respectively. Concentration of herbicide mixture of 160 µL L^{-1} recorded a colony diameter (2.77 cm) which was followed by other concentrations of 180, 200 and 220 µL L^{-1}. All these treatments were statistically different from each other. These treatments recorded the colony diameter of 2.77, 2.10, 1.57 and 0.47 cm respectively with a growth inhibition of 69.26, 76.67, 82.59 and 94.81 per cent, respectively. Critical appraisal of data

revealed that, more than 50 per cent inhibition in mycelial growth was observed at concentrations above 120 μL L^{-1}. The maximum growth inhibition (94.81 per cent) was observed in the highest tested concentration (220 μL L^{-1}) corresponding to the herbicide dose of 110 g ha^{-1}. These results pointed out that, the post emergence application of bispyribac sodium + metamifop not only control the weeds, but also inhibit the growth of soil borne pathogen, *Rhizoctonia solani* which cause the major disease, sheath blight in rice.

4.3.2 *In Vitro* Sensitivity of Penoxsulam + Cyhalofop Butyl to Soil Borne Pathogen *Rhizoctonia solani* (Table 53)

In vitro sensitivity of penoxsulam + cyhalofop to major soil borne pathogen *Rhizoctonia solani* was studied under laboratory condition. The observations were recorded on sixth day after incubation, when full radial growth of mycelia was observed in the control plate. The data were statistically analysed and presented in the Table 53.

In general, with an increase in the concentration of herbicide, a corresponding reduction in the mycelial growth of *Rhizoctonia solani* was observed. All the concentrations of penoxsulam + cyhalofop butyl significantly inhibited the radial growth of mycelia and the inhibition ranged from 12.61 to 90.74 per cent. Critical appraisal of the data revealed that more than 50 per cent inhibition in the mycelial growth of *Rhizoctonia* was observed in concentration of 250 μL L^{-1}. The maximum inhibition in the growth of *Rhizoctonia* (90.74 per cent) was observed in 290 μL L^{-1} with a colony diameter of 0.83 cm. The lowest inhibition (12.61 per cent) was observed in 220 μL L^{-1} with the highest radial mycelial growth (7.87 cm) excluding control. The tested field doses of herbicide mixture *i.e.,* 120, 125, 130 and 135 g ha^{-1} corresponding to 240, 250, 260 and 270 μL L^{-1} registered an inhibition in the mycelial growth of *Rhizoctonia solani* by 42.22, 52.59, 63.70 and 77.04 per cent, respectively. These results indicated that the application of penoxsulam + cyhalofop butyl as post emergence herbicide not only control the weeds but also inhibit the growth of *Rhizoctonia solani*.

Table 53. *In vitro* sensitivity of *Rhizoctonia solani* to herbicide mixtures, bispyribac sodium + metamfop and penoxsulam + cyhalofop as indicated by radial mycelial growth

Bispyribac sodium + metamifop					Penoxsulam + cyhalofop butyl				
Bispyribac sodium + metamifop dose tested (µL L^{-1})	Growth of *Rhizoctonia solani*				Penoxsulam + cyhalofop butyl dose tested (µL L^{-1})	Growth of *Rhizoctonia solani*			
	Colony diameter at 6 DAI (cm)		Percentage Inhibition			Colony diameter at 6 DAI (cm)		Percentage Inhibition	
0 (Control)	9.00	(3.08)	0		0 (Control)	9.00	(3.08)	0	
100	5.27	(2.40)	41.48	(40.09)	230	7.87	(2.89)	12.61	(20.07)
120	3.93	(2.10)	56.30	(48.62)	240	5.20	(2.39)	42.22	(40.52)
140	3.83	(2.08)	57.41	(49.27)	250	4.27	(2.18)	52.59	(46.49)
160	2.77	(1.81)	69.26	(56.33)	260	3.27	(1.94)	63.70	(52.95)
180	2.10	(1.61)	76.67	(61.13)	270	2.07	(1.60)	77.04	(61.37)
200	1.57	(1.43)	82.59	(65.35)	280	1.23	(1.31)	86.30	(68.28)
220	0.47	(0.98)	94.81	(76.85)	290	0.83	(1.15)	90.74	(72.311)
SEm (±)		0.022		0.619	SEm (±)		0.032		1.578
CD (0.05)		0.066		1.880	CD (0.05)		0.095		4.732

DAI - Days after incubation, values in parentheses are transformed values (colony diameter-square root transformation$\sqrt{(x+0.5)}$, per cent inhibition - arcsine transformation)

4.4 PART IV - IN VITRO SENSITIVITY TO BENEFICIAL ORGANISMS

4.4.1 *In Vitro* Sensitivity to Bio Control Agents (Table 54 to 56)

4.4.1.1 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Bio Control Agents

The results are presented in Tables 54 and 55.

4.4.1.1.1 Trichoderma viride (Table 54)

The sensitivity of *Trichoderma viride* to bispyribac sodium + metamifop at tested concentrations is presented in Table 54. Bispyribac sodium + metamifop significantly influenced the colony diameter and percentage growth inhibition. Significant variation in mycelial growth of *Trichoderma viride* was observed in the medium poisoned with tested concentrations of 100, 120, 140, 160, 180, 200 and 220 µL L^{-1} correspond to 50, 60, 70, 90, 100 and 110 g ha^{1}. In general, with increase in concentration of herbicide in the medium, a decrease in colony diameter and increase in percentage growth inhibitions were observed. The control treatment (0 µL L^{-1}) recorded 100 per cent colony growth (9 cm) at 6 days after incubation (DAI). This was followed by 100 µL L^{-1} (8.53 cm) which was on par with 120 µL L^{-1} (8.27 cm) with a growth inhibition of 5.19 and 8.15 per cent respectively. Concentrations of 140 and 160 µL L^{-1} recorded a colony diameter of 7.57 and 7.50, respectively with a growth inhibition of 15.93 and 16.67 per cent and these concentrations were on par with each other. This was followed by 180 µL L^{-1} (6.93 cm), 200 µL L^{-1} (6. 17 cm) and 220 µL L^{-1} (5.67) with a growth inhibition of 22.96, 31.48 and 37.04 per cent, respectively and these treatments were significantly different from each other. Even the highest concentration of bispyribac sodium + metamifop (220 µL L^{-1}) recorded only a growth inhibition of 37.04 per cent indicating the compatibility *Trichoderma viride* with bispyribac sodium + metamifop

Table 54. *In vitro* sensitivity of *Trichoderma viride* to herbicide mixtures, bispyribac sodium + metamfop and penoxsulam + cyhalofop as indicated by radial mycelial growth

Bispyribac sodium + metamifop				Penoxsulam + cyhalofop butyl				
Bispyribac sodium + metamifop dose tested (µL L^{-1})	Growth of *Trichoderma viride*			Penoxsulam + cyhalofop butyl dose tested (µL L^{-1})	Growth of *Trichoderma viride*			
	Colony diameter at 6 DAI (cm)	Percentage Inhibition			Colony diameter at 6 DAI (cm)		Percentage Inhibition	
0 (Control)	9.00	0		0 (Control)	9.00	(3.08)	0	
100	8.53	5.19	(13.15)	230	4.33	(2.20)	51.85	(46.06)
120	8.27	8.15	(16.44)	240	4.27	(2.18)	52.59	(46.49)
140	7.57	15.93	(23.52)	250	4.20	(2.17)	52.96	(46.70)
160	7.50	16.67	(24.10)	260	4.17	(2.16)	53.70	(47.12)
180	6.93	22.96	(28.63)	270	4.10	(2.14)	54.44	(47.55)
200	6.17	31.48	(34.11)	280	3.83	(2.08)	57.44	(49.27)
220	5.67	37.04	(37.49)	290	2.27	(1.66)	74.82	(59.88)
SEm (±)	0.093		0.841	SEm (±)		0.026		0.795
CD (0.05)	0.271		2.550	CD (0.05)		0.082		2.413

DAI- Days after incubation, values in parentheses are transformed values (colony diameter-square root transformation$\sqrt{(x+0.5)}$, per cent inhibition- arcsine transformation)

Table 55. *In vitro sensitivity* of bispyribac sodium + metamiop on the growth of *Pseudomomas fluorescens*, *Azospirillum lipoferum* and *Azotobacter chroococcum*

Bispyribac sodium + metamifop tested (µL L^{-1})	*Pseudomonas fluorescens*		*Azospirillum lipoferum*		*Azotobacter chroococcum*	
	Inhibition zone at 3 DAI (mm)	Growth	Inhibition zone at 3 DAI (mm)	Growth	Inhibition zone at 3 DAI (mm)	Growth
0 (Control)	Nil	+	Nil	+	Nil	+
100	Nil	+	Nil	+	Nil	+
120	Nil	+	Nil	+	Nil	+
140	Nil	+	Nil	+	Nil	+
160	Nil	+	Nil	+	Nil	+
180	Nil	+	Nil	+	Nil	+
200	Nil	+	Nil	+	Nil	+
220	Nil	+	Nil	+	Nil	+

+ : positive growth around the sterile disc, DAI- days after incubation

4.4.1.1.2 Pseudomonas fluorescens (Table 55)

Pseudomonas fluorescens was tested *in vitro* for sensitivity to different concentrations of bispyribac sodium + metamifop by disc diffusion method. Results revealed that bispyribac sodium + metamifop at different tested concentrations *viz*., 100, 120, 140, 160, 180, 200 and 220 µL L^{-1} correspond to 50, 60, 70, 80.90, 100 and 110 g ha^{-1}) did not exert any inhibition on the growth of *Pseudomonas fluorescens* as indicated by zero inhibition zone in the tested herbicide concentrations. The growth of *Pseudomonas fluorescens* under different tested concentrations was found to be positive (+), thus indicating the compatibility of bispyribac sodium + metamifop with *Pseudomonas fluorescens*, the widely used biocontrol agent in rice.

4.4.1.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Bio Control Agents

The results are presented in Tables 54 and 56.

4.4.1.2.1 Trichoderma viride (Table 54)

The results on sensitivity of *Trichoderma viride* to penoxsulam + cyhalofop butyl are presented in Table 54. The colony diameter and percentage growth inhibition were significantly influenced by different concentrations of penoxsulam + cyhalofop butyl. In general, *Trichoderma viride* showed variation in mycelial growth under medium poisoned with different concentrations of penoxsulam + cyhalofop butyl. Among the tested doses, the highest colony diameter was observed in the lower concentration of the herbicide (230 µL L^{-1}). The results also revealed that, with increase in concentration of penoxsulam + cyhalofop butyl, a decrease in colony diameter was observed. The lowest colony diameter was observed in the highest concentration of penoxsulam + cyhalofop butyl (290 µL L^{-1}) with maximum growth inhibition of 74.82 per cent. The tested field doses of 120, 125, 130 and 135 g ha^{-1} corresponding to 240, 250, 260 and 270 µL L^{-1} were statistically on par in colony formation. These treatments were statistically comparable and recorded a growth inhibition of 52.59, 52.96, 53.70

and 54.44 per cent respectively. These results indicate the possibility of using the herbicide, penoxsulam + cyhalofop in the field at tested doses, in conjunction with *Trichoderma viride* for weed management and management of phytopathogens.

4.4.1.2.2 Pseudomonas fluorescens (Table 56)

Pseudomonas fluorescens was tested *in vitro* for sensitivity to different concentrations of penoxsulam + cyhalofop butyl by disc diffusion method. Results revealed that *Pseudomonas fluorescens* was not sensitive to any of the tested doses of penoxsulam + cyhalofop butyl. Inhibition zone was not observed around the sterile filter paper disc impregnated with herbicide at tested concentrations of penoxsulam + cyhalofop butyl (230 to 290 µL L^{-1}). The growth of *Pseudomonas fluorescens* under the influence of penoxsulam + cyhalofop butyl (230 to 290 µL L^{-1}) was found to be positive, thus indicating no significant adverse impact of the herbicide, penoxsulam + cyhalofop butyl on the growth of *Pseudomonas fluorescens*.

4.4.2 *In Vitro* Sensitivity of Herbicide Mixtures to Bio Fertilizer Organisms

4.4.2.1 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Bio Fertilizer Organisms

4.4.2.1.1 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Azospirillum lipoferum (Table 55)

In vitro studies were carried out to assess the compatibility of *Azospirillum lipoferum* with different doses of bispyribac sodium + metamifop by disc diffusion method. The study indicated that bispyribac sodium + metamifop at tested concentrations from 100 to 220 µL L^{-1} were not detrimental to the growth of *Azospirillum lipoferum*. No inhibition zone was observed around the filter paper disc impregnated with different tested concentrations of bispyribac sodium + metamifop and the growth was found to be positive. *Azospirillum lipoferum* grow unimpeded regardless of the tested concentrations of bispyribac sodium +

metamifop, establishing the compatibility of this herbicide mixture with *Azospirillum lipoferum*, the commonly used N bio fertilizer in lowland condition.

4.4.2.1.2 In Vitro Sensitivity of Bispyribac Sodium + Metamifop to Azotobacter chroococcum (Table 55)

The compatibility of *Azotobacter chroococcum* with different doses of bispyribac sodium was tested *in vitro* by disc diffusion method. The results revealed that the tested doses of bispyribac sodium + metamifop (100 to 220 µL L^{-1}) had no inhibitory effect on the growth of *Azotobacter chroococcum* and growth was found to be positive. No inhibition zone was observed around the filter paper disc impregnated with different tested concentrations of the herbicide mixture. The uninhibited growth of *Azotobacter chroococcum* revealed its compatibility with the tested doses of herbicide mixture, bispyribac sodium + metamifop.

4.4.2.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Bio Fertilizer Organisms

4.4.2.2.1 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Azospirillum lipoferum (Table 56)

In vitro studies were carried out to assess the compatibility of penoxsulam + cyhalofop butyl at different doses on the growth of *Azospirillum lipoferum* by disc diffusion method. Results revealed that penoxsulam + cyhalofop butyl at different concentrations ranging from 230 to 290 µL L^{-1} were not detrimental to the growth of *Azospirillum*. No inhibition in growth was observed at all the tested concentrations. The uninhibited growth revealed the compatibility of penoxsulam + cyhalofop butyl with the associative nitrogen fixing bacteria *Azospirillum lipoferum*.

Table 56. *In vitro sensitivity* of penoxsulam + cyhalofop butyl on the growth of *Pseudomomas fluorescens*, *Azospirillum lipoferum* and *Azotobacter chroococcum*

Penoxsulam +cyhalofop butyl tested (µL L^{-1})	*Pseudomonas fluorescens*		*Azospirillum lipoferum*		*Azotobacter chroococcum*	
	Inhibition zone at 3 DAI (mm)	Growth	Inhibition zone at 3 DAI (mm)	Growth	Inhibition zone at 3 DAI (mm)	Growth
0 (Control)	Nil	+	Nil	+	Nil	+
230	Nil	+	Nil	+	Nil	+
240	Nil	+	Nil	+	Nil	+
250	Nil	+	Nil	+	Nil	+
260	Nil	+	Nil	+	Nil	+
270	Nil	+	Nil	+	Nil	+
280	Nil	+	Nil	+	Nil	+
290	Nil	+	Nil	+	Nil	+

+ : positive growth around the sterile disc, DAI- days after incubation

4.4.2.2.2 In Vitro Sensitivity of Penoxsulam + Cyhalofop Butyl to Azotobacter chroococcum (Table 56)

Effect of penoxsulam + cyahalofop butyl on the growth of free living nitrogen fixing bacteria, *Azotobacter chroococcum* was studied under *in vitro* condition by disc diffusion method. The results revealed that the tested doses of penoxsulam + cyhalofop butyl had no inhibitory effect on the growth of *Azotobacter chroococcum* establishing the fact that it was not sensitive to any of the tested doses of the herbicide mixture, penoxsulam + cyhalofop butyl. The growth was found to be positive. These compatibility studies indicate the possibility of combined application of tested doses of penoxsulam + cyhalofop butyl along with *Azotobacter chroococcum* in rice fields.

4.5 PART V - WEED SEED BANK ASSAY

Seed bank analysis play a major role in the study of weed population dynamics and planned weed control. Composite soil samples were taken from each treatment plot prior to sowing and after the harvest of both first and second crop, to assess the size and composition of weed seed bank. The count of sedges, grasses and BLW were taken at 14, 28, 42, 56 and 70 DAI (days after incubation) and the data were statistically analyzed and presented in Tables 57a to 64b.

4.5.1 Weed Seed Bank Assay before the First Crop (Tables 57a to 60a)

4.5.1.1 Sedges (Table 57a)

Perusal of data on the number of sedges emerged at different periods of incubation and total count during the whole period of 70 days revealed that there was no significant difference among the treatments. The maximum number of sedges was observed at 14 DA1 and the lowest count at 70 DAI.

4.5.1.2 Broad Leaf Weeds (BLW) (Table 58a)

Critical appraisal of data on BLW emerged at different incubation periods revealed that, similar to that of sedges there was no significant difference in the count of BLW among the treatments. Broad leaf weeds were more compared to grasses and sedges. A gradual increase in BLW was observed from 14 DAI to 28 DAI and after that a decline was observed. Maximum count was observed at 28 DAI and the lowest count at 70 DAI.

4.5.1.3 Grasses (Table 59a)

Critical appraisal of data on the number of grasses emerged at different incubation periods revealed that there was no significant difference among the treatments. Maximum count was observed at 14 DAI and a gradual decline was noticed thereafter.

4.5.1.4 Total Weed Count (Table 60a)

Data on the total weed count from the composite soil sample collected from each treatment plot revealed that there was no significant difference among the treatments at different incubation periods. A sharp increase was observed in the total weed count from 14 DAI to 28 DAI and after that a gradual decline was observed. The average number of weeds emerged for a period of 70 days incubation was 437.9 kg^{-1} soil.

Table 57a. Sedges emerged at different time intervals before the first crop as influenced by weed management treatments

Treatments	Sedges emerged (No. kg $^{-1}$soil)										Total sedges emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	46.7	(6.77)	17.0	(4.07)	16.0	(4.02)	15.7	(4.01)	11.7	(3.47)	107.0	(10.34)
T_2	76.0	(8.6)	31.3	(5.51)	25.7	(5.10)	27.3	(5.24)	17.0	(4.16)	177.3	(13.28)
T_3	52.7	(7.29)	36.3	(6.06)	26.7	(4.99)	16.3	(4.07)	13.0	(3.67)	145.0	(12.03)
T_4	60.3	(7.77)	39.3	(6.22)	21.3	(4.66)	22.3	(4.72)	16.7	(4.14)	160.0	(12.65)
T_5	35.3	(5.85)	24.7	(4.98)	13.3	(3.67)	12.7	(3.62)	7.0	(2.74)	93.0	(9.64)
T_6	63.7	(7.95)	41.3	(6.39)	23.7	(4.87)	28.3	(5.34)	23.7	(4.87)	180.7	(13.45)
T_7	51.7	(7.19)	40.7	(6.35)	20.0	(4.48)	34.0	(5.71)	13.7	(3.75)	160.0	(12.58)
T_8	61.7	(7.84)	45.3	(6.10)	24.7	(4.79)	24.0	(4.88)	20.0	(4.23)	175.7	(13.15)
T_9	52.3	(7.08)	35.7	(5.98)	21.3	(4.56)	23.7	(4.49)	13.7	(3.75)	146.7	(11.97)
T_{10}	54.3	(7.31)	37.0	(6.08)	19.0	(5.03)	22.7	(4.70)	18.7	(4.35)	151.7	(12.20)
T_{11}	67.0	(8.21)	39.0	(6.03)	19.7	(4.42)	5.04	(2.7)	16.7	(3.98)	169.3	(13.02)
T_{12}	50.3	(7.09)	42.0	(6.40)	23.0	(4.81)	25.3	(5.08)	19.0	(4.29)	159.7	(12.61)
SEm (±)		0.682		0.695		0.602		0.590		0.552		0.861
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 58a. Broad leaf weeds (BLW) emerged at different time intervals before the first crop as influenced by weed management treatments

Treatments	BLW emerged (No. kg $^{-1}$soil)										Total BLW emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	21.7	(4.55)	85.3	(8.98)	61.7	(7.60)	52.7	(7.03)	16.0	(4.18)	237.0	(15.04)
T_2	47.7	(6.85)	133.0	(11.28)	57.7	(7.52)	54.0	(7.27)	23.0	(4.80)	315.3	(17.59)
T_3	40.3	(6.38)	120.3	(10.74)	45.3	(6.75)	20.7	(4.55)	19.3	(4.44)	246.0	(15.66)
T_4	20.0	(4.17)	122.3	(10.96)	59.0	(7.68)	35.3	(5.95)	21.0	(4.60)	257.7	(16.05)
T_5	20.3	(4.29)	94.7	(9.71)	33.3	(5.74)	26.0	(5.14)	15.7	(4.00)	190.0	(13.74
T_6	28.3	(5.36)	141.0	(11.86)	69.0	(8.12)	32.3	(5.66)	30.3	(5.08)	301.0	(17.28)
T_7	17.0	(4.11)	101.7	(10.08)	66.3	(8.16)	80.0	(8.97)	43.7	(6.45)	310.0	(17.56)
T_8	26.3	(4.96)	103.7	(9.91)	44.3	(6.58)	33.0	(5.56)	22.3	(4.53)	229.7	(14.77)
T_9	32.0	(5.68)	97.7	(9.90)	44.0	(6.35)	42.7	(6.12)	20.0	(4.25)	236.3	(17.17)
T_{10}	36.3	(6.05)	93.7	(9.48)	80.7	(7.79)	43.0	(6.49)	21.7	(4.6)	255.3	(15.91)
T_{11}	41.0	(6.46)	102.0	(10.10)	43.7	(6.36)	67.3	(8.13)	40.3	6.32	294.7	(17.16)
T_{12}	21.0	(4.59)	130.0	(11.42)	77.0	(8.73)	63.3	(7.95)	28.7	(5.33)	320.0	(17.88)
SEm (±)		0.715		1.188		0.966		0.707		0.738		1.456
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 59a. Grasses emerged at different time intervals before the first crop as influenced by the weed management treatments

Treatments	Grasses emerged (No. kg $^{-1}$soil)										Total grasses emerged, (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	8.0	(2.83)	6.0	(2.41)	1.7	(1.39)	3.3	(1.90)	0.3	(0.88)	19.3	(4.32)
T_2	6.3	(2.61)	1.0	(1.17)	2.7	(1.66)	3.7	(1.97)	0.3	(0.88)	14.0	(3.78)
T_3	12.0	(3.53)	6.3	(2.49)	4.7	(2.16)	1.7	(1.44)	0.7	(1.17)	25.3	(5.05)
T_4	9.7	(3.13)	8.7	(2.91)	6.7	(2.65)	4.0	(2.11)	1.7	(1.39)	30.7	(5.54)
T_5	9.7	(3.07)	3.0	(1.62)	2.7	(1.72)	2.3	(1.64)	0.3	(0.88)	18.0	(4.14)
T_6	5.0	(2.34)	3.0	(1.58)	2.7	(1.74)	2.7	(1.74)	0.0	(0.71)	13.3	(3.70)
T_7	8.7	(2.99)	5.7	(2.45)	3.7	(1.96)	4.0	(2.09)	0.0	(0.71)	22.0	(4.65)
T_8	12.0	(3.51)	5.7	(2.45)	6.0	(2.55)	4.3	(1.97)	0.7	(1.05)	28.7	(5.36)
T_9	6.7	(2.68)	2.7	(1.64)	3.7	(2.02)	2.7	(1.74)	1.0	(1.10)	16.7	(4.14)
T_{10}	5.7	(2.47)	0.3	(0.88)	1.3	(1.34)	1.3	(1.31)	1.0	(1.10)	9.7	(3.16)
T_{11}	4.0	(2.11)	6.3	(2.54)	1.7	(1.35)	2.3	(1.53)	1.3	(1.34)	15.7	(4.02)
T_{12}	6.7	(2.65)	7.0	(2.74)	2.7	(1.74)	3.7	(1.99)	2.0	(1.48)	22.0	(4.63)
SEm (±)		0.315		0467		0.330		0.343		0.252		0.508
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values- $\sqrt{(x+0.5)}$, NS - non significant

Table 60a. Total weeds emerged at different time intervals before the first crop as influenced by the weed management treatments

Treatments	Total weeds emerged (No. kg $^{-1}$soil)										Total s weeds emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	76.3	(8.67)	108.3	(10.2)	79.3	(8.72)	71.7	(8.36)	28.0	(5.31)	363.7	(18.92)
T_2	130.0	(11.32)	165.3	(12.57)	86.0	(9.20)	85.0	(9.13)	40.3	(6.35)	506.7	(22.35)
T_3	105.0	(10.27)	163.0	(12.59)	76.7	(8.66)	38.7	(6.20)	33.0	(5.78)	416 .3	(20.40)
T_4	91.0	(9.41)	170.3	(12.97)	87.0	(9.34)	61.7	(7.82)	39.3	(6.29)	448.3	(21.18)
T_5	65.3	(7.83)	122.3	(10.91)	49.3	(6.98)	41.0	(6.44)	22.7	(4.81)	301.0	(17.31)
T_6	97.0	(9.84)	185.3	(13.57)	95.3	(9.65)	63.3	(7.98)	54.3	(7.28)	495.0	(22.22)
T_7	77.3	(8.79)	149.3	(12.23)	90.0	(9.51)	118.0	(10.86)	57.3	(7.46)	492.0	(22.17)
T_8	100.0	(9.92)	154.7	(12.26)	75.0	(8.52)	61.3	(7.64)	43.0	(6.25)	434.0	(20.57)
T_9	91.0	(9.44)	136.0	(11.68)	69.0	(8.07)	69.0	(7.97)	34.7	(5.63)	399.7	(19.74)
T_{10}	96.3	(9.79)	131.0	(11.35)	81.0	(8.99)	67.0	(8.08)	41.3	(6.42)	416.7	(20.35)
T_{11}	112.3	(10.62)	147.3	(11.90)	65.0	(8.05)	96.7	(9.67)	58.3	(7.55)	479.7	(21.91)
T_{12}	78.0	(8.82)	179.0	(13.37)	102.7	(10.08)	92.3	(9.62)	49.7	(7.01)	501.7	(22.40)
SEm (±)		0.861		1.156		0.955		0.962		0.826		1.354
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

4.5.2 Weed Seed Bank Assay after the First Crop (Tables 57b to 60b)

4.5.2.1 Sedges (Table 57b)

Significant reduction was observed in the number of sedges emerged in all herbicide treatmnts at all incubation periods. Weedy check recorded the highest count at all incubation periods.

Critical appraisal of data at 14 DAI revealed that among the treatments, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) recorded the lowest count of sedges. At 28 DAI, no significant difference was observed among the treatments. However at 42 DAI, significant difference was observed among the treatments and the lowest number of sedges was recorded in T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}). Observations at 56 DAI also revealed that, T_8 recorded the lowest number of sedges. However, at 70 DAI, the lowest number was recorded in T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), which was statistically on par with T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_8 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}).

Perusal of data on the total count of sedges emerged for the whole period of 70 days incubation revealed that, it was significantly influenced by the treatments. All the weed management treatments significantly reduced the seed bank of sedges in the soil compared to weedy check. The treatment T_8 recorded the lowest count of sedges (41.3 kg^{-1} soil) and it was statistically comparable with T_5, T_4, T_7 and T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}). Weedy check (T_{12}) recorded the highest count of sedges (104.3 kg^{-1} soil) and this treatment was significantly inferior to all other treatments.

4.5.2.2 Broad Leaf Weeds (BLW) (Table 58b)

Perusal of data at 14 DAI revealed that weed management treatments also had a significant effect on broad leaf weeds. The treatment T_7 (penoxsulam + cyhalofop buytl @ 130 g ha^{-1}) recorded the lowest count. However, at 28 DA1,

T_{11} (hand weeding twice) recorded the lowest count of BLW. T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}) recorded the lowest count at 42 DAI. At 56 DAI, T_3 (bispyribac sodium + metamifop @ 80 g ha^{-1}) recorded the lowest count and it was statistically on par with T_8. Observations at 70 DAI revealed that, T_8 recorded the lowest number of BLW among the other treatments.

Crtical appraisal of data on the total number of BLW emerged during the whole period of incubation (70 days) revealed that, T_8 recorded the lowest number which was on par with T_3 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}). The treatment T_{10} (penoxsulam @ 22.5 g ha^{-1}), T_{11} and T_{12} (weedy check) recorded significantly higher number and these treatments were inferior in reducing the seed bank of broad leaf weeds in soil.

4.5.2.3 Grasses (Table 59b)

The observation at 14 DAI revealed that the treatments had significant effect on grasses emerged from the soil. The lowest count was observed in the treatment T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}). However, at 28 and 42 DAI, number of grasses emerged was not significantly influenced by the weed management treatments. At 56 DAI and 70 DAI, T_6 recorded the lowest count of grasses among the treatments.

Perusal of data on the total number of grasses revealed that, the lowest count was recorded in T_6 and it was statistically comparable with T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}), T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}) and T_{11} (hand weeding twice). Weedy check recorded the highest count of grasses and it was statistically comparable with T_9 (bispyribac sodium @ 25 g ha^{-1}).

Table57b. Sedges emerged at different time intervals after the first crop as influenced by weed management treatments

Treatments	Sedges emerged (No. kg $^{-1}$soil)										Total sedges emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	5.0	(2.10)	14.7	(3.87)	22.7	(4.81)	14.7	(3.87)	11.3	(3.44)	68.3	(8.28)
T_2	2.3	(1.65)	24.3	(4.96)	24.0	(4.89)	13.7	(3.76)	9.3	(3.06)	73.7	(8.58)
T_3	5.0	(2.34)	17.7	(4.25)	16.7	(4.12)	16.3	(4.10)	8.0	(2.87)	63.7	(7.99)
T_4	2.7	(1.64)	20.0	(4.49)	14.3	(3.84)	8.0	(2.88)	6.3	(2.61)	51.3	(7.18)
T_5	2.3	(1.57)	18.0	(4.27)	12.3	(3.56)	8.0	(2.91)	4.7	(2.22)	45.3	(6.76)
T_6	6.7	(2.68)	16.0	(4.04)	17.7	(4.26)	9.0	(3.7)	8.0	(2.91)	57.3	(7.60)
T_7	4.3	(2.13)	13.0	(3.65)	18.7	(4.37)	11.0	(3.38)	5.7	(2.47)	52.7	(7.28)
T_8	4.3	(2.15)	16.3	(4.09)	8.0	(2.91)	7.0	(2.72)	5.7	(2.48)	41.3	(6.46)
T_9	5.0	(2.34)	16.0	(4.05)	19.7	(4.49)	14.7	(3.88)	9.7	(3.18)	65.0	(8.09)
T_{10}	3.3	(1.88)	8.7	(4.32)	16.3	(3.94)	12.3	(3.57)	12.3	(3.58)	63.0	(7.92)
T_{11}	6.7	(2.67)	20.0	(4.42)	22.0	(4.70)	17.0	(4.17)	10.0	(3.23)	75.7	(8.69)
T_{12}	15.7	(4.0)	22.7	(4.77)	25.3	(5.08)	23.7	(4.91)	17.0	(4.17)	104.3	(10.23)
SEm (±)		0.346		0.380		0.340		0.194		0.233		0.407
CD (0.05)		1.012		NS		0.993		0.569		0.680		1.188

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 58b. Broad leaf weeds (BLW) emerged at different time intervals after the first crop as influenced by weed management treatments

Treatments	BLW emerged (No. kg $^{-1}$soil)										Total BLW emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	3.7	(1.83)	41.0	(6.43)	50.0	(7.06)	57.7	(7.61)	63.0	(7.96)	215.3	(14.68)
T_2	3.0	(1.84)	31.0	(5.57)	58.7	(7.65)	60.7	(7.81)	41.7	(6.44)	195.0	(13.96)
T_3	5.0	(2.12)	36.0	(6.03)	43.7	(6.64)	32.7	(5.76)	34.0	(5.87)	151.3	(12.32)
T_4	2.0	(1.43)	32.7	(5.74)	39.0	(6.25)	49.3	(7.01)	37.7	(6.09)	159.7	(12.62)
T_5	2.7	(1.76)	46.0	(6.81)	45.6	(6.79)	67.0	(8.21)	53.7	(7.36)	215.0	(14.68)
T_6	1.7	(1.37)	33.0	(5.79)	57.0	(7.58)	62.0	(7.90)	47.0	(6.88)	200.7	(14.18)
T_7	1.0	(1.10)	32.7	(5.72)	62.0	(7.90)	63.0	(7.97)	40.3	(6.38)	199.0	(14.12)
T_8	5.0	(2.27)	34.0	(5.86)	28.3	(5.36)	36.7	(6.09)	31.3	(5.62)	135.3	(11.65)
T_9	1.3	(1.26)	37.0	(6.11)	51.7	(7.22)	71.0	(8.45)	53.7	(7.35)	214.7	(14.66)
T_{10}	3.7	(2.03)	36.0	(6.03)	58.3	(7.62)	63.3	(7.92)	57.3	(7.47)	218.7	(14.73)
T_{11}	3.0	(1.78)	26.7	(5.18)	70.0	(8.39)	88.7	(9.42)	73.7	(8.61)	262.0	(16.19)
T_{12}	2.0	(1.51)	44.7	(6.72)	82.7	(9.12)	92.0	(9.62)	92.7	(9.64)	314.0	(17.76)
SEm (±)		0.391		0.281		0.349		0.346		0.393		0.438
CD (0.05)		1.141		0.821		1.017		1.011		1.1470		1.279

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$

Table 59b. Grasses emerged at different time intervals after the first crop as influenced by the weed management treatments

Treatments	Grasses emerged (No. kg $^{-1}$soil)										Total grasses emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	2.0	(1.54)	2.0	(1.54)	3.0	(1.84)	5.7	(2.48)	2.7	(1.76)	15.3	(3.97)
T_2	2.7	(1.66)	1.7	(1.44)	1.3	(1.33)	1.7	(1.43)	2.3	(1.63)	9.7	(3.15)
T_3	5.0	(2.28)	1.0	(1.22)	3.7	(1.83)	4.7	(2.26)	3.7	(2.04)	18.0	(4.22)
T_4	4.7	(2.21)	1.7	(1.43)	2.0	(1.48)	2.3	(1.26)	2.7	(1.76)	13.3	(3.64)
T_5	4.0	(2.04)	1.0	(1.22)	1.0	(1.16)	3.0	(1.73)	3.0	(1.82)	12.0	(3.45)
T_6	1.0	(1.16)	0.0	(0.71)	1.3	(1.26)	0.7	(1.05)	1.3	(1.33)	4.3	(2.11)
T_7	3.3	(1.88)	1.0	(1.16)	1.7	(1.35)	2.0	(1.54)	1.3	(1.33)	9.3	(3.08)
T_8	3.3	(1.93)	2.0	(1.48)	1.0	(1.22)	1.3	(1.33)	2.0	(1.52)	9.7	(3.18)
T_9	6.0	(2.53)	3.0	(1.81)	3.3	(1.95)	3.3	(1.95)	4.7	(2.26)	20.3	(4.54)
T_{10}	3.7	(2.04)	0.7	(1.0)	1.7	(1.43)	2.7	(1.76)	3.3	(1.93)	12.0	(3.53)
T_{11}	2.7	(1.73)	1.7	(1.43)	1.3	(1.33)	1.7	(1.37)	2.3	(1.65)	9.7	(3.19)
T_{12}	12.7	(3.59)	2.3	(1.49)	2.7	(1.56)	7.7	(2.83)	7.7	(2.84)	33.0	(5.69)
SEm (±)		0.302		0.252		0.330		0.274		0.192		0.429
CD (0.05)		0.882		NS		NS		0.801		0.560		1.250

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 60b. Total weeds emerged at different time intervals after the first crop as influenced by the weed management treatments

Treatments	Total weeds emerged (No. kg $^{-1}$soil)										Total s weeds emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	10.7	(3.30)	57.7	(7.62)	75.7	(8.70)	78.0	(8.85)	77.0	(8.8)	299.0	(17.30)
T_2	8.0	(2.86)	57.0	(7.58)	84.0	(9.17)	76.0	(8.73)	53.3	(7.27)	278.3	(16.70)
T_3	15.0	(3.91)	54.7	(7.42)	64.0	(8.02)	53.7	(7.36)	45.7	(6.79)	233.0	(15.28)
T_4	9.3	(3.11)	54.3	(7.40)	55.3	(7.45)	59.7	(7.73)	45.7	(6.79)	224.3	(14.99)
T_5	9.0	(3.08)	65.0	(8.09)	59.0	(7.70)	78.0	(8.86)	61.3	(7.86)	272.3	(16.52)
T_6	9.3	(3.12)	49.0	(7.03)	76.0	(8.74)	71.7	(8.50)	56.3	(7.53)	262.3	(16.21)
T_7	8.7	(2.97)	46.7	(6.86)	82.3	(9.10)	76.0	(8.74)	47.3	(6.91)	261.0	(16.17)
T_8	12.7	(3.60)	52.3	(7.27)	37.3	(6.14)	45.0	(6.74)	39.0	(6.27)	186.3	(13.67)
T_9	12.3	(3.58)	56.0	(7.51)	74.7	(8.67)	89.0	(9.45)	68.0	(8.27)	300.0	(17.33)
T_{10}	10.7	(3.33)	55.3	(7.45)	76.3	(8.76)	78.3	(8.83)	73.0	(8.47)	293.7	(17.13)
T_{11}	12.3	(3.58)	48.3	(6.97)	93.3	(9.66)	107.3	(10.37)	86.0	(9.3)	347.3	(18.63)
T_{12}	30.3	(5.54)	69.7	(8.37)	110.7	(10.54)	123.3	(11.12)	117.3	(10.85)	451.0	(21.26)
SEm (±)		0.267		0.249		0.303		0.303		0.376		0.381
CD (0.05)		0.778		0.726		0.884		0.884		1.098		1.113

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$

4.5.2.4 Total Weed Count (Table 60b)

The data on total number of weeds emerged at 14 DAI revealed that, the treatment, T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}) recorded the lowest total count of weeds, however at 28 DAI, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}) recorded the lowest total count. At 42, 56 and 70 DAI, T_8 recorded the lowest value.

Critical appraisal of data on the total count weed seeds emerged during the whole period of incubation (70 days) revealed that non herbicide treatments *viz.*, weedy check and hand weeding twice (T_{11} and T_{12}) recorded the highest count of weeds and were significantly inferior in reducing the size of the weed seed bank. The lowest count was observed in T_8 and was significantly superior in reducing the weed seed bank.

4.5.3 Weed Seed Bank Assay before the Second Crop

4.5.3.1 Sedges (Table 61a)

Composite soil samples were taken from each treatment plot prior to sowing of second crop and sedges emerged at different time intervals were counted. The results revealed that there was no significant difference in the number of sedges emerged at different periods of incubation and also in the total number of sedges emerged for the whole incubation period of 70 days. At 28 DAI there was an increase, in the number of sedges emerged compared to 14 DAI. However, a decline in the number of sedges was observed thereafter.

4.5.3.2 Broad Leaf Weeds (BLW) (Table 62a)

Perusal of data on broad leaf weeds emerged at different incubation periods revealed that, similar to that of sedges; there was no significant difference in the emergence of BLW (broad leaved weeds) from each treatment plot prior to the second crop. A gradual increase in the count was observed from 14 DAI to 42 DAI after that a decline was observed. At 70 DAI, again an increase in the number of broad leaf weeds was noticed.

Table 61a. Sedges emerged at different time intervals before the second crop as influenced by the weed management treatments

Treatments	Sedges emerged (No. kg $^{-1}$soil)										Total sedges emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	14.3	(3.63)	8.0	(2.88)	17.0	(4.18)	21.3	(4.66)	12.7	(3.54)	73.3	(8.58)
T_2	13.7	(3.70)	25.6	(5.99)	27.7	(4.96)	21.7	(4.63)	18.7	(4.37)	117.3	(10.80)
T_3	16.7	(4.11)	23.0	(4.79)	19.0	(4.27)	15.3	(3.42)	8.0	(2.91)	82.0	(8.91)
T_4	11.3	(3.03)	29.0	(5.11)	10.3	(3.23)	9.0	(3.05)	11.7	(3.46)	71.3	(8.25)
T_5	4.7	(2.05)	6.3	(2.51)	16.3	(4.0)	12.7	(3.62)	23.7	(4.88)	63.7	(7.97)
T_6	14.7	(3.76)	19.7	(4.42)	29.0	(5.34)	24.0	(4.85)	14.0	(3.80)	101.3	(10.08)
T_7	17.3	(4.21)	22.0	(4.72)	23.0	(4.85)	15.7	(3.97)	14.7	(3.68)	92.7	(9.62)
T_8	20.0	(4.22)	31.0	(5.46)	6.0	(2.40)	17.0	(4.13)	12.7	(3.60)	86.7	(9.24)
T_9	9.3	(3.11)	15.7	(4.00)	23.0	(4.75)	9.3	(3.08)	12.0	(3.44)	69.3	(8.33)
T_{10}	16.7	(4.05)	20.0	(4.49)	29.7	(4.98)	11.3	(3.40)	8.7	(2.84)	86.3	(9.24)
T_{11}	9.7	(3.09)	20.3	(4.55)	27.3	(5.26)	15.7	(3.83)	8.0	(2.89)	81.0	(8.97)
T_{12}	19.7	(4.83)	24.7	(4.68)	14.3	(4.42)	16.3	(4.00)	16.0	(4.01)	91.0	(9.55)
SEm (±)		0.688		0.660		0.822		0.646		0.477		0.784
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 62a. Broad leaf weeds (BLW) emerged at different time intervals before the second crop as influenced by weed management treatments

Treatments	BLW emerged (No. kg $^{-1}$soil)										Total BLW emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	25.3	(5.00)	60.3	(7.65)	63.0	(7.86)	44.3	(6.16)	38.0	(5.93)	231.0	(14.81)
T_2	27.7	(4.66)	75.3	(8.57)	95.7	(9.70)	18.7	(4.31)	37.0	(6.08)	254.3	(15.92)
T_3	18.3	(4.33)	54.0	(7.37)	61.0	(7.82)	20.0	(4.47)	27.7	(5.26)	181.0	(13.46)
T_4	11.0	(3.34)	65.6	(7.54)	52.0	(5.78)	24.7	(5.00)	38.3	(6.03)	191.7	(13.36)
T_5	17.7	(4.23)	47.0	(6.89)	80.0	(9.88)	24.3	(4.87)	41.3	(6.46)	210.3	(14.41)
T_6	25.3	(4.81)	81.3	(9.00)	90.0	(9.37)	67.00	(8.21)	86.0	(9.21)	349.7	(18.63)
T_7	25.0	(4.96)	71.0	(8.35)	63.7	(8.33)	58.00	(7.33)	109.3	(10.21)	327.0	(18.02)
T_8	14.3	(3.79)	87.3	(8.99)	55.7	(7.17)	52.7	(7.06)	57.0	(7.14)	267.0	(15.89)
T_9	16.3	(3.83)	122.3	(10.78)	81.0	(8.84)	32.0	(5.47)	53.7	(7.27)	305.3	(17.49)
T_{10}	13.7	(3.75)	68.3	(8.29)	95.0	(9.53)	64.3	(7.99)	53.3	(7.30)	294.7	(17.16)
T_{11}	13.3	(3.64)	70.7	(8.42)	124.0	(11.11)	75.7	(8.52)	70.0	(8.06)	353.7	(18.68)
T_{12}	13.7	(3.76)	61.0	(7.67)	83.3	(9.11)	65.3	(7.92)	72.3	(8.50)	295.7	(17.15)
SEm (±)		0.559		1.172		1.096		1.075		1.084		1.576
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$, NS - non significant

Table 63a. Grasses emerged at different time intervals before the second crop as influenced by weed management treatments

Treatments	Grasses emerged (No. kg $^{-1}$soil)										Total grasses emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	6.3	(2.61)	4.3	(1.70)	4.7	(2.02)	5.0	(2.16)	2.0	(1.54)	22.3	(4.54)
T_2	3.7	(2.33)	1.7	(1.43)	15.3	(3.91)	5.0	(2.12)	2.0	(1.46)	27.7	(5.28)
T_3	5.7	(2.57)	5.0	(2.28)	6.3	(2.33)	3.3	(1.96)	2.3	(1.65)	22.7	(4.73)
T_4	8.3	(2.85)	6.7	(2.57)	7.0	(2.74)	4.7	(2.24)	1.7	(1.43)	28.3	(5.35)
T_5	4.0	(2.04)	4.7	(2.11)	4.3	(1.94)	1.3	(1.27)	1.0	(1.16)	15.3	(3.80)
T_6	1.7	(1.26)	1.7	(1.35)	2.3	(1.63)	1.0	(1.16)	2.0	(1.54)	8.7	(2.88)
T_7	3.0	(1.81)	3.3	(1.80)	3.3	(1.83)	1.7	(1.35)	1.3	(1.33)	12.7	(3.56)
T_8	7.3	(2.44)	3.3	(1.92)	6.0	(2.40)	0.7	(1.05)	2.0	(1.52)	19.3	(4.44)
T_9	7.7	(2.72)	6.3	(2.34)	8.7	(2.97)	3.7	(1.72)	3.0	(1.77)	29.3	(5.30)
T_{10}	1.0	(1.16)	3.0	(1.77)	1.3	(1.33)	2.3	(1.65)	2.3	(1.65)	10.0	(3.20)
T_{11}	2.3	(1.65)	6.0	(2.49)	2.0	(1.54)	1.7	(1.43)	2.3	(1.63)	14.3	(3.83)
T_{12}	2.7	(1.74)	1.3	(1.33)	4.7	(2.26)	7.7	(2.67)	3.3	(1.88)	19.7	(4.39)
SEm (±)		0.460		0.523		0.497		0.467		0.260		0.631
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 64a. Total weeds emerged at different time intervals before the second crop as influenced by the weed management treatments

Treatments	Total weeds emerged (No. kg $^{-1}$soil)										Total weeds emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	46.0	(6.72)	72.7	(8.52)	84.7	(9.18)	70.7	(8.24)	52.7	(7.06)	326.7	(17.98)
T_2	45.0	(6.72)	112.7	(10.56)	138.7	(11.65)	45.3	(6.68)	57.7	(7.59)	399.3	(19.96)
T_3	40.7	(6.41)	82.0	(9.08)	86.3	(9.24)	38.7	(5.97)	38.0	(6.17)	285.7	(16.86)
T_4	30.7	(5.56)	101.3	(10.04)	69.3	(7.97)	38.3	(6.22)	51.7	(7.07)	291.3	(16.68)
T_5	26.3	(5.18)	58.0	(7.64)	100.7	(10.05)	38.3	(6.17)	66.0	(8.14)	289.3	(16.94)
T_6	41.7	(6.25)	102.7	(10.11)	121.3	(10.96)	92.0	(9.59)	102.0	(10.06)	459.7	(21.40)
T_7	45.3	(6.72)	96.3	(9.80)	90.0	(9.50)	75.3	(8.41)	125.3	(10.92)	432.3	(20.73)
T_8	41.7	(6.47)	121.7	(10.80)	67.7	(7.92)	70.3	(8.20)	71.7	(8.11)	373.3	(18.94)
T_9	33.3	(5.80)	144.3	(11.77)	112.7	(10.52)	45.0	(6.66)	68.7	(8.30)	404.0	(20.10)
T_{10}	31.3	(5.58)	91.3	(9.56)	126.0	(11.16)	78.0	(8.79)	64.3	(8.01)	391.0	(19.78)
T_{11}	25.3	(5.08)	97.0	(9.86)	153.3	(12.37)	93.0	(9.43)	80.3	(8.68)	449.0	(21.06)
T_{12}	36.0	(6.04)	87.0	(9.29)	102.3	(10.09)	89.3	(9.41)	91.7	(9.58)	406.3	(20.11)
SEm (±)		0.541		0.895		1.034		1.045		1.075		1.532
CD (0.05)		NS		NS		NS		NS		NS		NS

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$, NS - non significant

4.5.3.3 Grasses (Table 63a)

Critical appraisal of data revealed that no significant difference was observed in the number of grasses emerged at different incubation periods from each plot prior to second crop. The highest number of grasses was noticed at 42 DAI and the lowest at 70 DAI.

4.5.3.4 Total Weed Count (Table 64a)

Data on the total count of weeds emerged from the soil collected from each treatment plot before the second crop also revealed that there was no significant difference among the treatments. The average number of weeds emerged for a period of 70 days incubation from a kilogram of soil was 375.6, with maximum number at 42 DAI and the minimum number at 14 DAI.

4.5.4 Weed Seed Bank Assay after the Second Crop (Tables 61b to 64b)

4.5.4.1 Sedges (Table 61b)

Critical appraisal of data revealed that the number of sedges at different incubation periods was significantly influenced by the weed management treatments. Significant reduction in the number of sedges was noticed due to herbicide application at all incubation periods.

Data on the number of sedges emerged at 14 DAI revealed that among the treatments T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}) recorded the lowest count. Observations at 28 DAI, revealed that sedges were absent in the treatments T_8, T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}), T_4 and T_3 (bispyribac sodium + metamifop @ 90 and 80 g ha^{-1}). At 42 DAI, sedges were absent in the treatments T_7, T_6, T_5 and T_2 (bispyribac sodium + metamifop @ 70 g ha^{-1}) and observation at 70 DAI revealed that, sedges were absent in all the treatments including weedy check.

Critical appraisal of data on the total number of sedges emerged during the whole period of incubation revealed a significant reduction in the emergence rate

of sedges in all the treatments including weedy check compared to data on the count of sedges, before the second crop. The treatment, T_8 recorded the lowest count of sedges. Weedy check recorded the highest number of sedges emerged from a kilogram of soil (82.3) and was significantly inferior among all the treatments in reducing the seed bank of sedges.

4.5.4.2 Broad Leaf Weeds (BLW) (Table 62b)

Similar to that of sedges, there was reduction in the count of BLW in all the treatments including weedy check compared to data on the number of BLW emerged before the second crop. The highest count of broad leaf weeds was observed in weedy check at all incubation intervals studied.

At 14 DAI, T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}), recorded the lowest count of BLW and at 28 DAI, the treatments T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}) and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}) recorded zero count. Similar to 28 DAI, T_6 recorded the lowest BLW count at 42 DAI. However, at 56 and 70 DAI, T_8 recorded the lowest count of BLW among the other treatments.

Perusal of data on the total count of BLW emerged during the whole period of incubation revealed that T_6 recorded the lowest number and it was statistically on par with T_8, T_4, T_3 (bispyribac sodium + metamifop @ 80 g ha^{-1}), T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}), T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) and T_{10} (penoxsulam @ 22.5 g ha^{-1}). The highest count was observed in weedy check and it was statistically on par with T_{11} (hand weeding twice).

Table 61b. Sedges emerged at different time intervals after the second crop as influenced by the weed management treatments

Treatments	Sedges emerged (No. kg $^{-1}$soil)										Total sedges emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	21.0	(4.5)	4.3	(2.20)	2.7	(1.65)	1.0	(1.16)	0.0		29.0	(5.29)
T_2	19.3	(4.39)	1.0	(1.10)	0.0	(0.71)	0.0	(0.71)	0.0		20.3	(4.49)
T_3	16.7	(3.98)	0.0	(0.71)	0.3	(0.88)	0.0	(0.71)	0.0		17.0	(4.02)
T_4	13.3	(3.69)	0.0	(0.71)	3.7	(1.87)	0.0	(0.71)	0.0		17.0	(4.12)
T_5	10.3	(3.28)	0.7	(0.99)	0.0	(0.71)	0.3	(0.88)	0.0		11.3	(3.42)
T_6	14.0	(3.80)	0.0	(0.71)	0.0	(0.71)	0.0	(0.71)	0.0		14.0	(3.80)
T_7	13.3	(3.72)	0.0	(0.71)	0.0	(0.71)	1.0	(1.16)	0.0		14.3	(3.84)
T_8	8.7	(2.92)	0.0	(0.71)	0.7	(1.18)	0.0	(0.71)	0.0		9.3	(3.09)
T_9	19.7	(4.45)	4.7	(2.26)	3.7	(2.00)	4.0	(2.12)	0.0		32.0	(5.68)
T_{10}	19.3	(4.20)	1.3	(1.27)	2.7	(1.73)	2.0	(1.32)	0.0		25.3	(4.84)
T_{11}	21.0	(4.51)	2.7	(1.45)	1.3	(1.33)	3.7	(1.97)	0.0		28.7	(5.31)
T_{12}	42.7	(6.57)	17.7	(4.26)	15.7	(3.98)	6.3	(2.61)	0.0		82.3	(9.09)
SEm (±)		0.552		0.282		0.298		0.240				0.586
CD (0.05)		1.612		0.825		0.868		0.701				1.710

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$

Table 62b. Broad leaf weeds (BLW) emerged at different time intervals after the second crop as influenced by weed management treatments

Treatments	BLW emerged (No. kg $^{-1}$soil)										Total BLW emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	2.7	(1.74)	18.7	(4.37)	17.7	(4.11)	4.7	(2.15)	4.3	(2.15)	48.0	(6.94)
T_2	3.7	(1.85)	10.3	(2.89)	19.7	(4.17)	7.3	(2.65)	1.7	(1.26)	42.7	(6.18)
T_3	0.7	(0.99)	10.7	(2.83)	4.7	(2.05)	5.7	(2.24)	0.7	(1.05)	22.3	(4.37)
T_4	1.0	(1.16)	0.0	(0.71)	7.3	(2.62)	2.3	(1.49)	0.7	(1.05)	11.3	(3.43)
T_5	2.3	(1.57)	14.0	(2.87)	4.7	(2.05)	4.7	(2.05)	1.7	(1.37)	27.3	(4.65)
T_6	1.0	(1.10)	0.0	(0.71)	2.7	(1.45)	2.0	(1.48)	1.0	(1.16)	6.67	(2.62)
T_7	1.3	(1.26)	8.0	(2.59)	8.0	(2.59)	2.7	(12.64)	1.0	(1.10)	21.0	(4.54)
T_8	0.0	(0.71)	4.7	(1.74)	6.0	(1.91)	1.0	(1.10)	0.7	(0.99)	12.3	(2.75)
T_9	2.3	(1.39)	11.7	(3.43)	13.0	(3.66)	5.3	(2.12)	3.7	(1.99)	36.0	(6.02)
T_{10}	1.3	(1.27)	12.0	(3.50)	4.0	(1.95)	5.3	(2.30)	3.0	(1.84)	25.7	(5.11)
T_{11}	0.3	(0.88)	45.0	(6.74)	21.7	(4.69)	9.0	(3.08)	6.0	(2.41)	82.0	(9.07)
T_{12}	12.7	(3.49)	58.0	(7.64)	34.7	(5.67)	18.7	(4.36)	12.0	(3.63)	136.0	(11.62)
SEm (±)		0.412		0.833		0.831		0.529		0.335		0.991
CD (0.05)		1.209		2.444		2.438		1.552		0.984		2.907

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x + 0.5)}$

Table 63b. Grasses emerged at different time intervals after the second crop as influenced by weed management treatments

Treatments	Grasses emerged (No. kg $^{-1}$soil)										Total s grasses emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	12.0	(3.19)	0.0	(0.71)	0.7	(0.99)	0.7	(0.99)	0.0		13.0	(3.54)
T_2	9.0	(3.07)	0.3	(0.88)	0.3	(0.88)	0.3	(0.88)	0.0		10.0	(3.22)
T_3	13.0	(3.66)	0.0	(0.71)	0.3	(0.88)	0.0	(0.71)	0.0		13.3	(3.70)
T_4	16.3	(3.70)	0.0	(0.71)	0.7	(0.98)	0.0	(0.71)	0.0		17.0	(4.13)
T_5	11.3	(3.01)	0.7	(0.99)	0.0	(0.71)	0.0	(0.71)	0.0		12.0	(3.10)
T_6	5.0	(2.22)	0.0	(0.71)	0.0	(0.71)	0.0	(0.71)	0.0		5.0	(2.23)
T_7	9.0	(3.02)	1.0	(1.16)	0.0	(0.71)	0.3	(0.88)	0.0		10.3	(3.2)
T_8	13.3	(3.69)	1.0	(1.10)	0.3	(0.88)	0.0	(0.71)	0.0		14.7	(3.85)
T_9	27.3	(5.26)	0.0	(0.71)	4.0	(1.93)	1.0	(1.16)	0.0		32.3	(5.72)
T_{10}	14.7	(3.88)	0.0 (0.71)	(0.71)	1.7	(1.44)	1.0	(1.16)	0.0		17.3	(4.21)
T_{11}	8.3	(2.92)	1.0	(1.16)	4.3	(2.20)	1.0	(1.16)	0.0		14.7	(3.88)
T_{12}	34.0	(5.86)	4.3	(1.97)	6.7	(2.67)	7.0	(2.74)	0.0		52.0	(7.25)
SEm (±)		0.590		0.265		0.240		0.163				0.554
CD (0.05)		1.723		NS		0.703		0.477				1.616

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$, NS - non significant

Table 64b. Total weeds emerged at different time intervals after the second crop as influenced by the weed management treatments

Treatments	Total weeds emerged (No. kg $^{-1}$soil)										Total weeds emerged (No.kg^{-1}soil in 70 days)	
	14 DAI		28 DAI		42 DAI		56 DAI		70 DAI			
T_1	35.7	(6.01)	23.0	(4.84)	21.0	(4.53)	6.3	(2.51)	4.3	(2.15)	91.3	(9.57)
T_2	32.0	(5.68)	11.7	(3.04)	20.0	(4.19)	7.7	(2.71)	1.7	(1.26)	73.0	(8.38)
T_3	30.3	(5.48)	10.7	(2.83)	5.3	(2.15)	5.7	(2.24)	0.7	(1.05)	52.7	(7.22)
T_4	30.7	(5.58)	0.0	(0.71)	11.7	(3.47)	2.3	(1.49)	0.7	(1.05)	45.3	(6.76)
T_5	24.0	(4.86)	15.3	(2.97)	4.7	(2.05)	5.0	(2.10)	1.7	(1.37)	50.7	(6.70)
T_6	20.0	(4.50)	0.0	(0.71)	2.7	(1.45)	2.0	(1.48)	1.0	(1.16)	25.7	(5.10)
T_7	23.7	(4.88)	9.0	(2.73)	8.0	(2.59)	4.0	(1.93)	1.0	(1.10)	45.7	(6.72)
T_8	22.0	(4.70)	5.7	(1.87)	7.0	(2.45)	1.0	(1.10)	0.7	(0.99)	36.3	(5.82)
T_9	49.3	(7.04)	16.3	(4.07)	20.7	(4.58)	10.3	(3.19)	3.7	(1.99)	100.3	(10.3)
T_{10}	35.3	(5.82)	13.3	(3.66)	8.3	(2.84)	8.3	(2.96)	3.0	(1.84)	68.3	(8.21)
T_{11}	29.7	(5.43)	48.7	(6.99)	27.3	(5.26)	13.7	(3.74)	6.0	(2.41)	125.3	(11.18)
T_{12}	89.3	(9.47)	80.0	(8.95)	57.0	(7.53)	32.0	(5.68)	12.0	(3.63)	270.3	(16.44)
SEm (±)		0.501		0.892		0.718		0.525		0.337		0.859
CD (0.05)		1.462		2.606		2.097		1.534		0.984		2.507

DAI - Days after incubation, values in parentheses are transformed values - $\sqrt{(x+0.5)}$

4.5.4.3 Grasses (Table 63b)

The numner of grasses emerged were counted at 14, 28, 42 and 56 and 70 DAI and the data were statistically analyzed.

At 14 DAI, T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}) recorded the lowest count of grasses and at 28 DAI no significant difference was observed among the treatments in the number of grasses emerged. However, at 42 DAI grasses were absent in the treatments T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}), T_6, and T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}). At 56 DAI, T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}), T_6, T_5, T_4 and T_3 (bispyribac sodium + metamifop @ 90 and 80 g ha^{-1}) recorded no grasses and at 70 DAI, grass was absent in all treatments.

Data on the total number of grasses emerged during the whole period of incubation (70 days) revealed that, T_6 recorded the lowest count, which was on par with T_5, T_7, T_2 and T_1 (bispyribac sodium + metamifop @ 70 and 60 g ha^{-1}), T_3 and T_8. Weedy check recorded the highest count and was significantly inferior to all the treatments in reducing the seed bank of grasses.

4.5.4.4 Total Weed Count (64b)

Total weed count was recorded at 14, 28, 42, 56 and 70 DAI. The maximum count of weeds was observed at 14 DAI and the minimum at 70 DAI.

Data on the total count of weeds at 14 DAI revealed that the lowest count of weeds was observed in the treatment T_6 (penoxsulam + cyhalofop butyl @ 125 g ha^{-1}) and the data at 28 DAI revealed that weeds were absent in the treatments T_6 and T_4 (bispyribac sodium + metamifop @ 90 g ha^{-1}). The observations at 48 DAI revealed that, the treatment T_6 recorded the lowest count of weeds. However, at 56 and 70 DAI, the treatment T_8 (penoxsulam + cyhalofop butyl @ 135 g ha^{-1}) recorded the lowest number.

Data on the total count of weeds emerged during the whole incubation period revealed that T_6 recorded the lowest count (25.7 kg^{-1} soil) which was statistically comparable with T_8, T_5 (penoxsulam + cyhalofop butyl @ 120 g ha^{-1}) and T_7 (penoxsulam + cyhalofop butyl @ 130 g ha^{-1}). Weedy check (T_{12}) recorded the highest total count of weeds, which was significantly inferior to other treatments in reducing the weed seed bank.

Discussion

5. DISCUSSION

Weeds are the prime biological constraint in direct seeded rice. Acute labour shortage and hike in wage rate force the farmers to rely more on herbicides for weed control. But the continuous use of same herbicide or herbicides with similar mode of action will lead to the development of herbicide resistance in weeds and shift in weed flora. Use of herbicide mixtures is one among the various solutions suggested by weed scientists to overcome the above problems. Hence, the present study "Herbicide mixtures for weed management in direct seeded puddled rice (*Oryza sativa* L.)" was carried out. The results of the field and laboratory experiments presented in chapter four are discussed below.

5.1 PART I - BIO-EFFICACY OF POST EMERGENCE HERBICIDE MIXTURES IN DIRECT SEEDED RICE

5.1.1 Herbicide Phytotoxicity on Rice

Bio-efficacy of two post emergent herbicide mixtures, bispyribac sodium + metamifop and penoxsulam + cyhalofopbutyl for weed control in wet seeded rice was studied during the first and second crop seasons of 2014-15. The herbicides were applied at 15 days after sowing (DAS). Herbicide toxicity on rice was assessed by visual scoring at 7 days after herbicide application. The data indicated that both the herbicide mixtures at the tested doses did not have any visual symptom of phytotoxicity in rice plant. This result is in conformity with the findings of Lap *et al.* (2013), who opined that post emergence application of penoxsulam + cyhalofop butyl at rates up to five times the labelled use rate (300 g ha^{-1}) did not produce any phytotoxic symptom in rice plant. Similarly bispyribac sodium + metamifop @ 140 g ha^{-1} was also reported to be highly selective in rice (Raj *et al.*, 2013a).

5.1.2 Effect of Weed Management Treatments on Growth Attributes

Weed management treatments did have a positive influence on the growth attributes *viz*., plant height, leaf area index (LAI), dry matter production (DMP) and tillers m^{-2} of wet direct seeded rice (Tables 3 and 4). In general, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} recorded higher values of growth attributes *viz*., plant height, leaf area index, tillers m^{-2} and DMP.

Compared to weedy check, plants in the herbicide treated plots recorded more height at 30 and 60 DAS and at harvest stage (Table 3). This better growth of rice in weed management treatments is due to the efficient management of weeds at the early growth stage of the crop. Weed free environment may have resulted in lesser crop weed competition, better root growth and nutrient uptake (Fig. 10a and 10b) and all these may have resulted in increased plant height.

Tillers m^{-2} is an important growth parameter which plays a vital role in weed suppression thus reducing the competition for space, moisture and sunlight finally contributing to higher yield. Perusal of data on tiller production and LAI revealed that, among the weed management treatments, in general, higher doses of penoxsulam + cyhalofop butyl (125, 130 and 135 g ha^{-1}) and the highest tested dose of bispyribac sodium + metamifop (90 g ha^{-1}) recorded comparatively more number of tillers and LAI during both the seasons. The timely and effective broad spectrum control of weeds by these treatments provided a favorable environment for the better availability of moisture, nutrients and sunlight. These factors might have increased the total chlorophyll content and photosynthetic rate, leading to higher supply of carbohydrates resulting in enhanced tiller production and better LAI. Thiyagarajan *et al*. (2002) reported that an increase in tiller production might have facilitated higher photosynthetic rate and an increased leaf area index. Less weed population also provides ample space for root growth; this may also have contributed to the enhanced tiller production in these treatments. Weedy check recorded the lowest number of tillers m^{-2} and LAI at all the stages of observation during both the seasons. The present finding is in agreement with the

findings of several earlier workers (Gopinath and Kundu, 2008; Reshma, 2014; Arya, 2015). Srinivasan and Palaniappan (1994) reported that severe weed infestation throughout the crop growth increased the tiller mortality and decreased the straw and grain production.

Among the growth attributes studied, DMP was also significantly influenced by the weed management treatments. DMP depends on the potential ability of the plant population to photosynthesis, which in turn depend on the leaf area, nutrient uptake and favorable environmental conditions (De Datta, 1981). At harvest stage of both the first and second crop season, the highest DMP was recorded by penoxsulam + cyhalofop butyl applied at two higher doses of 130 and 135 g ha^{-1}. Due to the better control of weeds in these treatments, the competition for resources *viz*., light, space and nutrient might have been reduced. Increased uptake of nutrients (Fig. 10a and 10b) helps in maintaining a balanced nutritional environment inside the plant resulting in higher leaf area and chlorophyll content. This might have accelerated the photosynthesis rate which in turn increased the supply of carbohydrates to the plant parts thus resulting in higher DMP. Reduction in weed growth with herbicide application allow the crop to attain its best potential resulting in increased DMP in direct seeded rice was also reported by Bhat *et al*. (2011) and Ganai *et al*. (2014).

5.1.3 Effect of Weed Management Treatments on Yield Attributes

Yield attributes were significantly influenced by the weed management treatments. Panicles m^{-2} is the main factor that determines the productivity of rice (Reddy, 1988). During both the seasons, penoxsulam + cyhalofop butyl applied at three higher doses of 125, 130 and 135 g ha^{-1} and penoxsulam applied alone @ 22.5 g ha^{-1} recorded higher number of panicles m^{-2} compared to other treatments. The percentage increase in panicle number m^{-2}, compared to weedy check in these treatments were 48.54, 58.83, 50.78 and 61.08 during first crop season and 55.45, 58.62, 60.73 and 56.51, respectively during second crop season. The production of more number of panicles m^{-2} in these treatments, might be due to the better

growth of plants resulting from the reduced crop weed competition at critical stages of crop growth (Fig. 5 and 6), better availability of nutrients (Fig. 9a and 9b) and increased availability of space and light and their utilization. All these might have resulted in enhanced crop growth as evidenced from the data on tiller m^{-2} (Fig. 3), which ultimately led to the production of more panicles m^{-2}. Weedy check recorded significantly lower number of panicles m^{-2} during both the seasons. This might be due to severe competition from weeds resulting in poor growth and development of crop, which tend to produce lesser number of tillers and panicles m^{-2}. The above results are in conformity with the findings of Mahajan *et al.* (2009), Maity and Mukherjee (2008) and Mallikarjun *et al.* (2014).

Number of filled grains $panicle^{-1}$ was also significantly influenced by the weed management treatments. During first crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} recorded significantly higher number of filled grains $panicle^{-1}$ and during second crop season, the same herbicide mixture at all the three higher doses behaved similarly in this regard. The higher number of filled grains $panicle^{-1}$ recorded in these treatments might be due to the better control of weeds resulting in reduced crop weed competition leading to better nutrient uptake which in turn resulted in proper grain filling.

Panicle weight was also significantly influenced by the weed management treatments. During first crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} recorded the maximum panicle weight (3.10 g) which was statistically on par with the highest dose (135 g ha^{-1}) and bispyribac sodium + metamifop @ 90 g ha^{-1}. During second crop season, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the maximum panicle weight and it was significantly superior to other treatments. This was due to higher number of filled grains $panicle^{-1}$ and lower sterility percentage registered in these treatments (Table 5). Prakash *et al.* (2013) reported that, combination herbicides recorded significantly higher number of panicles and panicle weight over weedy check.

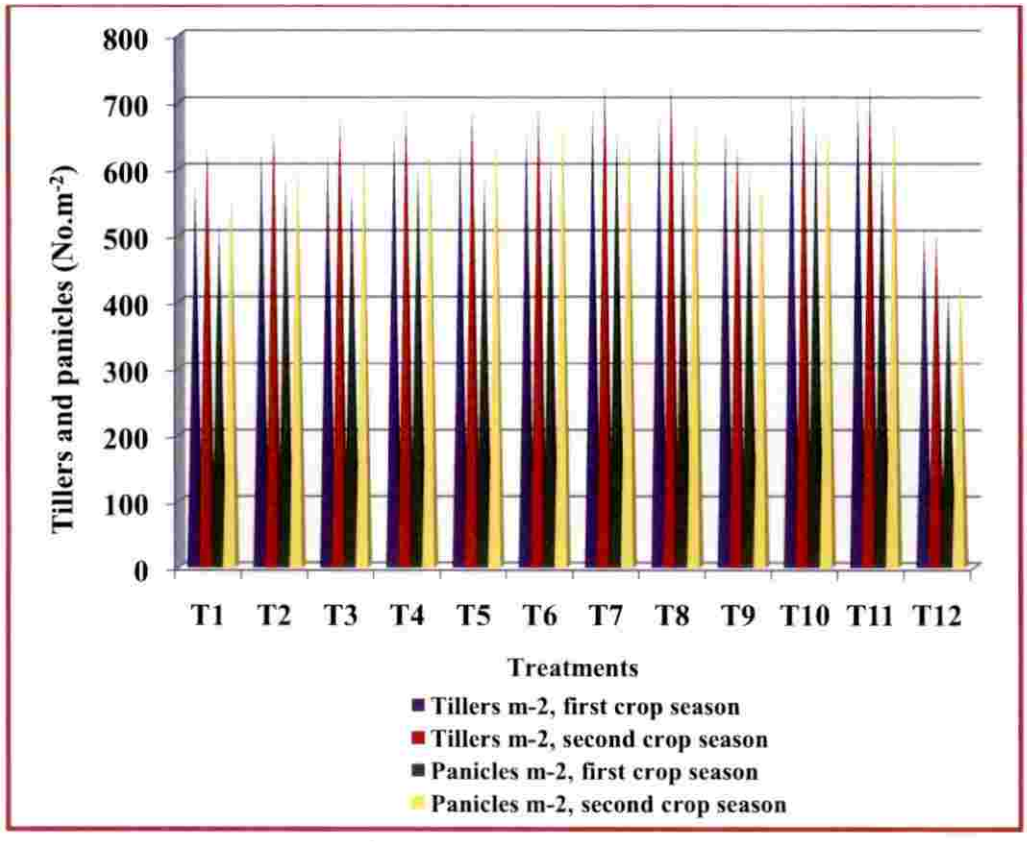

Fig.3. Tillers and panicles m^{-2} at harvest stage as influenced by weed management treatments (first and second crop seasons)

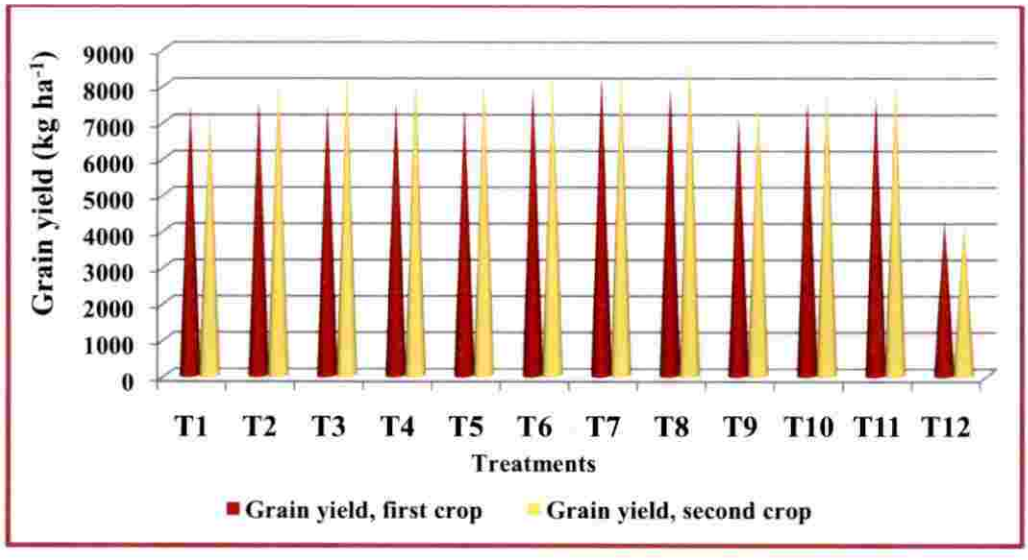

Fig.4. Grain yield as influenced by weed management treatments (first and second crop seasons)

5.1.4 Effect of Weed Management Treatments on Yield, Harvest index and Weed Index

Grain yield was significantly influenced by the weed management treatments during both the seasons. Grain production is the final product of growth and development, which is controlled by the dry matter production during the ripening stage. Herbicide mixtures tested in this study significantly enhanced the grain yield as compared to weedy check during both the seasons (Fig. 4). Phuong *et al.* (2005) reported that any reduction in weed pressure can be expected to promote yield, as it reduces the competition for resources. The weed management practices enhanced the grain yield from 4285 to 8295 kg ha^{-1} during first crop season and from 4240 to 8889 kg ha^{-1} during second crop season. Season long weed competition caused 40.33 to 48.34 per cent reduction in yield during first crop season and the magnitude of yield reduction in second crop season ranged from 42.59 to 52.30 per cent. Pooled data revealed that uncontrolled weeds throughout the crop growth caused 50.38 per cent reduction in yield in wet seeded rice.

Penoxsulam + cyhalofop buyl @125, 130 and 135 g ha^{-1} recorded higher grain yield during first crop season. However, during second crop season, the highest dose of the same herbicide mixture recorded significantly higher grain yield compared to other treatments. Pooled analysis also revealed the superiority of the three higher doses of penoxsulam + cyhalofop butyl (125, 130 and 135 g ha^{-1}). The growth and yield attributes also showed a similar trend. The increased grain yield recorded in these treatments might be due to the better expression of growth and yield attributes resulting from the better control of weeds (Fig. 5 and 6) and enhanced uptake of nutrients (Fig. 10a and 10b) at the critical growth stages of the crop. Higher availability and uptake of nutrients at critical stages of crop growth ultimately led to the production of more number of panicles. De Datta (1981) opined that the number of panicles is determined during the vegetative stage of the crop. In this particular investigation also, higher weed control efficiency as well as nutrient uptake by crop were observed during

vegetative stage due to the application of penoxsulam + cyhalofop butyl at three higher doses (120, 125 and 130 g ha^{-1}). Yadav and Singh (1997) pointed out that higher uptake of nutrients resulted in higher grain yield. Ramachandra *et al.* (2015) pointed out that application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} at 15 DAT recorded higher grain yield (6640 kg ha^{-1}) than hand weeding (6266 kg ha^{-1}) in transplanted rice. The superiority of tank mix applications of herbicides in increasing the grain yield over individual application of herbicides has also been demonstrated earlier by Kumavat *et al.* 1998. Weedy check recorded significantly lower grain yield during both the years as a consequence of greatest removal of nutrients by weeds at the critical stages of crop growth (Tables 38a and 38b), which resulted in poor expression of yield attributes. This result is in conformity with the findings of Mohan *et al.* (2010), Raj *et al.* (2013b), Mallikarjun *et al.* (2014) and Jacob *et al.* (2014). However, the straw yield was not significantly influenced by the weed management treatments during both the seasons of study.

Harvest index was significantly influenced by the weed management treatments. Herbicide treated plots and hand weeding recorded significantly higher harvest index compared to weedy check. The enhanced availability of nutrients in these treatments (Fig. 9a and 9b), due to better partitioning of photosynthates from source to sink ultimately leads to higher harvest index. Similar observations were also reported by Yadav (2006), Dayaram (2013), Sasna (2014) and Reshma (2014). The lowest harvest index observed in weedy check treatment could be due to the poor partitioning of photosynthates from source to sink as reported by Payman and Singh (2008).

Weed index is an ideal parameter which describes the yield loss due to weed infestation in comparison with weed free plots (Jayasuria *et al.*, 2011). Low weed index, reflects the high efficacy of applied herbicides in securing high yield against weed competition (Khaliq *et al.*, 2012a). During first crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} and during second crop season the same herbicide mixture @ 135 g ha^{-1} registered the highest grain yield. The pooled data revealed that, both the treatments were on par in terms of weed

index. The relatively higher grain yield in these treatments has resulted in low weed index and this could be attributed to the efficient control of weeds and consequent better resource utilization. Fischer *et al.* (2004) and Damalas (2005) pointed out that, herbicide mixtures with different mode of action, broaden the spectrum of weed control and increases the herbicide efficacy. Lap *et al.* (2013) reported that, premix formulations of penoxsulam + cyhalofop butyl applied @ 10 g ha^{-1} + 50 g ha^{-1} to 12.5 g ha^{-1} + 62.5 g ha^{-1}, at seven to 18 DAS or DAT were found to be more effective in reducing the weeds and increasing the productivity in rice.

Among the different doses of bispyribac sodium + metamifop tested, the higher dose of 90 g ha^{-1} recorded the lowest weed index of 6.34 per cent, which was statistically on par with hand weeding and significantly superior to bispyribac sodium applied alone @ 25 g ha^{-1} and penoxsulam applied alone @ 25 g ha^{-1}. Priya and Chinnusamy (2013) reported that post emergence application of bispyribac sodium + metamifop kept the weed density and weed dry matter below the economic threshold level and increased the grain yield.

Pooled data on weed index also revealed that, presence of weeds resulted in a yield reduction of 50.38 per cent in wet direct seeded rice. Similar reports of severe yield reduction in direct seeded rice due to season long crop weed competition has been reported by Gopinath and Kundu (2008), Raj *et al.* (2013a) and Raj *et al.* (2013b).

Cyperus iria

Cyperus difformis

Fimbristylis miliaceae

Schoenoplectus juncoides

Plate 4. Major sedges present in the experimental field

Monochoria vaginalis

Ludwigia perennis

Bergia capensis

Marsilea quadrifolia

Plate 5a. Major broad leaf weeds present in the experimental field

Commelina diffusa

Limnocharis flava

Sphenoclea zeylanica

Plate 5b. Major broad leaf weeds present in the experimental field

Isachne miliacea

Plate 6. Major grass species present in the experimental field

5.1.5 Effect of Weed Management Treatments on Weed Flora

As far as weed flora is concerned, there was considerable diversity in weed species infesting the experimental area. Juraimi *et al.* (2013) opined that weed-rice ecological relationship is very complex and dynamic. The weed spectrum and degree of weed infestation in rice fields are often determined by the establishment methods and rice ecosystems. Data on the quantitative assessment of weed vegetation in the experimental field *viz.*, absolute density, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio during both the seasons indicated that, the dominant weed flora in the experimental field was sedges followed by broad leaf weeds. The population of grass was comparatively low. The present result is in conformity with the findings of Azmi and Mashor (1995), Gressel (2002), Mortimer and Hill (1999), Yaduraju and Mishra, (2005) who have opined that direct seeding favours the population of sedges.

Schoenoplectus juncoides, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* were the major sedges observed in the experimental field (Plate 4). Broad leaf weeds in the experimental field comprised of *Ludwigia perennis*, *Limnocharis flava*, *Sphenoclea zeylanica*, *Marsilea quadrifolia*, *Bergia capensis*, *Commelina diffussa* and *Monochoria vaginalis* (Plate 5a and 5b). *Isachne miliacea* was the only one grass species present in the experimental area (Plate 6). The species diversity was found to be more in broad leaf weeds (7 species) as compared to sedges (4 species). Diversity in weed flora in the paddy fields of Nemom block has been documented earlier by Dayaram (2013), Rajogopal (2013) and Sasna (2014).

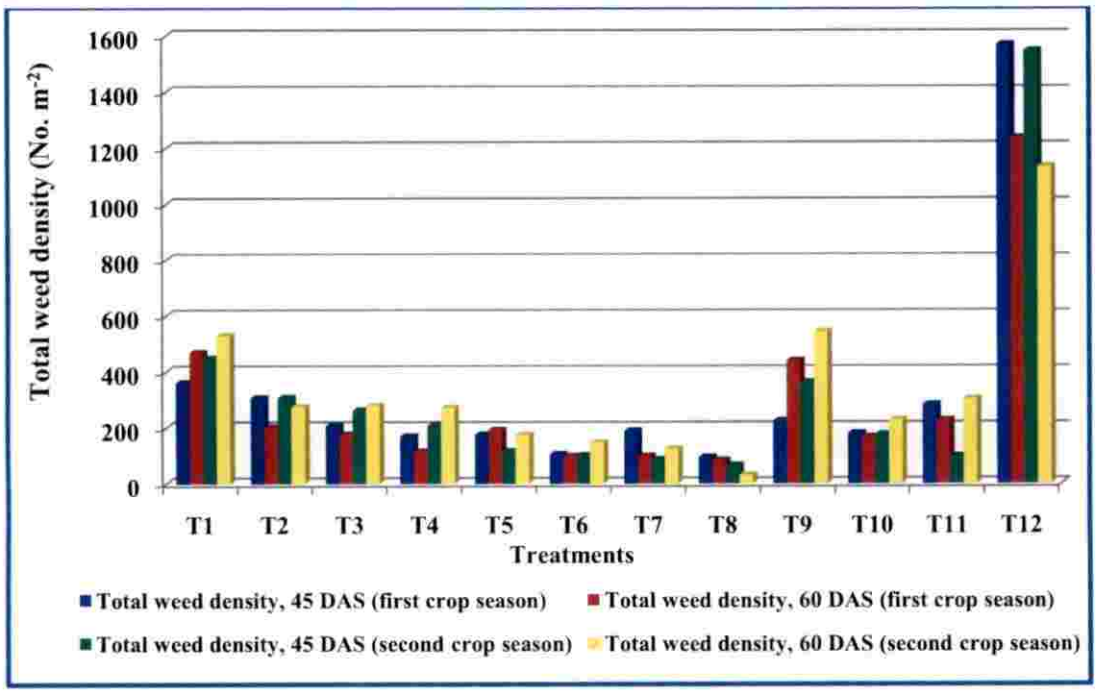

Fig.5. Total weed density as influenced by weed management treatments (first and second crop seasons)

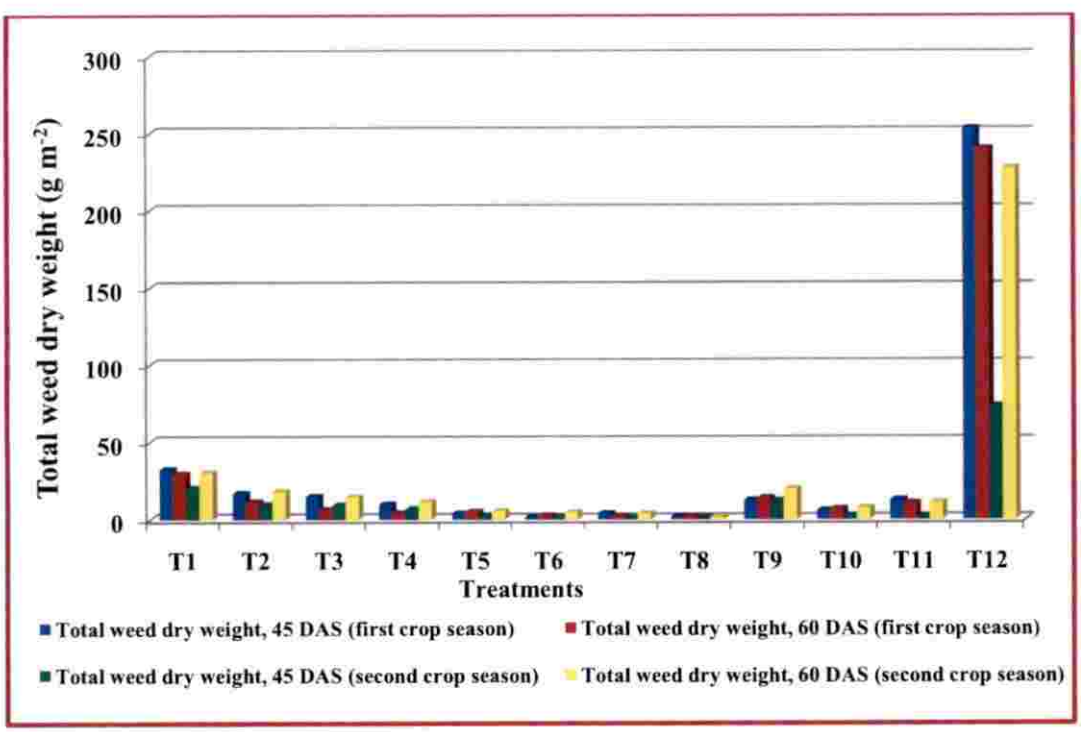

Fig.6. Total weed dry weight as influenced by weed management treatments (first and second crop seasons)

DAS – days after sowing

Plate 7. Effect of weed control treatments at 25 days after sowing (10 days after herbicide application)

Plate 8. Effect of weed control treatments at 60 days after sowing (DAS)

5.1.6 Effect of Weed Management Treatments on Weed Density and Dry Matter

The most important quantitative parameters used for assessing the effectiveness of weed management treatments are density and dry matter accumulation of weeds.

Penoxsulam + cyahlofop butyl @ 135, 130 and 125 g ha^{-1} recorded lower dry weight of sedges and BLW during both the seasons. Better weed control in early crop growth stage in these treatments enhanced the competitive behavior of rice crop resulting in lower weed population and dry weight. This result is in line with the findings of Yadav *et al.* (2015). Significantly lower dry weight of sedges and BLW in these treatments might be due to the better control of sedges and BLW. Among the different doses of bispyribac sodium + metamifop, 90 g ha^{-1} was found to be better in reducing the dry weight of sedges and BLW. Dixit and Varshney (2008) opined that post emergence application of herbicide mixtures was more effective than application of individual herbicides in reducing the dry weight of sedges and BLW.

During both the seasons, weed management using penoxsulam + cyhalofop butyl @ 125, 130, 135 and 120 g ha^{-1} and bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} were found to be better than bispyribac sodium and penoxsulam applied alone in reducing the dry weight of grasses at 60 DAS which is the most critical period of weed competition. This might be due to the better weed control efficiency of the herbicide mixtures compared to individual application of herbicide as reported by Paswan *et al.* (2012).

The total dry weight of weeds was also significantly influenced by the weed management treatments. Penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} were found to be more effective in reducing the total dry weight of weeds at all stages of observation (Fig. 6). This result is in agreement with the findings of Abraham and Menon (2015) who reported that post emergence

application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} resulted in very good control of all types of weeds in wet direct seeded rice. Among the different doses of bispyribac sodium + metamifop, 90 g ha^{-1} was found to be better in reducing the total dry weight of weeds. Raj *et al.* (2013a) reported that bispyribac sodium + metamifop @ 70 and 140 g ha^{-1} were more efficient than bispyribac sodium applied alone in reducing the dry weight of weeds. The superiority of ready mix herbicide mixtures in reducing the weed dry matter was also reported by Senthilkumar and Jayakumar (2012).

Data depicted in Tables 13 and 14 on the density of sedges and BLW, revealed that, among the two herbicide mixtures tested, penoxsulam + cyhalofop butyl was more effective in reducing the density of sedges and BLW. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest density of sedges and BLW at 30 and 60 DAS. Penoxsulam + cyhalofop butyl is a premix combination of penoxsulam, a broad spectrum herbicide of chemical group triazolopyrimidine sulfonamide inhibiting ALS enzyme in susceptible species and cyhalofop butyl, a grass effective herbicide belonging to the chemical group aryloxy phenoxypropionate which inhibits the activity of acetyl coenzyme-A carboxylase - the enzyme which has a major role in fatty acid metabolism. The combined application of herbicides with different mode of action appeared to be more effective than their single application (Rahman *et al.* 2012). Yadav *et al.* (2015) reported that post emergence application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was more effective in controlling sedges than bispyribac sodium @ 25 g ha^{-1} and mixture of bispyribac sodium + fenoxaprop-p-ethyl @ 25 g ha^{-1} + 60.4 g ha^{-1}. Ottis *et al.* (2003) observed a very good control of broad leaf weeds was obtained, when penoxsulam was applied along with cyhalofop butyl, propanil or quinclorac.

Weed management treatments significantly influenced the density of grasses at all stages of crop growth. The two tested herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl were found to be more or less similar in reducing the density of grasses. At 30 and 60 DAS

during first crop season, all the tested doses of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl were found to be significantly superior to bispyribac sodium @ 25 g ha^{-1} and penoxsulam @ 22.5 g ha^{-1}. However, during second crop season, the comparative performance at the lowest doses of the herbicide mixtures tested *viz.*, 60 g ha^{-1} of bispyribac sodium + metamifop and 120 g ha^{-1} of penoxsulam + cyhalofop butyl was poor. Results of the investigation revealed that combined application of bispyribac sodium + metamifop and penoxsulam + cyhalofop was more effective than individual application of bispyribac sodium and penoxsulam in controlling grasses. Rahman *et al* (2012) revealed that post emergence application of the herbicide mixture, cyhalofop butyl + bensulfuron, control grasses and BLW more effectively. They have also reported that, proprietary mixture or tank mixture of herbicides with different mode of action was more effective than their single application. The findings of the present study are in agreement with their result.

During both the seasons the weed management treatments significantly reduced the total density of weeds at all stages of crop growth, compared to weedy check. Weedy check registered a total weed count of 1075.3, 1570.0 and 1236.7 m^{-2} and 1071.0, 1547.7 and 1132.3 m^{-2}, respectively at 30 and 60 DAS and at harvest stage during first and second crop season, implying the severity of biological constraint offered by the weeds in DSR and the importance of early weed management. The intense and uncontrolled weed growth adversely affected the crop growth and yield in weedy check. This is in conformity with the observations of Gopinath and Kundu (2008), Ganai *et al.* (2014) and Arya (2015). In general, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was found to be more effective in reducing the total density of weeds at all stages of observation. Combined application of two or more herbicides with different mode of action might have helped to broaden the spectrum of weed control. Lap *et al* (2013) reported that post emergence application of penoxsulam + cyhalofop butyl @ 60 g ha^{-1} to 75 g ha^{-1} resulted in 90 per cent control of weeds in rice.

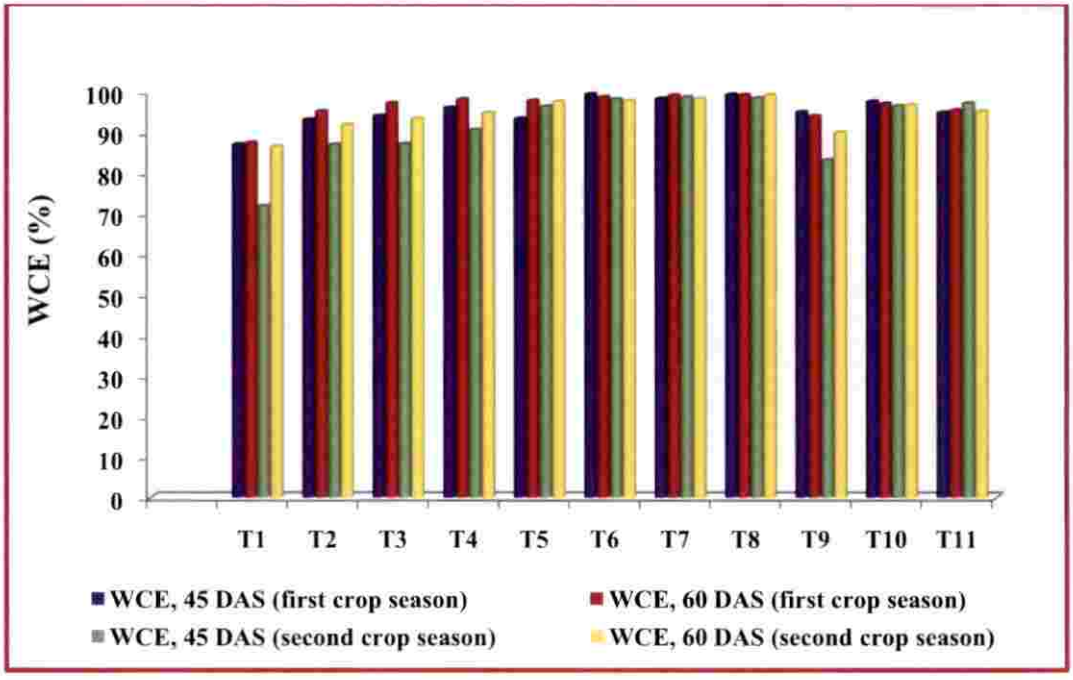

Fig.7. Weed control efficiency (WCE) as influenced by weed management treatments (first and second crop seasons)

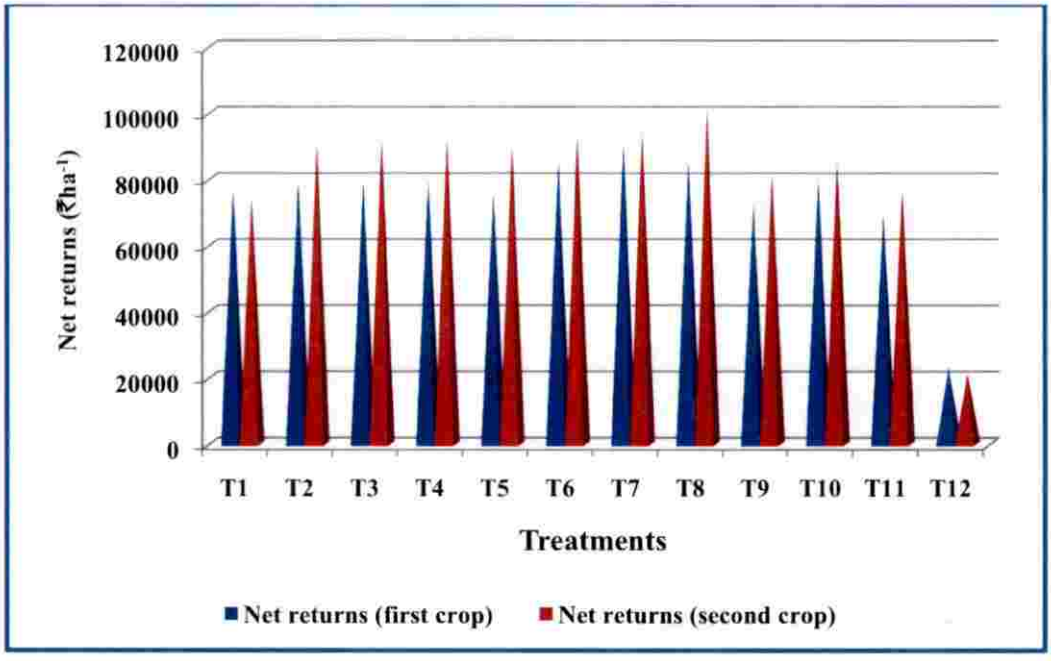

Fig.8. Net returns as influenced by weed management treatments (first and second crop seasons)

Avudaithai and Veerabadran (2000) also reported that combined application of different herbicides even at lower doses was more effective against a broad spectrum of weeds. Among the different doses of bispyribac sodium + metamifop, application @ 90 g ha^{-1} was found to be better than its lower doses and individual application of penoxsulam and bispyribac sodium. Khaliq *et al.* (2012b) observed that application of tank mixture of bispyribac sodium + ethoxysulfuron resulted in greater weed suppression.

Data at 60 DAS during both the seasons revealed that, all herbicide treatments except bispyribac sodium + metamifop @ 60 g ha^{-1} and bispyribac sodium applied alone @ 25 g ha^{-1} recorded lower density of weeds than hand weeding. Hand weeding failed to control the weeds effectively because of the regeneration or escape of weeds (Singh, 2008).

5.1.7 Effect of Weed Management Treatments on Weed Control Efficiency

Weed control efficiency measures the relative reduction in weed dry weight due to weed management treatments. Among the two premix herbicides tested, penoxulam + cyhalofop butyl was found to be more effective than bispyribac sodium + metamifop. At 45 and 60 DAS, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} were found more effective in reducing the dry weight of weeds as compared to other weed management treatments and recorded higher weed control efficiency (Fig. 7), implying its effectiveness in reducing the already emerged weeds and viable weed seeds present in the soil.

Among the different doses of bispyriac sodium + metamifop tested, the highest dose (90 g ha^{-1}) registered higher weed control efficiency due to the better efficacy in reducing the dry weight of weeds (Fig. 6) as compared to other tested doses. Use of single herbicides seldom furnishes satisfactory and season long weed control due to narrow spectrum of activity, while the herbicide mixture containing different herbicides with different target site action broaden the spectrum of weed control in single application (Fischer *et al.*, 2004; Damalas,

2005). Better weed control efficiency achieved by the combined application of herbicides was also reported by Saha (2009). Bispyribac sodium + metamifop @ 60 g ha^{-1} registered the highest weed dry weight among the weed management treatments at 45 and 60 DAS during both the seasons. The reason might be its lesser efficacy in reducing the density and dry weight of sedges and BLW (Tables 9, 10, 14 and 15), the predominant weed flora in the experimental area.

5.1.8 Effect of Weed Management Treatments on Net Returns and B: C Ratio

Economic evaluation of a weed control treatment is of great importance for its acceptance at farmers' level. Cost effectiveness along with high weed control efficiency should be the criteria for the selection of herbicides for weed management (Khaliq *et al.*, 2011).

During first crop season, penoxsulam + cyhalofop butyl at three higher doses (125, 130 and 135 g ha^{-1}) recorded the highest net returns (Fig. 8). However, during second crop season, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded a net return of 1,01,353 ₹ ha^{-1} which was significantly superior to all the other treatments (Fig. 8).

Pooled data revealed that, penoxsulam + cyhalofop butyl @ 130 and135 g ha^{-1} recorded higher net returns. The percentage increase in net returns in these treatments, compared to hand weeding was 26.93 and 27.91, respectively; however, compared to weedy check, the percentage increase was 321.24 and 324.51, respectively. The results also revealed that the higher doses of the herbicide mixture, penoxsulam + cyhalofop butyl (135, 130 and 125 g ha^{-1}) recorded significantly higher net returns than penoxsulam applied alone @ 22.5 g ha^{1} and bispyribac sodium applied alone @ 25 g ha^{-1}. Penoxsulam + cyhalofop butyl @ 120 g ha^{-1} and bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1} recorded net returns, which were significantly superior than bispyribac sodium applied alone, but statistically on par with penoxsulam applied alone.

B: C ratio also followed the same trend. Mann *et al.* (2007) reported that use of two or more herbicides in combination broadens the spectrum of weed control and reduces the production cost. Low cost involved in weed management coupled with high economic yield realized in these treatments resulted in higher net returns and B: C ratio. Ramachandiran *et al.* (2012) reported that post emergence application of fenoxyprop ethyl + ethoxy sulfuron registered higher net returns and B: C ratio in direct seeded aerobic rice.

As compared to herbicidal treatments, hand weeding recorded the lowest net returns and B: C ratio; due to high cost incurred for manual weeding. Begum *et al.* (2011) reported that 190 man day's ha^{-1} were needed for the manual removal of weeds in one hectare. Yaduraju and Mishra (2008) reported that manual and mechanical methods are less effective than chemical methods and did not find much acceptance among the farmers because of the high cost, scarcity of labour during the critical period of crop weed competition and unfavourable weather at the time of weeding. Economic benefit of herbicide application over manual weeding has also been reported by several researchers (Seema, 2004; Yadav, 2006; Kiran *et al.*, 2010). Prasad *et al.* (1992) opined that, compared to manual weeding, herbicides can save 75 per cent energy input and improve the energy use efficiency in rice cultivation. Apart from the yield advantage, economic advantage of using pre-mix herbicide mixtures for weed control is of profound significance in Kerala, where labour is scarce and costly.

5.1.9 Effect of Weed Management Treatments on Nutrient Uptake by Weeds

Uptake of nutrients by weeds was significantly influenced by the weed management treatments. All the herbicide treatments and hand weeding reduced the nitrogen, phosphorus and potash uptake by weeds significantly, compared to weedy check during both the seasons. Weeds removed substantial quantity of nutrients, as they grow faster than crop and absorb applied nutrients more rapidly than rice crop (Rao, 2011). The loss of nutrients due to weeds varied with intensity of weeds and its dry matter accumulation and percentage nutrient

content. It has been observed that, among the three major plant nutrients, weeds removed more quantity of N than P and K (Tables 38a and 38b). The result is in agreement with the findings of Yadav (2006), Dayaram (2013) and Sasna (2014).

Among the weed management treatments, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} recorded lower N, P and K uptake by the weeds at 30 and 60 DAS. Among the different doses of bispyribac sodium + metamifop, the higher dose of 90 g ha^{-1} recorded the lower values of N, P and K uptake by weeds. This was owing to the fact that, these treatments recorded lower dry weight of weeds due to effective control of weeds during the critical growth periods (Fig. 5 and 6). This minimizes the crop weed competition and increases the uptake of nutrients. Nutrient uptake by weeds was directly related to weed dry matter and inversely related to the rice grain yield (Raju and Reddy, 1986). Reduction in nutrient uptake by weeds due to weed management treatments in direct seeded rice was also reported by Rana *et al.* (2002), Payman and Singh (2008) and Gowda *et al.* (2009).

Compared to weedy check, herbicide treatments reduced the nitrogen removal by weeds to the tune of 59.63 to 97.13 per cent and 60.24 to 98.15 per cent, respectively at 30 DAS and 89.04 to 99.22 per cent and 89.67 to 99.36 per cent, respectively at 60 DAS during first and second crop seasons. Phosphorus removal by weeds has been reduced to the tune of 62.79 to 97.67 per cent and 70.59 to 98.04 per cent, respectively at 30 DAS and by 89.00 to 99.49 per cent and 89.54 to 99.47 per cent, respectively at 60 DAS during first and second crop seasons. Similarly, K removal has been reduced to the tune of 84.06 to 97.83 per cent and 76.86 to 96.72 per cent, respectively at 30 DAS; at 60 DAS reduced to a tune of 84.51 to 99.01 per cent and 86.22 to 99.42 per cent, respectively during first and second crop seasons. These results highlighted the necessity of weed control up to 60 DAS to avoid the excessive loss of nutrients through weeds in DSR. The highest uptake of nutrients by weeds in weedy check was due to high population of weeds present in those treatments.

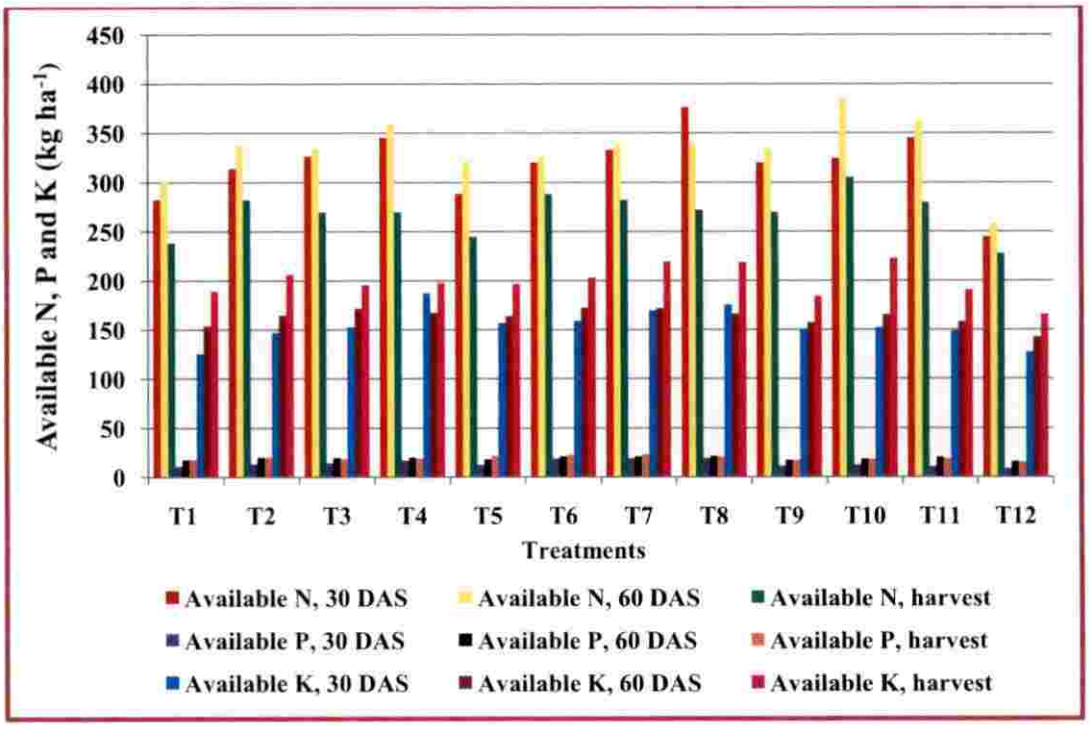

Fig.9a. Available N, P and K status of soil as influenced by weed management treatments (first crop season)

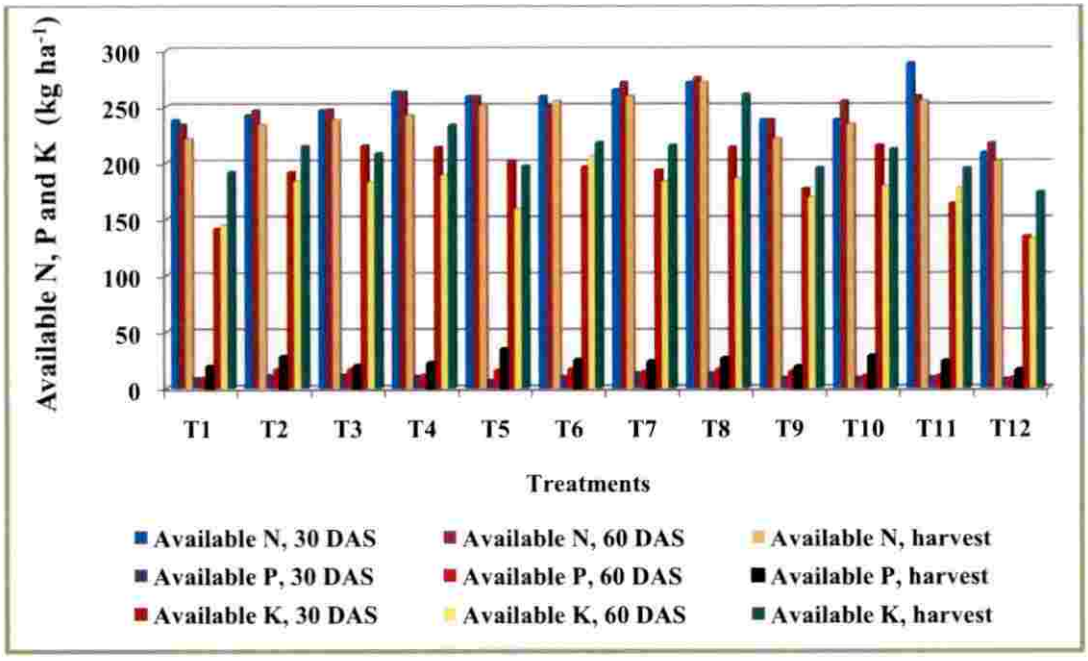

Fig.9b. Available N, P and K status of soil as influenced by weed management treatments (second crop season)

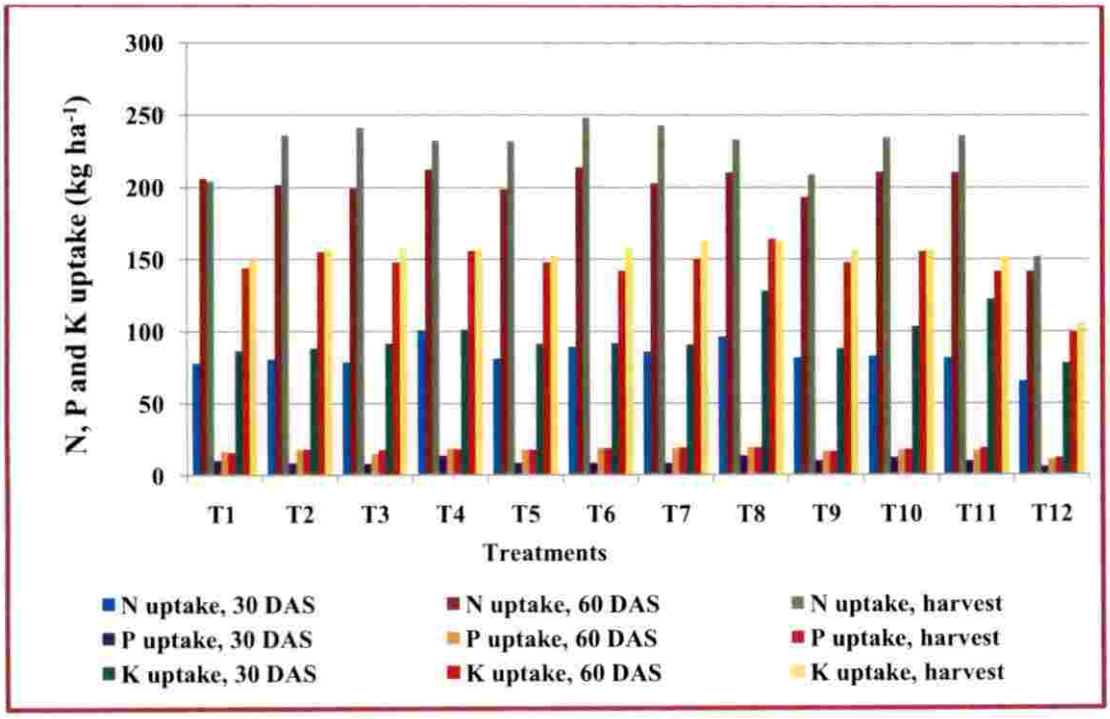

Fig.10a. N, P and K uptake by crop as influenced by weed management treatments (first crop season)

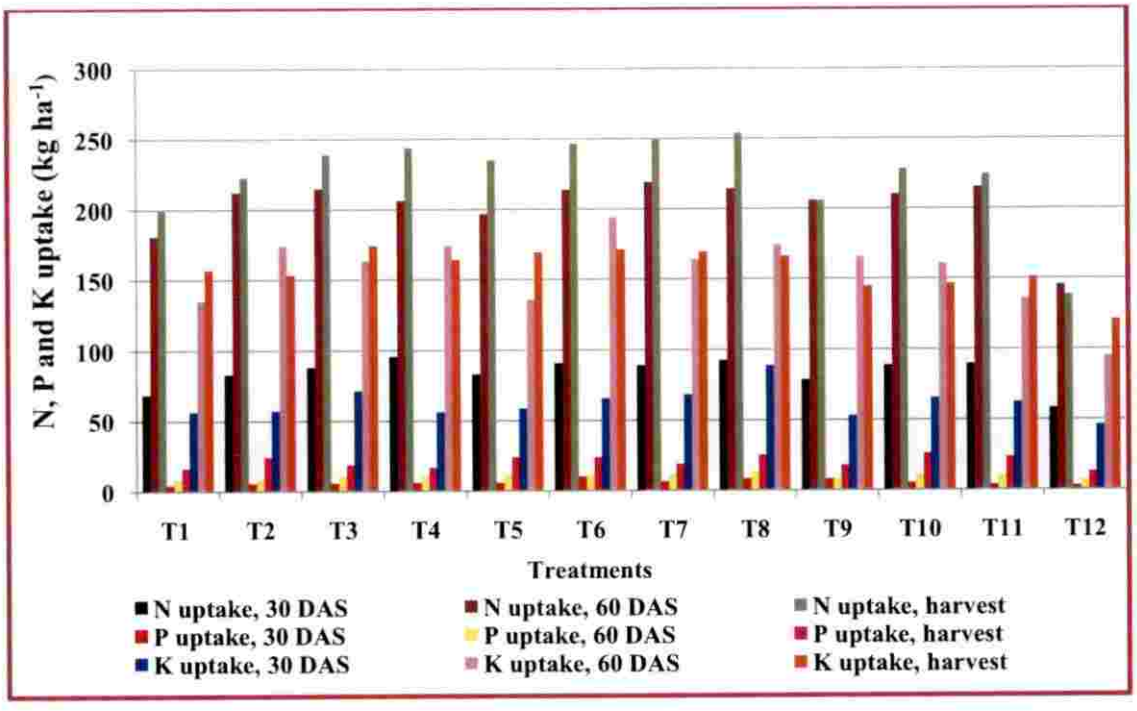

Fig.10b. N, P and K uptake by crop as influenced by weed management treatments (second crop season)

Similar increase in nutrient uptake by increase in weed population was also reported by Deepa and Jayakumar (2008), Babar and Velayudham (2012) and Nath *et al.* (2014). Sharma *et al.* (2007) and Gowda *et al.* (2009) also reported that initial weed free period up to 40 to 45 DAS or longer resulted in lower weed dry weight and nutrient uptake by weeds and also in higher grain yield in DSR.

5.1.10 Effect of Weed Management Treatments on Available Nutrient Status of Soil

Weed management treatments significantly influenced the available soil nutrient status at all stages of crop growth. During both the seasons, weedy check recorded the lowest available nutrient status at all stages. This is due to severe competition exerted by the weeds throughout the crop growth and increased nutrient removal by weeds (Tables 38a and 38b). Weeds usually have faster growth and competitive advantage of absorbing more nutrients from the soil than the crop. Compared to weedy check, all the herbicide treatments recorded higher available soil nutrient status. Application of herbicides effectively controlled the weeds and reduced nutrient removal by weeds (Kumar *et al.*, 2010) and thus increased the nutrient availability in soil. The enhanced availability of nutrients in soil also might have contributed to higher grain yield in these treatments. At 60 DAS, weeds removed 70.47 kg N, 7.82 kg P_2O_5 and 36.27 kg K_2O during first crop season and 60.77 kg of N, 7.55 kg P_2O_5 and 30.98 kg K_2O during second crop season, respectively from soil. The result of the present study is also in line with the findings of Raju and Gangwar (2004).

The present study also indicated the need for effective control of weeds at the critical stages of crop growth to prevent the excessive removal of nutrients, which would have otherwise been utilized by the crop plants for growth and development, contributing to final yield.

The availability of N, P and K did not follow the similar trend at different stages of crop growth. Critical appraisal of N, P and K availability at 30 and 60 DAS and at harvest stage revealed that, penoxsulam + cyhalofop butyl @ 135,130 and 120 g ha^{-1}, bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1}, penoxsulam applied alone @ 22.5 g ha^{-1} and hand weeding were more effective in maintaining a high level of availability of these nutrients in the soil. In all these treatments, availability of nutrients showed an increasing trend from 30 DAS to harvest (Fig. 9a and 9b); this clearly showed the efficacy of herbicides in controlling the major weeds and reducing the competition for the applied nutrients thereby making them available for crop at critical stages of growth. The better and consistent supply of nutrients in these treatments also might be due to enhanced microbial activity (Tables 39a and 39b) as evidenced by increased dehydrogenase enzymatic activity (Fig. 11a and 11b). Enhanced nutrient availability due to the control of weeds was also reported by Yadav (2006), Dayaram (2013) and Sasna (2014).

5.1.11 Effect of Weed Management Treatments on Organic Carbon Content in Soil

Weed management treatments significantly influenced the organic carbon content of the soil at 30 and 60 DAS and at harvest stage during both the seasons. It has been revealed that, as compared to weedy check, the hand weeding treatment and herbicide treatments recorded comparable or higher organic carbon content in the soil at 30 DAS (15 days after herbicide application), 60 DAS (45 days after herbicide application) and at harvest stage. Also an increase in organic carbon content was observed up to 60 DAS. These results indicated that, the applied herbicides and their doses did not have any adverse impact on the organic carbon content of the soil. This might be due to the increased microbial activity due to the release of root exudates into the rhizosphere. Root exudates are organic substrates comprising of simple and complex sugars, amino acids, vitamins, proteins and phenolics which stimulate the microbial growth (Dakora and Philips, 2002). The quantity of organic carbon released by plants to the

rhizosphere may amount to 40 per cent of the total dry matter produced by the plant (Lynch and Whips, 1990). Maximum organic carbon content in the soil was observed at 60 DAS, it might be due to the vigorous crop growth at the booting stage resulting in greater root exudation (Dotanita *et al.*, 2014). Sebiomo *et al* (2011) reported that organic matter content of the soil increased from second week of herbicide application. Similarly increase in organic carbon content in soil by the application of pendimethalin, oxyfluorfen and pretilachlor was also observed by Trimurtulu *et al.* (2015). Organic carbon showed a reduction in content at harvest stage might be due to the decline in the release of root exudates into the soil by plant roots and continuous decomposition of organic matter.

5.1.12 Effect of Weed Management Treatments on Nutrient Uptake by Rice

Nutrient uptake by crop is a function of nutrient content in dry matter and the dry matter production. Nutrient content is related to the photosynthetic activity of leaves, because the essential nutrients *viz.*, N, P and K are directly and indirectly involved in photosynthesis and respiration. A linear relationship exists between nutrient absorbed by the plant and the grain yield or economic produce (Ramamoorthy *et al.*, 1967).

Weed management treatments significantly influenced the N uptake by crop at 30 and 60 DAS and at harvest stage. The uptake of N by the crop steadily increased from active tillering stage to harvest stage (Fig. 10a and 10b). At 30 DAS during both the seasons, bispyribac sodium + metamifop @ 90 g ha^{-1} recorded the highest uptake of nitrogen. However, at 60 DAS and harvest stage of first crop season, penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the highest N uptake and second crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} recorded the highest uptake at 60 DAS and at harvest stage its higher dose of 135 g ha^{-1} recorded the highest uptake. This was due to high nitrogen content and DMP registered in these treatments. Increased availability of N (Fig. 9a and 9b) in these treatments resulted in better uptake of N. Since, nutrient uptake is partly

a function of dry matter production and concentration of nutrients in the plant, increased N content in the plant parts increased the N uptake. The lowest N uptake by weedy check at all stages of crop growth might be due to severe competition for growth factors. This result is in agreement with the findings of Nath *et al.* (2014).

Similarly, P uptake by the crop was also significantly influenced by the weed management treatments during both the seasons. Similar to N uptake, uptake of phosphorous showed an increasing trend from seedling to harvest stage (Fig.10a and 10b). Better control of weeds resulted by the application of herbicides and hand weeding in the weed management treatments, minimized the crop weed competition and enhanced the P availability and uptake. Similar observations were also made by Babar and Velayutham (2012) and Kumar *et al.* (2010). At 30 DAS, during first crop season, bispyribac sodium + metamifop @ 90 g ha^{-1} and during second crop season, penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the highest P uptake. However, at 60 DAS during both the seasons, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the highest P uptake and during the harvest stage, penoxsulam + cyhalofop butyl @130 g ha^{-1} and penoxsulam applied alone @ 22.5 g ha^{-1} recorded the highest P uptake during first and second crop seasons, respectively. The increased P availability (Fig. 9a and 9b) in these treatments at different stages of crop growth might have resulted in greater P content and crop uptake. Mali *et al.* (2015) reported that, the P uptake by crop largely depends on dry matter accumulation and concentration of P in the plant parts at cellular level and availability of P in the soil.

Similar to N and P uptake by crop, K uptake was also significantly influenced by the weed management treatments. Potassium uptake by the crop also showed an increasing trend from 30 DAS to harvest (Fig. 10a and 10b). All the weed management treatments registered higher uptake of K by the crop than weedy check. This was due to the enhanced availability of soil K and better expression of growth attributes by the crop (Tables 3 and 4), resulting from the better control of weeds. Similar findings have also been reported by several

researchers (Ramamoorthy *et al.*, 1998; Payman and Singh, 2008; Gowda *et al.*, 2009). At 30 DAS, during both the seasons, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the highest K uptake. However, at 60 DAS penoxsulam + cyhalofop butyl @ 135 and 125g ha^{-1} recorded the highest P uptake during first and second crop seasons, respectively. At harvest stage, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} and bispyribac sodium + metamifop @ 80 g ha^{-1} recorded the highest uptake during first and second crop seasons, respectively. The highest uptake of K in these treatments at different growth stages is a direct reflection of high K content as well as high dry matter accumulation in the crop.

5.1.13 Effect of Weed Management Treatments on Microbial Population

Soil microorganisms are the important link in soil-plant-herbicide-fauna-man relationship; their activity and diversity may serve as the bio indicators of soil health following herbicide application (Milosevic and Govedarica, 2002).

Results of the study showed an increase in bacterial population at 15 days after herbicide application (30 DAS), except in bispyribac sodium + metamifop @ 60 and 70 g ha^{-1} during second crop season. Though reduction in bacterial population was observed in the above treatments, it was comparable with weedy check. Barman and Varshney (2008) opined that, generally in field condition, a very short initial depressive effect is noticed by herbicide application which was recouped fast. The increase in bacterial population might be because of the increase in the population of relatively resistant strains or due to the increase in the availability of nutrients either by the decomposition of the weeds or by the decomposition and degradation of applied herbicides. Sebiomo *et al.* (2011) also reported an increase in total bacterial population from 2^{nd} week of herbicide application. After the 8^{th} day of herbicide application, there a rapid increase in total bacterial population was observed in plots treated with pendimethalin, oxyfluorfen, and pretlilachlor (Trimurtulu *et al.*, 2015).

Similar to observations at 30 DAS, at 60 DAS also an increase in population was observed in all the herbicide treatments except in penoxsulam +

cyhalofop butyl @ 135 g ha^{-1}, bispyribac sodium applied alone and penoxsulam applied alone during first crop season. But these treatments also recorded bacterial population comparable or significantly higher than that of weedy check (control). These results imply that, the tested herbicides and their doses did not cause any adverse impact on soil bacteria, the most predominant group of microflora in the soil. This is in conformity with the findings of Kalyanasundaram and Kavitha (2012) and Kumar *et al.* (2009) who observed that, the adverse effect of herbicides reduced gradually with passage of time and practically there was no impact on microbial population as a whole.

Fungal population was also significantly influenced by the herbicide treatments at 30 and 60 DAS during both the seasons. During first crop season at 30 DAS, an increase in population was observed in all the treatments including weedy check and hand weeding as compared to observations at 15 DAS (just before herbicide application). During second crop season, a decrease in population was observed in weedy check, hand weeding, bispribac sosium + metamifop @ 60 and 90 g ha^{-1}, penoxsulam + cyhalofop butyl @125 g ha^{-1} and penoxsulam applied alone @ 25 g ha^{-1}. Though a decline in fungal population was observed in these herbicide treatments, it was comparable with weedy check. The result is in line with the findings of Rajagopal (2013), who observed that at six days after the application of bensulfuron methyl + pretilachlor and azimsulfuron, the count of fungi showed substantial increase over weedy check and hand weeding treatment. Das *et al.* (2006) reported that fungi are known to be extremely adaptable in different environments due to their ability to break down many complex substances including herbicides. During first crop season, at 60 DAS, an increase in fungal population was observed in some treatments and a decrease in population in some other treatments. Those herbicide treatments which showed decline in population were also statistically comparable with hand weeding or weedy check. Variation observed in the fungal population among the treatments might be due to the fact that, the herbicidal effects on fungal growth are specific to herbicide type and dose, microbial species and environmental

condition (Bollen, 1961; Hattori, 1973). During second crop season, a decline in fungal population was observed in all treatments. The decline in fungal population might be due to the competition exerted by the tremendous increase in bacterial population (Table 39b). These results indicated that, the applied herbicides and their tested doses had no adverse impact on soil fungi, the predominant microbial flora in the soil.

Contrary to fungal and bacterial population, reduction in population of actinomycetes was observed at 30 DAS (15 DAHA) in both herbicide treated and non-treated plots. Reduction in the population of actinomycetes might be due to competitive influence of various microorganisms on the population of actinomycetes in the rhizosphere as well as the toxic effect of the herbicides (Pal *et al.*, 2013). Filimon *et al.* (2012) reported a decline in actinomycetes population after the application of sulfonyl urea herbicides. Observation at 60 DAS (45 DAHA) during first crop season indicated that, the population of actinomycetes was more as compared to 30 DAS. During second crop season, a reduction in population was observed in all the treatments. The reduction observed at 60 DAS during second crop season, might be due to the tremendous increase in bacterial population (Table 39b). At 30 and 60 DAS, during both the seasons, certain herbicide treatments showed significantly lower actinomycetes population as compared to non-treated plots *viz.*, hand weeding and weedy check. However, the trend was not similar in both the seasons. Hence, the reduction in actinomycetes population observed in these treatments might be due to variation in edaphic factors, as reported by Singh and Singh (2009).

Critical appraisal of the data on microbial population during both the seasons revealed no inhibitory action on microbial population by the application of herbicide mixtures *viz.*, penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop. Most microorganisms are capable of decomposing herbicides and using them most frequently as sources of biogenic elements for their own physiological process, which lead to an increase in microflora (Milosevic and Govedarica, 2002; Bera and Ghosh, 2013). Araujo *et al.* (2003) observed that an

ideal herbicide should be degraded quickly into non-toxic substances and exerts less toxic effects on soil microbes. Since, both the tested herbicide mixtures did not exert any harmful effect on soil microflora, it could be concluded that, both of them are ideal herbicides that degrade quickly to non-toxic substances and are environmentally safe.

5.1.14 Effect of Weed Management Treatments on Earthworms

There was no significant difference in the earthworm population among the treatments during both the years before and after the experiments. Though not significantly different, an increase in earth worm population was observed in the herbicide treatments as compared to weedy check and hand weeding (Fig. 11). This implies that, the tested herbicide mixtures and their doses did not leave any toxic residue in soil which will affect the earth worm population. The results of the experiment also conforms the findings of Scott and Pollak (2005), who reported that post emergence herbicides tend to require low application rate and are less persistent. Zarea (2010) also reported that, herbicides in general showed low toxicity towards earth worms. Several workers had also reported that herbicide used for weed control did not harm the earth worm (Mele and Carter (1999); Yadav (2006); Shitha *et al.*, 2015). Observations at harvest stage during second year indicated an increase in earth worm population was observed in the treatments as compared to first crop season. This might be due to higher organic carbon content in the soil (Table 33). Fonte *et al.* (2009) reported that earth worm population in the soil appears to be closely linked with total soil carbon and N content.

5.1.15 Effect of Weed Management Treatments on Enzyme Activity in Soil

Dehydrogenase is an enzyme that oxidizes soil organic carbon by transferring protons and electrons from substrates to acceptors. Dehydrogenase enzyme activity in soil is the biological indicator of overall microbial respiratory activity of soil (Bolton *et al.*, 1985).

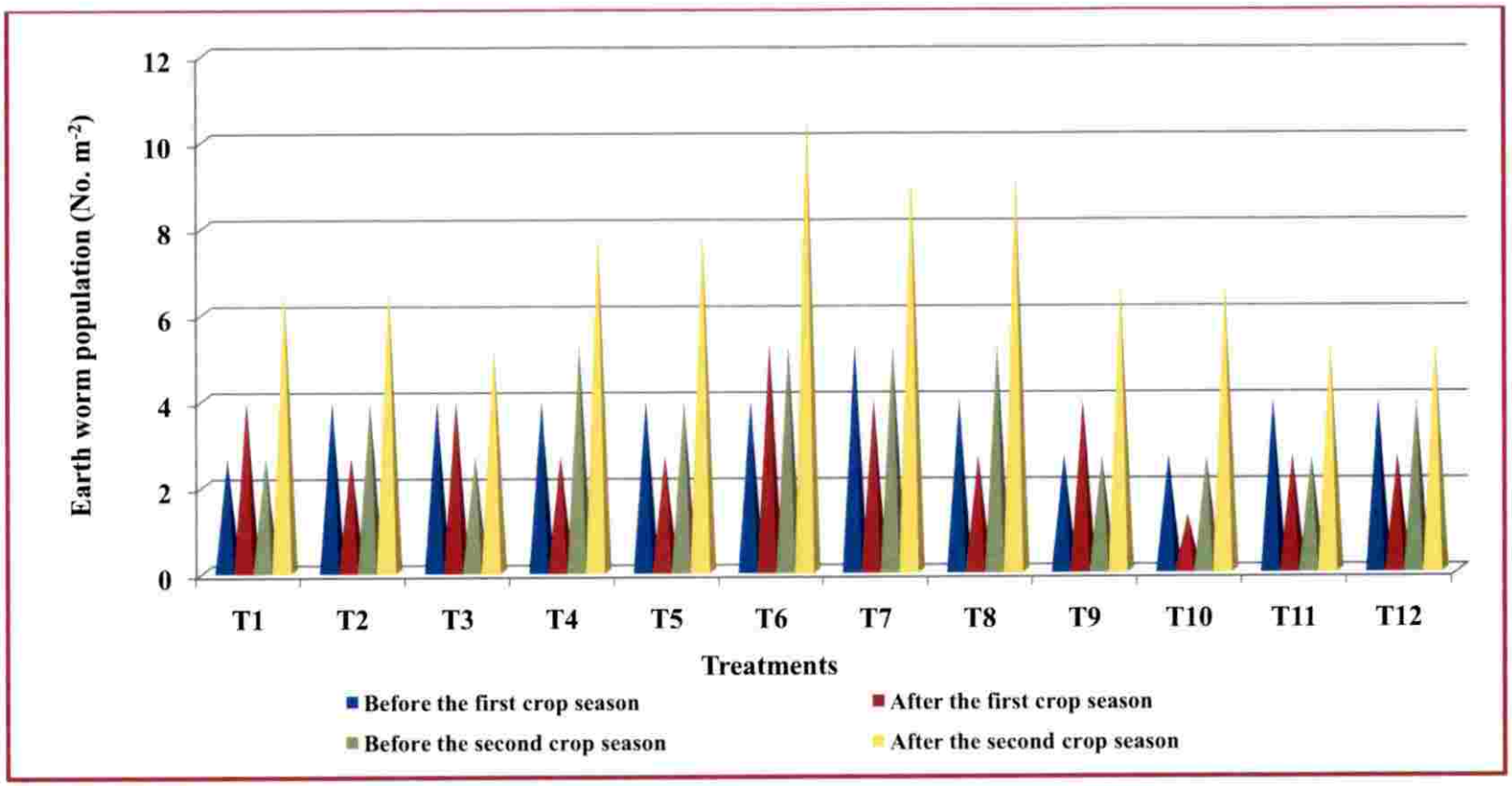

Fig.11. Earth worm population as influenced by weed management treatments before and after the first and second crop

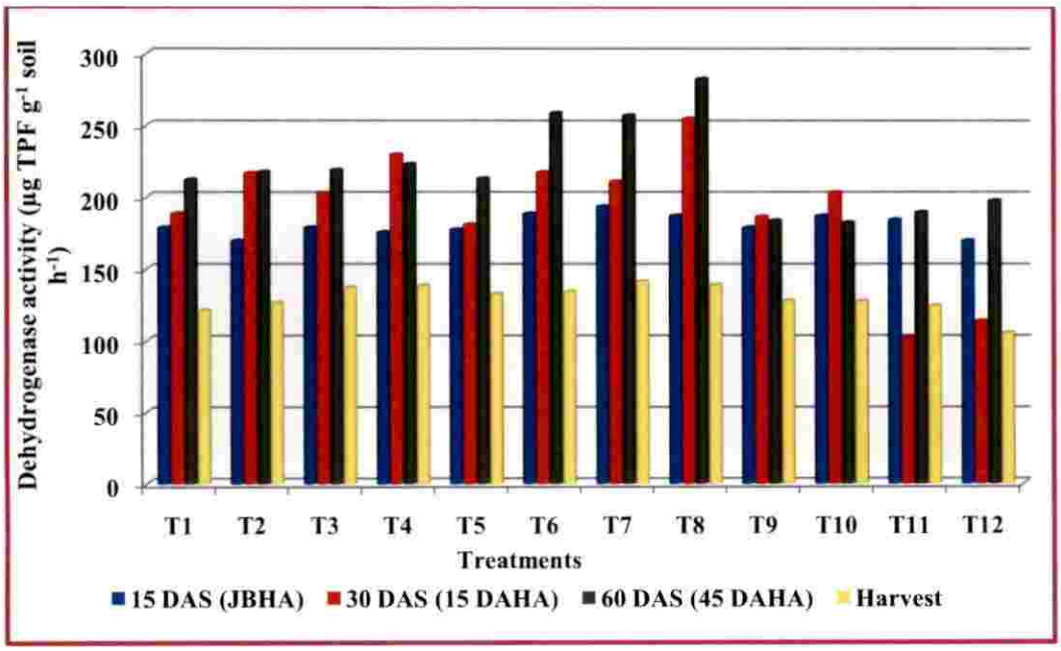

Fig.12a. Dehydrogenase activity in soil as influenced by weed management treatments (first crop season)

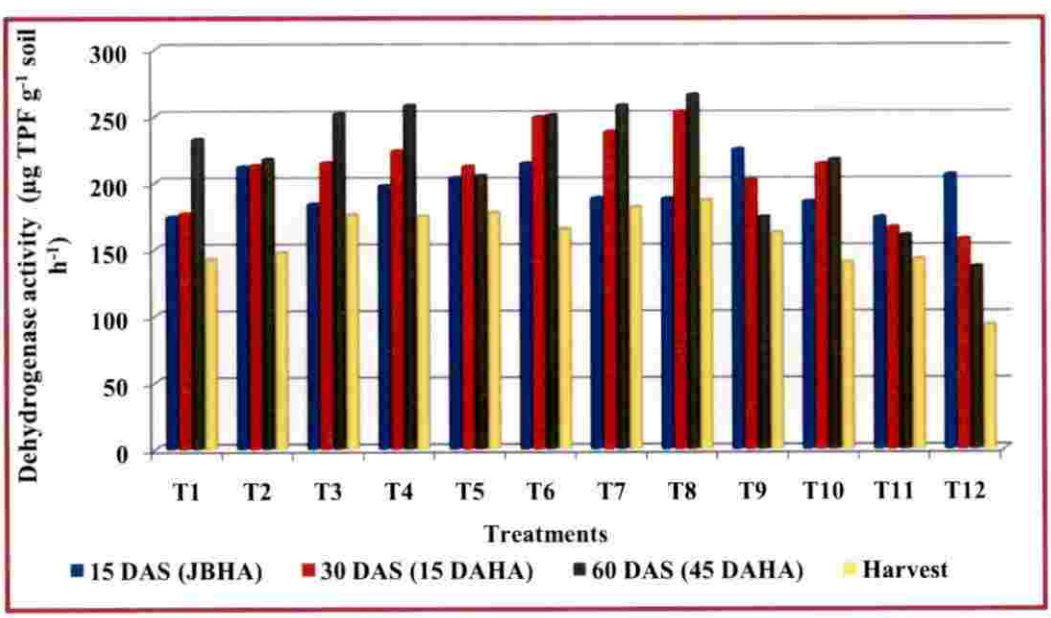

Fig.12b. Dehydrogenase activity in soil as influenced by weed management treatments (second crop season)

DAS - days after sowing
JBHA - just before herbicide application
DAHA - days after herbicide application

Herbicide treatments significantly influenced dehydrogenase activity at 30 and 60 DAS and at harvest stage. Compared to initial enzyme activity (just before herbicide application), a reduction was observed in non-herbicide treated plots. But the activity of dehydrogenase enzyme was comparatively higher in herbicide treated plots than in non-treated plots (Fig. 12a and 12b). The increase in dehydrogenase activity observed in herbicide treated plots compared to control plots might be due to the increase in microbial population in herbicide plots resulting from the greater availability of carbon source by the degradation and decomposition of herbicides and also by the decomposition of weeds. The result is in conformity with the findings of Sebiomo *et al.* (2011), Vandana *et al.* (2012), Nadiger *et al.* (2013) and Shitha *et al.* (2015). Among the tested doses of herbicide mixtures, the highest dose of penoxsulam + cyhlalofop butyl and bispyribac sodium + metamifop recorded higher dehydrogenase activity at 30 and 60 DAS. This is in agreement with the observations of Hang *et al.* (2002) who reported that the dehydrogenase enzyme activities were higher in soil samples treated with higher doses of butachlor than its lower dose. During both the seasons, the maximum dehydrogenase activity was observed at 60 DAS, this might be due to the increase in microbial population at 60 DAS compared to 30 DAS (Table 39a and 39b). During both the seasons, at harvest stage a decline in activity was observed due to the aerobic condition prevailed at the time of harvest. The microorganisms responsible for dehydrogenase activity prefer anaerobic conditions and belong to obligate anaerobes (Baruah and Mishra, 1984; Tiwari *et al.*, 1989; Makoi and Ndakidemi, 2008; Wolinska and Stepniewska, 2012).

β glucosidase is a common and predominant enzyme involved in the hydrolysis of various glucosides present in the decomposing plant debris in the soil ecosystem. It is an enzyme limiting the rate of microbial degradation of cellulose to glucose, an important source of carbon for the life of microorganisms in soil (Esen, 1993; Tabatabai, 1994).

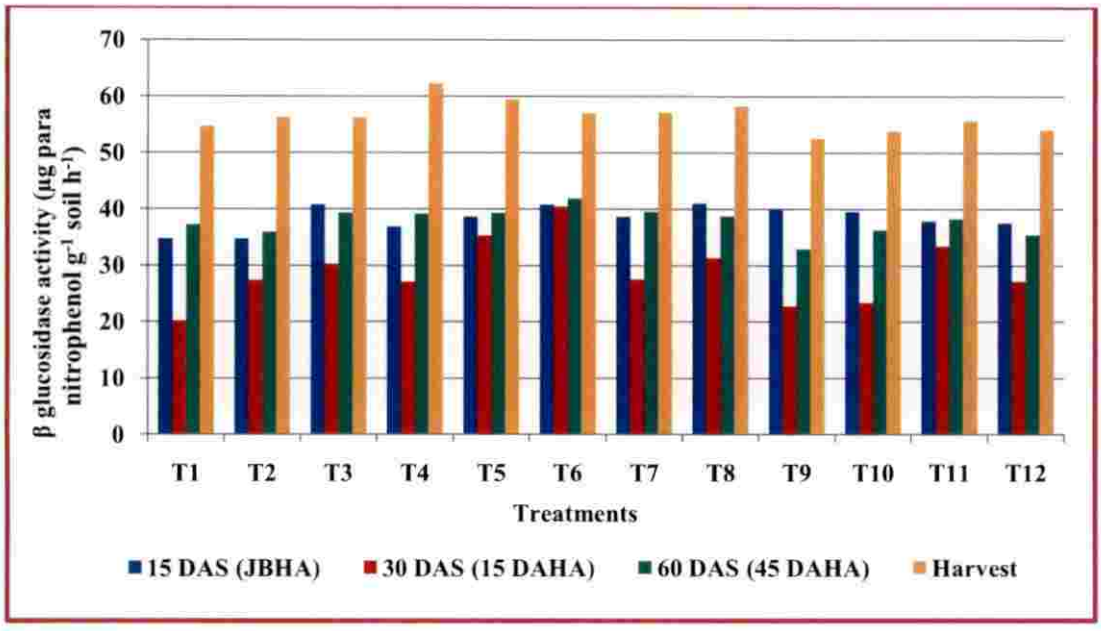

Fig.13a. β glucosidase activity in soil as influenced by weed management treatments (first crop season)

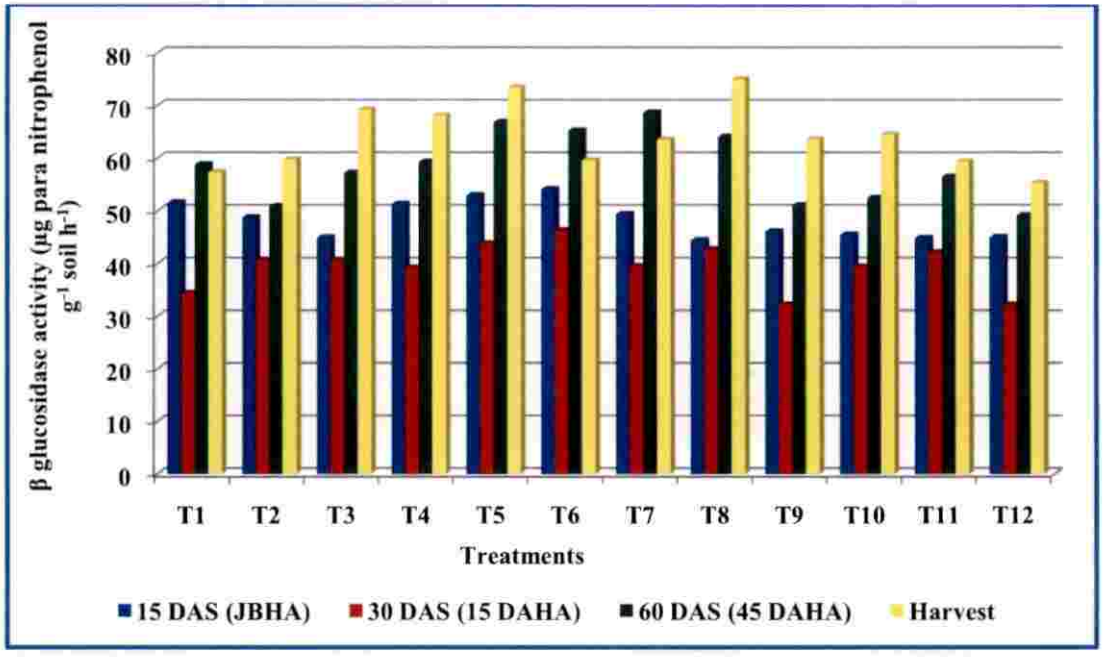

Fig.13b. β glucosidase activity in soil as influenced by weed management treatments (second crop season)

DAS - days after sowing
JBHA - just before herbicide application
DAHA - days after herbicide application

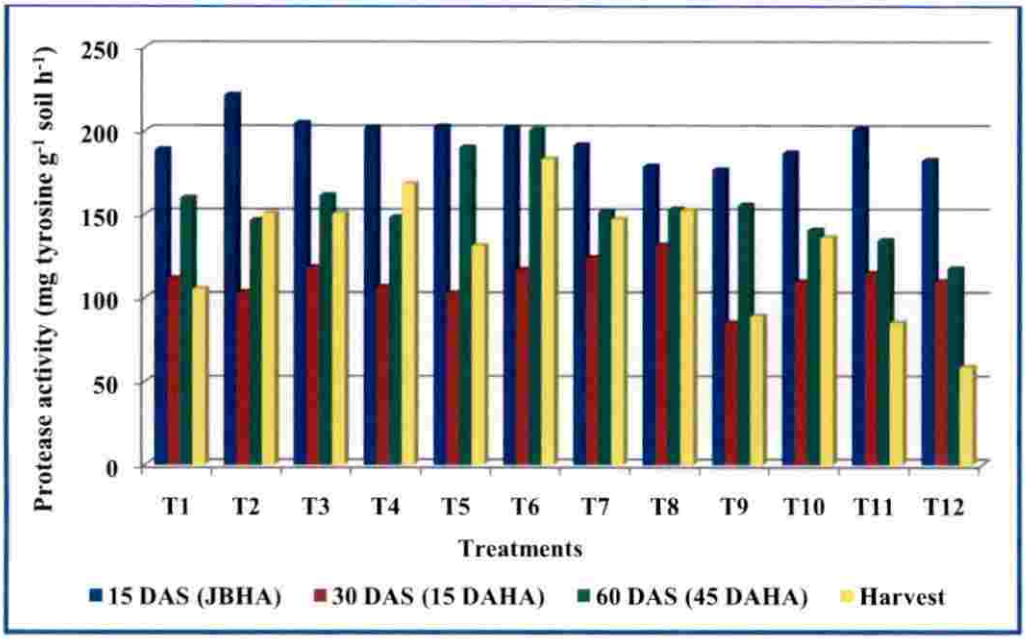

Fig.14a. Protease enzyme activity in soil as influenced by weed management treatments (first crop season)

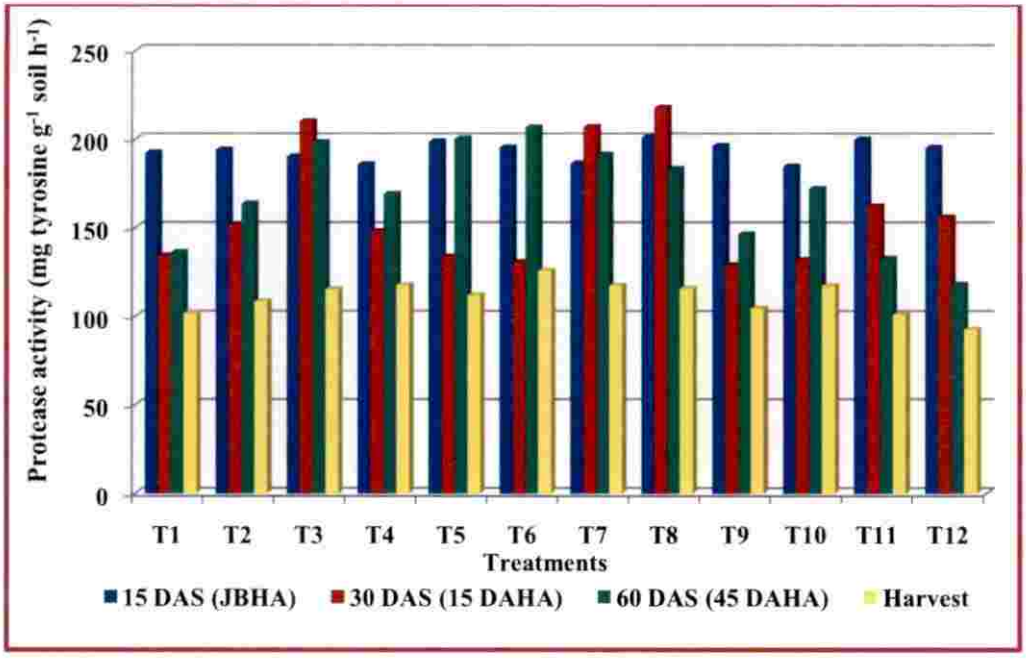

Fig.14b. Protease enzyme activity in soil as influenced by weed management treatments (second crop season)

DAS - days after sowing
JBHA - just before herbicide application
DAHA - days after herbicide application

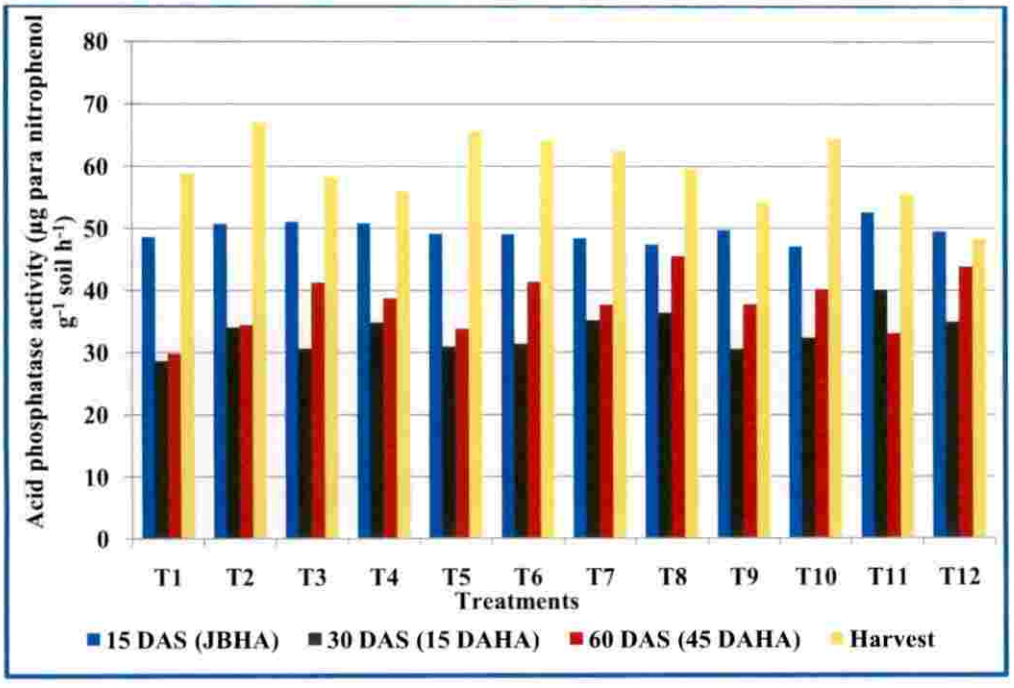

Fig.15a. Acid phosphatase activity in soil as influenced by weed management treatments (first crop season)

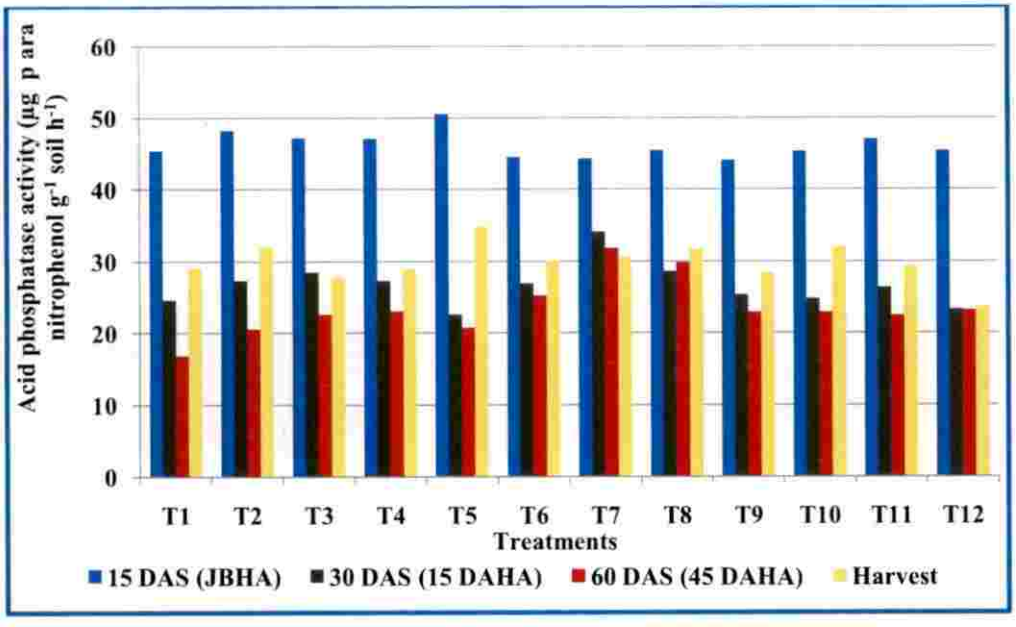

Fig.15b. Acid phosphatase activity in soil as influenced by weed management treatments (second crop season)

DAS	- days after sowing
JBHA	- just before herbicide application
DAHA	- days after herbicide application

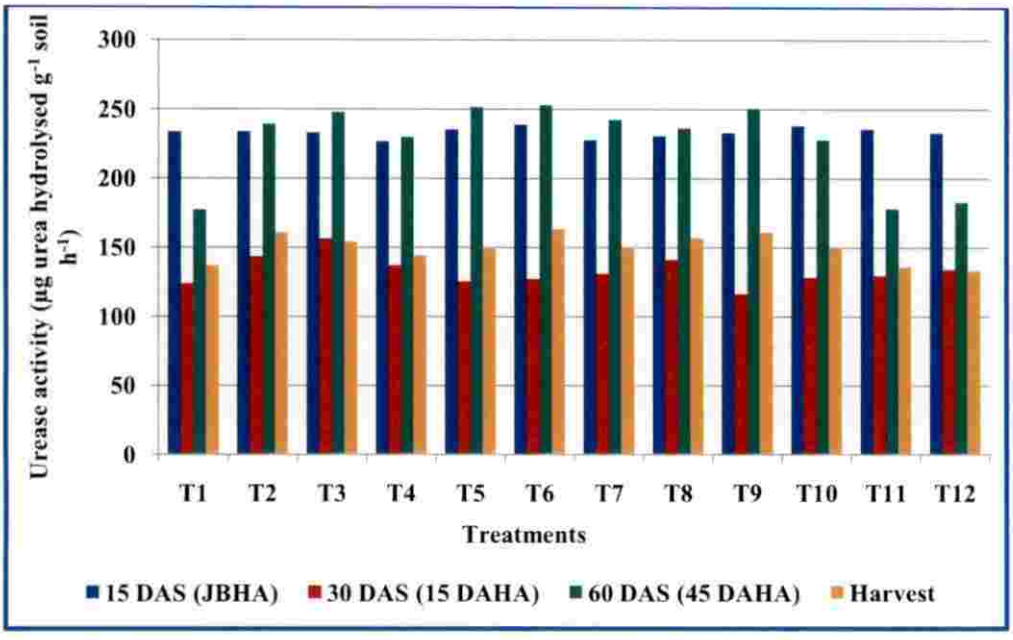

Fig.16a. Urease enzyme activity in soil as influenced by weed management treatments (first crop season)

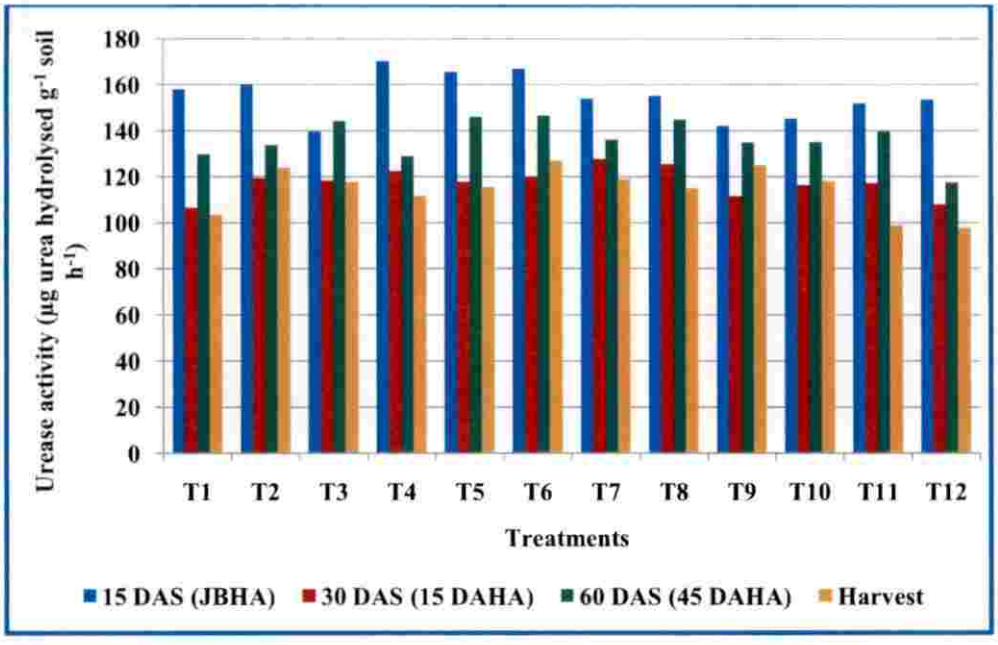

Fig.16b. Urease enzyme activity in soil as influenced by weed management treatments (first crop season)

DAS	- days after sowing
JBHA	- just before herbicide application
DAHA	- days after herbicide application

β glucosidase enzyme activity in soil was significantly influenced by weed management treatments at 30 and 60 DAS and at harvest stage during both the seasons (Fig. 13a and 13b). During both the seasons, a decline in glucosidase enzyme activity was observed at 30 DAS (15 DAHA). The decline in enzyme activity might be due to the soil and environmental factors. β glucosidase enzyme activity is very sensitive to pH changes and soil management practices and are positively correlated with soil pH (Martinez and Tabatabai, 2000). It has been observed from the results that, all the herbicide treated plots recorded higher or comparable glucosidase activity at 30 and 60 DAS and at harvest stage with non-herbicide treated plots. This implies that, the applied herbicides did not have any adverse impact on β glucosidase activity in soil. Several researchers have reported the enhanced β glucosidase activity followed by herbicide application (Sofo *et al.*, 2012; Saha *et al.*, 2012; Santric *et al.*, 2014). The β glucosidase enzyme activity was found to increase from 30 DAS, and reached the maximum at harvest stage. At harvest stage, the soil was in aerobic condition and the crop reached senescence stage. This might have increases the bacterial population in the soil, which might have increased the glucosidase activity. There is considerable evidence suggesting that β glucosidase is an extra cellular enzyme secreted mainly by bacteria and fungi (Sinsabaugh and Moorhead, 1994; Veena *et al.*, 2011). Larson *et al.* (2002) reported that increased inputs of soluble organic constituents' increased the glucosidase enzyme activity in soil.

Protease enzyme which plays a major role in N mineralization was significantly influenced by weed management treatments at 30 and 60 DAS and at harvest stage (Fig. 14a and 14b). The tested herbicide mixtures, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl and their doses recorded comparable or significantly higher values of protease enzyme activity at 30 DAS (15 days after herbicide application), 60 DAS (45 days after herbicide application) and at harvest stage as compared to weedy check or hand weeding, except in the treatment bispyribac sodium + metamifop @ 60 g ha^{-1} at 60 DAS, during second crop season.

The reduction in protease enzyme activity observed in the treatment bispyribac sodium + metamifop @ 60 g ha^{-1} was not consistent over the seasons. This result emphasizes that the applied herbicides did not have any adverse impact on protease enzyme activity in soil. The variation in protease activity observed among the treatments might be due to the variation in the amount of proteinaceous substrate availability, microbial composition especially proteolytic bacteria (Sardans *et al.*, 2011; Anjaneyulu *et al.*, 2011), physicochemical properties of the soil and NH_4N accumulation in soil organic matter (Sardans and Penuelas, 2005; Tischer, 2005). Baboo *et al.* (2013) reported that protease activity in soil treated with butachlor, pyrazosulfuron and glyphosate showed an increasing trend from 7^{th} to 28^{th} day of incubation. The reduction in protease enzyme activity observed at harvest stage might be due to the accumulation of NH_4N in soil organic matter.

Acid phosphatase enzyme plays a major role in the hydrolysis of organic phosphorus and release of free phosphate which contributes to the P nutrition of the plants. Acid phosphatase activity in soil was significantly influenced by weed management treatments at 30 and 60 DAS and at harvest, during both the seasons (Fig. 15a and 15b). A reduction in phosphatase activity was observed in all the treatments at 30 DAS (15 DAHA) including the weedy check and hand weeding, though increase in bacterial and fungal population was observed. This might be due to environmental factors or change in soil pH or other chemical properties of the soil. The rate of release of phosphatase enzyme by the plant roots and microorganism are mainly influenced by the soil pH (Tabatabai, 1994; Martinez and Tabatabai, 2000) and soil microbial community (Renella *et al.*, 2006; Renella *et al.*, 2007). Comparatively higher values of acid phosphatase were observed in all treatments at 15 DAS (just before herbicide application) as compared to 30 and 60 DAS during both the seasons, though no statistical difference was observed among the treatments. At 15 DAS, the crop is in the seedling stage having great demand for P for the development of root system. Phosphatase enzymes are actively secreted in to the soil by plants and microbes in response to P demand (Utobo and Tewari, 2015). At 30 and 60 DAS and at harvest stage, during both

the seasons, all the herbicide treatments recorded the acid phosphatase value which was comparable or higher than that of hand weeding or weedy check, except in the treatment bispyribac sodium + metamifop @ 60 g ha^{-1} during first crop season at 30 DAS and at 60 DAS during second crop season. The reduction in phosphatase activity in bispyribac sodium + metamifop @ 60 g ha^{-1} was also not consistent over the years. This has shown that, tested herbicides and their doses did not have any inhibitory effect on acid phosphatase activity in soil. The variation in phosphatase activity observed among the treatments might be due to the variation in the composition of microflora (Makoi and Ndakidemi, 2008), root exudates of the crop plant, pH and organic P present in the soil (Turner and Haygarth, 2005). This is in agreement with the findings of Bacmaga *et al.* (2012), Rao *et al.* (2012) who observed that herbicides had no negative effect on acid phosphatase activity in soil. After an initial decline at 30 DAS, the acid phosphatase activity was found to increase up to harvest stage. The increased phosphatase activity observed at 60 DAS might be due to the increase in microbial population (Tables 39a and 39b) and also due to the increased production of root exudates by the crop, since the crop is in the most active stage of crop growth, *i.e.*, the booting stage. Dotaniya *et al.* (2014) reported that, maximum acid phosphatase activity was observed at 75 days after transplanting of rice crop. The increase in phosphatase activity observed at harvest stage might be due to the continuous build-up of microbial population.

Urease activity in soil was significantly influenced by the weed management treatments. Urease plays a major role in the hydrolysis of urea to NH_3 and CO_2. During both the seasons at all stages, the herbicide treatments recorded significantly higher or comparable urease activity in soil compared to non-herbicide treatments (Fig. 16a and 16b), indicating that the tested herbicides and their doses did not have any inhibitory effect on this enzyme activity in soil. Several researchers have reported that, herbicide application enhanced the urease activity in soil (Baboo *et al.*, 2013; Pal *et al.*, 2013; Tomkiel *et al.*, 2014).

The maximum urease activity was observed at 15 DAS, followed by a decline at 30 DAS and again an increase at 60 DAS again followed by a decline at harvest stage during both the seasons. The maximum urease activity observed at 15 DAS might be due to the enhanced availability of substrate N and other nutrients as evident from initial soil nutrient status. Aparna (2000) reported that, higher availability of substrate nitrogen and other nutrients promoted the urease activity. Though, an increase in microbial population was observed at 30 DAS, a decline in urease activity was observed, might be due to changes in soil pH and soil temperature and reduction in substrate availability. Urease activity in soil depends on the microbial community, physical and chemical properties of the soil, particularly soil pH and temperature (Corstanje *et al.*, 2007; Yang *et al.*, 2006). Higher urease activity observed at 60 DAS was due to the increase in the microbial population (Tables 39a and 39b) and substrate availability (Tables 34 and 35) due to application of third split dose of fertilizers at 55 DAS. Urease enzyme found in large number of microorganisms, especially in ureolytic bacteria and fungi as both intra and extra cellular (Bremner and Mulvaney, 1978). The decrease in urease activity observed at 30 DAS and harvest stage might also be related to the moisture content in the field. At 25 to 30 DAS, a thin film of water was maintained in the field to promote tillering and at harvest stage the field was completely drained to facilitate early ripening and easiness in harvest. Rasool *et al.* (2014) reported that, the urease activity was stimulated by herbicide treatments under flooded condition than unflooded condition.

5.2 PART II - BIOASSAY

5.2.1 Screening of Indicator Plants and Preparation of Standard Curve

Plant bioassay is the simple, accurate, inexpensive and direct method used to measure the biological response of living plants to herbicides and to quantify their concentration in a substrate. Stork and Hannah (1996) reported it as a very useful tool that complements the analytical methods and provides information regarding the herbicide residue and its possible phytotoxic effect. Bioassays are usually conducted with sensitive plant species.

Plate 9. Screening of indicator plants for bispyribac sodium + metamifop

Plate 10. Screening of indicator plants for penoxsulam + cyhalofop butyl

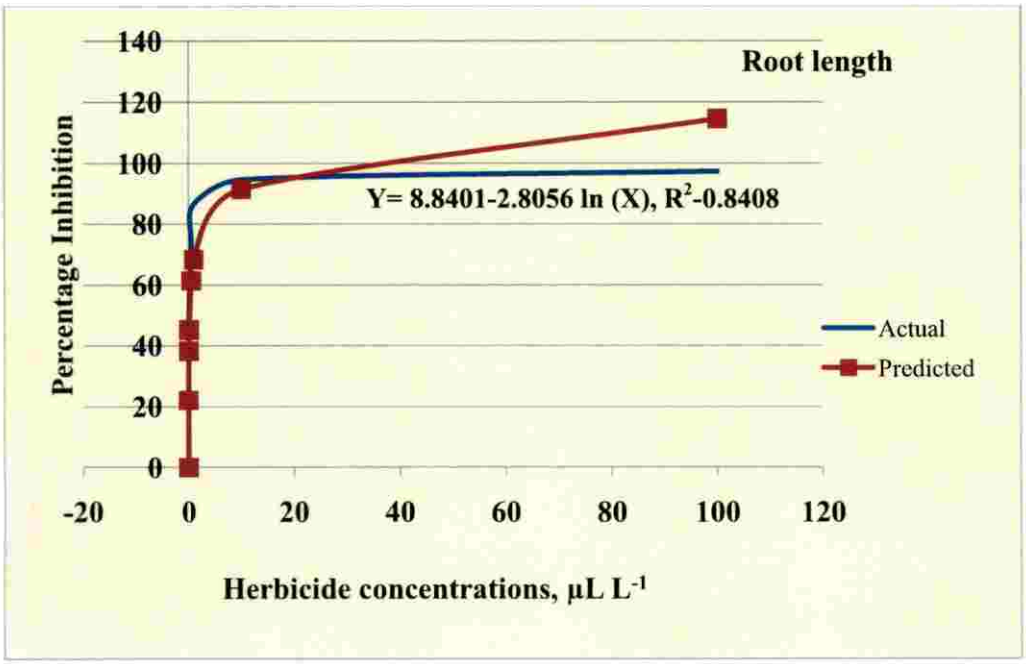

Fig.17a. Percentage growth inhibition in the root length of maize, as influenced by different concentrations of bispyribac sodium + metamifop

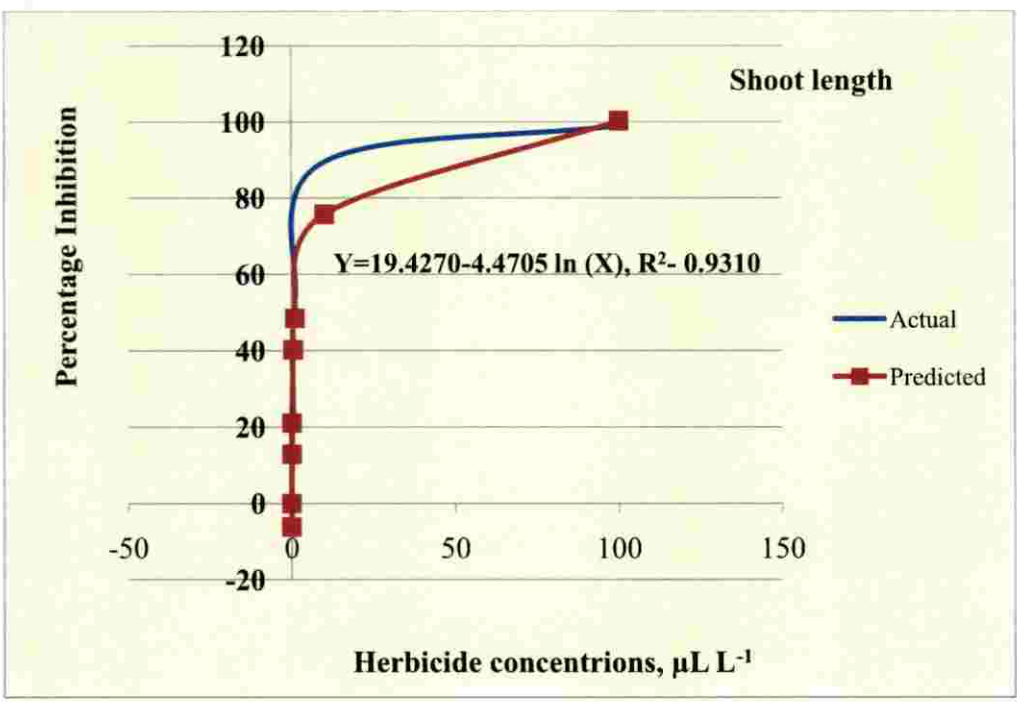

Fig. 17b. Percentage growth inhibition in the shoot length of maize, as influenced by different concentrations of bispyribac sodium + metamifop

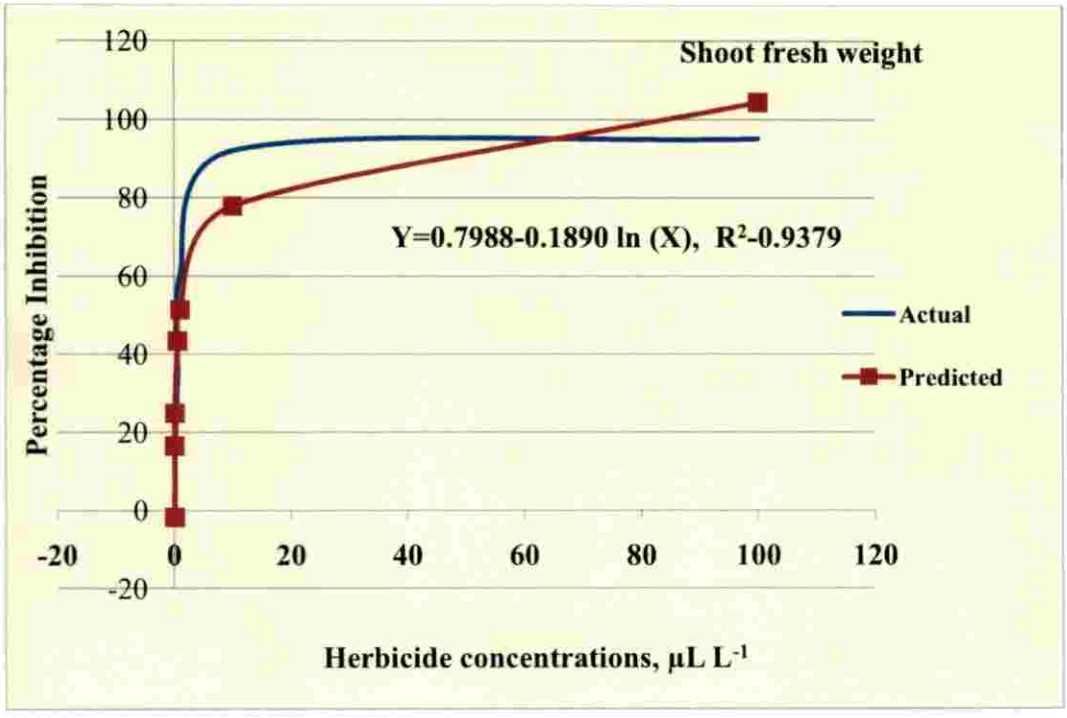

Fig. 17c. Percentage growth inhibition in the shoot fresh weight of maize, as influenced by different concentrations of bispyribac sodium + metamifop

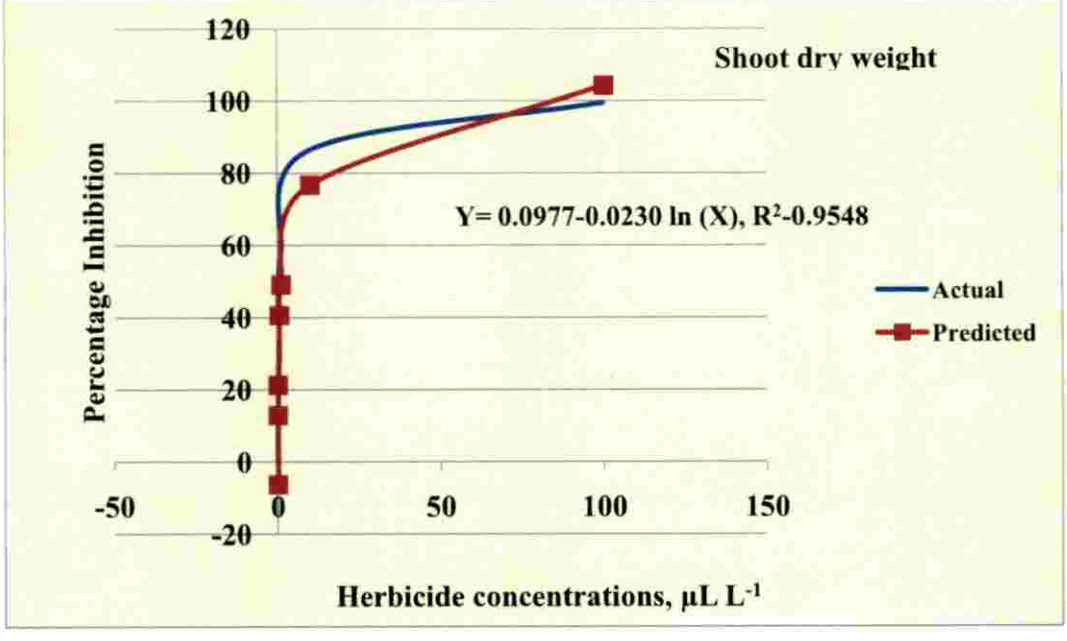

Fig. 17d. Percentage growth inhibition in the shoot dry weight of maize, as influenced by different concentrations of bispyribac sodium + metamifop

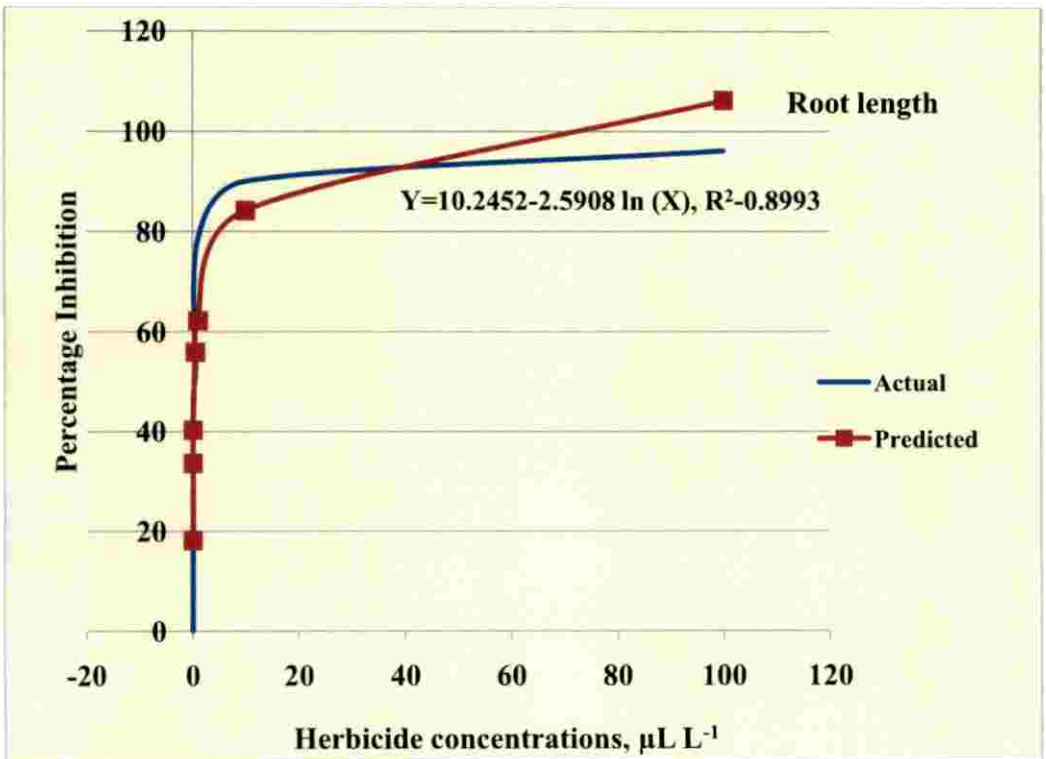

Fig.18a. Percentage growth inhibition in the root length of maize, as influenced by different concentrations of penoxsulam + cyhalofop butyl

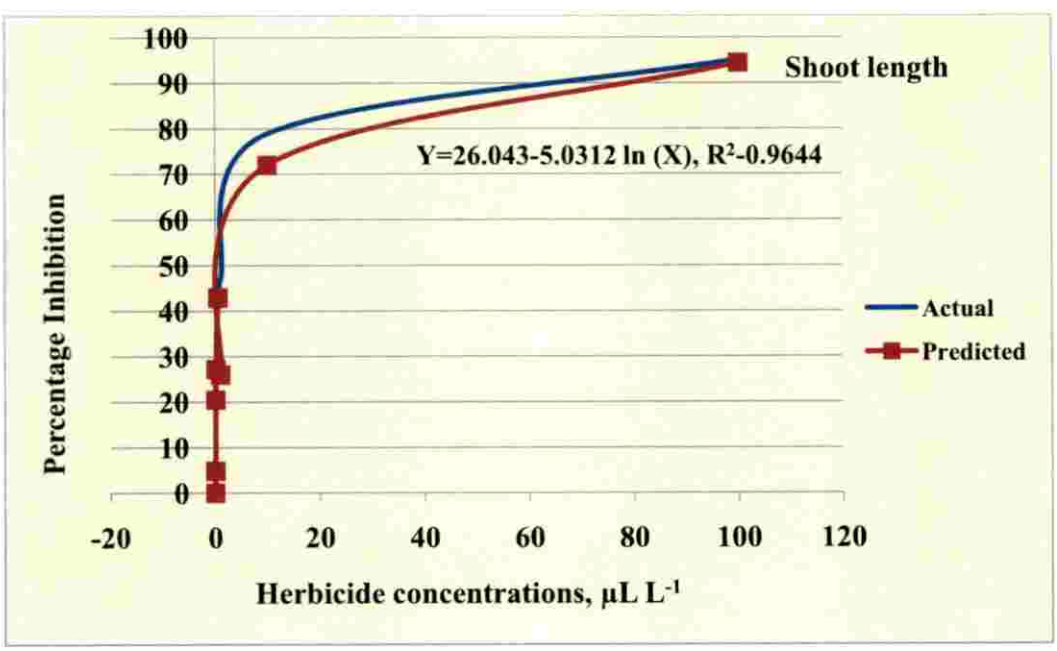

Fig.18b. Percentage growth inhibition in the shoot length of maize, as influenced by different concentrations of penoxsulam + cyhalofop butyl

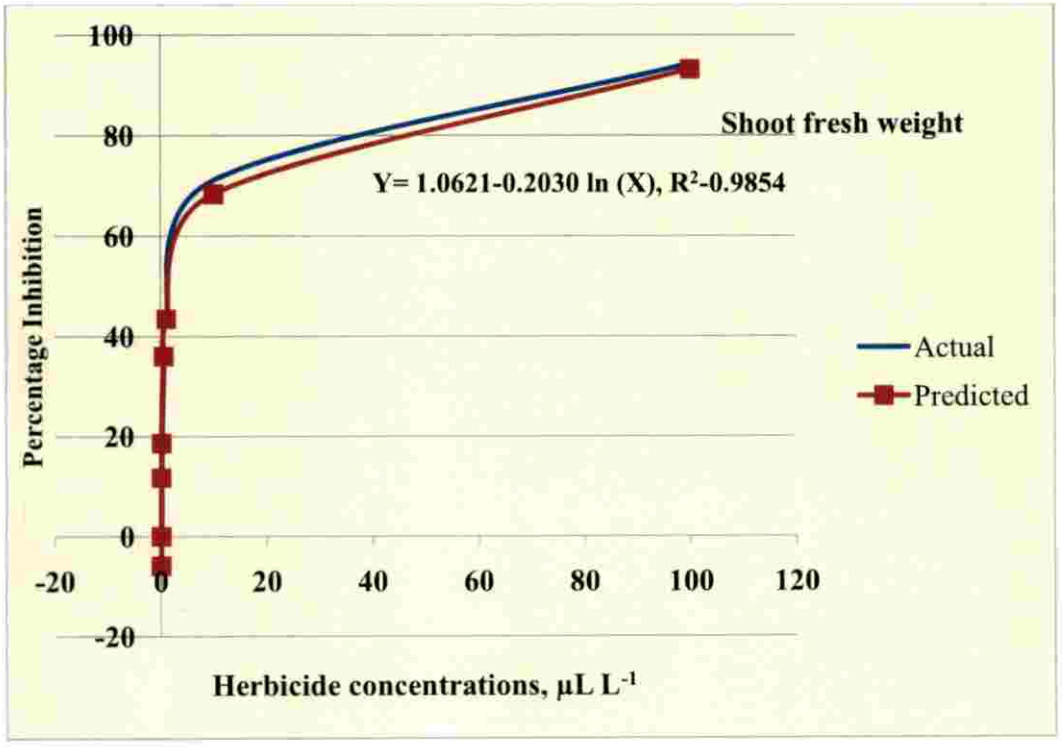

Fig.18c. Percentage growth inhibition in the shoot fresh weight of maize, as influenced by different concentrations of penoxsulam + cyhalofop butyl

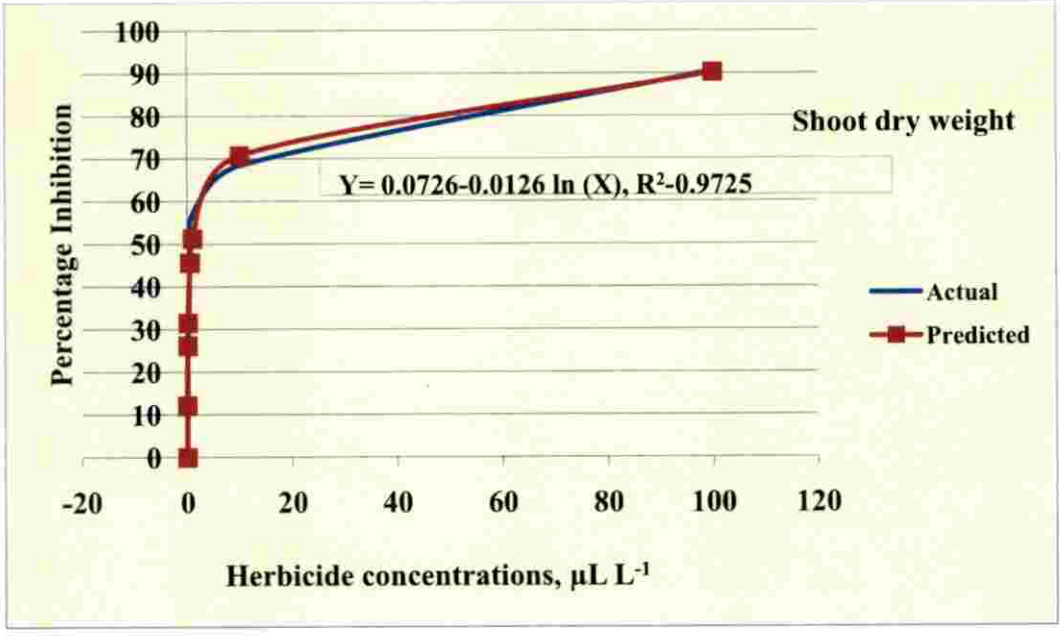

Fig.18d. Percentage growth inhibition in the shoot dry weight of maize, as influenced by different concentrations of penoxsulam + cyhalofop butyl

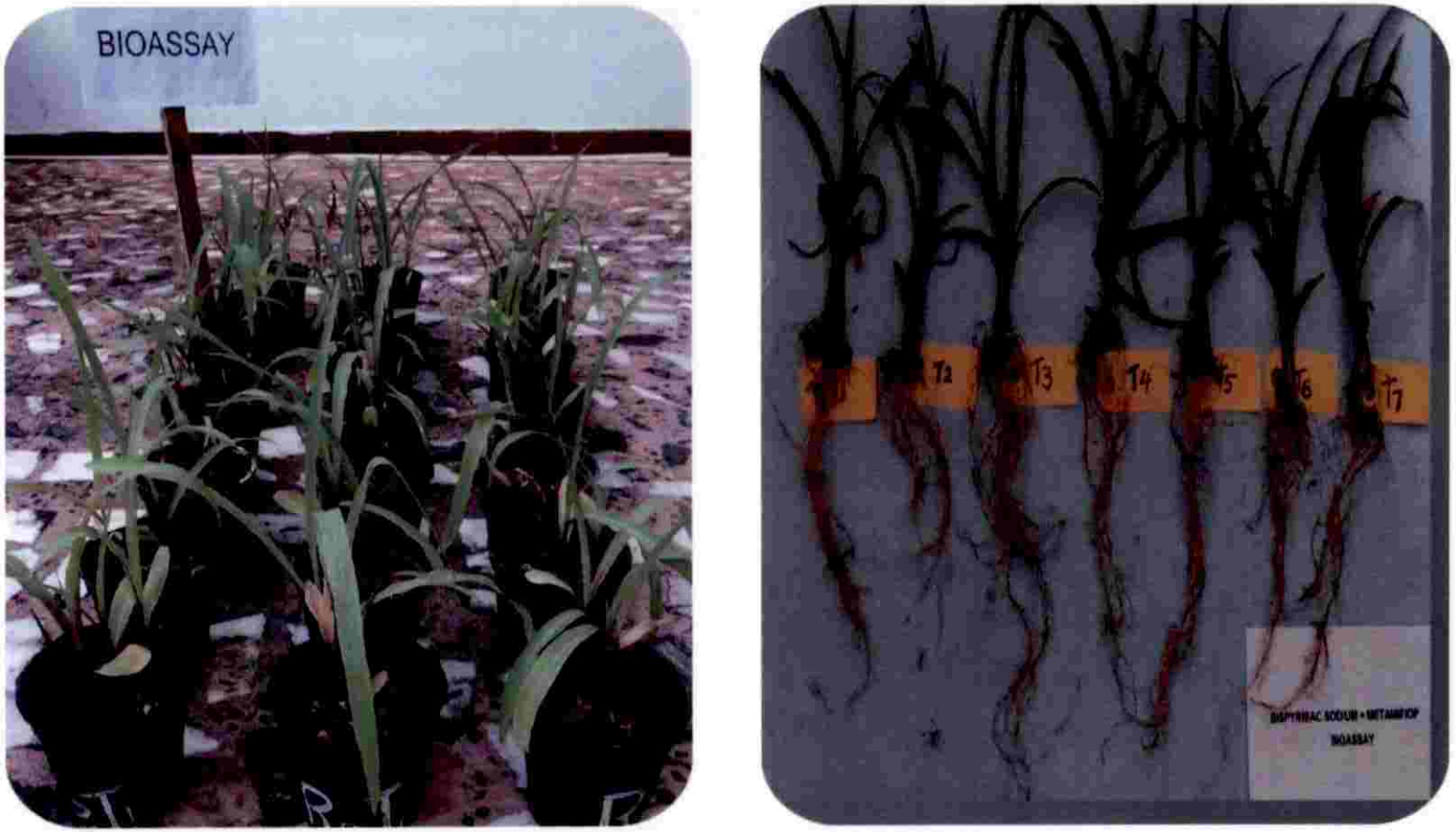

Plate 11. Residual effect of bispyribac sodium + metamifop in post experiment soil

Plate 12. Residual effect of penoxsulam + cyhalofop butyl in post experiment soil

Results of the screening trial for identifying the most suitable indicator plant for the herbicide mixture, bispyribac sodium + metamifop revealed that, among the three indicator plants tested *viz*., cucumber, sunflower and maize, maize was selected as the most sensitive indicator plant to estimate the residues of bispyribac sodium + metamifop in soil, since it recorded the highest R^2 values for shoot dry weight, shoot fresh weight, root length and shoot length, the parameters tested (Fig. 17a, 17b, 17c and 17d). The best parameter for the detection of residue in the soil was maize shoot dry weight (Fig. 17 d), since it recorded the highest R^2 value (0.9548) among the tested parameters and the log linear regression equation, Y= 0.0977 - 0.0230 ln (X) was developed.

For determining the herbicide residues of penoxsulam + cyhalofop butyl, cucumber, maize and sunflower were screened to identify the best sensitive indicator plant. Maize was selected as the best indicator plant for this herbicide mixture also, since it recorded the highest R^2 values for shoot dry weight, shoot fresh weight, shoot length and root length, the parameters tested (Fig. 18a, 18b, 18c and 18d). The best parameter for the detection of residue in the soil was maize shoot fresh weight (Fig. 18 c), since it recorded the highest R^2 (0.9854) and the log linear regression equation, Y= 1.0621 - 0.2030 ln (X) was developed for this parameter.

The best plant parameter selected for bioassay has to be very sensitive and correlate well with herbicide concentration (Szmigielski *et al*., 2009). In the present study, shoot dry weight and shoot fresh weight were very sensitive and correlated significantly with tested concentrations of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl, respectively. Hernandez-Sevillano *et al*. (2001) and Huang *et al*. (2001) reported that maize and sunflower were the most suitable indicator plants for detecting the residue of sulfonyl urea herbicides. Similarly, maize was used as the indicator plant to detect the residue of herbicide sethoxydin (Satisha *et al*., 2003). Gowda *et al*. (2003) opined that in soil bioassay, fresh weight of setaria seedlings showed wide range of response and

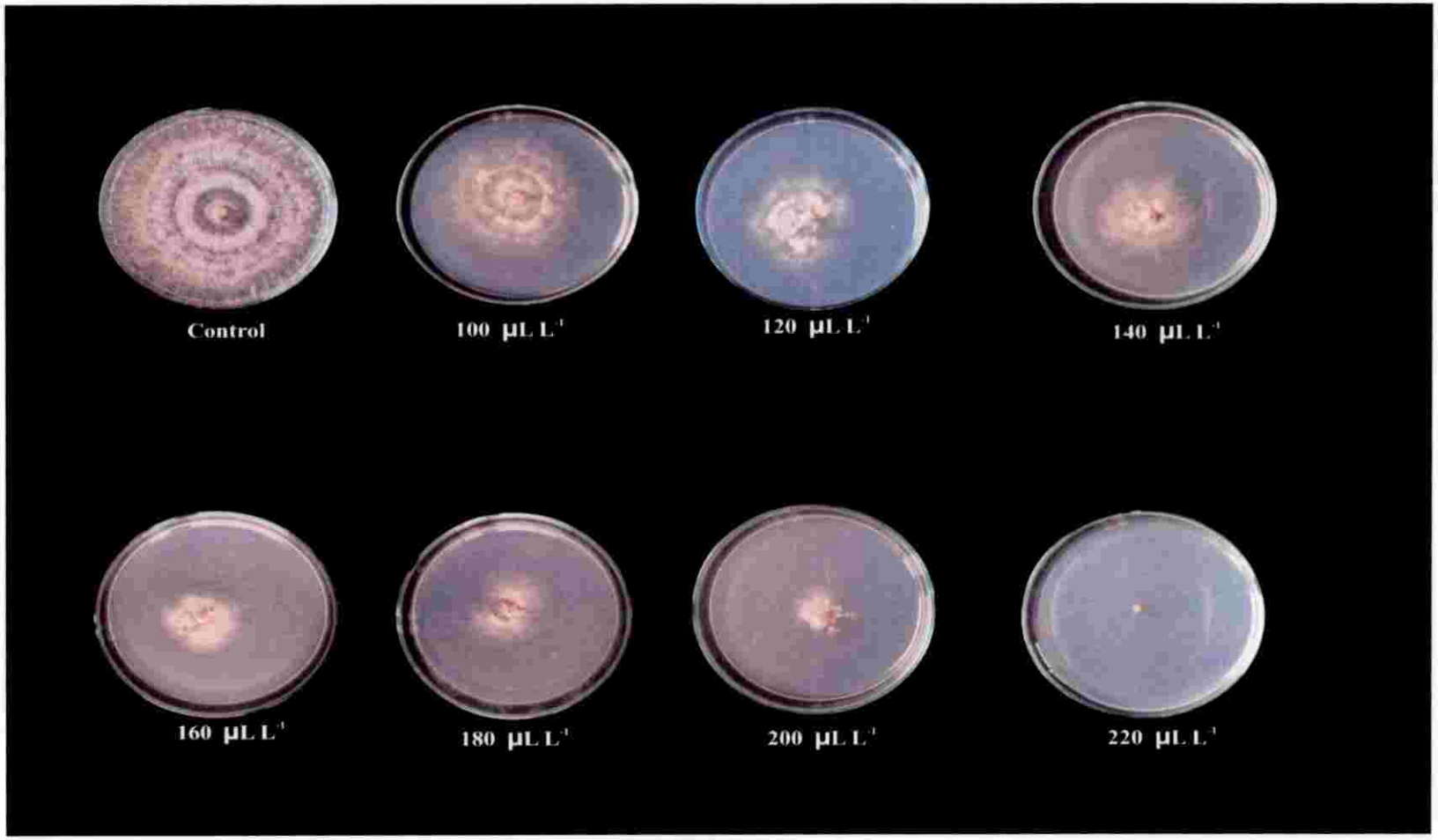

Plate 13. *In vitro* sensitivity of *Rhizoctonia solani* to bispyribac sodium + metamifop

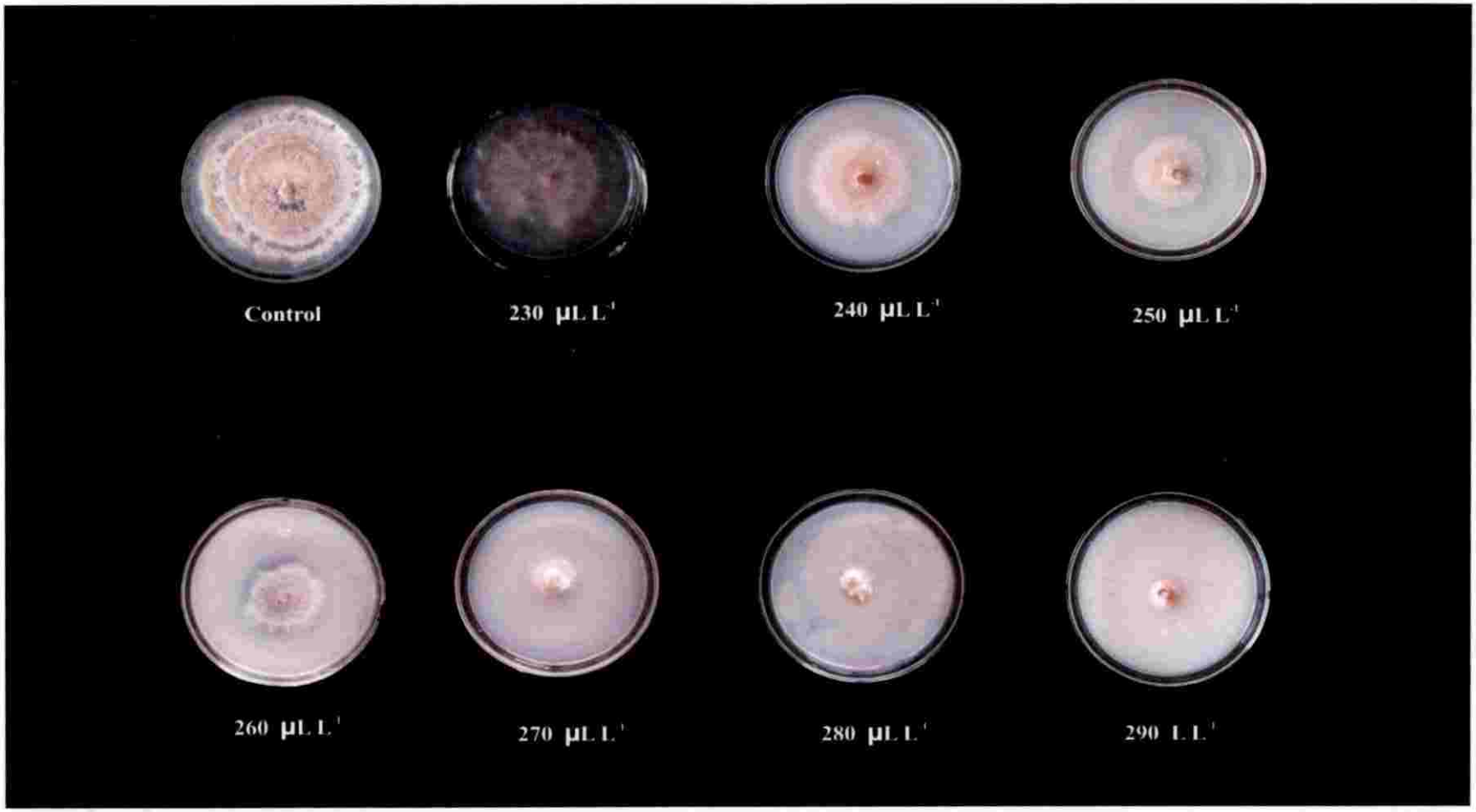

Plate 14. *In vitro* sensitivity of *Rhizoctonia solani* to penoxsulam + cyhalofop butyl

high R^2 value (0.93) compared to other parameters (shoot length and dry weight) and was selected as the most sensitive parameter for detecting the fluazifop-p-butyl residue in soil. Several research reports revealed that plant height or plant dry or fresh weight were the sensitive parameters for the detection of sulfonyl urea herbicide residue in soil (Walker and Welch, 1989; Blacklow and Pheloung, 1991; Gunther *et al.*, 1993; Vicari *et al.*, 1994; Stork and Hannah, 1996).

5.2.2 Residual Effect of Herbicide Mixtures in Soil

The residual effect of the herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl were studied separately with maize as the indicator plant.

In the case of bispyribac sodium + metamifop, though shoot dry weight of maize was selected as the best parameter to detect the herbicide residue, other growth parameters were also assessed. Results of the study revealed that there was no significant difference among the treatments during both the seasons in the parameters studied *viz.*, germination percentage, shoot length, root length, fresh weight and dry weight of maize plant. Thus it can be assumed that the herbicide mixture did not leave any residue in soil.

In the case of detecting penoxsulam + cyhalofop butyl residue in soil, growth parameters *viz.*, germination per cent, shoot length, root length and shoot dry weight were recorded along with the most sensitive parameter, maize shoot fresh weight. Results of residue studies of the first and second crop season revealed no significant difference among the treatments *viz.*, penoxsulam + cyhalofop butyl @ 120, 125, 130 and 135 g ha^{-1}, hand weeding and weedy check in the parameters studied. Thus it could be inferred that the herbicide mixture, penoxsulam + cyhalofop butyl did not leave any phytotoxic residue in soil and are environmentally safe.

Both the herbicide mixtures can be used as effective alternative to manual weeding in direct wet seeded rice, because it can control weeds in rice without causing injury to subsequent crop. Bioassay with baby corn, cucumber and soybean indicated that residues from pre-emergence herbicides *viz*., acetochlor, alachlor, clomazone, isoxaflutole, metribuzin, oxadiazon, pendimethalin + oxadiazon and metribuzin + pendimethalin did not have any phytotoxic effect or growth retardation in the tested plants (Pornprom *et al.* 2010). Ramani and Khanpara (2010) reported that the post emergence herbicides *viz*., oxadiargyl @ 90 g ha^{-1}, quizalofop-ethyl @ 40 g ha^{-1} and fenoxaprop-p-ethyl @ 75 g ha^{-1} when applied at 60 DAS showed no reduction in germination percentage, plant height and dry weight of indicator plants, sorghum and cucumber indicating no residual phytotoxic effect. The application of oxyfluorfen at different concentrations (150 to 300 g ha^{-1}) for the control of weeds in DSR did not hamper the population of succeeding crops of lentil, linseed and coriander after the rice indicating that oxyfluorfen did not leave any phytotoxic residue in soil.

5.3 PART III - *IN VITRO* SENSITIVITY OF MAJOR SOIL BORNE PATHOGEN- *Rhizoctonia solani* TO HERBICIDE MIXTURES

Herbicides not only control the target weeds, but also the plant pathogens. This herbicidal effect has been reported by several workers. Madhuri *et al.* (2013) reported that, this herbicidal effect in controlling plant disease is either by altering the virulence of the pathogen or the level of resistance in the host plant.

Results of the study on the *in vitro* effect of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl revealed that different concentrations of the herbicide mixtures tested significantly inhibited the radial growth of pathogen at the sixth day. As the concentration of the herbicide increases, a decrease in radial growth of the *Rhizoctonia solani* was observed (Plates 13 and 14).

The lowest tested concentration of bispyribac sodium + metamifop (100 µL L^{-1}) recorded the maximum colony diameter of 5.27 cm with a growth inhibition of 41.48 per cent and the highest tested concentration (220 µL L^{-1}) recorded the colony diameter of 0.47 cm with a growth inhibition of 94.81 per cent. The tested field doses of bispyribac sodium + metamifop *viz.*, 60, 70, 80 and 90 g ha^{-1} corresponding to laboratory doses of 120, 140, 160 and 180 µL L^{-1} registered an inhibition in the mycelial growth of *Rhizoctonia solani* by 56.30, 57.41, 69.26 and 76.67 per cent, respectively. The variation in the inhibitory effect on *Rhizoctonia solani* observed among the treatments might be due to the difference in the concentration of the herbicide. This is in line with the observations made by Bollen (1961), Hattori (1973) and Sebiomo *et al.* (2011). The inhibitory effect of bispyribac sodium + metamifop on the growth of *Rhizoctonia solani* along with their effectiveness in weed control can be exploited under integrated pest and disease management programme. Madhuri and Reddy (2013) reported that pendimethalin, alachlor and quizalfop-p-ethyl recorded 100 per cent growth inhibition of *Rhizoctonia solani* and 2, 4-D sodium salt recorded 100 per cent inhibition in the radial growth of *Fusarium udum*. Mycelial growth of *Rhizoctonia solani* was inhibited by oxyfluorfen, butachlor, acetochlor, cinmethylin and oxadiazon under *in vitro* conditions. Similarly, Das (1986) and Harikrishnan and Yang (2001) reported that pendimethalin significantly reduced the mycelial growth of *Rhizoctonia solani*.

In the case of penoxsulam + cyhalofop butyl, the tested field doses of 120, 125, 130 and 135 g ha^{-1} corresponding to laboratory doses of 240, 250, 260 and 270 µL L^{-1} registered an inhibition in the mycelial growth of *Rhizoctonia solani* by 42.22, 52.59, 63.70 and 77.04 per cent, respectively. The highest tested dose (290 µL L^{-1}) inhibited the radial growth of *Rhizoctonia solani* by 90.74 per cent. The difference in the concentrations of the herbicide has resulted in variation in mycelial growth. Sebiomo *et al.* (2011) reported that the effect of herbicides on soil fungi varied among herbicides depending on the application rates. The above findings throw light on the additional benefits that can be derived through the

application of herbicide mixture, penoxsulam + cyhalofop butyl. In addition to its powerful effect in reducing the weed density in direct seeded rice, the *in vitro* results have shown that it has immense suppressive effect on the growth of dreaded soil borne pathogen, which cause sheath blight disease in rice. The compatibility of this herbicide mixture with *Pseudomonas fluorescens* (Plate 18) and its inhibitory effect on the growth of *Rhizoctonia solani*, penoxsulam + cyhalofop butyl at tested doses can be successfully utilized in integrated pest and disease management programme. Several researchers have reported the effectiveness of herbicides in inhibiting the growth of *Rhizoctonia solani* under *in vitro* condition. Under *in vitro* condition, butachlor @ 400 µL L^{-1} was found superior in inhibiting the mycelial growth of *Sclerotium oryzae* by 97.1 per cent as compared to oxadiargyl @ 150 µL L^{-1} (27.9 per cent) Gopika *et al.* (2011). Abdel (2002) has well documented the effectiveness of herbicides trifluralin and butralin in inhibiting the growth of *Rhizoctonia solani* and *Sclerotinia sclerotiorum*. Das (1986) and Pathak *et al.* (1996) reported that 2, 4-D inhibited the growth of *Rhizoctonia solani* under *in vitro* condition. Yadav (2006) also reported that mycelial growth and sclerotia production of *Rhizoctonia solani* decreased, as the concentration of pyrazosulfuron ethyl in the medium increased from 20 to 70 mg L^{-1} under *in vitro* condition.

5.4 PART 1V- *IN VITRO* SENSITIVITY OF BENEFICIAL ORGANISMS TO HERBICIDE MIXTURES

5.4.1 Effect of Herbicide Mixtures on the Growth of *Trichoderma viride*

Alves *et al.* (1998) pointed out that, *in vitro* tests have the advantage of maximum exposure of microorganism to the chemical of interest which does not occur in the field studies, where various factors can interfere with the exposure. Hence, selectivity obtained through *in vitro* studies offer a greater degree of assurance that the product will not affect the biological agent when used in the field. Selectivity will contribute to the preservation of biological agents encouraging biological equilibrium.

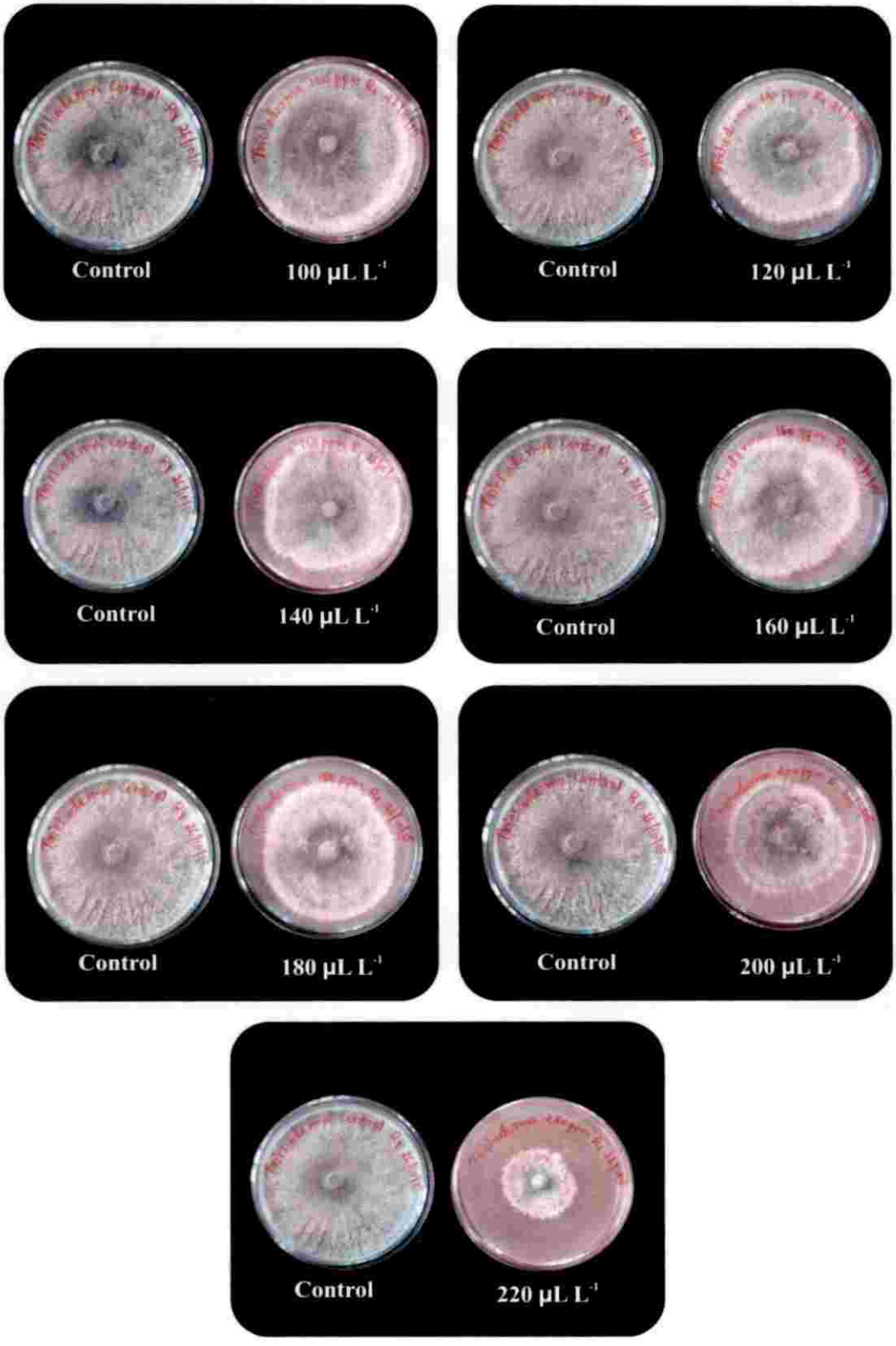

Plate 15. *In vitro* sensitivity of *Trichoderma viride* to bispyribac sodium + metamifop

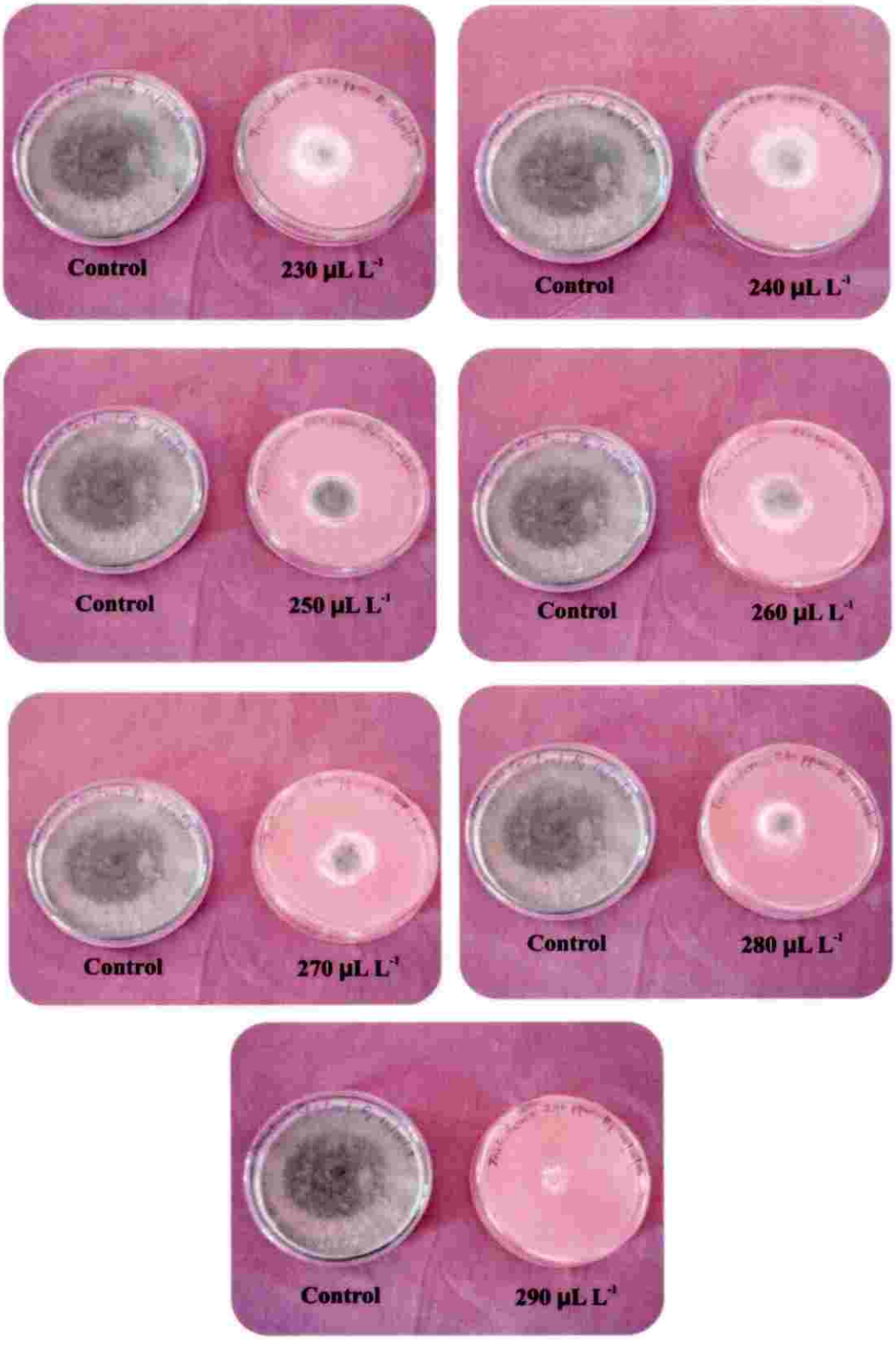

Plate 16. *In vitro* sensitivity of *Trichoderma viride* to penoxsulam + cyhalofop butyl

Results on the *in vitro* effect of bispyribac sodium + metamifop on *Trichoderma viride* revealed that tested concentrations of the herbicide mixture significantly influenced the radial growth of *Trichoderma viride* (Plate 15). The lowest concentration recorded the highest colony diameter (8.53 cm) and the highest tested concentration recorded the lowest colony diameter (5.67 cm). The growth inhibition registered by *Trichoderma viride*, exposed to bispyribac sodium + metamifop @ 100 µL L^{-1} to 220 µL L^{-1} ranged from 5.19 to 37.04 per cent. The field level tested doses 60, 70, 80 and 90 g ha^{-1} corresponding to laboratory doses of 120, 140, 160 and 180 µL L^{-1} recorded the growth inhibition of 8.15 to 22.96 per cent only. According to International Organisation for Biological Control (IOBC) toxicity classification scheme (Sterk *et al.*, 2002), the herbicide mixture, bispyribac sodium + metamifop falls in Class I toxicity category (produced < 25 per cent growth inhibition in the radial mycelial growth of *Trichoderma viride*) and is considered harmless to the antagonistic fungus *Trichoderma viride*. The results of present study indicated that the herbicide mixture bispyribac sodium + metamifop can be safely used in field, where *Trichoderma viride* is applied as seed inoculant against bacterial diseases or to conserve the natural inoculum in the field. Santora *et al.* (2014) reported that, the herbicides, 2, 4-D, clomazone and imazapyr were compatible with *Trichoderma atroviride*.

Results of the *in vitro* effect of penoxsulam + cyhalofop butyl on the growth of *Trichoderma viride* revealed that this herbicide mixture at different concentrations tested significantly influenced the radial growth of *Trichoderma viride* (Plate 16). The growth inhibition was more with increasing concentration of the herbicide mixture. The lowest colony diameter (2.27 cm) was observed in the highest concentration of penoxsulam + cyhalofop butyl (290 µL L^{-1}) recording the maximum growth inhibition of 74. 82 per cent. The highest colony diameter (4.3 cm) was observed in the lowest tested concentration of penoxsulam + cyhalofop butyl (230 µL L^{-1}), with a growth inhibition of 51.85 per cent. The tested field doses *viz.*, 120, 125, 130 and 135 g ha^{-1} were found to be on par in their effect on the radial growth of *Trichoderma viride* and recorded growth

inhibition ranging from 52.59 per cent to 54.44 per cent. According to IOBC toxicity classification scheme (Sterk *et al.*, 2002), penoxsulam + cyhalofop butyl is moderately harmful to *Trichoderma viride,* since the tested doses of herbicide mixture falls in Class III toxicity category (the percentage growth inhibition is between 51 to 75 per cent). The *in vitro* studies also revealed that, the antagonist fungus *Trichoderma viride* is more sensitive to penoxsulam + cyhalofop butyl compared to bispyribac sodium + metamifop. This is because the herbicidal effects on fungal growth are specific with respect to herbicide type and dose (Bollen, 1961; Hattori, 1973). Zain *et al.* (2013) reported that, the inhibitory effect of herbicides on the growth of fungus through soil treatments was lower compared to direct exposure (*in vitro*). Herbicides may undergo certain natural degradation processes (biological, chemical and physical) in soil which could reduce its toxicity to the fungal population (Wilkinson and Lucas, 1969). Hence, there is a possibility of using *Trichoderma viride* for seed treatment or soil application in fields, where the post emergence application of penoxsulam + cyhalofop butyl is intended for weed control.

5.4.2 Effect of Herbicide Mixtures on the Growth of *Pseudomonas fluorescens*

Results of the *in vitro* effect of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl on the growth of *Pseudomonas fluorescens* revealed that both the herbicide mixtures at their tested concentrations did not produce any zone of inhibition around the disc impregnated with the herbicides (Plates 17 and 18). These results indicated that *Pseudomonas fluorescens*, the commonly used biocontrol agent against various bacterial and fungal diseases in rice was highly compatible with the tested herbicide mixtures indicating the suitability of combined application. This will reduce the cost of plant protection. Combination of bio control agents with agrochemicals will have an additive effect and result in enhanced disease control compared to their individual application (Guetsky *et al.*, 2002).

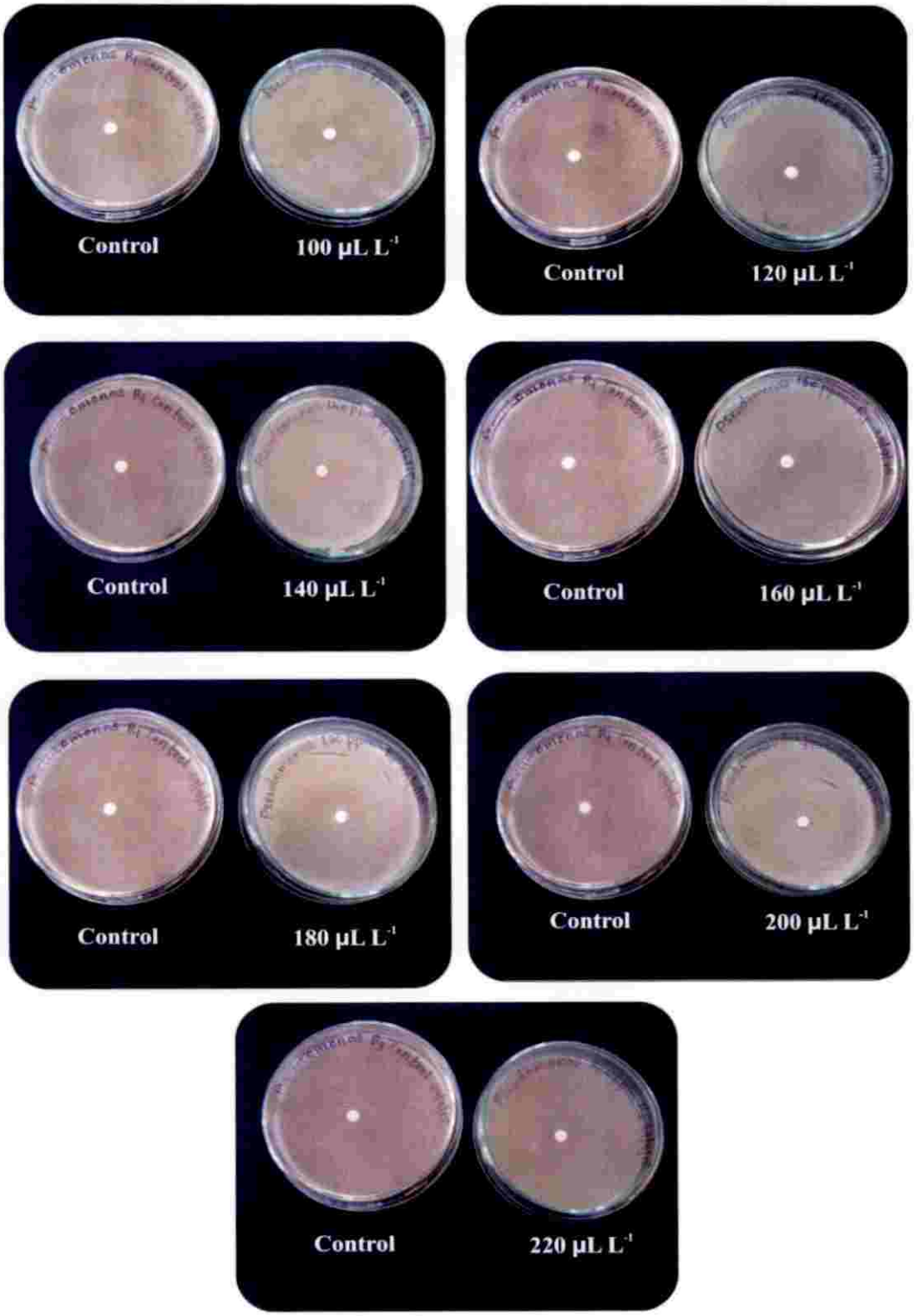

Plate 17. *In vitro* sensitivity of *Pseudomonas fluorescens* to bispyribac sodium + metamifop

Plate 18. *In vitro* sensitivity of *Pseudomonas fluorescens* to penoxsulam + cyhalofop butyl

Several researchers reported that, among the bacteria, *Pseudomonas fluorescens* plays a major role in the degradation of herbicides in the soil, by utilizing it as a source of energy (Jacob *et al.*, 1988; Moneke *et al.*, 2010; Kavikarunya and Reetha, 2012). Hence the use of *Pseudomonas fluorescens* under integrated pest and disease management programme in conjunction with these herbicide mixtures, not only control the disease but also help in reducing the residual effect. The compatibility of *Pseudomonas fluorescens* with herbicides has already been reported by Goutam *et al.* (2004), Surendran *et al.* (2012) and Gangwar, (2013b).

5.4.3 *In vitro* Sensitivity of Bio Fertilizer Organisms to Herbicide Mixtures

Results on the *in vitro* effects of herbicide mixtures on the growth of *Azospirillum lipoferum* and *Azotobacter chroococcum* to assess the compatibility of these organisms to herbicide mixtures *viz*., bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl revealed that, the tested herbicide mixtures and their doses did not have any inhibitory effect on the growth of both these organisms (Plates 19, 20, 21 and 22). These compatibility results indicated the possibility of combined application of tested doses of both the herbicide mixtures along with *Azotobacter chroococcum* and *Azospirillum lipoferum* in rice fields. So the present findings revealed that soil application of the N fixing organism could be exploited along with these herbicide mixtures at tested concentrations.

No serious effect was observed under field conditions on free living N fixers following the herbicide application at recommended dose (Barman and Varshney, 2008). Patnaik and Rao (1994) reported that under normal N fixing conditions, on exposure to 2, 4-D at concentration up to 5 mg L^{-1} stimulate the nitrogenase activity of *Azospirillum*. Saha *et al.* (1991) observed that, *Azospirillum lipoferum* isolated from the pendimethalin treated barley rhizosphere showed *in vitro* tolerance to high concentrations of the herbicide in N free media. Similarly, Madhurima *et al.* (2008) reported that, carbofuran is compatible with *Azospirillum*.

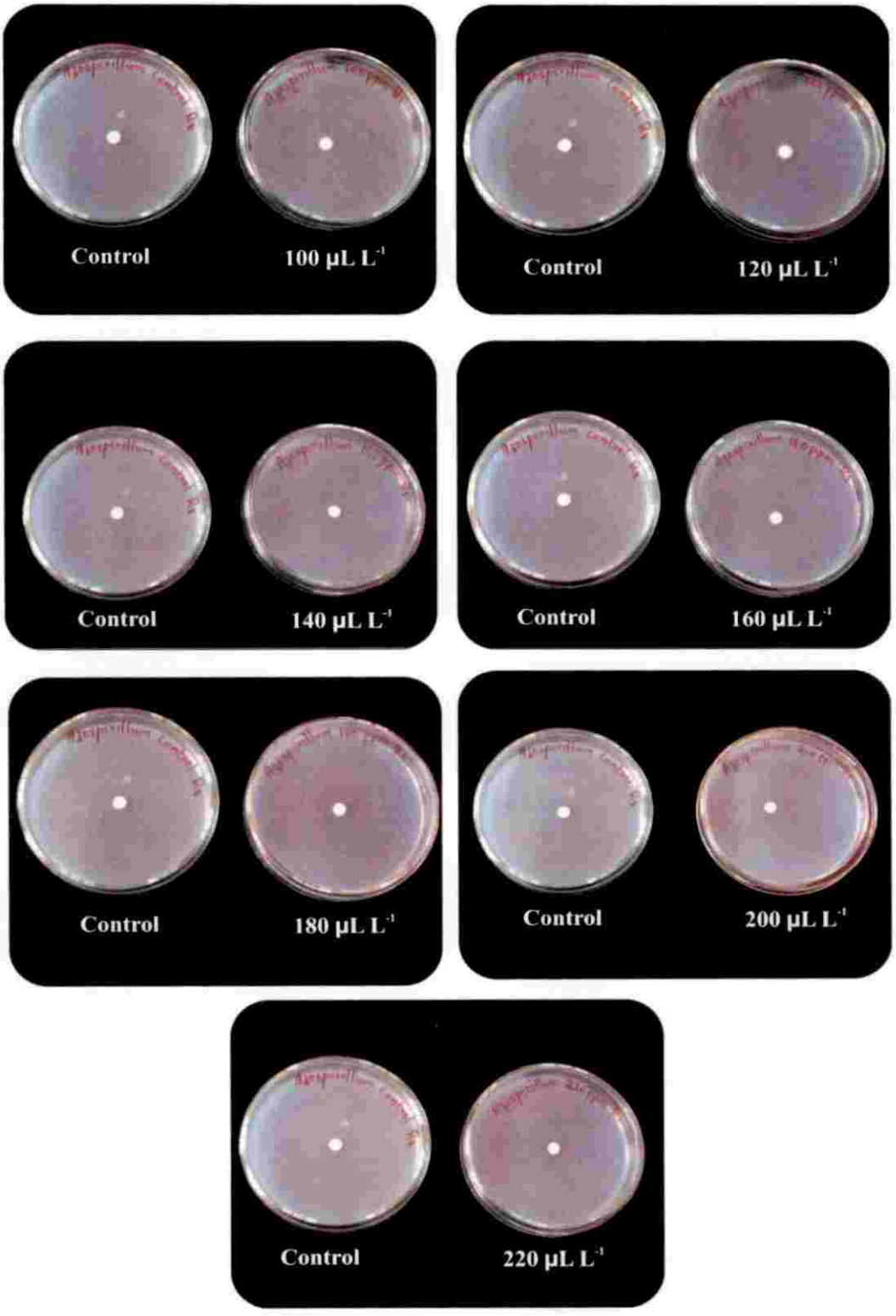

Plate 19. *In vitro* sensitivity of *Azospirillum lipoferum* to bispyribac sodium + metamifop

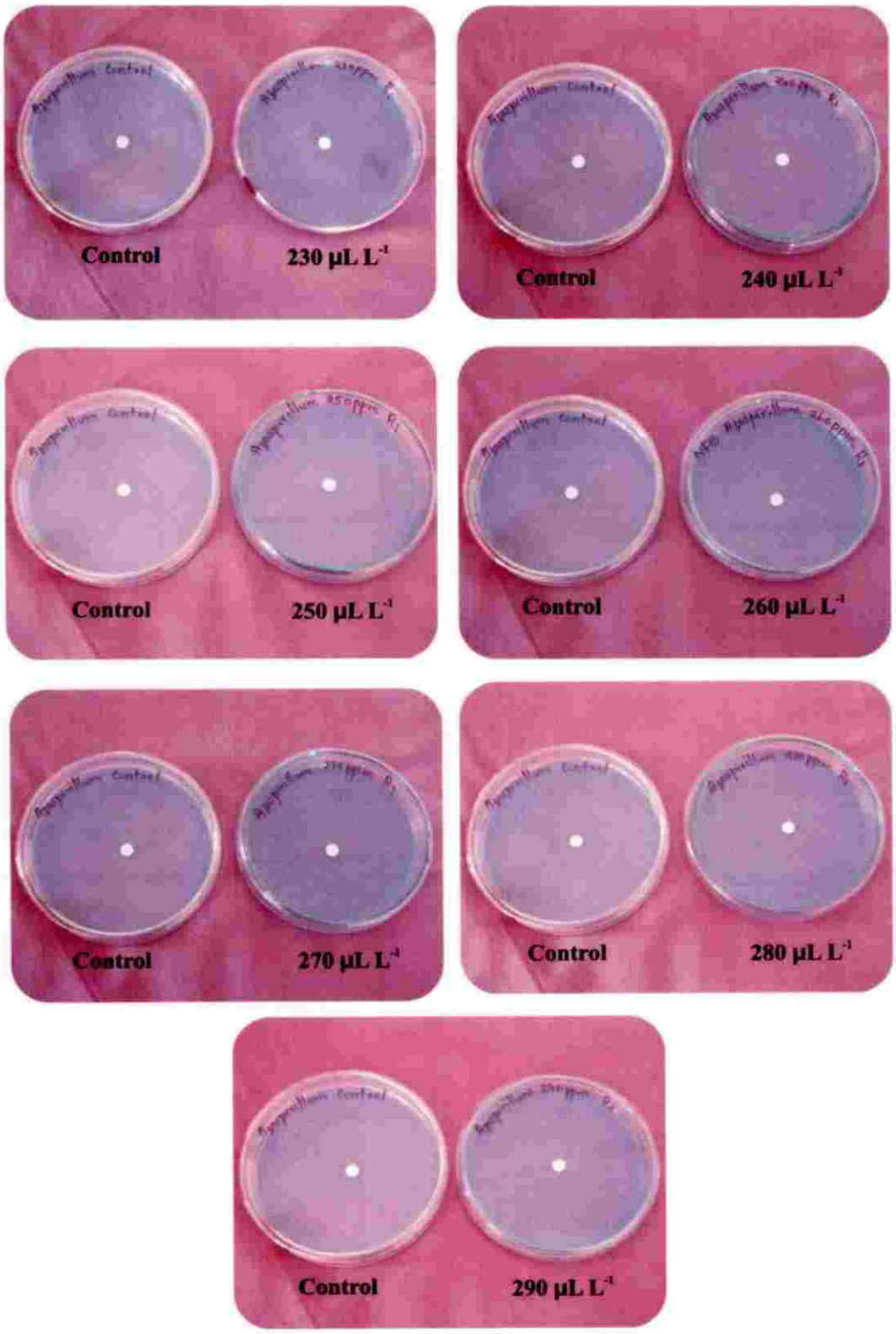

Plate 20. *In vitro* sensitivity of *Azospirillum lipoferum* to penoxsulam + cyhalofop butyl

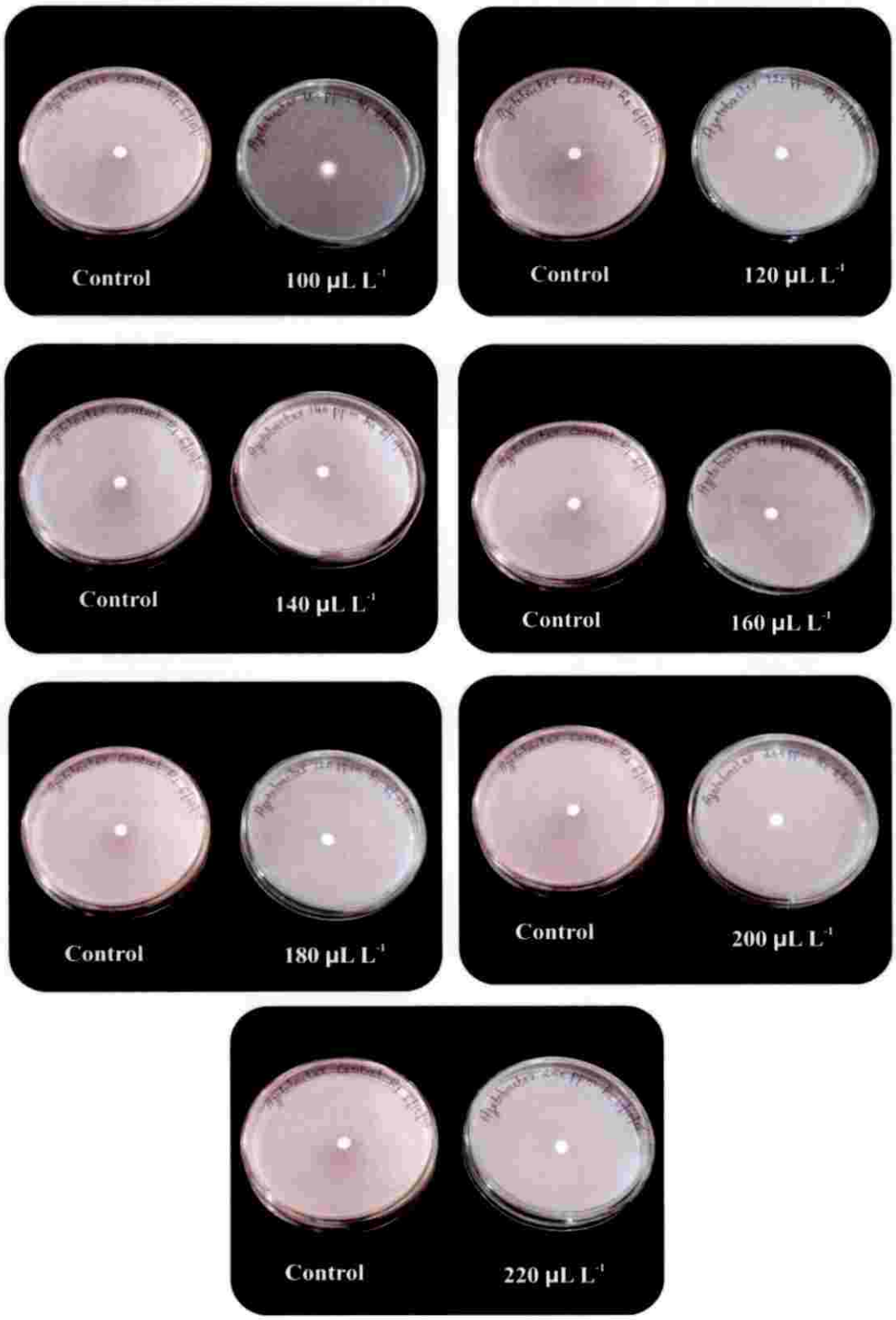

Plate 21. *In vitro* sensitivity of *Azotobacter chroococcum* to bispyribac sodium + metamifop

Plate 22. *In vitro* sensitivity of *Azotobacter chroococcum* to penoxsulam + cyhalofop butyl

Azotobacter chroococcum strains isolated from agricultural soil remain unaffected up to 50 mg L^{-1} concentrations of 2, 4-D in liquid media (Gahlot and Narula, 1996). Mrkovacki *et al.* (2002) reported that the growth of three tested strains of *Azotobacter chroococcum* was unaffected even at 10 times recommended dose of herbicides *viz.*, cycloate and chloridazon. Apart from fixing nitrogen these organisms have the ability to degrade herbicides. So the results of compatibility tests could be exploited for the combined application of these organisms along with the herbicide mixtures at their tested doses, to enhance their population in the soil, as these bacteria are important for sustaining the productivity of soil. Kole *et al.* (1994) pointed out that pendimethalin was effectively degraded by *Azotobacter chroococcum*, utilizing it as a source of carbon. Das *et al.* (2012) also made similar observations for the herbicide quizalofop. Similarly, Khalid and Khokhar (2013) opined that *Azospirillum* and *Azorhizobium* remain active in the presence of herbicides triasulfuron + terbutryn and sulfosulfuron and were able to mitigate the carry over effect of these two herbicides.

5.5 EFFECT OF WEED MANAGEMENT TREATMENTS ON WEED SEED BANK

Size and composition of the seed bank as well as the above ground weed flora reflect the past and present weed and crop composition and soil management practices followed (Roberts and Neilson, 1981). Chauhan (2012) opined that weeds are only the symptom of problem; the main problem is the weed seed bank. Reducing the size of the weed seed bank has been a long term goal of weed management practices, especially when the fields are cropped continuously.

Weed seed bank assay carried out before the first and second crop season revealed that there was no significant difference among the treatments in the number of sedges, BLW and grasses and total weeds emerged from the soil at different time intervals. However, compared to first crop season, weed seed bank assay before the second crop season revealed that there was considerable reduction in the total count of weeds. This implies that weed control measures adopted during the first crop season significantly reduced the number of weed seeds entering the weed seed bank. This is in conformity with the findings of Barberi *et al.* (1998). There was variation

in the pattern of emergence of sedges, BLW and grasses at different time intervals, might be due to the difference in weed seed dormancy and depth of weed seed burial. Weed seed bank possesses different forms of seed dormancy which influence the weed emergence potential (Forcella *et al.*, 1992; Benvenuti, 2007).

Weed seed bank assay after the first and second crop season revealed, significant difference among the treatments in the population of individual as well as total weed flora. Variation was observed in the pattern of emergence of sedges, BLW and grasses in each treatment, at different time intervals. This might be due to the variation in the dormancy of weed seeds and seed buried depth (Akobondu, 1987; Mester and Buhler, 1991).

Application of herbicides and hand weeding registered a significant reduction in the population of sedges after both the first and second crop season (Fig. 19). Among the herbicide mixtures, penoxsulam + cyhalofop butyl was found to be better than bispyribac sodium + metamifop in reducing the weed seed bank of sedges. In both the experiments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest count of sedges emerged from the soil. In the field experiments also, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was found to be more effective in reducing the density of sedges. Weed seed bank observations indicated that, compared to weedy check, population of sedges was reduced by 60.40 and 88.70 per cent, respectively after the first and second crop season; however, compared to hand weeding, the percentage reduction was 45.44 and 67.60 per cent, respectively. Compared to penoxsulam applied alone @ 22.5 g ha^{-1}, the percentage reduction in the found of sedges by the application of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was 34.44 and 63.24, respectively and compared to bispyribac sodium applied alone @ 25 g ha^{-1} the percentage reduction was 36.46 and 70.94, respectively after the first and second crop season. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} significantly reduced the density of sedges (Tables 8 and 13). This might be the plausible reason for the reduction in the weed seed bank of sedges in this treatment. Singh *et al.* (2012) reported that the main source of weed seeds in the seed bank is the local matured weeds that set seed. Weedy check recorded the highest number of sedges emerged and this implies that, if weeds are not controlled timely before flowering, enormous quantity of seeds are produced which will replenish the weed seed bank.

Before the first crop

After the second crop

Plate 23. Weed seed bank assay

Perusal of data on weed seed bank assay after the first and second crop season on the population of BLW revealed that, as compared to weedy check there was significant reduction in the emergence of BLW in all the herbicide treatments and hand weeding. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest population of BLW after the first crop season and penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest population after the second crop season (Fig. 20). Both these treatments were statistically on par with bispyribac sodium + metamifop @ 80 and 90 g ha^{-1}. However, after the second crop season penoxsulam + cyhalofop butyl @ 125 g ha^{-1} was also on par with its higher dose of 135 g ha^{-1}.

It has been observed that, as compared to hand weeding, the treatments bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} reduced the emergence of BLW by 42.25 and 39.05 per cent and 72.80 and 86.22 per cent, respectively after the first and second crop seasons. Compared to penoxsulam applied alone @ 22.5 g ha^{-1}, bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} recorded a reduction in the emergence of BLW by 30.82 and 26.98 and 13.23 and 56.03 per cent, respectively. Compared to bispyribac sodium applied alone @ 22.5 g ha^{-1}, these treatments reduced the emergence of BLW by 29.53 and 25.62 per cent and 68.61 and 38.06 per cent, respectively after first and second crop seasons.

As compared to hand weeding, penoxsualm + cyhalofop @ 125 and 135 g ha^{-1} reduced the emergence of BLW by 23.40 and 48.36 per cent and 91.87 and 85.0 per cent, respectively after the first and second crop season. Compared to penoxsulam @ 22.5 g ha^{-1}, the percentage reduction of BLW was 8.23 and 38.13 and 74.04 and 52.14, respectively and compared to bispyribac sodium @ 25 g ha^{-1} the percentage reduction was 6.52 and 36.98 and 81.47 and 65.83, respectively.

The reduction in the weed seed bank of BLW in these treatments might be due to the better control of BLW well before flowering and seed setting (Tables 9 and 14). Higher population of BLW in the weedy check might have enhanced the seed rain from mature weeds, as the weeds were not controlled and allowed to grow throughout the season. Roberts (1982) reported that weedy field may contain large

amount of viable weed seeds; similarly Sheibani and Ghadiri (2012) reported that weedy plots had the highest number of weed seeds in 0-15 cm depth.

Similar to sedges and BLW, a significant reduction in the emergence of grasses was also observed in the herbicide treated pots and hand weeding treatment as compared to weedy check. Weed seed bank assay carried out after the first and second crop season indicated that penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest emergence of grasses among the treatments (Fig. 21). After the first and second crop season, as compared to hand weeding, penoxsulam + cyhalofop butyl @ 125 g ha^{-1} reduced the grass population by 55.67 and 65.99 per cent, respectively. While compared to bispyribac sodium applied alone at 25 g ha^{-1}, the percentage reduction in the grass population was 78.82 and 84.52, respectively and compared to penoxsulam applied alone @ 22.5 g ha^{-1}, the percentage reduction was 64.17 and 71.10, respectively. Significant reduction in the weed seed bank of grasses in this treatment might be due to the better control of grasses. Sheibani and Ghadiri (2012) opined that herbicide application indirectly affect the weed seed bank by reducing the number of seed producing plants.

Data on the total weed population after the first and second crop season revealed that non herbicide treatments *viz.*, weedy check and hand weeding recorded the highest emergence of weeds and were significantly inferior in reducing the size of the weed seed bank. Buhler *et al.* (2001) pointed out that when weeds were controlled by cultivation only, the seed bank was approximately 25 times greater than where herbicides in conjunction with cultivation practices were adopted for weed control. Many researchers have the opinion that absence of herbicides has resulted in increased weed seed bank (Hyvonen and Salonen, 2002). Among the treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest weed seed bank after the first crop season and the percentage reduction was 57.07 per cent. Compared to weedy check, the percentage reduction was 58.69 and compared to hand weeding, the percentage reduction was 46.36. Compared to individual application of penoxsulam @ 22.5 and bispyribac sodium @ 25 g ha^{-1}, the percentage reduction was 36.57 and 37.90, respectively.

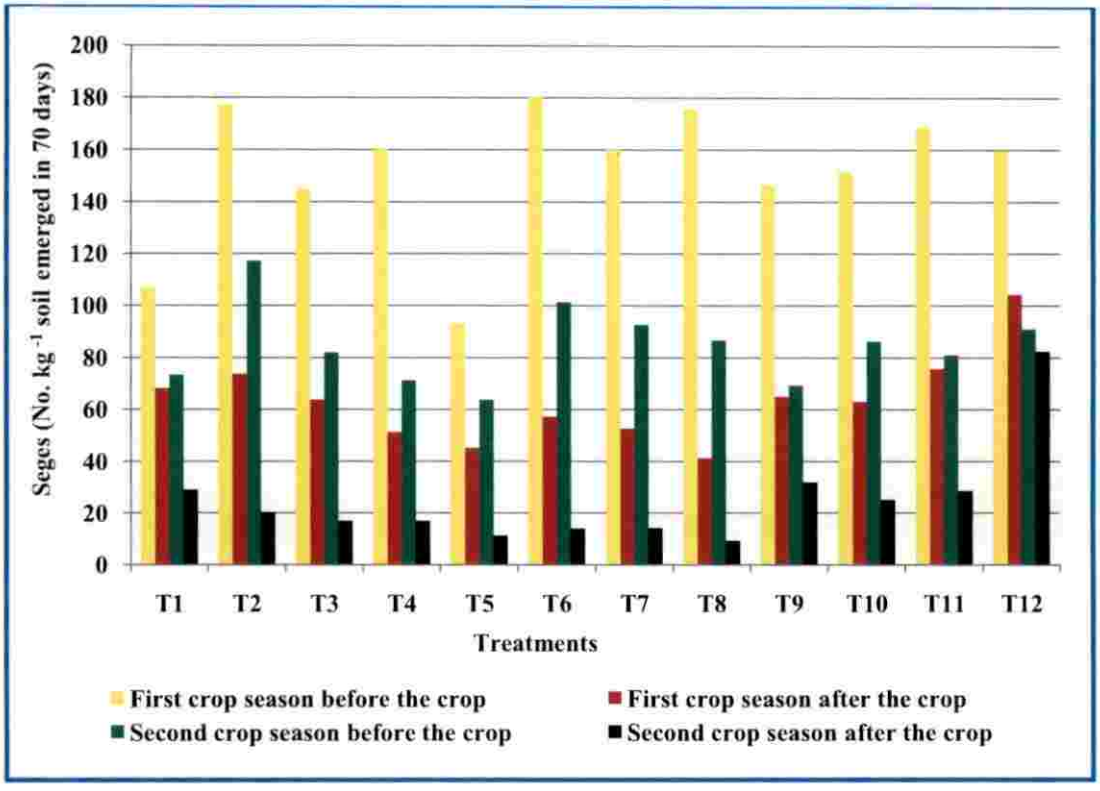

Fig 19. Emergence of sedges as influenced by weed management treatments before and after the first and second crop

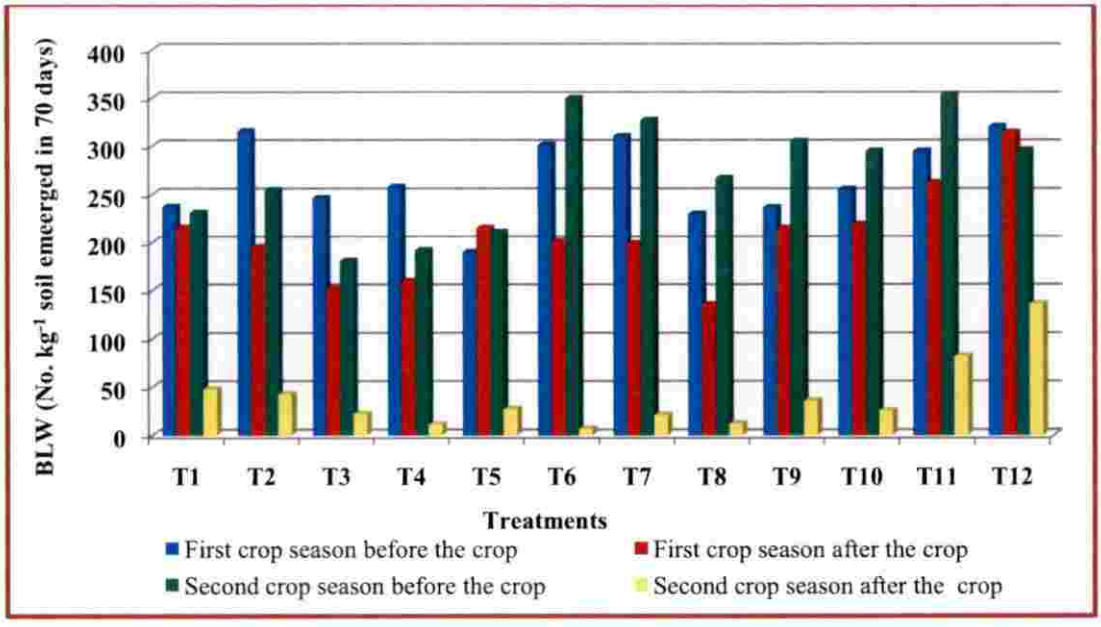

Fig 20. Emergence of broad leaf weeds (BLW) as influenced by weed management treatments before and after the first and second crop

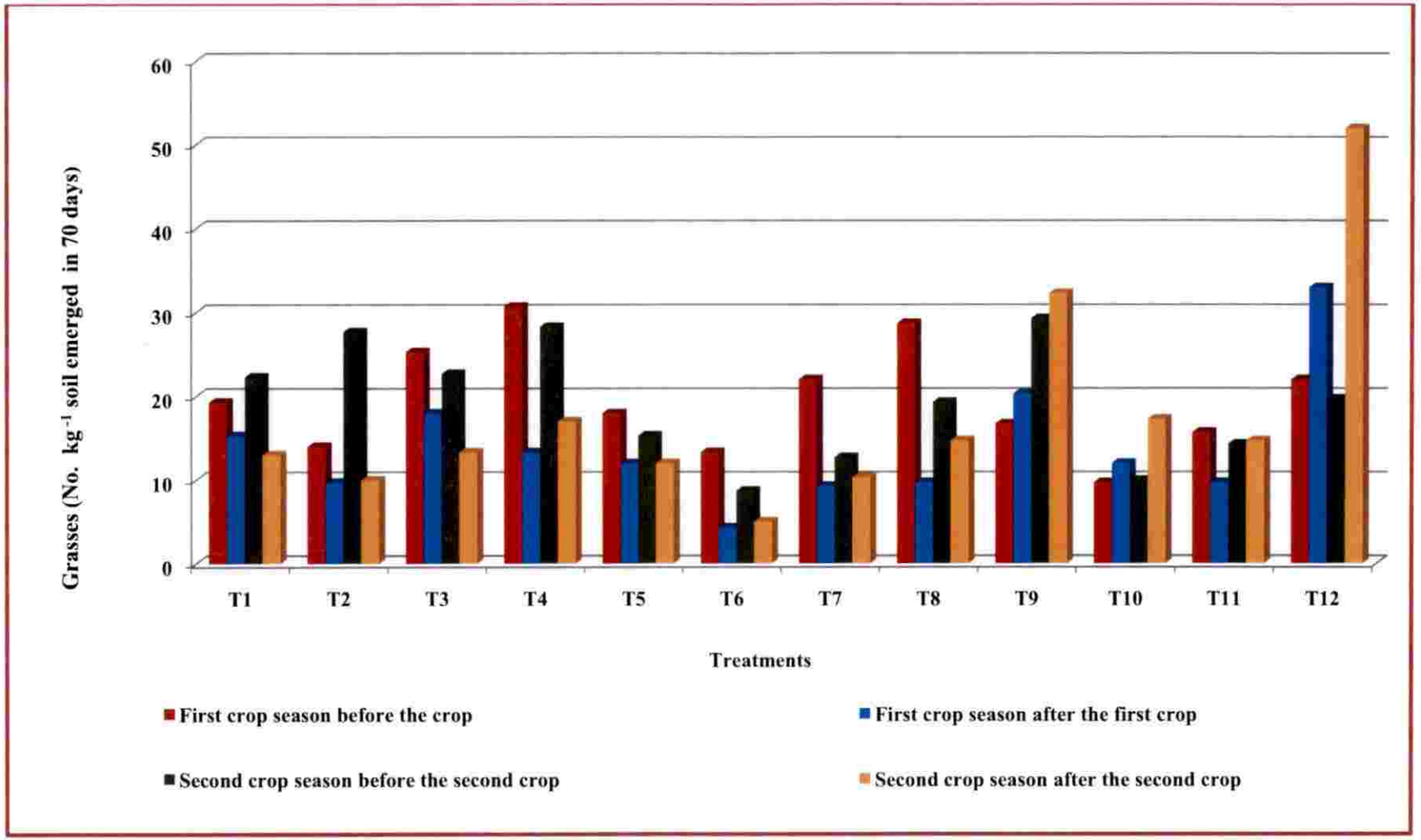

Fig 21. Emergence of grasses as influenced by weed management treatments before and after the first and second crop

Weed seed bank assay after the second crop season revealed that penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest weed population and was on par with its higher doses of 135 and 130 g ha^{-1}. These treatments reduced the weed seed bank by 94.41, 90.28 and 89.43 per cent, respectively. The percentage reduction in the emergence of weeds in treatments penoxsulam + cyhalofop butyl @ 125 and 135 g ha^{-1} as compared to hand weeding were 79.48 and 71.03 per cent, respectively. Compared to bispyribac sodium @ 25 g ha^{-1} the percentage reduction was 74.38 and 63.81 per cent, respectively and compared to penoxsulam @ 22.5 g ha^{-1}, the reduction was 62.37 and 46.85 per cent, respectively. Significant reduction of weed seed bank in these treatments might be due to the better control of weeds before flowering and decay of seeds already present in the soil. Voll *et al.* (1996) reported that application of herbicides can lead to exhaustion of the weed seed bank and similarly Carmona (1992) observed that application of certain chemicals contributed to an accelerated decay rate of seeds in the soil. Among the different doses of bispyribac sodium + metamifop tested, its highest dose (90 g ha^{-1}) was better than other three doses in reducing the weed seed bank. This was mainly because of the better efficacy in controlling the sedges, BLW and grasses, the major group of weeds present in the soil. Schweizer and Zimdahl (1984) reported that the number of weed seeds in continuous corn dropped by approximately 70 per cent after three years of herbicide application and inter row cultivation. Several researchers (Jain *et al.*, 2006; Walia and Brar, 2006; Konstantinovic and Blagojevic, 2014) have reported that herbicide use reduced the weed seed bank considerably.

From the weed seed bank assay results it could be concluded that the herbicide mixtures *viz.*, penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop were not only effective in reducing the current density of weeds but also effective in depleting the weed seed bank, than their individual application. Similar to field investigation, weed seed bank assay results also revealed that penoxsulam + cyhalofop butyl was more effective in reducing the weeds than bispyribac sodium + metamifop in direct seeded rice. Among the tested doses of

penoxsulam + cyhalofop butyl the higher doses of 135, 130 and 125 were more effective than its lower dose of 120 g ha^{-1}.

The present study revealed the importance of weed management in direct seeded rice. Due to the simultaneous emergence of crop and weed and absence of water at the time of crop emergence, weeds gain competitive advantage over the crop and resulted in 50.38 per cent yield reduction in wet direct seeded rice. The study also revealed the superiority of herbicide mixtures *viz*., penoxsulam + cyhalofop butyl @ 125, 130 and 135 g ha^{-1} and bispyribac sodium + metamifop @ 70, 80 and 90 g ha^{-1} applied on 15 DAS over individual application of penoxsulam @ 22.5 g ha^{-1} and bispyribac sodium @ 25 g ha^{-1}. However, penoxsulam + cyhalofop butyl @ 130 and 135 g ha^{-1} can be recommended as a cost effective and ecofriendly weed management practice for wet seeded rice, as it ensures broad spectrum control of weeds, better depletion of weed seed bank, better net returns and B: C ratio, environmental safety, better reduction in the mycelial growth of fungus, *Rizoctonia solani* which cause sheath blight disease in rice and compatibility with all beneficial organisms tested in this investigation *Pseudomonas fluorescens*, *Trichoderma viride*, *Azospirillum lipoferum* and *Azotobacter chroococcum*.

Summary

6. SUMMARY

The experiment entitled "Herbicide mixtures for weed management in direct seeded puddled rice *Oryza sativa* L." was carried out during the first and second crop seasons of 2014-15. The main objectives of the experiment were to assess the bio-efficacy of the herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl for weed control in direct seeded rice; to study their residual effect in soil using bioassay technique; to study the impact of these herbicide mixtures on soil microorganisms, enzyme activity and earth worm population in soil and weed seed bank; to assess the *in vitro* sensitivity of these herbicide mixtures to soil borne pathogen *viz.*, *Rhizoctonia solani*, beneficial microorganisms *viz.*, *Pseudomonas fluorescens*, *Trichoderma viride* and N fixing organisms *Azospirillum lipoferum* and *Azotobacter chroococcum*. The investigation comprised of five parts *viz.*, bio-efficacy of post emergence herbicide mixtures in direct seeded rice, bioassay studies, *in vitro* sensitivity to soil borne pathogen-*Rhizoctonia solani*, *in vitro* sensitivity to beneficial organisms and weed seed bank assay.

The first part of the study was a field experiment undertaken in farmer's field in Upanniyoor padashekaram during the period from May 2014 to March 2015 for two consecutive seasons. The field experiment was laid out in RBD with 12 treatments and three replications. The treatments comprised of four doses of bispyribac sodium + metamifop *viz.*, 60 (T_1), 70 (T_2), 80 (T_3) and 90 g ha^{-1} (T_4), four doses of penoxsulam + cyhalofop butyl *i.e.*, 120 (T_5), 125 (T_6), 130 (T_7) and 135 g ha^{-1} (T_8), bispyribac sodium applied alone @ 25 g ha^{-1} (T_9), penoxsulam applied alone @ 22.5 g ha^{-1} (T_{10}), hand weeding twice (T_{11}) and weedy check (T_{12}). The results of the field experiment are summarized below.

Visual phytotoxicity rating recorded seven days after herbicide spraying, adopting 1- 10 scale, indicated that the herbicide mixtures, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl at the tested doses did not produce any phytotoxic symptom in rice plant.

Weed control treatments significantly influenced the growth attributes *viz.*, plant height, LAI, DMP and tillers m^{-2} of wet seeded rice. Plants in the herbicide treated plots registered more height at 30 and 60 DAS and at harvest stage compared to weedy check. Weedy check recorded significantly lower values for tillers m^{-2}, leaf area index and dry matter production at all the stages of plant growth. In general, penoxsulam + cyhalofop butyl @ 125, 130 and 135 and bispyribac sodium + metamifop @ 90 g ha^{-1} recorded higher values for these growth characters.

Weed control treatments significantly influenced all the yield attributes except thousand grain weight. Weedy check registered significantly lower values for panicles m^{-2}, fertile grains per panicle, panicle weight, sterility percentage and 1000 grain weight. The herbicide treatments, penoxsulam + cyhalofop butyl @ 125, 130 and 135 g ha^{-1} recorded higher values for yield attributes *viz.*, panicles m^{-2}, fertile grains per panicle, panicle weight and 1000 grain weight and lower values for sterility percentage during first and second crop season. Among the different doses of bispyribac sodium + metamifop tested, its higher dose (90 g ha^{-1}) recorded higher values for yield attributes *viz.*, panicles m^{-2}, fertile grains per panicle, panicle weight and 1000 grain weight and lower sterility percentage during both the seasons.

Grain yield was significantly influenced by the weed control treatments during both the seasons. The weed management practices enhanced the grain yield from 4285 to 8295 kg ha^{-1} during first crop season and from 4240 to 8889 kg ha^{-1} during second crop season with 48.34 and 52.30 per cent increase in yield respectively. During first crop season, penoxsulam + cyhalofop buyl @ 130 g ha^{-1} recorded the highest grain yield which was statistically on par with penoxsulam + cyhalofop butyl @ 135 g ha^{-1} and 125 g ha^{-1}. However, during second crop season, penoxsulam + cyhalofop buyl @ 135 g ha^{-1} recorded the highest grain yield which was significantly superior to all other treatments. Pooled analysis of two seasons data revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the highest grain yield which was statistically on par with its lower doses

viz., 130 and 125 g ha^{-1}. Among the different doses of bispyribac sodium + metamifop, its highest dose (90 g ha^{-1}) recorded the highest grain yield and it was on par with penoxsulam + cyhalofop butyl @ 125 g ha^{-1} and bispyribac sodium + metamifop @ 80 g ha^{-1}.

The straw yield was not significantly influenced by the weed control treatments during both the seasons. Pooled analysis of data also revealed that, weed control treatments did not exert any significant effect on straw yield.

Harvest index varied significantly influenced due to the weed control treatments. Herbicide treated plots and hand weeding twice recorded significantly higher harvest index compared to weedy check during both the seasons of study.

Economic analysis also confirmed the superiority of herbicide mixtures. During first crop season, penoxsulam + cyhalofop butyl @ 130 g ha^{-1} recorded the highest net returns, which was on par with its higher dose (135 g ha^{-1}) and the lower dose (125 g ha^{-1}); however, during second crop season, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded a net return of 1,013,53 ₹ ha^{-1} which was significantly superior to other treatments. Pooled analysis of data revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the highest net returns, which was on par with its lower dose, 130 g ha^{-1}. B: C ratio also followed the same trend.

Observations on weed flora indicated that, there was considerable diversity in weed species infesting the experimental area. The quantitative assessment of weed vegetation analysis parameters *viz.*, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio of the experimental area revealed that, sedges were the predominant weed flora, followed by BLW. The grass weed population was comparatively low.

Among the sedges, the major ones were *Schoenoplectus juncoides*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea*. Broad leaf weeds in the experimental field comprised of *Ludwigia perennis*, *Limnocharis flava*, *Sphenoclea zeylanica*, *Marsilea quadrifolia*, *Bergia capensis*, *Commelina diffussa*

and *Monochoria vaginalis*. *Isachne miliacea* was the only grass species present in the experimental area.

Among the two herbicide mixtures tested, penoxsulam + cyhalofop butyl was more effective in reducing the density of sedges and BLW. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} registered the lowest density of sedges and BLW among the treatments at 30 and 60 DAS. The two tested herbicide mixtures *viz*., bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl were found to be more or less similar in effectiveness in reducing the density of grasses.

Weed control treatments significantly reduced the total density of weeds compared to weedy check. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was found to be more effective in reducing the total density of weeds at all stages of plant growth. It has also been observed that at 60 DAS during both the seasons, all herbicide treatments except, bispyribac sodium + metamifop @ 60 g ha^{-1} and bispyribac sodium applied alone @ 25 g ha^{-1}, recorded lower density of weeds than hand weeding twice.

Penoxsulam + cyahlofop butyl @ 135, 130 and 125 g ha^{-1} recorded lower dry weight of sedges and broad leaf weeds as compared to hand weeding twice, penoxsulam alone and bispyribac sodium alone at 30 and 60 DAS during both the seasons. Among the different doses of bispyribac sodium + metamifop, its highest dose *viz*., 90 g ha^{-1} was found to be better in reducing the dry weight of sedges and BLW. Penoxsulam + cyhalofop butyl @ 120, 125, 130 and 135 g ha^{-1} and bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} controlled grasses more effectively than the individual application of bispyribac sodium and penoxsulam.

Weedy check registered the highest total dry weight of weeds at all stages of plant growth and was significantly inferior to the rest of the treatments. Among the treatments, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} were found to be more effective in reducing the total dry weight of weeds at all stages

of growth. Bispyribac sodium + metamifop applied @ 90 g ha^{-1} registered lower total dry weight of weeds as compared to its other tested doses.

Weed control efficiency varied significantly due to weed control treatments during both the seasons. Among the two premix herbicides tested, penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} registered higher weed control efficiency than bispyribac sodium + metamifop. Among the different doses of bispyriac sodium + metamifop tested, its highest dose (90 g ha^{-1}) recorded higher weed control efficiency.

Weed index which indicates the percentage yield reduction due to weeds, was also significantly influenced by the weed control treatments. Pooled analysis of data revealed that, the lowest weed index was recorded in penoxsulam + cyhalofop butyl @ 135 g ha^{-1} which was statistically on par with its lower dose (130 g ha^{-1}). It was also revealed that, weeds caused a yield reduction of 50.38 per cent.

Compared to weedy check, all the herbicide treatments reduced the nutrient uptake by weeds during both the seasons. Herbicide treatments reduced the nitrogen uptake by weeds over weedy check, to the tune of 89.04 to 99.22 per cent and 89.67 to 99.36 per cent, respectively, phosphorus uptake was reduced by 89.00 to 99.49 per cent and 89.54 to 99.47 per cent, respectively and K uptake was reduced by 84.51 to 99.01 per cent and 86.22 to 99.42 per cent, respectively during first and second crop season seasons. Among the three primary plant nutrients, substantial quantity of N was removed by weeds than P and K. Penoxsulam + cyhalofop butyl @ 135, 130 and 125 g ha^{-1} recorded lower N, P and K uptake by the weeds at 30 and 60 DAS. Among the different doses of bispyribac sodium + metamifop, its higher dose of 90 g ha^{-1} recorded lower N, P and K uptake by weeds.

Compared to weedy check, all the herbicide treated plots recorded higher amount of available N, P and K in the soil at all stages of observation. At 60

DAS, weeds removed 70.47 kg N, 7.82 kg P_2O_5 and 36.27 kg K_2O during first crop season and 60.77 kg of N, 7.55 kg P_2O_5 and 30.98 kg K_2O during second crop season. Nutrient availability at 30 and 60 DAS and at harvest stage revealed that, penoxsulam + cyhalofop butyl @ 135,130 and 125 g ha^{-1}, bispyribac sodium + metamifop @ 90, 80 and 70 g ha^{-1}, penoxsulam applied alone and hand weeding twice were more effective in maintaining a high level of available N, P and K in the soil.

N uptake by crop at 30 and 60 DAS and at harvest stage was also significantly influenced by the weed control treatments. Uptake of nutrients by the crop steadily increased from active tillering to harvest stage. At all stages of crop growth, weedy check recorded the lowest uptake of N, P and K.

Dynamics of soil microbial population consequent to the application of herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl revealed that these herbicide mixtures and their tested doses did not have any inhibitory effect on the growth of soil bacteria, fungi and actinomycetes at different stages of observation.

Assay of dehydrogenase, β glucosidase, protease, acid phosphatase and urease activity in soil at different crop growth stages revealed that, the tested herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl and their tested doses did not have any negative impact on the activity of soil enzymes. These treatments registered significantly higher or comparable values for dehydrogenase, β glucosidase, protease, acid phosphatase and urease activity with that of non-herbicide treatments *viz.*, weedy check and hand weeding twice.

Earth worm population was also not affected by the weed control treatments during both the years.

Weed management treatments significantly influenced the organic carbon content of the soil at 30 and 60 DAS (corresponding to 15 and 45 DAHA) and at

harvest stage during both the seasons. An increase in organic carbon content in soil was observed from 30 to 60 DAS during both seasons. As compared to weedy check, the hand weeding treatment and herbicide treatments recorded comparable or higher organic carbon content in the soil at 30 and 60 DAS and at harvest stage. Results indicated that, the applied herbicides and their doses did not have any adverse impact on organic carbon content of soil.

A critical review of the impact of the present study on soil health parameters *viz*., soil microbial count, enzyme assay, earth worm count and organic carbon content in soil at different growth stages confirmed the environmental safety of the two tested herbicide mixtures *viz*., bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl, at tested field doses.

Screening of indicator plant was conducted as the second part of the investigation, wherein the most sensitive indicator plant for these two herbicide mixtures were screened out to study the residual effect of tested herbicide mixtures *viz*., bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl in soil. Maize was selected as the most sensitive indicator plant for assessing the residual effect of both the herbicide mixtures among the three indicator plants tested *viz*., cucumber, sunflower and maize. Among the various parameters compared, shoot dry weight of maize was selected as the best parameter for assessing the residual effect of bispyribc sodium + metamifop in soil based on the response curve and response equations developed. Logarithmic linear regression equation developed for maize shoot dry weight was $Y= 0.0977 - 0.0230 \ln (X)$, $R^2 = 0.9548$. Similarly for the herbicide mixture, penoxsulam + cyhalofop butyl, fresh weight of maize shoot was selected as the most sensitive parameter for determining the residual effect in soil. Logarithmic linear regression equation developed for fresh weight of maize shoot was $Y= 1.0621 - 0.2030 \ln (X)$, $R^2 = 0.9854$.

Using maize as indicator plant, pot culture bioassay studies conducted in the post experiment soil revealed that there were no significant differences among

the treatments in the parameters studied during both the seasons. These results confirm that, the herbicide mixtures at the doses did not have any toxic residual effect.

In vitro studies were carried out as the third part of the experiment to test the effect of herbicide mixtures bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl on soil borne rice pathogen *Rhizoctonia solani* causing sheath blight disease. As the concentration of the herbicide increases, a decrease in radial growth of the fungi was observed in both the herbicide mixtures. The tested field doses of penoxsulam + cyhalofop butyl *viz.*, 120, 125, 130 and 135 g ha^{-1} corresponding to laboratory doses of 230, 240, 260 and 270 µL L^{-1} registered an inhibition in the mycelial growth of *Rhizoctonia solani* by 42.22, 52.59, 63.70 and 77.04 per cent, respectively. The highest tested dose (290 µL L^{-1}) inhibited the radial growth of *Rhizoctonia solani* by 90.74 per cent. In the case of bispyrbac sodium + metamifop, the lowest tested concentration of 100 µL L^{-1} recorded the maximum colony diameter of 5.27 cm with a growth inhibition of 41.48 per cent and the highest tested concentration (220 µL L^{-1}) recorded the colony diameter of 0.47 cm with a growth inhibition of 94.81 per cent. The above findings throw light on the additional benefits of disease suppression that can be derived through the application of herbicide mixtures, penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop. The inhibitory effect of herbicide mixtures on the growth of *Rhizoctonia solani* along with their effectiveness in weed control can be exploited under integrated pest and disease management programmes.

In vitro sensitivity of beneficial organisms to herbicide mixtures was assessed as the fourth part of the experiment. The field level tested doses of bispyribac sodium + metamifop *viz.*, 60, 70, 80 and 90 g ha^{-1} corresponding to laboratory doses of 120, 140, 160 and 180 µL L^{-1} recorded a growth inhibition of 8.15 to 21.56 per cent, only. The results confirm that seed and soil application of *Trichoderma viride* is possible without any detrimental effect along with tested field doses of bispyribac sodium + metamifop @ 60, 70, 80 and 90 g ha^{-1} under

bio intensive pest management programme. Results on the *in vitro* effect of penoxsulam + cyhalofop butyl on *Trichoderma viri*de revealed that, as compared to bispyribac sodium + metamifop, the antagonist fungus, *Trichoderma viride* is more sensitive to penoxsulam + cyhalofop butyl. The tested field doses of penoxslam + cyhalofop butyl *viz*., 120, 125, 130 and 135 g ha^{-1} were found to be on par in their effect on radial growth of the fungal mycelium and recorded the growth inhibition of 52.59 to 54.44 per cent, indicating the possibility of using this antagonist fungi for soil application in fields, where the post emergence application of penoxsulam + cyhalofop butyl is intended for weed control.

In vitro effect of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl on the growth of *Pseudomonas fluorescens,* the most widely used bio control organism in rice pointed out that both the herbicide mixtures at their tested concentrations did not produce any zone of inhibition around the filter paper disc impregnated with the herbicides at the tested concentrations. These results indicate the possibility of combined application of *Pseudomonas fluorescens* and tested herbicide mixtures in integrated pest and disease management programme.

In vitro compatibility studies of N fixing organism *viz*., *Azospirillum lipoferum* and *Azotobacter chroococcum* with herbicide mixtures *viz*., penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop revealed that, the herbicide mixtures at the tested doses did not have any inhibitory effect on the growth of both N fixing organisms. These results confirm the possibility of combined application of both the herbicide mixtures along with *Azotobacter chroococcum* and *Azospirillum lipoferum* in rice fields.

Weed seed bank assay were carried out before and after the first and second crop season as the fifth part of the experiment. Results of the weed seed bank assay after the first and second crop season indicated that significant reduction was observed in the emergence of sedges, BLW and grasses in all the herbicide treatments. It has also been revealed that, among the herbicide

mixtures, penoxsulam + cyhalofop butyl was found to be better than bispyribac sodium + metamifop in reducing the seed bank of sedges. Among the treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest sedges population.

Weed seed bank assay after the first crop season revealed that, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded significantly lower population of BLW population. However, after the second crop season, penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest BLW population, but it was on par with 135 g ha^{-1}. Both these treatments were statistically on par with bispyribac sodium + metamifop @ 80 and 90 g ha^{-1} in reducing the seed bank of BLW.

Similar to sedges and BLW, significant reduction was observed in the emergence of grasses in herbicide treated plots. Penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest emergence of grasses, among the treatments.

Data on the total weed population after the first and second crop season revealed that non herbicide treatments *viz.*, weedy check and hand weeding twice recorded the highest emergence of weeds and were significantly inferior in reducing the size of the weed seed bank. Among the treatments, penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the lowest weed seed bank after the first crop season. However, after the second crop season penoxsulam + cyhalofop butyl @ 125 g ha^{-1} recorded the lowest weed population and was on par with its higher doses of 135 and 130 g ha^{-1}.

From the weed seed bank assay results it can be concluded that both the herbicide mixtures were effective in reducing the weed seed bank than their individual application. Among the herbicide mixtures, penoxsulam + cyhalofop butyl was found to be more effective in the depletion of weed seed bank. The higher doses of penoxsulam + cyhalofop butyl (135, 130 and 125 g ha^{-1}) were found to be more effective than its lower dose of 120 g ha^{-1}. Among the tested

doses of bispyribac sodium + metamifop, its higher doses (90 and 80 g ha^{-1}) were better than other two lower doses in reducing the weed seed bank.

The present study emphasized the superiority of herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl applied @ 125, 130 and 135 g ha^{-1} and 70, 80 and 90 g ha^{-1}, respectively over the individual application of penoxsulam @ 25 g ha^{-1} and bisyribac sodium @ 22.5 g ha^{-1}. The bioassay as well as soil health impact assessment *viz.*, estimation of microbial count, earth worm population and enzyme assays ensures the safety of the herbicide mixtures, penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop to soil environment. However, based on economic analysis, weed seed bank assay, compatibility with beneficial organisms *viz.*, *Pseudomonas fluorescens*, *Trichoderma viride*, *Azospirillum lipoferum and Azotobacter chroococcum* and its inhibitory effect towards the mycelial growth of *Rhizoctonia solani*, penoxsulam + cyhalofop butyl @ 135 and 130 g ha^{-1} could be adjudged as the best treatments for effective weed management in wet seeded rice.

Future line of work

- The persistence and dissipation of these herbicide mixtures in soil and the major microorganisms involved in their degradation needs further investigation.
- A detailed study to find out the changes on weed flora consequent to the application of penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop under upland and semi-dry conditions is required.
- Effect of these herbicide mixtures on sheath blight incidence under field condition needs investigation.

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*Original not seen

Abstract

HERBICIDE MIXTURES FOR WEED MANAGEMENT IN DIRECT SEEDED PUDDLED RICE (*Oryza sativa* L.)

by

SHEEJA K RAJ
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2016

ABSTRACT

The experiment entitled "Herbicide mixtures for weed management in direct seeded puddled rice *Oryza sativa* L." was carried out at College of Agriculture, Vellayani, during the period from 2013 - 2016, to assess the bio-efficacy of two post emergence herbicide mixtures *viz.*, bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl in direct seeded rice; to study the residual effect in soil; to investigate the impact on microbial and earth worm population, soil enzyme activity and weed seed bank and also to assess the *in vitro* sensitivity to soil borne pathogen, *Rhizoctonia solani*, bio control agents and bio fertilizer organisms.

Field experiment was undertaken during first and second crop seasons of 2014-15 at Nemom block at farmer's field. The experiment was laid out in RBD with 12 treatments and three replications. Bispyribac sodium + metamifop @ 60, 70, 80 and 90 g ha^{-1}, penoxsulam + cyhalofop butyl @ 120, 125, 130 and 135 g ha^{-1}, bispyribac sodium @ 25 g ha^{-1}, penoxsulam @ 22.5 g ha^{-1}, hand weeding twice and weedy check constituted the treatments.

The higher three tested doses of penoxsulam + cyhalofop butyl *viz.*,125, 130 and 135 g ha^{-1} and the highest tested dose of bispyribac sodium + metamifop *viz.*, 90 g ha^{-1} were better than other weed management treatments in improving the growth and yield attributes of rice. Pooled analysis indicated the superiority of penoxsulam + cyhalofop butyl @ 135 g ha^{-1} which recorded the highest grain yield (8463 kg ha^{-1}) and it was statistically on par with its lower doses (130 and 125 g ha^{-1}). Straw yield was not significantly influenced by the weed control treatments. Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} recorded the highest net returns (93744 ₹ ha^{-1}) and B: C ratio (2.43), which was on par with its lower dose (130 g ha^{-1}).

Penoxsulam + cyhalofop butyl @ 135 g ha^{-1} was more effective in reducing the total density of weeds. With regard to the control of sedges and BLW, penoxsulam + cyhalofop butyl was more effective, but with respect to grasses, both the herbicide mixtures were more or less similar in effectiveness. Penoxsulam + cyhalofop butyl @ 135 and 130 registered higher weed control efficiency and lower weed index than other treatments. Uncontrolled weed growth caused a yield reduction of 50.38 per cent.

Herbicide treatments significantly reduced the nutrient uptake by weeds and enhanced the nutrient uptake by crop over weedy check. The higher doses of penoxsulam + cyhalofop butyl (125, 130 and 135 g ha^{-1}) and bispyribac sodium + metamifop (70, 80 and 90 g ha^{-1}) were more effective in maintaining higher nutrient content in soil.

Dynamics of soil microbial population, earthworm population, soil enzyme status and organic carbon content of soil consequent to the application of herbicide mixtures revealed that, both penoxsulam + cyhalofop butyl and bispyribac sodium + metamifop at their tested doses did not have any inhibitory effect.

Results of screening trial revealed that maize was the most sensitive indicator plant for both the herbicide mixtures. Dry weight and fresh weight of maize shoot were adjudged as the best parameters for assessing the residual effect of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl in soil respectively. Pot culture bioassay studies revealed that the tested herbicide mixtures and their doses did not have any residual effect.

In vitro sensitivity studies of bispyribac sodium + metamifop and penoxsulam + cyhalofop butyl to *Rhizoctonia solani* pointed out that both the herbicide mixtures inhibit the growth of *Rhizoctonia solani*. Studies on the *in vitro* effect of herbicide mixtures to *Trichoderma viride* indicated that bispyribac sodium + metamifop was safe to the fungus, whereas penoxsulam + cyhalofop

butyl was moderately toxic. Compatibility studies revealed that both the herbicide mixtures were highly compatible with *Pseudomonas fluorescens*, *Azospirillum lipoferum* and *Azotobacter chroococcum*.

Weed seed bank assay results indicated the effectiveness of the higher doses of penoxsulam + cyhalofop butyl (135, 130 and 125 g ha^{-1}) in depleting the seed bank compared to other treatments.

The present study revealed the superiority of herbicide mixtures over individual herbicides in the management of weeds in wet seeded rice. Application of penoxsulam + cyhalofop butyl @ 135 or 130 g ha^{-1}, at 15 DAS could be adjudged as the most economic and ecofriendly weed management practice for wet seeded rice as evidenced by high weed control efficiency, net returns and B: C ratio; environmental safety, high inhibitory effect to *Rhizoctonia solani* and good compatibility with bio control agents and bio fertilizer organisms.

സംഗ്രഹം

നെൽകൃഷിയിലെ കളനിയന്ത്രണത്തിനായി ബിസ്പിരിബാക്ക് സോഡിയം + മെറ്റാമിഫോപ്പ്, പെനോക്സുലാം + സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ എന്നീ രണ്ട് കളനാശിനി മിശ്രിതങ്ങളുടെ കാര്യക്ഷമത പരിശോധിക്കുന്നതിനായി വെള്ളായണി കാർഷിക കോളജിലെ അഗ്രോണി വിഭാഗത്തിൽ 2013-2016 കാലഘട്ടങ്ങളിൽ ഒരു പരീക്ഷണം നടക്കുകയുണ്ടായി. ഈ കളനാശിനി മിശ്രിതങ്ങൾ ഉപയോഗിക്കുമ്പോൾ മണ്ണിലും പരിസ്ഥിതിയിലും ഉണ്ടാകുന്ന വ്യതിയാനവും പഠനവിധേയ മാക്കി.

പ്രസ്തുത പഠനത്തിൽ നിന്നും ചേറ്റുവിതയിലെ കളനിയന്ത്രണ ത്തിനും, നല്ല വിളവിനും, അറ്റാദായത്തിനും പെനോക്സുലാം + സൈഹാലോഫോപ്പ് ബ്യൂട്ടൈൽ എന്ന കളനാശിനി മിശ്രിതം ഹെക്ട റിന് 130 ഗ്രം എന്ന തോതിലോ, 135 ഗ്രാം എന്ന തോതിലോ ഉപയോഗി ക്കുന്നതാണ് ഉത്തമമെന്ന് ബോദ്ധ്യപ്പെട്ടു. പരീക്ഷിക്കപ്പെട്ട രണ്ട് കളനാ ശിനി മിശ്രിതത്തിന്റെയും ഉപയോഗം മണ്ണിലെ ജീവാണുക്കളുടെ എണ്ണ ത്തിനോ, എൻസൈമുകളുടെ പ്രവർത്തനത്തിനോ ജൈവാംശത്തിന്റെ അളവിനോ ഒരു കുറവും ഉണ്ടാക്കുന്നില്ല. നെല്ലിൽ അവിച്ചിൽ ഉണ്ടാ ക്കുന്ന റൈസോക്റ്റോണിയ സൊളാനി എന്ന കുമിളിന്റെ വളർച്ചയെ ഈ കളനാശിനി മിശ്രിതങ്ങൾ തടസ്സപ്പെടുത്തുന്നതായും കണ്ടു. കൂടാതെ ജീവാണുവളങ്ങളായ അസോസ്പിരിലം ലിപ്പോഫിറം, അസോട്ടോബാക്ടർ ക്രൂക്കോക്കം, മിത്രകുമിൾ നാശിനികളായ ട്രൈക്കോ ഡെർമ വിരിഡേ, സ്യൂടോമോണാസ് ഫ്ളൂറസൻസ് എന്നിവയുടെ വളർച്ചയെ തടസ്സപ്പെടുത്തുന്നില്ലെന്നും കാണാൻ കഴിഞ്ഞു. രണ്ട് കള നാശിനി മിശ്രിതങ്ങളും മണ്ണിൽ ദോഷകരമായ അളവിൽ അവശിഷ്ടം നിലനിറുത്തിന്നില്ല എന്നും ബോദ്ധ്യപ്പെട്ടു. പെനോക്സുലാം + സൈഹാ ലോഫോപ്പ് ബ്യൂട്ടൈൽ എന്ന കളനാശിനി മിശ്രിതം ഹെക്ടറൊന്നിന് 135 ഗ്രാം എന്ന തോതിലോ 130 ഗ്രാം എന്ന തോതിലോ തളിക്കുന്നത് മണ്ണിൽ അടങ്ങിയിരിക്കുന്ന കളവിത്തിന്റെ അങ്കുരണശേഷി കുറയ്ക്കു മെന്നും കണ്ടെത്തി.

Appendices

APPENDIX - I

Weather data during the first crop season (May 2014 to September 2014)

Standard week	Temperature, ° C		Sunshine hours	Rainfall, mm	Relative Humidity, %	
	Maximum	Minimum			Maximum	Minimum
22	31.8	25.6	9.3	3.6	92.5	75.2
23	30.1	24.5	8.2	34.3	94.3	83.3
24	30.7	25.1	9.0	23.0	90.9	77.4
25	31.1	25.7	9.3	19.4	92.3	77.7
26	30.5	25.0	9.5	33.9	92.7	79.1
27	30.4	24.7	9.2	7.6	90.9	79.0
28	29.7	24.2	8.7	24.2	92.9	80.4
29	30.1	24.2	9.3	19.4	90.4	76.7
30	29.9	24.2	9.3	14.6	91.6	73.6
31	29.2	23.5	8.6	94.2	95.3	85.9
32	29.4	23.5	8.7	88.7	88.6	77.3
33	29.7	24.0	8.9	4.0	89.7	79.6
34	29.8	24.0	8.1	219.0	94.0	80.9
35	29.9	23.9	8.7	206.6	87.6	84.1
36	29.2	23.9	8.8	80.0	96.1	79.3
37	30.1	24.5	9.7	3.0	89.3	74.1
38	30.5	24.6	9.8	0.0	85.0	75.6

APPENDIX - II

Weather data during the second crop season (November 2014 to March 2015)

Standard week	Temperature, ° C		Sunshine hours	Rainfall, mm	Relative Humidity, %	
	Maximum	Minimum				Maximum
47	29.4	23.4	6.1	46.9	95.1	67.7
48	29.1	23.1	7.4	41.4	91.1	63.9
49	30.6	22.6	9.0	15.4	95.4	64.6
50	29.9	23.3	7.2	24.3	92.6	65.0
51	30.6	23.4	7.7	14.7	92.1	64.3
52	29.9	23.8	8.3	6.0	94.4	60.7
1	30.5	21.3	9.1	4.0	95.1	67.7
2	30.4	21.2	9.0	0.0	91.1	63.9
3	30.8	21.8	9.2	0.0	95.4	64.6
4	30.5	21.6	9.3	4.0	92.6	65.0
5	32.0	22.4	9.3	0.0	92.1	64.3
6	31.6	23.2	9.2	0.0	94.4	60.7
7	31.1	22.5	9.3	0.0	93.0	61.9
8	31.2	21.0	9.5	0.0	90.3	70.1
9	32.1	23.3	9.2	1.0	88.7	66.6
10	32.1	23.3	9.4	0.0	88.6	66.3
11	32.1	23.6	9.6	45.7	91.4	69.3

APPENDIX - III

The dilution and media used for the estimation of microflora

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

APPENDIX - IV

Media composition for microbial study

1.Nutrient Agar Medium (pH -7.0)

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

2. Kenknights Agar Medium

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

3. Martin's Rose Bengal Agar Medium

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

4. Double strength Potato Dextrose Agar Medium

Sl. No.	Chemicals	Quantity required
1	Potato	400 g
2	Dextrose	40 g
3	Agar	40 g
4	Distilled water	1000 mL

5. Jensen's media (pH 7 -7.3)

Sl. No.	Chemicals	Quantity required
1	Sucrose	20 g
2	Dipotassium phosphate	1 g
3	Magnesium sulphate	0.5 g
4	Sodium chloride	0.5 g
5	Ferrous sulphate	0.1 g
6	Sodium molybdate	0.005 g
7	Calcium carbonate	2 g
8	Agar	15 g
9	Distilled water	1000 mL

6. King's B Medium (pH- 7.2)

Sl. No.	Chemicals	Quantity required
1	Peptone	20 g
2	Dipotassium phosphate	1.5 g
3	Magnesium sulphate	1.5 g
4	Glycerol	10 mL
5	Agar	15 g
6	Distilled water	1000 mL

6. NFb Medium

Sl. No.	Chemicals	Quantity required
1.	Malic acid	5.0 g
2	Dipotassium hydrogen phosphate	0.5 g
3	Magnesium sulphate heptahydrate	0.2 g
4	Sodium chloride	0.1 g
5	Calcium chloride	0.02 g
6	*Trace element solution	2 mL
7	Bromothymol blue (0.5% aqueous solution dissolved in 0.2 N KOH)	2 mL
8	Iron EDTA solution (1.64%)	4 mL
9	**Vitamin solution	1 mL
10	Potassium hydroxide	4 mL
11	Distilled water	1000 mL

*Trace element solution:

1. Sodium molybdate dehydrate : 0.2 g
2. Mangnous sulphate monohydrate : 0.235 g
3. Boric acid : 0.28 g
4. Copper sulphate pentahydrate : 0.008 g
5. Zinc sulphate heptahydrate : 0.024 g
6. Distilled water : 1000 ml

**Vitamin solution:

1. Biotin : 0.01 g
2. Pyridoxin : 0.02 g
3. Distilled water : 1000 ml

APPENDIX - V

Varietal characteristics of Kanchana (PTB 50)

Variety group	Hybrid derivative (IR 36 x Pavizham)
Leaf colour	Green
Leaf length (cm)	45
Leaf breadth (cm)	1.4
Culm length (cm)	65
Girth (cm)	1.4
Panicle length (cm)	23
Exsertion	Moderately well exserted
Number of spikelets panicle^{-1}	140
Awn	Absent
100 seed weight (g)	2.6
Classification FAO Scale	Long bold
Seed coat (bran colour)	Red
Endosperm type	Non waxy
Days to 50 % flowering	80-85
Productive tillers per hill	9
Height of the plant (cm)	88
Average grain yield (t ha^{-1})	5.5
Other Characters	Excellent milling recovery Good cooking quality High volume expansion on cooking Comparatively high protein content

(KAU, 2003)