EVALUATION OF THE NEW GENERATION HERBICIDE PENOXSULAM IN TRANSPLANTED RICE (*Oryza sativa* L.)

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by

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THESIS

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KERALA, INDIA

2014

DECLARATION

I, hereby declare that this thesis entitled "EVALUATION OF THE NEW GENERATION HERBICIDE PENOXSULAM IN TRANSPLANTED RICE (*Oryza sativa* L.)" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "EVALUATION OF THE NEW GENERATION HERBICIDE PENOXSULAM IN TRANSPLANTED RICE (*Oryza sativa* L.)" is a record of research work done independently by Sasna S. (2012-11-123) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Mrs. Sasna S. (2012-11-123),** a candidate for the degree of **Master of Science in Agriculture** with major in Agronomy, agree that this thesis entitled **"EVALUATION OF THE NEW GENERATION HERBICIDE PENOXSULAM IN TRANSPLANTED RICE (*Oryza sativa* L.)"** may be submitted by Mrs. Sasna S**.** in partial fulfilment of the requirement for the degree.

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Sasna S.

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LIST OF ABBREVIATIONS

a.i	_	Active ingredient
ALS	_	Aceto lactate synthase
B: C ratio	_	Benefit Cost Ratio
BLW	_	Broad Leaved Weeds
CD (0.05)	_	Critical difference at 5 % level
cm	_	Centimeter
DAS	–	Days after spraying
day^{-1}	–	Per day
et al.	–	And others
Fig.	–	Figure
g	–	Gram
$g\ m^{-2}$	_	Gram per square metre
ha	–	Hectare
HI	_	Harvest index
HWT	_	Hand Weeding Twice
$hill^{-1}$	_	Per hill
i.e.	–	That is
K	–	Potassium
KAU	_	Kerala Agricultural University
Kg	–	Kilogram
$kg\ ha^{-1}$	–	Kilogram per hectare
l^{-1}	–	Per litre
LAI	_	Leaf area index
LTR	_	Light transmission ratio
M	–	Metre

LIST OF ABBREVIATIONS CONTINUED

m^{-2}	–	Per square metre
MOP	_	Muriate of Potash
MSL	_	Mean sea level
N	–	Nitrogen
NAR	_	Net assimilation rate
NRCWS	_	National research centre for weed science
NS	–	Non significant
P	–	Phosphorus
$Plant^{-1}$	_	Per plant
$Panicle^{-1}$	_	per panicle
PAR	_	Photosynthetically active radiation
PDA	_	Potato dextrose Agar
P^H	_	Negative logarithm of hydrogen ion concentration
RH	_	Relative humidity
Rs. ha^{-1}	–	Rupees per hectare
SE	–	Standard error
sp.	–	Species
t ha^{-1}	–	Tonnes per hectare
viz.,	–	Namely

LIST OF SYMBOLS

%	_	Per cent
>	_	More than
&	_	And
°C	_	Degree Celsius
@	_	At the rate of

INTRODUCTION

1. INTRODUCTION

India is the second largest producer of rice after China and being the staple food, rice plays vital role in India's economy occupying a central position in shaping the agricultural policy (Dangwal *et al.*, 2011). World's rice demand is projected to increase by 25 percent from 2001 to 2025 to keep pace with population growth (Maclean *et al.*, 2002), and therefore, meeting ever increasing rice demand in a sustainable way with shrinking natural resources is a great challenge.

Among the various factors responsible for low rice productivity, weeds are considered to be one of the major limiting factors due to their manifold harmful effects (Singh *et al.*, 2009). Weeds grow profusely in the rice fields and reduce crop yields drastically. The weed flora under transplanted condition is very much diverse and consists of grasses, sedges and broad leaved weeds causing yield reduction of rice up to 76 per cent (Singh *et al.*, 2004). The effective control of weeds at initial stages (0 - 40 DAT) help in improving productivity of this crop. Uncontrolled weeds cause 80 percent reduction in grain yield and sometimes result in complete failure of rice crop (Pandey *et al.,* 2000).

Labour shortage coupled with high labour cost necessitate to give more thrust on chemical weeding. The use of herbicides also offers scope for economical control of weeds right from the beginning, giviung rice crop an advantage of good start and competitive superiority. Continuous use of some herbicides has led to development of resistant weeds and has exacerbated weed problems. For example, in rice–wheat cropping system of Punjab and Haryana, *Phalaris minor* has developed resistance against isoproturon (Walia and Brar, 2006). Most of the traditional herbicides are applied at a rate of 1 kg a. i ha^{-1}or more and hence the continuous use would end in high residual effect in soil and water.

Recent trend of herbicide use, is to find out an effective weed control measure by using low dose high efficiency herbicides which will not only reduce the total volume of herbicide use but also the application becomes easier and economic (Kathiresan, 2001). New generation herbicides are applied at very low doses and they degrade from the environment within a few weeks. With the recommended use rates, the quantity of herbicides applied to soil at one time is too small to have any detectable influence on soil physical or chemical state (Yaduraju and Mishra, 2002).

The present low dose era of herbicide use is characterized by crop selective weed control at use rates of 2-100 g a.i ha^{-1}. This provides 50-100 fold increase in herbicidal activity over traditional herbicides (Brown, 1990). An array of promising low dose high efficacy pre and post emergence herbicides are available for the control of wide spectrum of weed flora in transplanted rice (Moorthy, 2002). Eventhough, both pre and post emergence herbicides are available for weed control in transplanted rice, the need of post- emergence herbicides is often realized by farmers to combat weeds emerging during later growth stages of crop. Weed spectrum and degree of infestation in rice fields are often determined by rice ecosystem and establishment methods (Juraimi *et al.,* 2013).

Therefore, evaluation of post emergence micro herbicides for broad spectrum control of weed flora in transplanted rice in the southern part of Kerala is imperative. With this background, the present investigation was undertaken in Nemom block of Thiruvananthapuram district representing southern part of Kerala with the following objectives:

1. To assess the bio-efficacy of the post-emergence micro herbicide penoxsulam in transplanted rice.
2. To work out the economics.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Weeds have been a nemesis to agricultural endeavours since ancient times. Over the centuries, attempts to control or eradicate weeds have ranged from spiritual to pragmatic. Weeds are competitive and adaptable to all adverse environments, harmful to crops and exert a marked effect on crop yields. One technology which has a potential to yield substantial increase in the production of food grains is proper weed management as weeds alone accounts for about 15-85 per cent losses in the productivity. The reduction in yield of transplanted rice was estimated to the tune of 57-61% due to the weed infestation (Mukherjee *et al.,* 2008). Modern agriculture is productivity oriented and emphasizes on economic viability and sustainability of the system. Such an approach demands a weed management strategy that is selective, efficient and cost effective with little or no adverse ecological effects.

2.1. WEED SPECTRUM IN TRANSPLANTED RICE

The weed flora differs widely depending on soil as well as environmental conditions and hence detailed information on the spectrum of weed flora is essential for the formulation of effective weed management strategies (Vidya *et al.*, 2004). Identification of weeds is the basic step for planning sound weed management programme. Depending upon the weed species, different weed management options are given keeping in view their susceptibility when growing in a crop (Walia, 2006).

According to Singh *et al.* (2007) the dominant grass weed species were *Echinochloa crusgalli* and *Echinochloa colona,* sedges were *Cyperus iria* and *Fimbristylis miliacea* and broad-leaved weed species were *Ammania baccifera, Marsiliaquadrifolia and Potamogeton distinctus* under puddled condition of sandy clay loam soil during rainy season. The broad leaved constituted 34.1 per cent, grasses 42.2 per cent and sedges 23.6 percent of the total weed population under weedy conditions.

Subramanian *et al.* (2006) reported that weed flora of the experimental field were composite in nature, consisting of grasses such as *Echinocloa colonum* L., *E. crus-galli* L. and *Cynodon dactylon* L.; sedges such as *Cyperus rotundus* L., *C. difformis* L. and *C. iria* L.; broad leaved weeds such as *Eclipta alba* L. *Ammania baccifera* L., *Phyllanthus niruri* L. and *Ludwigia parviflora*.

The major weed composition reported in Nemom area were *Echinochloa colona* (L.)Link., *Cyperus difformis, Fimbristylis dichotoma (L.)* Vahl., *Limnocharis flava* (L.) Buchenau., *Monochoria vaginalis* (Burm. f.) Presl. Ex Kunth., *Ludwigia parviflora* Roxb., *Lindernia rotundifolia* blanc vert., *Salvinia molesta* D.S. Mitch., *Marsilea quadrifolia* Linn. and *Pistia stratiotes* L. Royle (Rathod, 2013).

The major weed flora reported in Vellayani, Thiruvananthapuram are *Echinochloa colona* (L.) Link., *Cyperus difformis, Fimbristylis dichotoma (L.)* Vahl., *Scirpus grossus* L.f., *Limnocharis flava* (L.) Buchenau., *Monochoria vaginalis* (Burm. f.) Presl. Ex Kunth., *Ludwigia parviflora* Roxb., *Ipomoea aquatic* Forsk., *Lindernia rotundifolia* blanc vert., *Salvinia molesta* D.S. Mitch., *Marsilea quadrifolia* Linn. and *Pistia stratiotes* L. Royle (Yadav, 2006). Biodiversity in weeds occur as a result of differential survival mechanism of individual plant species. Heterogeneous weed populations exploit weakness in weed management strategies and adapt well to remain competitive with crop plants. This successful behavior in a weed population is the aggregate of diverse, individual plant behaviors and understanding this weed diversity in a field is essential for effective management of weeds (Rao, 2000).

2.2 CROP WEED COMPETITION

Yield losses caused by weed species in rice are enormous. With increasing weed density, yield losses are increasing markedly. Weeds are self grown and appear simultaneously with crop plant creating severe competition for nutrient, space, moisture and solar energy resulting in low yield of crop. Grassy weeds were heavy competitors with rice crop and were followed by sedges and broad leaved weeds (Umapathy *et al.*, 2000). The outcome of the competition would depend not only on the competing species but also on their density, duration and the level of fertility (Moody, 1991). Chinnusamy (2000) reported that maintaining a weed free period up to 45 DAT was essential to augment the yield of medium duration rice. Critical period for crop weed competition in rice was up to 40 days after transplanting (Tewary and Singh, 1991; Thapa and Jha, 2002). Behra and Jena (1997) explained the major reasons for higher rice grain and straw yield under weed control treatments both in upland and transplanted situation as their effectiveness in controlling weeds during critical period of rice crop growth. Normally the loss in yield ranges between 15 – 20 per cent. Yet, in severe cases the yield losses can be more than 50 per cent depending upon the species and intensity of weeds (Hasanuzzaman *et al*., 2008).

Weed competition is complicated because various factors affect the extent to which it occurs and the degree of weed competition is determined by the weed species infesting the area, density of infestation and duration of infestation (Rao, 2000). Singh *et al.* (2002) observed that maintaining weed free condition till maturity gave significantly higher grain yield due to more panicles m^{-2}.

2.2.1 Critical Period of Crop Weed Competition

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. Critical period of weed competition is the period before and after which weed growth does not affect crop yield (Zimdahl, 2004). During early establishment, the weeds make 20 to 30 per cent of their growth, while the crop makes 2 - 3 percent of its growth (Moody, 1990). A weedy situation for the first 15 days only or weed free situation for the first 60 or 75 days produced grain yields comparable with weed free conditions (Muthukrishnan *et al*., 2010).

2.2.2 Competition for light

Most weeds and rice have maximum photosynthesis and growth in full sunlight (Ampong Nyarko and De Detta, 1991). The ability to compete for light depends largely on the comparative growth stature of the competitors. Thus plants which are tall or have an erect habit will have a competitive advantage over short or prostrate plants. Rice suffers little competition for light from *Monochoria vaginalis* (Burm.F.) Presl., a short-statured plant whereas competition from *Echinochloa cruss-galli* (L.) Beauv., a tall weed which eventually overtops the rice plant can be quite severe particularly in the later stages of growth (Moody, 1990).

Generally, weeds grow faster and shade the crop plants, if not checked. Even in case of shorter weeds, the lower leaves of crops are shaded by them. Weeds deplete the photosynthetically active radiation resulting in reduction in photosynthesis and shortening the life of lower leaves (Reddy and Reddy, 2008). A change in light quality due to the presence of canopy cover can affect the development of shaded plants through phytochrome mediated process (Ballare *et al*., 1990).

Srinivasan and Palaniappan (1994) indicated that number of filled grains panicle^{-1} was lowest with competition of *Echinochola* sp. ultimately resulting in the lowest percentage of filled grains. This might be due to the interception of light by tall growing *Echinochola* sp. resulting in poor photosynthesis and photo chemical energy supply, which ultimately affected the translocation of photosynthates to the developing grains.

2.2.3 Competition for Water

The more competitive plant has a faster growing and larger root system so that it is able to exploit a larger volume of soil quickly (Moody, 1995). If plants have similar root length, those with more widely spreading and less branched root systems will have a comparative advantage in competition for water (Zimdahl,1999) Competition for water and nutrients usually begins before competition for light and is thought to be more important. Competition is greatest when plant roots are closely intermingled, crops and weeds are obtaining their water from the same volume of soil. Less competition occurs if the roots and weeds are concentrated in different areas of the soil profile.

2.2.4 Competition for Space

Competition for space in atmosphere and rhizosphere leads to limited root volume and canopy spread. Optimum plant density per unit area is an important factor needed for realizing higher yield (Balasubramaniyan and Palaniappan, 2001). Competition between crop and weeds can be modified by manipulating crop geometry as increase in crop density can enhance the crop's share of the total resources. Plant population is affected the weed biomass production and it was highest with lower plant population (Ghuman *et al.,* 2008). Increased seeding rates and altered plant spatial arrangement to improve crop competitiveness have been proposed and tested as a component to weed management strategies in cereals (Kristensen *et al.*, 2008). Crop row spacing did not influence plant height of *Echinochloa colonum* and *Echinochloa crus-galli*, but the height of both species was influenced by their emergence time in the field. *Echinochloa colonum* emerging with rice sown in 30 cm rows produced 3000 seeds plant^{-1}, whereas narrowing rice rows to 20 cm reduced seed production to 2200 seeds plant^{-1}, 29 per cent reduction. Similarly *Echinochloa crusgalli* produced 2100 and 2900 seeds plant^{-1} when emerged with rice in 20 and 30 cm rows, respectively (Chauhan and Johnson, 2010).

2.2.5 Competition for Nutrients

Weeds usually grow faster than the crop plants and absorb added nutrient more rapidly and in larger quantities than by crops and thus deprive the supply of nutrients in time to the crop plants. Weeds removed nutrients (N, P and K) eight times higher under direct seeded rice compared to that of puddled transplanting (Singh *et al.*, 2002). Puniya *et al.* (2007) noticed that the highest loss of nutrients (N 42.07, P 10.00 and K 21.80 kg ha^{-1}) occurred with unweeded control due to more density and dry weight of weeds in transplanted rice during *kharif*. Weeds remove a large amount of plant nutrients from the soil. An estimate showed that weeds could deprive the crops of 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg (Balasubramaniyam and Palaniappan, 2001).

Uninterrupted weed growth in rice depleted 59.3 kg N, 10.5 kg P_2O_5 and 35.0 kg K_2O on per hectare basis (Raju and Gangwar, 2004).

Grassy weeds compete for mineral nutrients and soil water apart from light, CO_2 etc. as they have an extensive and fibrous root system. Similarly, sedges pose serious competition for nutrients. The roots of sedge dominate the surface feeding zone and obstruct nutrient flow to crop root. Non grassy weed being deep rooted, explores the subsurface zone for mineral and exert less competition for nutrients with rice (Raju and Reddy, 1986).

Singh *et al.* (1999) reported that initial weed free treatment for 45 days or longer resulted in significantly higher rice grain and straw yields and lower dry weight and nutrient uptake by weeds. Competition between crop and weeds is primarily for nitrogen with most intense competition occurring in the early stage. The uptake of nutrients (N, P and K) by rice was significantly higher in weed free treatment. The season long weedy treatment depleted 35 kg N, 15 kg P_2O_5 and 45 kg K_2O ha^{-1} by weeds, while rice crop under weed free up to maturity removed 60, 26 and 80 Kg ha^{-1} of N, P_2O_5 and K_2O respectively. Sankaran *et al.* (1974) showed that the uptake of nutrients by weeds in unweeded plots was nearly nine times higher than that from plots weeded manually or by using herbicides. Chakraborty (1981) reported that competition for nutrients, especially nitrogen was the major factor responsible for yield reduction in rice. Lakshmi (1983) reported that N and K_2O uptake by the crop was higher than P_2O_5 uptake at all stages of growth. Ali and Sankaran (1984) observed increased nitrogen, phosphorus and potassium uptake by rice through weed control.

Among the rice weeds, *Echinochloa* spp. was the most competitive weeds for nutrients (Sahai and Bhan, 1992). Nandal and Singh (1993) reported an increase in the nutrient uptake of rice by weed control treatment. In transplanted rice, the nutrient depletion by weeds was estimated to be 10.9, 2.6 and 9.8 kg ha^{-1} of N, P_2O_5 and K_2O respectively (Bhan and Mishra, 1993). Singh *et al.* (1999) reported that weed free condition resulted in lower uptake of nitrogen by weeds.

Rajan (2000) reported that N, P_2O_5 and K_2O uptake by weeds at harvest were 8.53, 4.18 and 9.26 kg ha^{-1} in weedy check.

2.2.6 Effect of Weed Competition on Crop Growth Characters and Yield Attributes

Infestation of weeds increased tiller mortality, decreased shoot and grain production (Srinivasan and Palaniappan, 1994). Singh *et al.* (2002) observed that maintaining weed free condition till maturity gave significantly higher grain yield due to more panicles m^{-2}. Veeraputhiran and Balasubramanian (2010) observed that maintaining weed free condition till maturity produced the grain yield of 7139 kg $ha^{-1}$of transplanted rice. The overall effect of crop weed competition is the reduction in the economics as well as biological yield of rice. Weeds are considered to be one of the dreaded groups of agricultural pests known to cause direct yield losses to the tune of 100 per cent, when weed pressure is severe at early stages of rice crop growth (WARDA, 1976). Reduction in crop yield due to weeds results from their multifarious ways of interfering with crop growth and culture and weed competition can lower rice grain yield to the extent of 62.6 per cent (Gopinath and Pandey, 2004). Ramamoorthy *et al.* (1974) observed that competition reduced the productive tillers m^{-2}.

Weed free conditions produced more productive tillers and fertile grains per panicle, compared to weed density 500 m^{-2} to 2000 m^{-2} (Begum *et al.*, 2009). Among the weed control treatments, weed free treatment recorded significantly higher effective tillers and grain yield as compared to partial weedy treatment (Walia *et al.*, 2009). Moody (1980) reported that yield reduction due to uncontrolled weed growth ranged from 20 to 25 per cent for transplanted rice. Weed competition in rice lowered the filled grains $panicle^{-1}$ by 13 per cent and test weight by 4 per cent (Ghobrial, 1981). Upadhyay and Gogoi (1993) reported that the loss of yield occurred from 25 to 30 per cent due to unchecked weed growth. Dhiman and Nandal (1995) estimated a yield reduction of 23.71 per cent in transplanted rice due to weeds. Begum *et al.* (2009) reported that weed competition significantly reduced straw biomass in the unweeded control.

Mahapatra *et al.* (2002) and Saini and Angiras (2002) reported a decrease in thousand grain weight due to weed competition. The control of weeds promoted the yield and yield attributes including productive tillers m^{-2}, number of filled grains per panicle and thousand grain weights in rice (Raju *et al.*, 2002: Yadav, 2006: Yadav *et al.*, 2009). Weed management is one of the major factors, which affect rice yield. Uncontrolled weeds cause grain yield reduction up to 76 per cent under transplanted conditions (Singh *et al.*, 2004). India suffers a yearly loss of 15 million tonnes due to weed competition (Kathiresan, 2001). Thousand grain weight was remained statistically unchanged due to different weed control methods *viz*., chemical as well as manual weeding (Hasanuzzaman *et al.*, 2008). All the weed control treatments significantly reduced the weeds as compared to weedy check and recorded higher grain yield of rice (Saha and Rao, 2010). Lowest number of productive tillers as well as total tillers was found in unweeded plot (Begum *et al.*, 2009).

2.3 WEED MANAGEMENT TECHNIQUES

Weed control was always been a basic indispensable and integral part of agriculture from time immemorial. Modern agriculture depends more on sustainable as well as comprehensive methods of weed control. In India the concept of micro herbicides gaining popularity as an economic and eco friendly option for effective weed management.

2.3.1 Hand Weeding

Hand weeding twice at 20 and 40 DAS was superior to the chemical weed control for all the growth and yield attributes, reflecting the higher grain yield of 2876 kg ha^{-1} in silty loam and calcareous soil during rainy season (Prasad *et al.*, 2001). Chander and Pandey (1996) observed that hand weeding increased grain as well as straw yields compared to herbicides and weedy check because of frequent elimination of weeds that resulted in the reduced weed competition.

The manual method of weed control is laborious, back breaking and time consuming (Mani and Gautam, 1973). According to Gogoi *et al.* (2001), manual weeding is difficult, many a time due to continuous rains prevailing during rainy seasons and also due to scanty labour. Ravindran (1976) pointed out that hand weeding on the 20th and 40th day after transplanting although gave higher yield, the net profit was lower due to increased labour charge.

Higher weed control efficiency was also recorded with hand weeding twice (AICRPWC, 1997). Hand weeding was more effective and the most common tool to control weeds in transplanted rice (Muthukrishnan *et al.*, 2010). According to Rao (2000) manual weeding is effective against annuals and biennials but do not control perennials and is expensive in areas where labour is scarce.

Two hand weedings at 20 and 40 DAT could control almost all categories of weeds (Bhowmick, 2002). Hand weeding twice recorded the least weed count and highest weed control efficiency (69.9 and 70.1%) during first and second season respectively (Gnanavel and Kathiresan, 2002). Kathirvelan and Vaiyapuri (2003) pointed out that hand weeding (20 and 40 DAT) recorded higher grain yield and straw yield (5.81 and 7.26 t ha^{-1}).

Manual weeding, although efficient in controlling weeds, has been restricted due to several economical and technological factors (Khaliq *et al.*, 2011). The lowest total weed density (1.40 m^{-2}), dry matter production (1.37 g m^{-2}) and weed control efficiency irrespective of weed species was recorded under two hand weeding at 20 and 40 DAT (Singh *et al* ., 2012). Among weed management practices the maximum yield was recorded with two hand weeding (20 and 45 DAS/DAT) which was statistically at par with herbicide (bispyribac sodium @ 25 g a.i ha^{-1} + one hand weeding and significantly superior over herbicide alone and weedy check (Singh and Singh, 2012). Manual method of weed control is labour intensive, tedious, back breaking and does not ensure weed removal at critical stage of crop weed competition due to non availability of labours.

2.3.2 Chemical Weed Control

Herbicide usage is one of the most labour saving innovations especially in case of the non availability of labour during peak season (Ampong Nyarko and Datta, 1991; Moody, 1995). Adigun *et al.* (2005) reported that application of herbicides before blossoming had effect on weed control and increased the performance of rice. Akbar *et al.* (2011), Jayasuria *et al.* (2011) and Khaliq *et al.* (2011) have also reported that herbicides were effective for weed management in rice. Economic benefits of herbicide application over manual weed control were reported earlier (Rangiah *et al.*, 1975; Versteeg and Maldonado, 1978; Lakshmi, 1983). Jacob (2002) opined that application of herbicides resulted in high net income and BCR. In rice growing areas of India, herbicide usage is gaining momentum due to high labour wages and non-availability of labour at right time; and chemical weed control is one of the feasible methods for large scale rice production. The conditions favorable for rice culture are equally suitable for the growth and reproduction of terrestrial, aquatic and semi-aquatic weeds. So in view of these problems, identification of new safer herbicides is essential.

Development of resistance in some previously susceptible weed species, as well as serious environmental concerns owing to high residual effects of herbicides in soil are major drawbacks associated with herbicide usage (Ahn *et al.*, 2005). Rajkhowa *et al.* (2001) pointed out that application of herbicides increased available N and K due to reduction in nutrient removal by weeds. Corroboratory results were reported by Jacob (2002) and Seema (2004). Narwal *et al.* (2002) explained that all herbicidal treatments gave significantly higher yield and better yield attributes than weedy check. Sharma *et al.* (2003) observed that all herbicidal treatments significantly reduced the density and dry weight of weeds over weedy check. Herbicides help farmers in increasing their crop yield, with efficient weed control. Several studies (Adigun *et al.*, 2005; Singh *et al.*, 2012; Mahajan *et al.*, 2003) have concluded that chemical weed control is feasible since it is quick, easy, and economical.

2.3.3 New Generation Herbicides

Weed control program should be environmentally benign and cost effective so that reduced herbicide use can help meet these goals. Continuous use of some herbicides has led to development of resistant weeds and has exacerbated weed problems. For example, in rice–wheat cropping system of Punjab and Haryana, *Phalaris minor* has developed resistance against isoproturon (Walia and Brar, 2006). Most of the post emergence herbicides are applied at a rate of 1 kg a. i ha^{-1} or more and hence the continuous use would end in high residual effect in soil and water. So new molecules with low dose and high efficacy is the need of the hour. It provides high effectiveness, compatibility, versatility and high bio - efficacy.

Many of the herbicides widely used in the 1960's and 1970's have been phased out and replaced by the newer and more potent herbicides discovered later. Use of some older herbicides have been considerably restricted, reduced and eliminated in view of environmental and toxicological problems and the availability of more effective and safer herbicides (Rao, 2000).

New generation herbicides that function by inhibiting the action of key plant enzymes are gaining popularity among farmers. As these herbicides are highly effective at very low rates; they are known as low dose high efficacy (LDHE) herbicides or micro herbicides. Saha (2006) reported that all the new generation herbicides he tested showed better control of weeds (weed control efficiency 79.9–95.1%) in comparison with the traditional recommended rice herbicides (weed control efficiency 73.3 – 78%) and gave higher yield of rice.

2.3.3.1 Penoxsulam

Penoxsulam is a promising new, early post-emergence rice herbicide of systemic nature belonging to the chemical class triazolopyrimidine sulfonamide, with ALS inhibiting mode of action which impedes the bio synthesis of the branched chain amino acids valine, leucine and isoleucine which are necessary for protein synthesis, leading to the rapid cessation of plant cell division and growth (Kogan *et al.*, 2011). It is a broad spectrum herbicide with a favorable toxicological and environmental profile that controls *Echinochloa sp.,* major broad leaved and sedge weeds. Penoxsulam disrupts the internal growth processes of weeds by inhibiting the AHAS/ALS enzyme that is only found in plants, resulting in death of susceptible weeds in 2 - 4 weeks following application. The potential for penoxsulam to accumulate in the food chain (bio concentrate) is low. It is absorbed by soil and has low to moderate leaching potential in most soil types. In soil penoxsulam is broken down by microbial degradation (Dow, 2009).

Penoxsulam is a new acetolactate synthase inhibitor herbicide for post emergence control of annual grasses, sedges and broadleaved weeds in rice culture (Jabusch and Tjeerdema, 2005). Penoxsulam 22.5g ha^{-1} applied at 10 DAT was found most effective in controlling weeds and maximizing rice grain yield (6287 kg ha^{-1}). Early post emergence application (10 DAT) of penoxsulam was better than its pre-emergence application (5DAT) in increasing grain yield. Grain yield of rice was significantly and negatively correlated (r = -0.82) with weed dry matter (Mishra *et al.,* 2007). Penoxsulam was rapidly dissipated in water with first order half- lives of 3-7 days, residues in the soil were low and transient in all flooded plots

Yadav *et al.* (2008) reported that penoxsulam at 25.0 g a.i ha^{-1} as pre emergence (3 DAT) application and 20.0-22.5 g a.i ha^{-1} as post emergence (10-12 DAT) application provided satisfactory control of weeds consequently resulting in grain yield of transplanted rice similar to weed free plots. Also there was no residual toxicity of penoxsulam on succeeding wheat crop. Also penoxsulam @ 22.5 g a.i ha^{-1} resulted in maximum reduction in density of broad leaved weeds and sedges and the density and dry weight of grassy weeds decreased with increased dose of penoxsulam. Percentage control of grassy weeds was in the range of 85-88% as post emergence application.

Pal *et al.* (2009) reported that penoxsulam 24 SC at 22.5 g ha^{-1} applied at 8-12 DAT was most effective to check all weed species and their growth and yielded maximum grain (3.53 t ha^{-1}) and straw (4.73 t ha^{-1}) of rice resulting in lowest weed index (5.61%). Yadav *et al.* (2007) reported penoxsulam as an effective post emergence herbicide against mixed weed flora in transplanted rice.

Penoxsulam was found efective especially against *Echinochloa* species and *Cyperus difformis* as compared to butachlor and pretilachlor and it recorded lower weed drymatter. Penoxsulam at 20-25 g ha^{-1} applied as pre emergence (3DAT) as well as early post emergence (10 DAT) effectively controlled weeds in transplanted rice and it had no phytotoxicity effect on rice crop up to 25 g ha^{-1} dose (Singh *et al.*, 2009).

Kholdnoosh *et al.* (2011) reported that penoxsulam at 24 and 48 g a.i ha^{-1} controlled barnyardgrass (*Echinochloa crusgalli*) better than the other herbicides *viz.*, anilophos + ethoxysulfuron, tank mixture of butachlor + bensulfurone methyl and butachlor + cinosulfuron in rice. Mehta *et al.* (2011) reported that penoxsulam 24 SC, was found to be effective against complex weed flora in transplanted rice at 22.5 g a.i ha^{-1} and 45 g a.i ha^{-1}. They also observed that there is no residue of penoxsulam 24 SC in soil, straw and grains in transplanted rice. Penoxsulam @ 22.5 g a.i ha^{-1} as early post emergence (10-12 DAT) gives satisfactory weed control and significantly higher yield than weedy check but at par with weed free and hand weeding treatments. (Bhat *et al.,* 2013). Penoxsulam applied post emergence provides excellent barnyard grass control and poor to moderate broad leaf weed control (Anonymous, 2003).

Penoxsulam was more effective than pretilachlor and butachlor and penoxsulam applied at pre emergence (3 DAT) was effective against sedges and broadleaf weeds irrespective of the rate. All the weed control treatments significantly reduced weed dry weight and the highest grain yield and benefit cost ratio were obtained with 25.0 g a.i of penoxsulam ha^{-1} applied at 3 or 10 DAT and also penoxsulam was most effective against all the weeds at 60 DAT. No phytotoxicity symptoms were observed on rice treated with penoxsulam (Malik *et al.,* 2011). Maximum suppression in individual and total weed density at 30 DAT was recorded for penoxsulam when used at its label dose (Khaliq *et al.,* 2011).

Singh *et al.* (2007) reported that comparatively lower dose of penoxsulam (22.5 g a.i ha^{-1}) could be used when it was applied at early post emergence (8-12 DAT) and it gave significantly higher number of panicles m^{-2} and grain yield also it was on par with higher dose (25.0 g a.i ha^{-1}). Penoxsulam at 25.0 g a.i ha^{-1} applied at 0 - 5 days after transplanting was most effective to check all types of weed growth. This treatment also gave maximum grain yield and straw yield, resulting in the lowest dry weight of weeds, and highest herbicidal efficiency, application of herbicide under test did not show any phytotoxic symptoms on rice plant (Prakash *et al.*, 2013).

2.3.3.2 Bispyribac Sodium

Bispyribac sodium, a pyramidinyl carboxy herbicide @ 25.0 g a.i ha^{-1} at 15 or 25 DAT is effective to control many annual and perennial grasses, sedges and broad leaved weeds in rice field (Yadav *et al.*, 2009). Walia *et al.* (2008) reported that post emergence application of bispyribac sodium 30.0 g a.i ha^{-1} produced higher grain yield in rice. Bispyribac sodium proved to be the best weedicides recording 90.5 per cent weed control efficiency and higher paddy yield (Hussain *et al.*, 2008). Khaliq *et al.* 2011 observed that the application of bispyribac sodium suppressed weeds at their label dose (30.0 g a.i ha^{-1}) at 30 DAT.

Total weed population and dry weight under bispyribac sodium at 25.0 g ha^{-1} were at par with the higher doses of bispyribac sodium at 35.0 and 50.0 g ha^{-1} during both the years of study. The weed control efficiency and weed index under bispyribac sodium at lower dose were also comparable with that of higher doses indicating the sufficiency of bispyribac-sodium at 25.0 g ha^{-1} for effective weed management in transplanted rice (Veeraputhiran and Balasubramanian, 2010).

The highest number of grains per panicle (119.73) was recorded in the treatment with post emergence application of bispyribac sodium was observed by Begum *et al.* (2009). Pre emergence application of oxyfluorfen @ 0.25 kg ha^{-1} followed by post emergence application of bispyribac sodium 0.05 kg + metsulfuron methyl @ 0.01 kg ha^{-1} recorded the least weed count (11.00 m^{-2}) and weed dry matter production (114.65 kg ha^{-1}) and highest WCE (90.12%) favoring higher grain yield of aromatic rice (5.32 t ha^{-1}). This was at par with the pre emergence application of butachlor @ 1.25 kg ha^{-1} followed by post emergence application bispyribac sodium 0.05 kg + metsulfuron 0.01 kg ha^{-1} and the pre emergence application of pendimethalin @ 1.0 kg ha^{-1} followed by post emergence application bispyribac sodium 0.05 kg + metsulfuron 0.01 kg ha^{-1} (Gnanavel and Anbhazhagan, 2010).

Yadav *et al.* (2007) reported that bispyribac sodium was very effective against mixed flora of weeds in wet seeded rice. Pre emergence application of pendimethalin (0.75 kg ha^{-1}) followed by bispyribac sodium (20 g ha^{-1}) recorded less weed dry weight (0.17 t ha^{-1}) (Walia *et al.*, 2008). According to Kiran *et al.* (2010) sequential application of oxadiargyl @ 75 g ha^{-1} and bispyribac sodium @ 30 g ha^{-1} recorded lowest weed density and dry weight with maximum WCE (88%) which was on par with hand weeding twice (89%). These results are also confirmed by Kiran and Subramanyan (2010). Bispyribac sodium was quite effective and reduced total weed density by more than 80% (Khaliq *et al.*, 2011).

Veeraputhiran and Balasubramanian (2010) recorded significant reduction in total weed dry weight and highest WCE of 98 percent with application of bispyribac sodium. Bispyribac sodium applied @ 15 or 25 DAT was found effective against grass weeds but control of broad leaved weeds and sedges was more when applied at 15 DAT (Yadav *et al.*, 2010). Mehta *et al.* (2010) got maximum weed control efficiency of bispyribac sodium when applied @ 30 g a.i ha^{-1} particularly against *Echinochloa crusgalli.* Bispyribac sodium 10%SC @ 25 g a.i ha $^{-1}$ showed best results in controlling all categories of weed with least biomass of weeds in transplanted rice also no phytotoxicity was observed even at higher dose of the herbicide and it can be used safely at the recommended rate in transplanted rice (Ghosh *et al.*, 2013). Schmidt *et al.* 1999 found bispyribac sodium as an effective post-emergence herbicide which can control many annual weeds such as grasses, sedges and broad leaved weeds of rice field.

2.3.3. 2, 4 –D sodium salt

The chloro phenoxy herbicide, 2, 4 - D (2, 4 – dichlorophenoxy acetic acid) has been available throughout most of the Asia for the past four or five decades. Many rice growers have been using it routinely for post emergence control of annual broad leaved weeds such as *Monochoria vaginalis, Sphenoclea zeylanica,* sedges such as *Cyperus difformis, C. irria* and *Fymbrisylis littoralis* (De Datta, 1981). Most dicotyledonous crops are sensitive to 2, 4 –D (Rao, 2000). Mahadevaswamy and Nanjapa (1991) observed reduced weed dry weight compared to un weeded control due to application of 2, 4 - D sodium salt @ 1 kg ha^{-1}. 2, 4 – D sodium salt is recommended at 1.0 kg a.i ha^{-1} at 20 DAS/DAT (KAU, 2002).

2.4 EFFECT OF HERBICIDES ON SOIL MICROBIAL ACTIVITY

Microorganisms are able to degrade herbicides and utilize them as a source of biogenic elements for their own physiological processes. The total microbial count is the direct measurement of qualitative change appearing after herbicide treatments. The toxic effects of herbicides are normally most severe immediately after application, when their concentrations in soil are the highest. Later on, micro organisms take part in a degradation process and herbicide concentration and its toxic effect gradually decline up to half-life. Then the degraded organic herbicide provides the substrate with carbon, which leads to an increase of the soil micro flora. Generally in field situation a short time initial depressive effect is followed by an increase in the total bacterial number reaching the normal level. This delayed stimulation is caused by the adaptation time of the bacteria.

There was no long term adverse effect on the microbial population of the soil in the rhizosphere due to the application of bispyribac sodium @ 30 g a.i ha^{-1} in transplanted kharif rice. Due to herbicides the bacterial population was adversely affected, whereas the fungal and actinomycets population remained unaltered by weed control treatments (Kalyanasundaram and Kavitha, 2012).

Application of herbicides above field dose affected population of fungi and bacteria (Allievi and Gigliotti, 2001). The increasing reliance of rice cultivation on herbicides has led to concern about their toxicological behavior in the rice field environment (Latha and Gopal, 2010).

The microorganisms involved in herbicide detoxification include bacteria, fungi, actinomycetes and algae. Among these, bacteria predominate (Rao, 2000). Population size of microorganisms serves as bio-indicators of the impact of herbicide application in the agro-ecosystem and enhancement of microbial population in herbicide treated plots was reported earlier by Radosevich *et al.* (2009). Lekshmi (1984) reported that 2, 4 - D sodium salt did not influence the fungal and actinomycetes population.

Devi (2002) found that population of micro-flora in rice soil varied with time, after application of 2, 4- D sodium salt. A negative influence of 2, 4 – D sodium salt on soil bacteria was observed in the early period. Application of 2, 4 - D sodium salt benefited soil fungi where the bacterial populations were depressed initially. In weedy check, the microbial population was found significantly higher over other weed management practices in most of the cases (Chowdhury *et al.,* 2008). Post emergence herbicide 2, 4 - D significantly influenced bacterial population but these effects were transient, being detectable only within the first 1-5 days of herbicide addition (Subhani *et al.*, 2000).

2.5 HERBICIDE RESIDUES IN THE ECOSYSTEM AND IN PLANT PARTS

Herbicides are increasingly used for control of weeds in crop and non-crop situations. With increased awareness on environmental pollution and health hazards the data on residual toxicity of recommended herbicides become indispensable for approving a herbicide for large scale commercial use. Herbicides commonly used have practically no toxicity problem. Extensive toxicological tests are conducted before the registration of an herbicide ensuring that no toxicity problem arises with its commercial use. Ideally, herbicide should remain active in soil for a period sufficient to provide satisfactory weed control and then it must degrade in to innocuous products before it is necessary to apply it again (Yadav *et al.,* 2007).

Most of the new generation micro herbicides are less persistent in addition to their low application rates and hence residue related problems are also less compared to traditional herbicides which are applied at higher doses. Residual studies of penoxsulam applied @ 22.5 g ha^{-1} in transplanted rice indicated that there were no residues of the herbicide in soil, straw and grains (Mehta *et al.,* 2011).

The problem of herbicide residue in plants is not as serious as that of residues of other pesticides. Several workers have detected residues of applied herbicides in rice plant parts, but they were below maximum residue limit (Jayakumar *et al.*, 1994 and Padmavatidevi *et al.*, 1994). The residue analysis from the HPLC result shows that bispyribac sodium could not be detected in straw, grain and soil at harvest (<0.01 ppm) bispyribac sodium in rice crop and soil substrate not pose any threat to the environment and any other commodities as it used in the recommended concentration. (Tamilselven *et al.*, 2013). Accumulation of 2, 4 – D is generally not a problem at recommended rates of application (1 kg a.i ha^{-1}); its indiscriminate use may led to residue accumulation in soil (Tejada *et al.*, 1995).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A field experiment was carried out to evaluate the bio - efficacy of the new generation herbicide, penoxsulam in transplanted rice. The materials used and the methods adopted for the investigation is presented in this chapter.

3.1. SITE DESCRIPTION

The field experiment was conducted in a farmer's field in Kanjirathadi padasekharam, in Nemom Block, Thiruvananthapuram district, Kerala State, located at 8.5° N latitude and 76.9° E longitude at an altitude of 29 m above mean sea level (MSL).

3.1.1. Climate and Season

The experimental site experiences warm humid tropical climate. The experiment was conducted during the summer season *i.e.*, December 2012 to April 2013. The data on various weather parameters, *viz.*, weekly rainfall, maximum and minimum temperature, relative humidity and sun shine hours during the period are presented in Appendix- 1 and graphically represented in Fig.1.

3.1.2 Soil

Soil samples were collected prior to the experiment from 30 cm depth and a composite sample was used for the determination of physico-chemical properties. The important physico-chemical properties studied are given in Table 1. The soil of the experimental site belonged to the textural class of sandy clay loam and the soil order is Oxisol. The soil pH was 6 and it was high in organic carbon, available P and medium in available N and K content.

3.1.3 Cropping History of the Experimental Site

The experimental site selected was under continuous rice cultivation for the past four years.

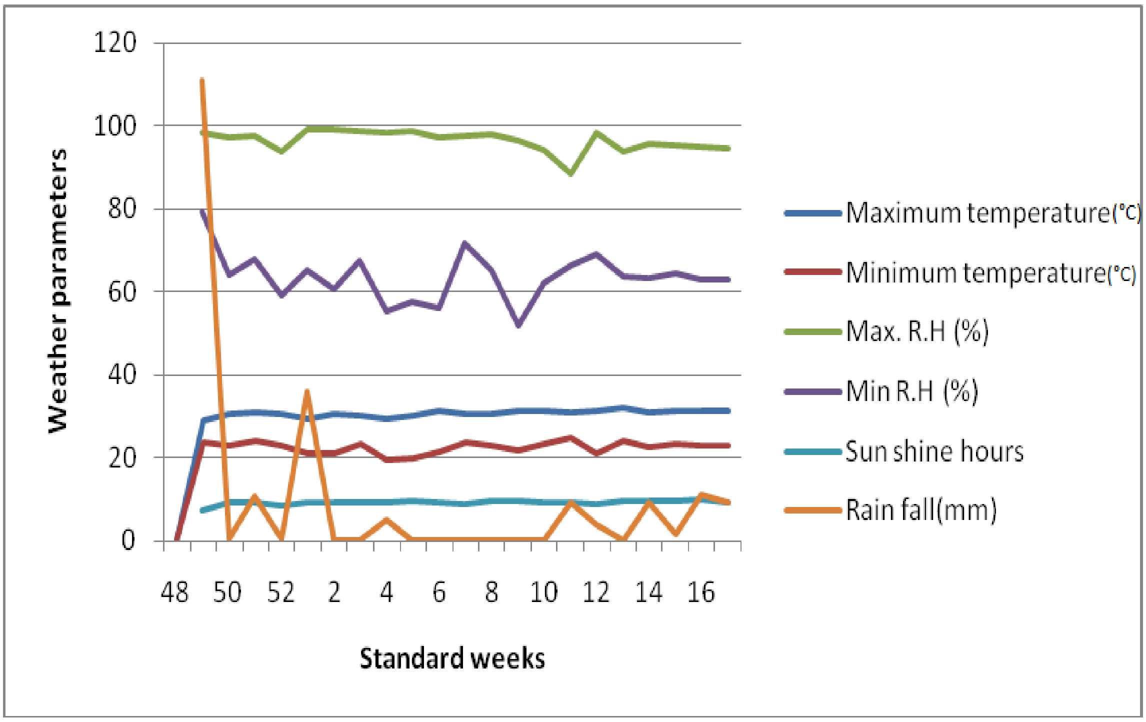

Fig 1.Weather parameters during the cropping period (December 2012- April 2013)

Table 1

Soil characters of the experimental field

A. Physical composition

Sl. No.	Fraction	Content in soil (%)	Method
1.	Coarse sand	47.65	International Pipette method (Bouyoucos , 1962)
2.	Fine sand	10.90	
3.	Silt	9.05	
4.	Clay	32.40	

B.Chemical composition

Sl. No.	Parameter	Content	Rating	Method
1.	Available nitrogen (kg ha^{-1})	500	Medium	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
2.	Available phosphorus (kg ha^{-1})	22.4	High	Bray colorimetric method (Jackson ,1973)
3.	Available potassium (kg ha^{-1})	170.1	Medium	Ammonium acetate method (Jackson, 1973)
4.	P^H	6.00	Slightly acidic	P^H meter with glass electrode (Jackson,1973)
5.	Organic carbon (%)	1.16	High	Ikley and Black's rapid titration (Jakson, 1973)

3.2 MATERIALS

3.2.1 Crop Variety

The rice variety selected for the experiment was Uma released from Rice Research Station, Moncompu of Kerala Agricultural University. It is a red-kernelled variety, having duration of 120-125 days. It is reported to be resistant to blast and blight diseases and brown plant hopper and gall midge.

3.2.2 Manures and Fertilizers

Well decomposed farm yard manure containing 0.55 per cent N, 0.23 per cent P_2O_5 and 0.46 per cent K_2O was used as the organic manure source. N, P and K were applied as urea (46 per cent N), factomphos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O), respectively

3.2.3 Herbicides

The technical information, toxicity data and other available information of the herbicides are given in Table 2.

3.3 METHODS

3.3.1 Design and Layout

Design	:	Randomised Block Design
No. of treatments	:	8
Replication	:	3
Plot size	:	5 m X 4 m

3.3.2 Treatment Details

T1 – Penoxsulam @ 17.5 g a.i ha^{-1} at 10-12 DAT

T2 – Penoxsulam @ 20 g a.i ha^{-1} at 10-12 DAT

T3 – Penoxsulam @ 22.5 g a.i ha^{-1} at 10-12 DAT

T4 – Penoxsulam @ 25g a.i ha^{-1} at 10-12 DAT

T5 – Bispyribac sodium @ 30 g a.i ha^{-1} at 20 DAT

T6 - 2, 4- D sodium salt @1 kg a.i ha^{-1}at 20 DAT

T7 – Hand weeding twice (HWT)

T8 – Weedy check

3.3.3 Crop Management

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

3.3.3.1 Nursery

The nursery area was ploughed thoroughly after the application of FYM @ 1 kg m^{-2} to raise beds of 5 to 10 cm height and 1 to 1.5 m width and of convenient length. Pre germinated seeds were sown in the nursery @ 80 kg ha^{-1}. Water was drained for 9 hours once in 5 days to encourage production of vigorous seedlings. Bird scaring was carried out for seven days initially.

3.3.3.2 Main Field Preparation

The experimental area was puddled twice and leveled. Weeds and stubbles were removed by hand picking. Three blocks with eight plots each were laid out in randomized block design. The blocks were separated with channels of 60 cm width. Each experimental plot was of 5 m X 4 m size and there were 24 plots for the experiment.

3.3.3.3 Application of Manures and Fertilizers

Farm yard manure was incorporated @ 5 t ha $^{-1}$ at the time of last ploughing. Urea, factomphos and muriate of potash were applied to supply N, P_2O_5 and K_2O @ 90, 45 and 45 kg ha $^{-1}$ respectively.

Full dose of phosphorus along with half dose of nitrogen and potassium were applied as basal dose. Top dressing of the remaining dose of chemical

Table 2. Technical information and toxicity data of the herbicides used in thestudy

Common name	Penoxsulam	2, 4 – D sodium salt	Bispyribacsodium
Trade name	Granite	Fernoxone	Nominee gold
Chemical name	3-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]triazolo[1,5-*c*]pyrimidin-2-yl)-α,α,α-trifluorotoluene-2-sulfonamide	2,4-dichlorophenoxyacetic acid	sodium 2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoate
Formulation	SC	WP	SC
Molecular weight	483.37	261.03	452.35
Physical state, color, odour	Off white liquid, musty odour	White powder	Odourless, white powder.
Acute oral toxicity LD50 (rats)	>5000 mg / kg	>1646 mg/kg	>2000 mg/kg
Acute dermal toxicity LD50	>5000 mg/kg	> 2000 mg/kg	>2000 mg/kg.
Colour code	Green	Yellow	Blue
Price	Rs 796/- for 37.5 ml	Rs 320/-for 1 kg	Rs 354 /- for 40 ml
Manufacturer	Dow agro chemicals	Aero agro chemicals.	P I Industries, Gujarat

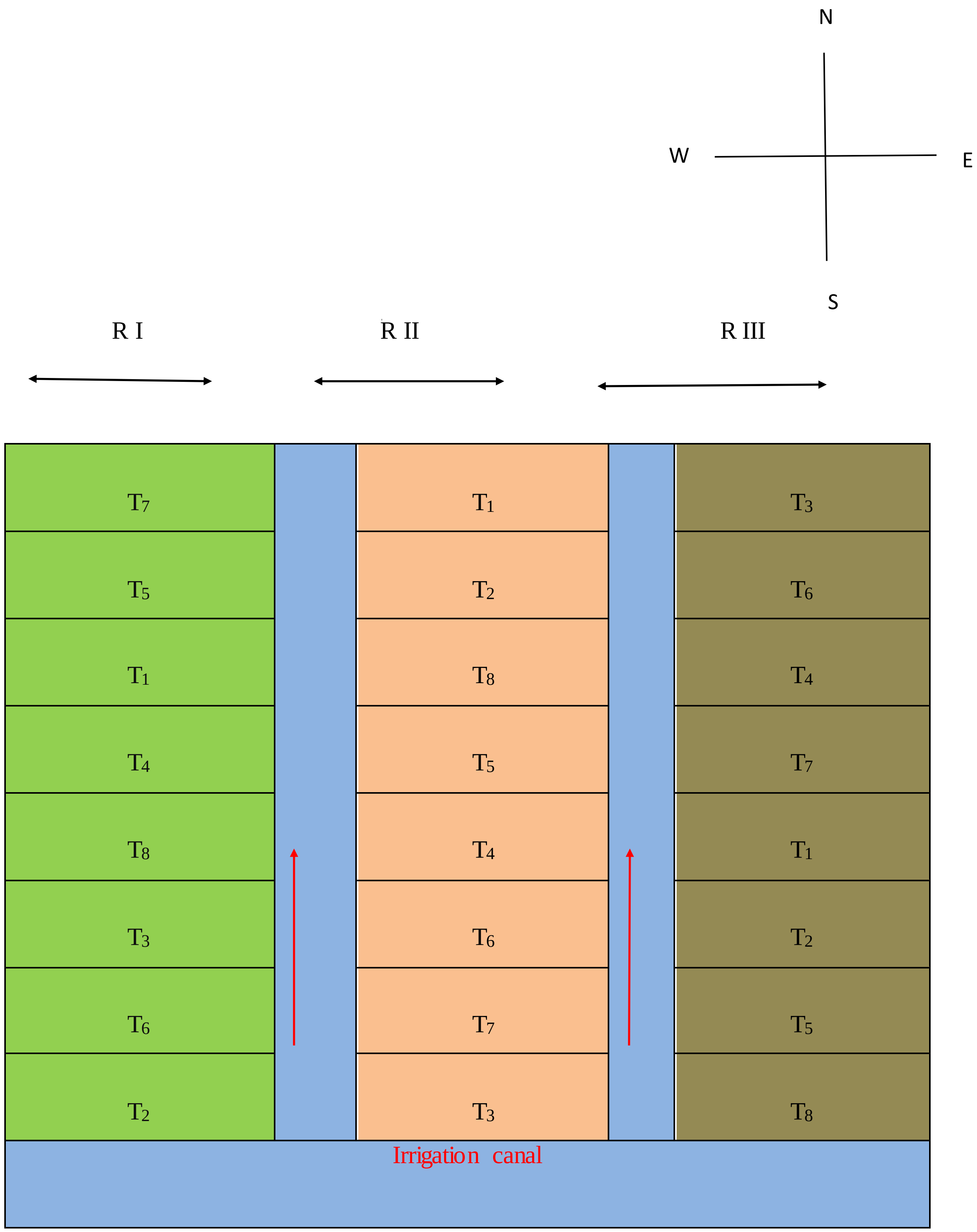

Fig 2. Lay out of the experimental field

fertilizers was carried out at 45 days after transplanting (DAT) as per the Package of Practices Recommendations 'Crops' (KAU, 2011).

3.3.3.4 Application of Lime

Lime @ 600 kg ha^{-1} was applied in two split doses *viz*., just after the second tillage and at tillering stage.

3.3.3.5 Transplanting

Twenty days old seedlings were transplanted in the main field @ 2-3 seedlings per hill and the water level was maintained at about 1.5 cm during transplanting. Thereafter, the water level was increased gradually to about 5 cm and the water level was maintained at 5 to 10 cm throughout the growth period except when drained for fertilizer and herbicide application. Field bunds were strengthened as and when necessary.

3.3.3.6 Weed Management

Weeding as per treatments was done. Herbicide solutions were prepared in water according to the treatments and sprayed with pneumatic sprayer. Care was taken to ensure uniformity in spraying and to avoid drift. Hand weeding was done at 20 and 40 DAT in T7, as per treatment.

3.3.3.7 Plant Protection

Cartap hydrochloride @ 0.1 per cent was applied against leaf folder during the crop period. No diseases were observed.

3.3.3.8 Harvest

Leaving two rows each on all sides, the net plot area was harvested separately, threshed, winnowed and weight of grains and straw from individual plots were recorded.

Plate 1. General view of the experimental field

3.4 OBSERVATIONS ON CROP

3.4.1 Growth and Growth Attributes

3.4.1.1 Phytotoxicity Rating

The treated plots were observed closely and the visual symptoms of herbicide phytotoxicity if any on the rice plants were recorded seven days after herbicide application.

3.4.1.2 Plant Height

The plant height was recorded at 20, 40, 60 DAT and at harvest. The height was measured from the base of the plant to the tip of the longest leaf at vegetative stage and to the tip of the longest ear head at harvest stage. The mean of the observations was expressed in centimeters.

3.4.1.3 Tillers m^{-2}

The number of tillers per square meter was counted and the average was worked out at 20, 40, 60 DAT and at harvest.

3.4.1.4 Dry Matter Production

From each plot, six sample hills were uprooted at harvest. They were washed and dried in shade and then dried in hot air oven at 80^{0}C till constant weight was attained. Dry weight of the sample was found out and dry matter production was expressed in kg ha^{-1}.

3.4.2 Yield Attributes and Yield

3.4.2.1 Productive Tillers m^{-2}

At harvest the number of productive tillers was obtained from six randomly selected hills in the net plot area and was expressed as number of productive tillers m^{-2}

3.4.2.2 Grain Weight Panicle^{-1}

Grain weight per panicle was obtained from ten randomly selected panicles and expressed in grams

3.4.2.3 Spikelet Panicle^{-1}

This observation was obtained by counting the spikelet from ten randomly selected panicles in each plot.

3.4.2.4 Sterility Percentage

Total number of spikelets per panicle and number of unfilled grains per panicle were obtained from ten randomly selected panicles and sterility percentage was worked out using the following formula;

$$\text{Sterility percent (\%)} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.4.2.5 Thousand Grain Weight

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

3.4.2.6 Grain Yield

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

3.4.2.7 Straw Yield

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

3.4.2.8 Harvest Index

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

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

3.5 OBSERVATIONS ON WEEDS

Quadrate of size 0.5 m^2 was placed at random in two sites the area set apart in each plot for destructive sampling and the weeds falling within the frames of the quadrate were collected at 20, 40 and 60 DAT and at harvest. The following observations were recorded and average worked out.

3.5.1 Floristic Composition of Weeds

The weeds were identified and categorized into grasses, sedges and broad leaved weeds.

3.5.2 Dry Matter Production

Weeds coming inside the quadrate with 0.5 m^2 were pulled out carefully with roots intact, washed, dried under shade and then oven dried to a constant weight. The dry weight was expressed in g m^{-2}. Weed dry weight was recorded at 20, 40 and 60 DAT.

3.5.3 Weed Control Efficiency

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

WCE = { (X - Y) / X } 100

Where,

WCE = Weed control efficiency

X = Weed dry weight from treatment which recorded maximum number of weeds (Weedy check)

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

3.5.4 Absolute Density (Ad)

Absolute weed density was recorded by placing quadrate at random in two sites in each plot and calculated the average. The weeds were categorized into three morphological classes *viz.*, grasses, sedges and broad leaved weeds and the absolute density was recorded at regular intervals of 20, 40 and 60 days after transplanting using the formula suggested by Philips (1959).

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

3.5.5 Relative Density (Rd)

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

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

3.5.6 Absolute Frequency (Af)

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

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

3.5.7 Relative Frequency (Rf)

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

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

3.5.8 Summed Dominance Ratio (SDR)

Summed Dominance Ratio (SDR) for each species was worked out based on the equation developed by Sen (1981)

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

3.5.9 Importance Value (IV)

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

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

3.6 CHEMICAL ANALYSIS

3.6.1 Plant Analysis

The weeds samples as well as sample crop plants uprooted at harvest were analyzed for total N, P and K. The samples were dried in an electric hot air oven to constant weight, ground and passed through a 0.5 mm sieve. The required quantity of samples were weighed out accurately in an electronic balance, subjected to acid extraction and used for analysis.

3.6.1.1 *Total Nitrogen Content*

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

3.6.1.2 *Total Phosphorus Content*

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

3.6.1.3 *Total Potassium Content*

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

3.6.2 UPTAKE OF NUTRIENTS

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

3.6.3 SOIL ANALYSIS

Soil samples were collected from the experimental area before and after the experiment. It was analyzed to determine the available N, available P_2O_5 and available K_2O. The physical composition and pH were determined for pre experiment soil sample.

3.6.3.1 Physical Composition of Soil

Percentage of coarse sand, fine sand, silt and clay in the pre - experiment composite soil sample were determined by International Pipette Method (Bouyoucos, 1962).

3.6.3.2 N, P, K content of soil

Samples collected before and after the experiment were dried in shade, sieved through 2 mm sieve and analysed to determine the available N content of the soil by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus content by Dickman and Brays molybdenum blue method using Bray No.1 reagent for extraction (Jackson, 1973) and available potassium was determined using neutral normal ammonium acetate extract and estimated using EEL Flame Photometer (Jackson, 1973).

3.6.3.3 Soil Reaction

pH of the pre - experiment composite soil sample was estimated using 1:2.5 soil water suspension using Perkin Elmer pH meter (Jackson, 1973).

3.7 MICROBIAL STUDIES

Enumeration of soil microbial population was carried out just before spraying the herbicides and 6 days after spraying the herbicide.

3.7.1 Soil Collection

Soil samples were taken at 0-15 cm depth, from each replication just before herbicide spraying and from each plot 6 days after spraying the herbicide.

3.7.2 Enumeration of soil fungi, bacteria and actinomycetes

The total count of fungi, bacteria and actinomycetes was enumerated by serial dilution technique (Johnson and Curl, 1972). The media and dilution used for isolation of different groups of microorganisms and the composition of the mentioned media are given in Appendix II.

Serial Dilution

One gram of soil was added to 100 ml of sterilized distilled water in a 250 ml conical flask under aseptic condition and shaken for 30 minutes in orbital shaker for uniform mixing for obtaining 10^{-2} dilution. With a sterile pipette, 1 ml of 10^{-2} dilution was transferred to 99 ml sterile water blank and mixed well to obtain a 10^{-4} dilution. Further 1 ml of 10^{-4} dilution was transferred to 99 ml of sterile water blank and mixed well to obtain a 10^{-6} dilution. One ml aliquots of 10^{-4} dilution were transferred to sterile petridishes for enumeration of fungi and bacteria. Similarly 1 ml aliquot of 10^{-6} dilution was used for the estimation of actinomycetes. Melted and cooled Rose Bengal Agar, Soil Extract Agar and Kenknights Agar media were poured into these petridishes @ 20 ml per dish for the estimation of fungi, bacteria and actinomycetes, respectively. Plates were incubated at 28^0C. Observations were recorded for appearances of colonies after

24 hours in the case of bacteria, 72 hours for fungi and 154 hours for actinomycetes.

3.8 ECONOMIC ANALYSIS

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

3.8.1 Net Income

Net income was computed using the formula,

Net income (Rs. ha^{-1}) = Gross income – Total expenditure

3.8.2 Benefit Cost Ratio (BCR)

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

3.9 STATISTICAL ANALYSIS

The data generated from the experiment were statistically analyzed using Analysis of Variance techniques (ANOVA) as applied to Randomized Block Design described by Cochran and Cox (1965). The data do not satisfy the basic assumptions of ANOVA, were transformed using square root transformation. Whenever the result was significant the critical difference was worked out at 5 per cent probability.

RESULTS

4. RESULTS

A field experiment was conducted at farmer's field to evaluate the bio - efficacy of the new generation herbicide, penoxsulam in transplanted rice. The data obtained was subjected to statistical analysis and the results are presented in this chapter.

4.1. OBSERVATIONS ON WEEDS

The observations recorded on various aspects of weeds *viz.,* floristic composition, dry weight, weed control efficiency, density, frequency, summed dominance ratio, importance value etc are presented in this section.

4.1.1 Floristic Composition of Weeds

The different weed species found in the experimental field were identified and categorized as grasses, sedges and broad leaved weeds and the details are furnished in Table 3.

4.1.2 Weed Dry Weight

The major weed flora observed in the experimental field were gathered at regular intervals and dry weight of each category was recorded and the data are presented in Tables 4 to 7.

4.1.2.1 Total Weed Dry Weight

The results are presented in Table 4.

At 20 DAT, total weed dry weight was recorded before the application of 2, 4 - D sodium salt, bispyribac sodium and hand weeding. Among the different doses of penoxsulam, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the lowest total weed dry weight which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}. At 40 DAT also T4 registered the lowest weed dry weight. However it was on par with other doses of penoxsulam, T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}) and T6 (2, 4 - D sodium salt). At 60 DAT, T4 was found to be the best treatment which recorded lowest total weed dry weight and it was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T2 (penoxsulam

Table 3. Major weed flora observed in the experimental field

Common name	Scientific name	Family	Malayalam name
GRASSES			
Jungle rice Ginger grass	*Echinochloa colona* (L.) Link *Panicum repens*	Poaceae Poaceae	Kavada Injipullu
SEDGES			
Slender sedge Forked fimbry Greater club rush	*Cyperus difformis* *Fimbristylis dichotoma(L.)* Vahl *Scirpus grossus* L.f	Cyperaceae Cyperaceae Cyperaceae	Muthanga Karimanchy Kora
BROADLEAVED WEEDS			
Water cabbage Pickerel weed Water primose Baby tears Kariba weed Airypepper wort Water lettuce	*Limnocharis flava* (L.) Buchenau *Monochoria vaginalis* (Burm.f.) Presl. Ex Kunth. *Ludwigia parviflora* Roxb. *Lindernia rotundifolia* blanc vert *Salvinia molesta* D.S. Mitch. *Marsilea quadrifolia* Linn. *Pistia sPistia stratiotes* L.Royle	Limnocharitaceae Pontederiaceae Onagraceae Scrophulariaceae Salviniaceae Marsiliaceae Araceae	Nagapola Neelolpalam Neergrambu African payal Naalila kodiyan Mutta payal

@ 20.0 g a.i ha^{-1} and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}). At all the stages of observation except at 20 DAT, weed dry weight recorded was highest in T8 (weedy check) and this treatment was significantly inferior to all other treatments.

4.1.2.2 Dry Weight of Grasses

The results are presented in Table 5.

At 20 DAT, lowest dry weight of grasses was recorded by T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and it was on par with T4 (penoxsulam @ 25.0 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT, lowest dry weight of grasses was recorded by T4, which was on par with T3, T2, T1 and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}). At 60 DAT also the lowest dry weight of grasses was recorded by T4. It was on par with T3, T1, T2 and T5. At all the stages of observation, T8 (weedy check) recorded the highest dry weight of grasses.

4.1.2.3 Dry Weight of Sedges

The results are presented in Table 6.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the lowest dry weight for sedges. At 40 DAT also lowest dry weight was recorded by T4 and it was on par with T3 (penoxsulam @ 22.50 g a.i ha^{-1}). At 60 DAT also T4 was found to be the best treatment with lowest weed dry weight of sedges and it was on par with T3 and T2 (penoxsulam @ 20.00 g a.i ha^{-1}).

4.1.2.4 Dry Weight of Broad Leaved Weeds

The results are presented in Table 7.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}) recorded the lowest dry weight of broad leaved weeds which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}), and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT also lowest weed dry weight was registered by T4, which was on par with T3. At 60 DAT also lowest weed dry weight was recorded by T4,

Table 4. Effect of weed management practices on total weed dry weight

Treatments	Total weed dry weight, g m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	2.04 (1.42)	2.62 (1.62)	9.06 (3.01)
T2	1.23 (1.11)	2.62 (1.62)	7.51 (2.74)
T3	0.55 (0.74)	2.43 (1.56)	6.45 (2.54)
T4	0.44 (0.66)	2.28 (1.51)	4.62 (2.15)
T5	12.96 (3.60)	2.43 (1.56)	7.62 (2.76)
T6	12.53 (3.54)	2.40 (1.55)	41.99 (6.48)
T7	13.76 (3.71)	5.48 (2.34)	60.06 (7.75)
T8	15.44 (3.93)	46.10 (6.79)	202.21 (14.22)
SE m(±)	0.06	0.04	0.22
CD (0.05)	0.193	0.122	0.696

Table 5. Effect of weed management practices on dry weight of grasses

Treatments	Dry weight of grasses, g m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	0.04 (1.02)	0.69 (1.28)	1.60 (1.58)
T2	0.04 (1.02)	0.72 (1.29)	1.70 (1.62)
T3	0.00 (1.00)	0.99 (1.31)	0.67 (1.27)
T4	0.04 (1.02)	0.29 (1.12)	0.30 (1.12)
T5	0.90 (1.38)	1.05 (1.33)	0.78 (1.31)
T6	0.91 (1.39)	5.38 (2.52)	2.68 (1.91)
T7	0.68 (1.30)	4.58 (2.36)	6.95 (2.82)
T8	1.30 (1.51)	9.32 (3.21)	14.53 (3.92)
SE m(±)	0.03	0.09	0.16
CD (0.05)	0.112	0.286	0.511

Figures in parenthesis denote transformed values

Table 6. Effect of weed management practices on dry weight of sedges

Treatments	Dry weight of sedges, g m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	1.10 (1.48)	1.49 (1.22)	4.10 (2.27)
T2	1.00 (1.42)	1.12 (1.06)	3.70 (2.17)
T3	0.6 (1.28)	0.13 (0.36)	2.10 (1.93)
T4	0.20 (1.10)	0.11 (0.33)	2.00 (1.74)
T5	7.90 (2.98)	1.17 (0.82)	4.10 (2.27)
T6	7.80 (2.98)	2.53 (1.59)	33.30 (5.83)
T7	8.10 (3.02)	3.67 (1.88)	34.0 (5.91)
T8	8.20 (3.04)	9.11 (3.01)	131.0 (11.48)
SE m(±)	0.03	0.13	0.16
CD (0.05)	0.095	0.410	0.507

Table 7. Effect of weed management practices on dry weight of broad leave weeds

Treatments	Dry weight of broad leaved weeds, g m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	0.80 (1.35)	1.40 (1.55)	3.30 (2.07)
T2	0.20 (1.11)	1.41 (1.57)	2.70 (1.93)
T3	0.22 (1.13)	0.60 (1.42)	3.00 (2.01)
T4	0.20 (1.11)	0.40 (1.20)	2.60 (1.91)
T5	4.50 (2.35)	1.32 (1.52)	3.10 (2.01)
T6	5.00 (2.46)	1.60 (1.62)	5.40 (2.34)
T7	5.00 (2.45)	3.00 (2.01)	25.50 (5.13)
T8	4.50 (2.36)	27.60 (5.35)	58.90 (7.74)
SE m(±)	0.09	0.08	0.16
CD (0.05)	0.282	0.251	0.507

Figures in parenthesis denote transformed values

which was on par to T6 (2, 4 –D sodium salt @ 1 kg a.i ha^{-1}), T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T3, T2 and T1.

4.1.3 Weed Control Efficiency

Weed control efficiency of grasses, sedges and broad leaved weeds were computed at 20, 40 and 60 DAT. The results are presented in Tables 8 to 11.

4.1.3.1 Total Weed Control Efficiency (WCE)

The results are presented in Table 8.

Weed control efficiency was worked out taking T8 (weedy check), *i.e.* the treatment with maximum weed count as the base treatment. The weed control treatments influenced weed control efficiency significantly. At 20 DAT, weed control efficiency was highest for T4 (penoxsulam @ 25.0 g a.i ha^{-1}) which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}). At 40 DAT also the highest total weed control efficiency (96.24 per cent) was recorded by T4 which was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T3, T2, and T5 (bispyribac @ 30.0 g a.i ha^{-1}). Total weed control efficiency was lowest for T7 (Hand weeding twice). At 60 DAT, T4 registered the highest value and it was on par with T3 and T2. The lowest total weed control efficiency was recorded by T7. At 40 and 60 DAT, with respect to weed control efficiency, new generation herbicides penoxsulam and bispyribac sodium were found to be highly efficient and significantly superior to the traditional herbicide 2, 4 – D sodium salt.

4.1.3.2 Weed Control Efficiency of Grasses

The results are presented in Table 9.

At 20 DAT, T3 (penoxsulam @ 22.5 g a.i ha^{-1}) recorded highest weed control efficiency which was on par with all the doses of penoxsulam *i.e.* T4 (penoxsulam @ 25.0 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT, highest weed control efficiency was registered by T4 which was on par with T5 (bispyribac @ 30.0 g a.i ha^{-1}), T3, T2 and T1. At this stage the lowest weed control efficiency for

Table 8. Effect of weed management practices on total weed control efficiency

Treatments	Total weed control efficiency, %		
	20 DAT	40 DAT	60 DAT
T1	86.84	95.52	95.30
T2	91.62	94.24	95.85
T3	93.58	94.58	96.33
T4	96.91	96.24	97.65
T5	15.56	92.15	95.76
T6	17.97	76.17	81.66
T7	10.70	75.14	67.38
T8	-	-	-
SE m(±)	2.36	1.54	0.60
CD (0.05)	7.300	4.770	1.860

Table 9. Effect of weed management practices on weed control efficiency of grasses

Treatments	Weed control efficiency of grasses, %		
	20 DAT	40 DAT	60DAT
T1	97.1	92.5	87.9
T2	97.2	92.0	87.5
T3	99.4	89.3	95.8
T4	99.2	96.6	97.2
T5	26.8	88.6	93.9
T6	30.6	42.2	81.4
T7	45.9	50.8	50.6
T8	-	-	-
SE m(±)	5.00	2.80	3.44
CD (0.05)	15.52	8.82	10.62

grasses was recorded by T6 (2, 4-D sodium salt @ 1 kg a.i ha^{-1}) and it was on par with T7 (hand weeding twice). The same trend was observed at 60 DAT also.

4.1.3.3 Weed Control Efficiency of Sedges

The results are presented in Table 10.

At 20 DAT, all the doses of the new generation herbicide penoxsulam exhibited successful control of sedges. Among the four doses, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) registered highest WCE (97.45%), which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT also T4 recorded the highest weed control efficiency which was on par with T3, T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T1 and T2. T7 (hand weeding twice) recorded the lowest weed control efficiency which was on par with T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1}). At 60 DAT also T4 recorded highest weed control efficiency which was on par with T3, T2 and T5.

4.1.3.4 Weed Control Efficiency of Broad Leaved Weeds

The results are presented in Table 11.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded highest weed control efficiency which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT, T1 found to be the best treatment and it was significantly superior to all other treatments. T1 was followed by T4 which was on par with T3 and T2. At 60 DAT,T4 registered the highest value and it was on par with T3, T2, T1, T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}) and T6 (2, 4-D sodium salt @ 1 kg a.i ha^{-1}) and the lowest WCE of broad leaved weeds was recorded by T7 (hand weeding twice).

4.1.4 Absolute Density of weeds

The effect of treatments was assessed on the basis of density of different morphological groups of weeds *viz.*, grasses, sedges and broad

Table 10. Effect of weed management practices on weed control efficiency of Sedges

Treatments	Weed control efficiency of sedges, %		
	20 DAT	40 DAT	60 DAT
T1	87.80	85.10	85.64
T2	97.10	84.70	87.64
T3	97.80	98.50	95.24
T4	98.40	98.70	97.45
T5	96.70	87.00	93.83
T6	74.30	72.20	81.27
T7	73.90	59.10	41.30
T8	-	-	-
SE m(±)	3.91	4.61	10.38
CD (0.05)	12.06	14.39	4.26

Table 11. Effect of weed management practices on weed control efficiency of broad leaved weeds

Treatments	Weed control efficiency of broad leaved weeds, %		
	20 DAT	40 DAT	60 DAT
T1	81.70	98.20	94.30
T2	94.80	94.60	95.30
T3	91.60	94.60	94.80
T4	95.10	95.20	95.50
T5	1.60	95.10	94.60
T6	-9.70	94.10	90.70
T7	-8.50	88.60	56.30
T8	-	-	-
SE m(±)	9.41	0.88	2.60
CD (0.05)	29.02	2.72	8.01

leaved weeds. Data were recorded at 20, 40 and 60 DAT and the results are presented in Tables 12, 13, 14 and 15.

4.1.4.1 Total Absolute Density

The results are presented in Table 12.

At 20 DAT, weed density observations were made after the application of the new generation herbicide penoxsulam and before the application of bispyribac sodium, 2, 4 - D sodium salt and hand weeding twice. Among the four doses of penoxsulam, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the least number of weeds and it was on par to other doses of penoxsulam. At 40 DAT also T4 recorded least number of weeds which was on par to T3 (penoxsulam @ 22.5 g a.i ha^{-1}). Comparing the three herbicides, total absolute density was highest for 2, 4-D sodium salt. At 60 DAT, also the same trend was noticed.

4.1.4.2 Absolute Density of Grasses

The results are presented in Table 13.

At 20 DAT, the density of grassy weeds was lowest with T4 (penoxsulam @ 25.0 g a.i ha^{-1}) as well as T3 (penoxsulam @ 22.5 g a.i ha^{-1}) which was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At 40 DAT, the weed management practices showed significant influence on the absolute density of the grassy weeds with T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recording the lowest weed count on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T3. At 60 DAT also T4 recorded the least number of weeds which was on par with T3 and T5.

4.1.4.3 Absolute Density of Sedges

The results are presented in Table 14.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded lowest absolute density of sedges which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}). At 40 DAT also T4 registered least count of sedges. However it was on par with T3. At 60 DAT, lowest numbers of sedges were recorded in T3 which was on par with all

Table 12. Effect of weed management practices on total absolute density of weeds

Treatments	Total absolute density of weeds number m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	27.35 (5.22)	24.21 (4.81)	30.25 (5.40)
T2	29.27 (5.40)	18.58 (4.18)	28.84 (5.27)
T3	26.32 (5.13)	9.61 (2.93)	16.97 (3.99)
T4	25.20 (5.01)	8.53 (2.75)	15.68 (3.82)
T5	202.49 (14.24)	33.29 (5.77)	21.62 (4.53)
T6	209.09 (14.47)	46.92 (6.88)	52.27 (7.16)
T7	204.20 (14.29)	58.98 (7.61)	58.98 (7.61)
T8	209.38 (14.46)	311.52 (17.62)	354.95 (18.81)
SE m(±)	0.27	0.22	0.18
CD (0.05)	0.835	0.674	0.560

Table 13. Effect of weed management practices on absolute density of grasses

Treatments	Absolute density of grasses, number m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	1.33 (1.48)	6.00 (2.43)	6.66 (2.53)
T2	2.66 (1.90)	4.66 (2.21)	8.00 (2.98)
T3	0.66 (1.24)	2.00 (1.65)	3.33 (1.96)
T4	0.66 (1.24)	0.66 (1.24)	0.66 (1.24)
T5	14.00 (3.85)	6.66 (2.76)	4.00 (2.07)
T6	16.00 (4.11)	12.00 (3.59)	18.00 (4.35)
T7	14.66 (3.94)	15.33 (4.04)	20.00 (4.57)
T8	12.00 (3.59)	97.33 (9.91)	126.00 (11.26)
SE m(±)	0.20	0.40	0.42
CD (0.05)	0.617	1.225	1.263

Figures in parenthesis denote transformed values.

other treatments except weedy check. Weedy check recorded the highest absolute density of sedges at all the growth stages.

4.1.4.4 Absolute Density of Broad Leaved Weeds (BLW)

The results are presented in Table 15.

At 20 DAT, among four different doses of penoxsulam tried, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) was found to be significantly superior to other doses and it successfully controlled the broad leaved weeds in the field. Other three doses *viz*., T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}), and T3 (penoxsulam @ 22.5 g a.i ha^{-1}) were found to be on par with each other. At 40 DAT, all the herbicides applied were found to be very effective in controlling broadleaved weeds and among them T4 was the best treatment, which was significantly superior to all other treatments. At 60 DAT also.T4 recorded the lowest absolute density of broad leaved weeds which was on par with T3. Low doses of penoxsulam *viz*., T1 and T2 were found to be on par with the traditional herbicide 2, 4 –D sodium salt @ 1 kg a.i ha^{-1} (T6). At all the stages maximum number of weeds were recorded in weedy check.

4.1.5 Relative density

4.1.5.1 Relative Density of Grasses

The data presented in the Table 16 on relative density of grasses indicated that the treatments did not vary significantly with respect to their influence on this character.

4.1.5.2 Relative Density of Sedges

The results are presented in Table 17.

No significance difference was observed among treatments for relative density of sedges at 20 and 60 DAT. However, at 40 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded lowest relative density which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}).

Table 14. Effect of weed management practices on absolute density of sedges

Treatments	Absolute density of sedges, number m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	14.66 (3.94)	10.00 (3.20)	8.66 (3.10)
T2	14.00 (3.86)	5.33 (2.34)	6.00 (2.62)
T3	8.00 (2.98)	1.33 (1.17)	4.66 (2.32)
T4	4.66 (2.37)	0.00 (1.00)	8.66 (3.10)
T5	94.00 (9.74)	6.66 (2.63)	5.33 (2.50)
T6	102.00 (10.12)	14.66 (3.88)	17.33 (4.27)
T7	95.00 (9.79)	15.33 (3.97)	14.00 (3.85)
T8	103.66 (10.19)	90.00 (10.42)	110.00 (10.52)
SE m(±)	0.32	0.23	0.83
CD (0.05)	0.992	0.726	2.532

Table 15. Effect of weed management practices on absolute density of broad leaved weeds

Treatments	Absolute density of broad leaved weeds, number m^{-2}		
	20 DAT	40 DAT	60 DAT
T1	16.00 (4.12)	7.33 (2.70)	14.00 (3.85)
T2	12.66 (3.69)	6.00 (2.42)	14.00 (3.86)
T3	13.33 (3.78)	4.33 (2.42)	8.00 (2.98)
T4	7.33 (2.64)	2.66 (1.60)	7.33 (2.88)
T5	94.66 (9.78)	16.00 (3.98)	11.33 (3.50)
T6	91.33 (9.60)	19.33 (4.38)	16.00 (4.11)
T7	94.66 (9.78)	27.33 (5.22)	30.66 (5.62)
T8	94.00 (9.75)	192.00 (10.24)	131.33 (11.50)
SE m(±)	0.32	0.19	0.18
CD (0.05)	0.982	0.600	0.548

Figures in parenthesis denote transformed values

Table 16. Effect of weed management practices on relative density of grasses

Treatments	Relative density of grasses, %		
	20 DAT	40 DAT	60 DAT
T1	4.16	24.67	21.28
T2	8.86	24.44	28.41
T3	3.03	12.22	19.44
T4	4.16	16.66	5.55
T5	6.87	23.65	17.77
T6	7.65	25.91	35.03
T7	7.15	26.45	31.03
T8	5.80	25.66	34.34
SE m(±)	-	-	-
CD (0.05)	NS	NS	NS

Table 17. Effect of weed management practices on relative density of sedges

Treatments	Relative density of sedges, %		
	20 DAT	40 DAT	60 DAT
T1	45.83	43.37	29.58
T2	47.73	31.11	21.04
T3	36.31	13.33	19.41
T4	52.77	0.00	34.04
T5	46.37	22.02	23.33
T6	48.58	31.30	33.65
T7	46.46	26.41	21.60
T8	48.77	34.81	29.90
SE m(±)	-	5.79	-
CD (0.05)	NS	17.610	NS

4.1.5.3 Relative Density of Broad Leaved Weeds

The results are presented in Table 18.

Relative density of broad leaved weeds was statistically significant at 40 and 60 DAT. At 40 DAT, relative density was lowest for T1 (penoxsulam @ 17.5 g a.i ha^{-1}) which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}), T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}) T7 (hand weeding twice), T6 (2, 4 –D sodium salt) and T8 (weedy check). At 60 DAT, T6 found be the best treatment and it recorded the lowest relative density of broad leaved weeds which was statistically superior to all other treatments.

4.1.6 Absolute Frequency

The data on total absolute weed frequency and absolute frequency of grasses, sedges and broadleaved weeds are presented in Table 19, 20, 21 and 22.

4.1.6.1 Total Absolute Weed Frequency

The results are presented in Table 19.

Total absolute frequency of weeds as influenced by different weed control treatments were recorded at regular intervals. At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the lowest total absolute frequency of weeds and it was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T3 (penoxsulam@ 22.5 g a.i ha^{-1}). At 40 DAT also T4 recorded the lowest (44%) total absolute frequency which was on par with T3 (77%). At 60 DAT, T3 and T4 recorded lowest total absolute weed frequency (88.88%) which was on par with T1, T2 and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}).

4.1.6.2 Absolute Frequency of Grasses

The results are presented in Table 20.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T3 (penoxsulam @ 22.5 g a.i ha^{-1}) recorded lowest absolute frequency of grasses which were on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}). At

Table 18. Effect of weed management practices on relative density of broad leaved weeds

Treatments	Relative density of broad leaved weeds, %		
	20 DAT	40 DAT	60 DAT
T1	50.0	31.9	49.1
T2	43.3	44.4	50.5
T3	60.9	64.4	49.8
T4	43.0	83.3	73.8
T5	46.7	54.3	56.1
T6	43.7	41.1	31.3
T7	46.3	47.1	47.3
T8	45.2	33.8	55.7
SE m(±)	-	8.90	5.00
CD (0.05)	NS	27.29	15.18

Table 19. Effect of weed management practices on total absolute weed frequency

Treatments	Total absolute weed frequency, %		
	20 DAT	40 DAT	60 DAT
T1	132.66	110.33	99.99
T2	132.66	99.33	122.21
T3	99.33	77.00	88.88
T4	77.33	44.00	88.88
T5	288.66	110.33	111.10
T6	277.33	210.33	144.43
T7	266.33	199.33	222.21
T8	255.33	300	266.66
SE m(±)	21.78	12.38	17.52
CD(0.05)	66.236	37.637	53.290

40 DAT, maximum control was obtained in T4 followed by T3 which were on par with T1, T2, and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}). Among the treatments T6 (2, 4 – D sodium salt) and T7 (hand weeding twice) recorded highest frequency on par with T8 (weedy check). T1, T2, T3, T4 and T5 were on par and controlled the weeds better than the remaining treatments. At 60 DAT, no significant difference was observed among the treatments.

4.1.6.3 Absolute Frequency of Sedges

The results are presented in Table 21.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}) recorded the lowest absolute frequency, which was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}), and T3 (penoxsulam @ 22.5 g a.i ha^{-1}). At 40 DAT, T4 recorded the lowest absolute frequency of sedges, which was on par with T2 and T3. All the treatments excluding T6 (2, 4-D sodium salt @ 1 kg a.i ha^{-1}) were found to control sedges.successfully. At 60 DAT, all the herbicide treatments were on par, and T2, T3, T4 and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}) recorded lowest absolute frequency of sedges.

4.1.6.4 Absolute Frequency of Broad Leaved Weeds

The results are presented in Table 22.

At 20 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the lowest absolute frequency which was on par with other three doses of penoxsulam. At 40 DAT, T4 recorded the lowest value which was on par with all the herbicide treatments. The same trend was observed at 60 DAT also.

4.1.7 Relative frequency

4.1.7.1 Relative Frequency of Grasses

The results are presented in Table 23.

At 20 DAT, relative frequency of grassy weeds was lowest in treatment having T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and it was on par with T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}). At

Table 20. Effect of weed management practices on absolute frequency of grasses

Treatments	Absolute frequency of grasses, %		
	20 DAT	40 DAT	60 DAT
T1	33.33	22.22	22.22
T2	55.55	22.22	23.33
T3	11.11	22.22	22.22
T4	11.11	11.11	11.11
T5	100.00	33.33	33.33
T6	88.88	77.77	88.88
T7	100.00	77.77	34.44
T8	100.00	100.00	88.88
SE m(±)	10.17	12.59	-
CD	30.877	38.218	NS

Table 21. Effect of weed management practices on absolute frequency of sedges

Treatments	Absolute frequency of sedges,%		
	20 DAT	40 DAT	60 DAT
T1	44.44	33.33	44.44
T2	33.33	23.33	33.33
T3	44.44	11.11	33.33
T4	33.33	0.00	33.33
T5	88.88	33.33	33.33
T6	100.00	88.88	44.44
T7	88.88	55.55	77.77
T8	77.77	100	100.0
SE m(±)	12.15	8.07	7.27
CD	32.166	24.49	22.065

Table 22. Effect of weed management practices on absolute frequency of broad leaved weeds

Treatments	Absolute frequency of broad leaved weeds,%		
	20 DAT	40 DAT	60 DAT
T1	55.55	55.55	33.33
T2	44.44	44.44	55.55
T3	44.44	44.44	33.33
T4	22.22	33.33	33.33
T5	100.00	44.44	44.44
T6	88.88	44.44	55.55
T7	88.88	66.66	100.00
T8	77.77	100.00	100.00
SE m(±)	12.15	9.03	10.17
CD	36.860	27.396	30.878

Table 23. Effect of weed management practices on relative frequency of grasses

Treatments	Relative frequency of grasses, %		
	20 DAT	40 DAT	60 DAT
T1	20.00	19.44	19.44
T2	41.11	19.44	27.77
T3	8.33	25.00	22.22
T4	11.11	16.66	11.11
T5	34.72	30.55	27.77
T6	31.94	37.30	49.52
T7	36.11	37.61	19.83
T8	42.22	33.33	30.55
SE m(±)	7.42	-	-
CD	22.532	NS	NS

40 DAT, T4 recorded zero relative frequency for grasses and this dose of penoxsulam was found to be statistically superior to all other treatments. At 60 DAT, T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1}) recorded the lowest relative frequency which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}).

4.1.7.2 Relative Frequency of Sedges

The results are presented in Table 24.

At 20 DAT, T2 (penoxsulam @ 20.0 g a.i ha^{-1}) recorded lowest relative frequency of sedges which was on par to T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T6 (2, 4-D sodium salt @ 1 kg a.i ha^{-1}), T7 (hand weeding twice) and T8 (weedy check). T4 recorded zero relative frequency for sedges at 40 DAT. At 60 DAT, the lowest frequency was recorded by T6 which was on par with T2, T5, T7 and T8.

4.1.7.3 Relative Frequency of Broad Leaved Weeds

Relative frequency of broad leaved weeds did not show any significance difference among treatments at any stage of crop growth.

4.1.8 Summed Dominance Ratio (SDR)

The data on summed dominance ratio of grasses, sedges and broad leaved weeds are presented in Tables 26 to 28.With respect to the SDR of grasses, sedges and broad leaved weeds, the treatments did not vary significantly except at 40 DAT for sedges and at 60 DAT for broad leaved weeds.

4.1.8.1 Summed Dominance Ratio of Grasses

The results on summed dominance ratio of grasses given in Table 26 shows that there is no significant difference among the treatments at 20, 40 and 60 DAT.

4.1.8.2 Summed Dominance Ratio of Sedges

The results are presented in Table 27.

Table 24. Effect of weed management practices on relative frequency of sedges

Treatments	Relative frequency of sedges,%		
	20 DAT	40 DAT	60 DAT
T1	36.66	30.55	44.44
T2	26.11	36.11	27.77
T3	44.44	16.66	38.88
T4	61.11	0.00	44.44
T5	30.55	30.55	36.11
T6	36.11	36.50	22.85
T7	31.94	29.20	34.91
T8	28.88	33.33	34.72
SE m(±)	8.69	7.38	4.91
CD (0.05)	26.388	5.850	14.911

Table 25. Effect of weed management practices on relative frequency of broad leaved weeds

Treatments	Relative frequency of broad leaved weeds,%		
	20 DAT	40 DAT	60 DAT
T1	43.33	49.99	36.11
T2	32.77	44.44	44.44
T3	47.22	50.00	38.88
T4	27.77	58.33	44.44
T5	34.72	38.88	44.44
T6	31.94	20.62	27.61
T7	31.94	33.17	45.13
T8	28.88	33.33	34.72
SE m(±)	7.78	-	5.80
CD (0.05)	NS	NS	NS

Summed dominance ratio of sedges indicated that the treatments did not vary significantly except at 40 DAT. At 40 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded zero summed dominance ratio of sedges which was significantly superior to all other treatments.

4.1.8.3 Summed Dominance Ratio of Broad Leaved Weeds

The results are presented in Table 28.

The data indicates that SDR of broad leaved weeds was significantly influenced by the treatments at 60 DAT only. At this stage, T1 (penoxsulam @ 17.5 g a.i ha^{-1}) recorded the lowest SDR of broad leaved weeds which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1})

4.1.9 Importance Value (IV)

The data on importance value of grasses, sedges and broad leaved weeds are furnished in Tables 29, 30 and 31.

4.1.9.1 Importance Value of Grasses

Importance Value of grasses indicated that the treatments did not vary significantly except at 20 DAT. At 20 DAT, T3 (penoxsulam @ 22.5 g a.i ha^{-1}) recorded the lowest Importance Value of grasses which was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}).

4.1.9.2 Importance Value of Sedges

The data presented in Table 30 revealed that the treatments exerted significant impact on this observation at 40 DAT only. At 40 DAT, T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded lowest importance value for sedges which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}). The highest value was recorded by T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1}) which was on par with T8 (weedy check). At 20 and 60 DAT, no significant difference was observed among treatments.

Table 26. Effect of weed management practices on summed dominance ratio of grasses

Treatments	Summed dominance ratio of grasses		
	20 DAT	40 DAT	60 DAT
T1	12.08	22.05	28.80
T2	24.98	21.94	36.43
T3	5.68	19.44	26.16
T4	7.63	16.66	24.99
T5	20.79	27.10	31.10
T6	19.79	31.60	31.30
T7	21.63	32.033	38.11
T8	24.01	29.49	34.53
SE m(±)	-	-	-
CD (0.01)	NS	NS	NS

Table 27. Effect of weed management practices on summed dominance ratio of sedges

Treatments	Summed dominance ratio of sedges		
	20 DAT	40 DAT	60 DAT
T1	41.24	36.96	37.01
T2	36.91	33.61	24.40
T3	40.37	15.00	29.14
T4	56.94	0.00	39.24
T5	37.06	26.00	29.71
T6	42.34	33.00	28.24
T7	39.19	27.00	28.27
T8	38.82	28.00	32.21
SE m(±)	-	17.00	-
CD (0.05)	NS	5.850	NS

Table 28. Effect of weed management practices on summed dominance ratio of broad leaved weeds

Treatments	Summed dominance ratio of broad leaved weeds		
	20 DAT	40 DAT	60 DAT
T1	46.66	40.97	34.02
T2	38.08	44.44	44.44
T3	54.06	57.22	51.66
T4	35.41	70.83	63.88
T5	40.73	46.59	53.26
T6	37.15	30.91	34.40
T7	39.15	40.14	46.17
T8	37.09	41.96	42.66
SE m(±)	-	-	5.62
CD (0.05)	NS	NS	17.05

Table 29. Effect of weed management practices on importance value of grasses

Treatments	Importance value of grasses		
	20 DAT	40 DAT	60 DAT
T1	24.16	44.11	40.73
T2	52.64	43.88	56.13
T3	11.36	47.22	41.66
T4	15.27	33.33	16.66
T5	41.59	54.21	39.99
T6	39.59	63.21	84.52
T7	43.26	64.07	50.84
T8	48.02	58.99	64.89
SE m(±)	8.81	-	-
CD (0.05)	26.75	NS	NS

4.1.9.3 Importance Value of Broad Leaved Weeds

With respect to the importance value of broad leaved weeds, significant variation among the treatments was noticed only at 40 and 60 DAT. At 40 DAT, T6 (2, 4 – D sodium salt @ 1 kg a.i ha^{-1}) recorded the lowest importance value for broad leaved weeds which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T7 (hand weeding twice). At 60 DAT, the lowest value was recorded by T6 which was on par with T1 (penoxsulam @ 17.5 g a.i ha^{-1}) and T3 (penoxsulam @ 22.5 g a.i ha^{-1})

4.2. OBSERVATIONS ON CROP

4.2.1 Growth and Growth Attributes

4.2.1.1 Phytotoxicity Rating

Seven days after herbicide spraying, phytotoxicity of rice plants was rated using a visual scale of 1-10, where 1 indicates no phytotoxicity and 10 indicates total crop damage. All the treatments registered a phytotoxicity rating 1 indicating that there was no phytotoxicity to rice plants consequent to the application of the tested herbicides *viz.,* penoxsulam, bispyribac sodium and 2, 4 –D sodium salt.

4.2.1.2 Plant Height

The plant height was not significantly influenced by the treatments except at harvest. At harvest, the highest value was recorded by T3 (penoxsulam @ 22.5 g a.i ha^{-1}) which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T4 (penoxsulam @ 25.0 g a.i ha^{-1}).

4.2.1.3 Number of **Tillers** *m^{-2}*

The results are presented in Table 33.

At 20 DAT, highest number of tillers m^{-2} was recorded by T4 (penoxsulam @ 25.0 g a.i ha^{-1}). This was significantly superior to other treatments. At 40 DAT also T4 recorded highest number of tillers which was on par with T3 (penoxsulam @ 22.5 ga.i ha^{-1}). At 60 DAT also T4 recorded highest number of tillers which was on par with T3 and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}).

Table 30. Effect of weed management practices on importance value of sedges

Treatments	Importance value of sedges		
	20 DAT	40 DAT	60 DAT
T1	82.50	73.92	74.02
T2	73.84	67.22	48.81
T3	80.75	30.00	58.30
T4	70.73	0.00	67.37
T5	79.58	52.57	64.99
T6	84.69	70.97	54.79
T7	78.40	53.39	56.55
T8	77.65	57.04	64.62
SE m(±)	-	3.19	-
CD (0.05)	NS	1.050	NS

Table 31. Effect of weed management practices on importance value of broad leaved weeds

Treatments	Importance value of broad leaved weeds		
	20 DAT	40 DAT	60 DAT
T1	93.3	93.0	85.2
T2	76.1	88.8	94.9
T3	108.1	114.4	83.1
T4	70.8	116.6	110.2
T5	81.4	93.2	100.5
T6	74.6	65.9	58.9
T7	78.2	89.0	92.6
T8	74.1	93.9	90.4
SE m(±)	-	8.4	9.6
CD (0.05)	NS	25.74	29.36

4.2.1.4 Dry Matter Production, kg ha^{-1}

The results are presented in table 33.

The weed control measures did significantly influence the dry matter production of the crop. The highest drymatter production was recorded by T4 (penoxsulam @ 25.0 g a.i ha^{-1}) which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}) , T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}). Lowest dry matter production was recorded by T8 (weedy check) which was significantly inferior to all other treatments.

4.2.2 Yield Attributes and Yield

4.2.2.1 Number of Productive Tillers m^{-2}

The results are presented in Table 34.

This yield attribute was significantly influenced by the weed control measures. The highest number of productive tillers m^{-2} was registered by T3 (penoxsulam @ 22.5 g ai ha^{-1}), which was statistically on par with T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}).

4.2.2.2 Grain Weight Panicle^{-1}

The data on grain weight per panicle are presented in Table 34. There was no significant difference among treatments.

4.2.2.3 Number of Spikelets Panicle^{-1}

The data on number of spikelets per panicle are presented in Table 34. No significance difference was observed among treatments.

4.2.2.4 Number of Filled Grains Panicle^{-1}

The highest number of filled grains per panicle was recorded by T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and it was statistically on par with T4 (penoxsulam @ 25.0 g a.i ha^{-1}), T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1}) and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}). The lowest number of filled grains per

Table 32. Effect of weed management practices on phytotoxicity and plant height

Treatments	Phytotoxicity rating and plant height				
	Phytotoxicity rating (1-10 scale)	plant height, cm			
		20 DAT	40 DAT	60 DAT	Harvest
T1	1	44.88	75.97	79.27	85.88
T2	1	47.02	68.72	85.30	90.16
T3	1	47.05	75.96	83.66	94.88
T4	1	44.22	72.69	81.16	80.36
T5	1	39.66	67.44	82.88	83.05
T6	1	44.49	74.86	79.00	80.70
T7	-	43.27	62.72	75.00	77.05
T8	-	41.53	68.46	71.00	89.84
SE m(±)	-	-	-	-	2.24
CD (0.05)	NS	NS	NS	NS	6.806

Table 33. Effect of weed management practices on number of tillers and plant dry matter production

Treatments	Number of tillers m^{-2}				Plant dry matter production harvest, (kg ha^{-1})
	20 DAT	40 DAT	60 DAT	Harvest	
T1	506.6	596.6	682.6	640.0	17161.5
T2	589.0	663.3	683.3	636.6	17583.3
T3	646.0	715.0	733.3	631.3	18094.3
T4	716.6	739.6	744.3	633.3	19067.1
T5	387.6	706.6	723.3	633.3	17365.0
T6	390.0	606.6	633.6	630.3	16036.0
T7	393.3	416.6	569.8	566.6	11388.8
T8	336.0	392.6	468.3	466.6	10710.0
SE m(±)	9.1	10.8	15.8	-	884.1
CD (0.05)	27.82	32.71	48.06	NS	2682.08

panicle was recorded by T8 (weedy check) and it was statistically inferior to all other treatments.

4.2.2.5 Sterility Percentage

The treatments exerted significant influence on this yield attribute also. The highest value for percentage sterility was recorded by T8 (weedy check) and it was statistically inferior to all other treatments. The lowest sterility percent was recorded by T3 (penoxsulam @ 22.5 g ai ha^{-1}) and it was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}), T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}).

4.2.2.6 Thousand Grain Weight

The data on thousand grain weight are presented in Table 34. No significance difference was observed among treatments.

4.2.2.7 Grain Yield

The results are presented in Table 35.

The highest grain yield of 5404 kg ha^{-1} was recorded by T3 (penoxsulam @ 22.5 g ai ha^{-1}), which was statistically on par with T4 (penoxsulam @ 25.0 g a.i ha^{-1}), T5 (penoxsulam @ 25.0 g a.i ha^{-1}), T6 (2, 4 – D sodium salt @ 1 kg a.i ha^{-1}), T1 (penoxsulam @ 17.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T7 (hand weeding twice). The lowest grain yield was recorded by T8 (weedy check), which was significantly inferior to all other treatments.

4.2.2.8 Straw Yield

The data on straw yield indicated that there was no significant difference among treatments with respect to this character.

4.2.2.9 Harvest Index

The results are presented in Table 35. No significance difference was observed among treatments.

Table 34. Effect of weed management practices on yield attributes of rice

Treatments	Productive tillers, number m^{-2}	Filled grains $panicle^{-1}$	Grain wt $panicle^{-1}$, g	spikelets $panicle^{-1}$	Sterility %	1000 grain wt, g
T1	566.66	106.66	1.56	131.66	19.43	22.33
T2	576.66	110.00	1.72	120.33	17.73	22.22
T3	683.33	120.00	1.87	138.00	15.02	24.44
T4	655.55	116.00	1.79	137.33	16.43	23.66
T5	610.22	116.00	1.64	131.33	17.97	21.10
T6	508.33	113.66	1.53	137.00	18.45	22.55
T7	458.33	109.33	1.51	130.33	19.16	19.99
T8	421.10	101.00	1.24	123.66	22.52	18.33
SE m(±)	37.28	2.8	-	-	0.78	-
CD (0.05)	113.102	8.501	NS	NS	2.390	NS

Table 35. Effect of weed management practices on grain yield, straw yield and harvest index

Treatments	Grain yield, kg/ha	Straw yield, kg/ha	Harvest index
T1	5141	9848	0.52
T2	5138	9483	0.52
T3	5404	9563	0.56
T4	5266	9860	0.55
T5	5256	9646	0.54
T6	5138	9793	0.52
T7	4912	10376	0.47
T8	4208	9201	0.45
SE m(±)	170	-	-
CD (0.05)	519.4	NS	NS

4.3 CHEMICAL ANALYSIS

4.3.1 Nutrient (NPK) Content of Crop

4.3.1.1 Nitrogen Content

No significant difference in nitrogen content of crop was observed due to treatments.

4.3.1.2 Phosphorus Content

There was no significant difference in phosphorus content of crop due to treatments.

4.3.1.3 Potassium Content

Potassium content of crop also did not vary significantly due to treatments.

4.3.2 Uptake of Nutriens by Crop (Harvest)

4.3.2.1 Nitrogen Uptake of Crop

The data on nitrogen uptake of crop at harvest is presented in Table 37. Nitrogen uptake was highest for T4 (penoxsulam @ 25.0 g a.i ha^{-1}) which was on par with T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}).

4.3.2.2 Phosphorus Uptake of Crop

The results are presented in Table 37.

T4 (penoxsulam @ 25.0 g a.i ha^{-1}) recorded the highest phosphorus uptake which was on par with T5 (bispyribac @ 30.0 g a.i ha^{-1}), T6 (2,4 – D sodium salt @ 1kg a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}). Lowest phosphorus uptake was recorded by T8 (weedy check), which was significantly inferior to all other treatments.

4.3.2.3 Potassium Uptake of Crop

The results are presented in Table 37.

The treatments exerted significant influence on the potassium uptake of crop at harvest. The highest potassium uptake was recorded by T4 (penoxsulam @ 25.0

Table 36. Effect of weed management practices on N P K content of crop

Treatments	NPK content of crop, %		
	Nitrogen	Phosphorus	Potassium
T1	0.84	0.21	1.15
T2	0.83	0.21	1.22
T3	0.84	0.22	1.19
T4	0.84	0.21	1.18
T5	0.84	0.22	1.16
T6	0.82	0.22	1.17
T7	0.83	0.22	1.15
T8	0.83	0.21	1.15
SE m(±)	-	-	-
CD (0.05)	NS	NS	NS

Table 37. Effect of weed management practices on N P K uptake of crop

Treatments	N P K uptake of crop, kg ha^{-1}		
	Nitrogen	Phosphorus	Potassium
T1	144.43	36.58	198.57
T2	146.21	36.92	214.70
T3	152.14	39.70	215.86
T4	161.43	41.35	224.98
T5	146.99	38.76	202.55
T6	131.88	35.71	187.57
T7	95.12	25.32	131.77
T8	89.27	23.01	123.92
SE m(±)	7.68	2.30	10.11
CD(0.05)	23.36	7.01	30.76

g a.i ha^{-1}) which was on par with T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T1 (penoxsulam @ 17.5 g a.i ha^{-1}).

4.3.3 Nutrient (NPK) Content of Weeds

4.3.3.1 Nitrogen Content

The data furnished in Table 38 indicated that there was no significant difference among the treatments with respect to nitrogen content of weeds, at harvest.

4.3.3.2 Phosphorus Content

There was no significant difference among the treatments with respect to phosphorus content of weeds at harvest and the data are furnished in Table 38.

4.3.3.3 Potassium Content

With respect to potassium content of weeds (Table 38) also there was no significant variation among the treatments.

4.3.4 Removal of Nutrients by Weeds

4.3.4.1 Nitrogen Removal by Weeds

The results are presented in Table 39.

The highest nitrogen removal was recorded by weedy check and the lowest by T4 (penoxsulam @ 25.0 g a.i ha^{-1}) which was on par to T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and T5 (bispyribac sodium @ 30 g a.i ha^{-1}).

4.3.4.2 Phosphorus Removal by Weeds

The results are presented in Table 39.

At harvest the highest phosphorus removal was recorded by T8 (weedy check), which was statistically inferior to all other treatments. The lowest phosphorus removal was recorded by T6 (2, 4- D @ 1 kg a.i ha^{-1}) which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}).

Table 38. Effect of weed management practices on N P K content of weeds

Treatments	N P K content of weeds, %		
	Nitrogen	Phosphorus	Potassium
T1	0.86	0.23	1.17
T2	0.85	0.25	1.17
T3	0.84	0.25	1.17
T4	0.85	0.25	1.17
T5	0.85	0.25	1.16
T6	0.85	0.25	1.17
T7	0.84	0.25	1.17
T8	0.84	0.28	1.15
SE m(±)	-	-	-
CD (0.05)	NS	NS	NS

Table 39. Effect of weed management practices on N P K removal by weeds

Treatments	N P K removal of weeds (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
T1	8.14	2.16	5.40
T2	5.82	2.11	4.50
T3	4.04	0.86	4.21
T4	3.95	0.98	4.63
T5	4.25	1.03	4.41
T6	7.64	0.74	4.15
T7	8.27	2.48	9.72
T8	14.16	3.41	19.40
SE m(±)	0.48	0.04	0.17
CD (0.05)	1.465	0.147	0.524

4.3.4.3 Potassium Removal by Weeds

The results are presented in Table 39.

At harvest, the lowest potassium removal was recorded by T6 (2, 4 - D sodium salt @ 1 kg a.i ha^{-1}) which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T4 (penoxsulam @ 25.0 g a.i ha^{-1}). The highest removal by weeds was in T8 (weedy check) and it was significantly inferior to all the other treatments.

4.4 POST HARVEST SOIL NUTRIENT STATUS

The results are presented in Table 40.

The content of N, P and K in post experiment soil was significantly influenced by various weed management practices. The nitrogen content of the soil after harvest was highest under T4 (penoxsulam @ 25.0 g a.i ha^{-1}) which was on par with T3 (penoxsulam @ 22.5 g a.i ha^{-1}). In the case of phosphorus content also T4 recorded highest value which was on par with T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}) and T2 (penoxsulam @ 20.0 g a.i ha^{-1}). Potassium content was highest for T3 which was on par with T5, T6 (2, 4 –D sodium salt @ 1 kg a.i ha^{-1}) and T4. T8 (Weedy check) recorded lowest N, P and K content in soil after the experiment and it was significantly inferior to all the other treatments. No significant difference was observed among treatments in the case of organic carbon content of post experiment soil.

4.5 MICROBIAL STUDIES

The total microbial population of the soil *viz.*, bacteria, fungi and actinomycetes were enumerated 6 days after spraying (DAS) the herbicides and the data are presented in Table 41.

Table 40. Effect of weed management practices on post harvest soil nutrient status

Treatments	Available N, kg ha^{-1}	Available P, kg ha^{-1}	Available K, kg ha^{-1}	Organic carbon (%)
T1	450.00	16.00	130.00	1.14
T2	462.00	18.00	128.00	1.16
T3	486.00	17.00	151.00	1.16
T4	493.00	20.00	140.00	1.15
T5	476.00	19.00	148.00	1.16
T6	474.00	16.00	143.00	1.16
T7	476.00	17.00	128.00	1.13
T8	438.00	14.00	113.00	1.13
SE m(±)	2.70	0.60	6.70	-
CD (0.05)	8.500	2.080	20.500	NS

Table 41. Effect of weed management practices on the population of soil bacteria, fungi and actinomycetes, 6 DAS

Treatments	Population of soil bacteria, ($\times 10^6$ cfu g^{-1} soil)	Population of soil fungi, ($\times 10^4$ cfu g^{-1} soil)	Population of soil actinomycetes, ($\times 10^4$ cfu g^{-1} soil)
T1	44.66	15.33	6.33
T2	48.00	13.33	7.00
T3	58.33	13.33	6.66
T4	42.00	12.50	7.00
T5	48.33	12.00	3.33
T6	45.33	13.33	3.66
T7	72.00	18.00	6.66
T8	73.00	18.66	8.00
SE m(±)	3.91	-	-
CD (0.05)	11.955	NS	NS

4.5.1 Soil Bacterial Population

Before herbicide spraying composite soil samples collected from the experimental area had a total bacterial population of 75 × 10^6 cfu g^{-1} soil. A perusal of the data on soil bacterial population recorded at 6 DAS showed that there was significant variation among the treatments. The highest count was registered by T8 (weedy check) and it was on par with T7 (hand weeding twice), and significantly higher than that recorded in the herbicide treated plots. The lowest bacterial count was registered by T4 (penoxsulam @ 25.0 g a.i ha^{-1}) and it was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and T5 bispyribac sodium @ 30.0 g a.i ha^{-1})

4.5.2 Soil Fungal Population

The results are presented in Table 41.

No significant difference was observed among the treatments.

4.5.3 Soil Actinomycetes Population

The results are presented in Table 41.

No significant difference was observed among the treatments.

4.6 ECONOMICS OF CULTIVATION

The data on net income and benefit: cost ratio (BCR) computed for weed control treatments are presented in Table 42. Among various treatments, maximum net income (Rs.49065/- ha^{-1}) and BCR (1.67) were observed for T3 (penoxsulam @ 22.5 g a.i ha^{-1}) and it was on par with all other treatments except hand weeding twice and weedy check. T8 (Weedy check) recorded the lowest net returns (Rs.29363/- ha^{-1}) as well as BCR (1.31). Net returns and BCR recorded for hand weeding twice treatments were Rs. 35011/- ha^{-1} and 1.46, respectively.

Table 42. Effect of weed management practices on net income and B:C ratio

Treatments	Net income, Rs. ha^{-1}	B: C ratio
T1	45012	1.61
T2	44348	1.60
T3	49065	1.67
T4	45833	1.63
T5	45749	1.62
T6	45984	1.62
T7	35011	1.46
T8	29363	1.31
SE m(±)	2455	0.40
CD (0.05)	7479.9	0.122

DISCUSSION

5. DISCUSSION

The intensive use of traditional high dose herbicides year after year has resulted in herbicide resistance problem and consequently management of weed is becoming more difficult and complex. As a result now researchers focus on low dose high efficacy herbicides with less environmental persistence and low toxicity to non target organisms. In view of the above fact the present study was undertaken to evaluate the bio- efficacy of the new generation herbicide penoxsulam in transplanted rice in comparison with the standard new generation herbicide bispyribac sodium and the traditional herbicide 2, 4 - D sodium salt. The results of the experiment presented in the previous chapter are discussed hereunder.

5.1. OBSERVATIONS ON WEEDS

5.1.1 Effect of Weed Management Practices on Weed Flora

The weed flora found in the experimental field was diverse in nature consisting of all the three morphological classes, *viz.,* grasses, sedges and broadleaved weeds. The major weeds identified in the experimental field were *Echinochloa colona* (L.) Link. *Panicum repens, Cyperus difformis, Fimbristylis dichotoma (L.)* Vahl., *Scirpus grossus, Limnocharis flava* (L.) Buchenau., *Monochoria vaginalis* (Burm. f.) Presl. Ex Kunth., *Ludwigia parviflora* Roxb., *Lindernia rotundifolia* blanc vert., *Salvinia molesta* D.S. Mitch., *Marsilea quadrifolia* Linn. and *Pistia stratiotes* L. Royle.

Such diversity in rice weed flora in Nemom area has been documented earlier (Rathod, 2013 and Rajagopal, 2013). Diversity of weed flora in transplanted low land rice was confirmed by many weed scientists (Ravindran, 1976; Jacob, 2002; Yadav, 2006). Another interesting observation is that the flora of the experimental field in Nemom block dominated by broad leaved weeds (7 *sp.*) and sedges (3 *sp.*) compared to grasses (2 *sp.*). This is in conformity with the findings of Rathod (2013) and Rajagopal (2013). According to Singh *et al.* (2004) weed flora under

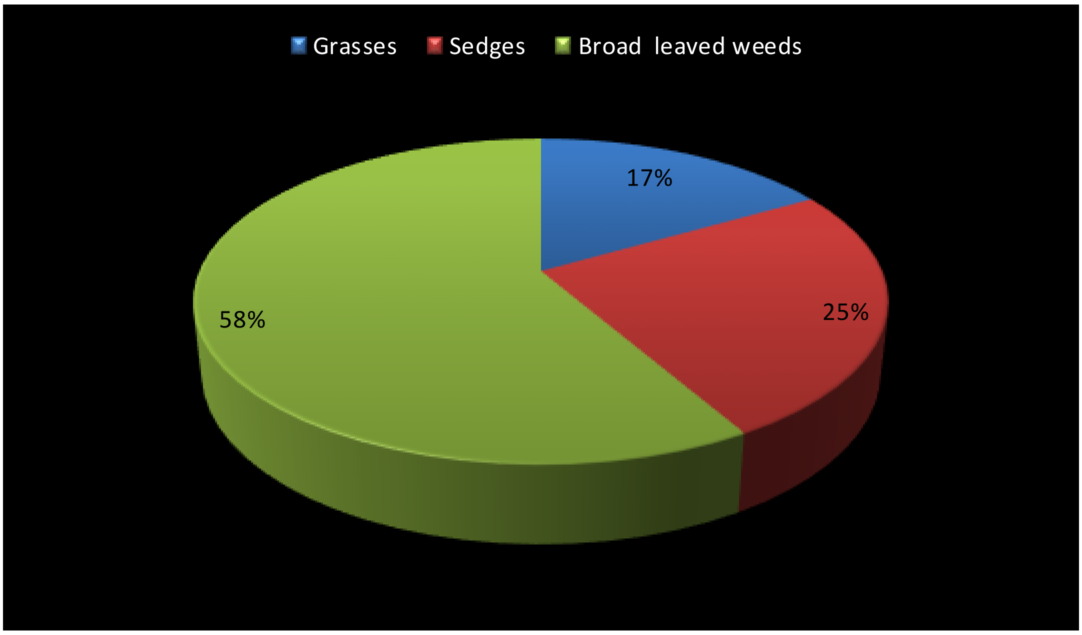

Fig 3. Percentage composition of weed flora identified in the field

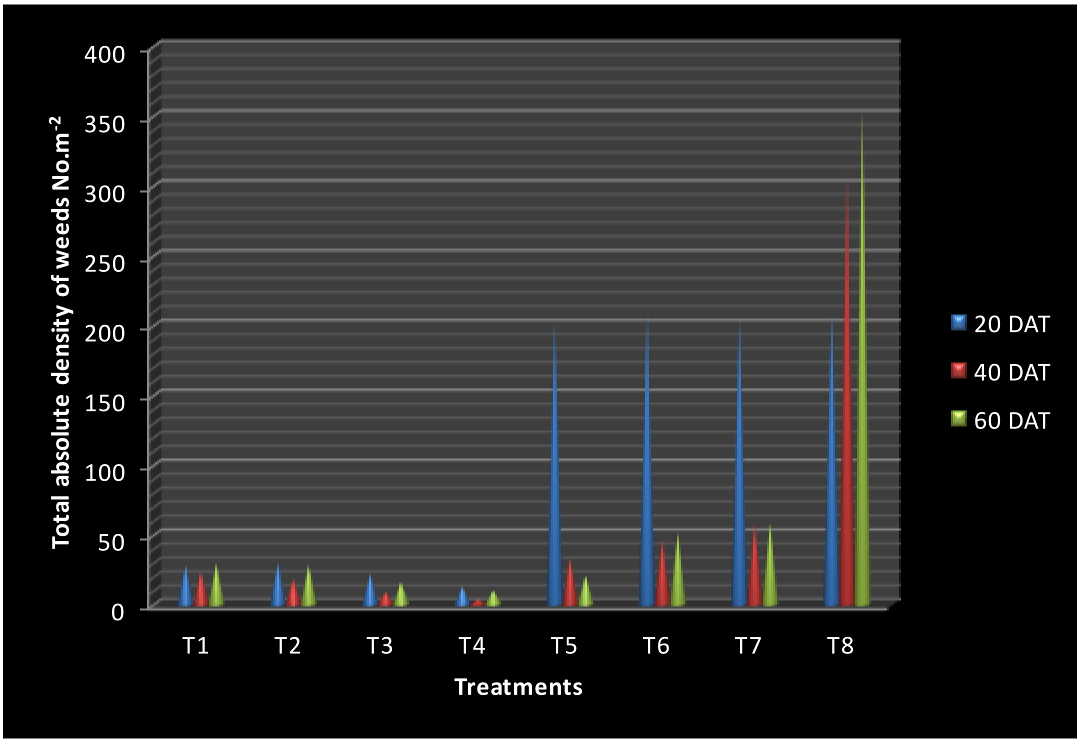

Fig 4. Effect of weed management practices on total absolute density of weeds

transplanted condition is very much diverse and consists of grasses, sedges and broad leaved weeds causing yield reduction of rice crop up to 76 percent.

5.1.2 **Quantitative Assessment of Weed Response to Weed Management Treatments**.

By assessing the quantitative parameters *viz.*, absolute density, relative density, absolute frequency, weed dry weight, weed control efficiency (WCE), relative frequency, summed dominance ratio and importance value, the weed scientist can determine the effect of the treatments on weed growth.

Weed count is one of the most widely used parameters for quantitative assessment of weed response (Rana *et al.*, 2002). The weed management practices adopted in the study influenced the growth of all categories of weeds and resulted in significant reduction in weed population. The tested herbicides penoxsulam was applied on 10 DAT as an early post emergence herbicide and its impact on density of weeds was evident even at the time of first observation *i.e.* 20.0 DAT. The results indicated that treatments involving higher doses of penoxsulam (25.0 and 22.5 g a.i ha^{-1}) recorded lower absolute density of sedges, grasses and broad leaved weeds as well as total density of weeds compared to other treatments. This high weed growth suppression may be attributed to its revolutionary dual systemic action as it is absorbed mainly by leaves and secondarily by roots in the target plants (Larelle *et al.*, 2003). Similar suppressive effect of penoxsulam on total and individual weed density was reported earlier (Yadav *et al.*, 2008; Pal *et al.*, 2009; Khaliq *et al.*, 2011;). Bispyribac sodium @ 30.0 g a.i ha^{-1} reduced the density of sedges, grassy weeds and broad leaved weeds to a lesser extent. Similar results were reported by Walia *et al.* (2008) and Rathod (2013). With advancement in stage of growth of the crop there was gradual increase in the total density of weeds ; however this increase was only marginal in the case of new generation herbicides compared to 2,4 – D sodium salt and hand weeding treatment indicating the favorable effects of these new molecules in suppressing new flushes of weeds. Favorable effect of penoxsulam in reducing weed density was confirmed earlier by Yadav *et al.* (2008).

Biswas and Sattar (1991) pointed out that when weed density exceeded 40 m^{-2}, rice grain yield was significantly reduced. In the present study, in the weedy check the total absolute density of weeds at 20, 40 and 60 DAT were 209.6, 310.6 and 354 respectively. Uninterrupted weed growth in weedy check led to the germination of weed seeds resulting in such high absolute density of weeds. The corresponding values for the most effective herbicide treatment T4 (penoxsulam @ 25.0 g a.i ha^{-1}) were 12.6, 3.3 and 10 respectively. Similar observations were reported by Dixit and Varshney (2008) and Subramanian *et al.* (2006). The result on relative density implies the efficacy of herbicide to control a particular class of weed and the present study revealed that the highest dose of penoxsulam *i.e.* 25.0 g a.i ha^{-1} was highly effective to control sedges as it recorded zero relative density for sedges at 40 DAT, the most critical period of weed competition. However this treatment was on par with the lower dose of penoxsulam *i.e.* 22.5 g a.i ha^{-1}.

The results of the present study also revealed that the biomass accumulation of weeds could be substantially reduced by all weed control treatments. Higher doses of the new generation herbicide penoxsulam *i.e.* 25.0 g a.i ha^{-1} (T4) and 22.5 g a.i ha^{-1} (T3) recorded significantly lower total dry matter production compared to its lower doses. These results are in agreement with the findings of Yadav *et al.* (2008) and Malik *et al.* (2011). The effectiveness of 2, 4 – D sodium salt in reducing dry weight of broad leaved weeds has been reported earlier (Rao, 2000). Also the broad spectrum weed control efficacy of the post emergence micro herbicide bispyribac sodium has already been reported (Walia *et al.,* 2008; Yadav *et al.*, 2009 Khaliq *et al.,* 2011).

Plate 2. Plot treated with penoxsulam (T4)

Plate 3. Plot treated with @25 g a.i ha^{-1} Penoxsulam @ 22.5 g a.i ha^{-1} (T3)

Plate 4. Plot treated with bispyribac @ 30.0 g a.i ha^{-1}(T5)

Plate 5. Plot treated with 2, 4 – D sodium salt @ 1 kg a.i ha^{-1}(T6)

Plate 6. Hand weeding twice (T7)

Plate 7. Weedy check (T8)

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Another observation based on the study is that with increasing concentration of penoxsulam the total weed dry matter production substantially decreased and this result was confirmed by Singh *et al.* (2009) and Yadav *et al.* (2008). Among the herbicides, at the most critical stage of weed competition *viz.,* 40 DAT both penoxsulam as well as bispyribac sodium registered significantly lower dry weight of grassy weeds compared to the traditional herbicide, 2, 4 - D sodium salt which was on par with hand weeding twice. These results are confirmed by Kiran and Subramanyan (2010) and Pal *et al.* (2009). Penoxsulam is reported as an effective herbicide for post emergent control of grasses. In the experimental field only two species of grasses were observed. However, the higher doses of penoxsulam, *viz.*, 25.0 g a.i ha^{-1} (T4) and 22.5 g a.i ha^{-1} (T3) registered low dry weight for grasses. Similar observations were reported by Yadav *et al.* (2008) also.

With respect to hand weeding twice (HWT), during the most critical period of crop weed competition in rice *i.e*. at 40 DAT, total weed dry weight was low but inferior to herbicides. This result was confirmed by many weed scientists (Chander and Pandey, 1996; Bhowmick, 2002; Singh *et al*., 2012). At 60 DAT also this treatment was significantly inferior to the herbicide treatments indicating the necessity for controlling the growth of subsequent flushes of weeds in the experimental field. This result further emphasizes the scope for chemical weed management for season long weed control in transplanted rice.

The data clearly indicated that the total weed dry weight was the highest in weedy check at all the stages of observation. The uncontrolled weed growth must have resulted in exploitation of the available resources in greater amounts and ultimately resulted in high bio mass accumulation. This explains the poor growth and yield of the crop in this treatment. Similar observations were made by Jacob (2002), Yadav (2006), Rathod (2013) and Rajagopal (2013). Density also showed a similar trend.

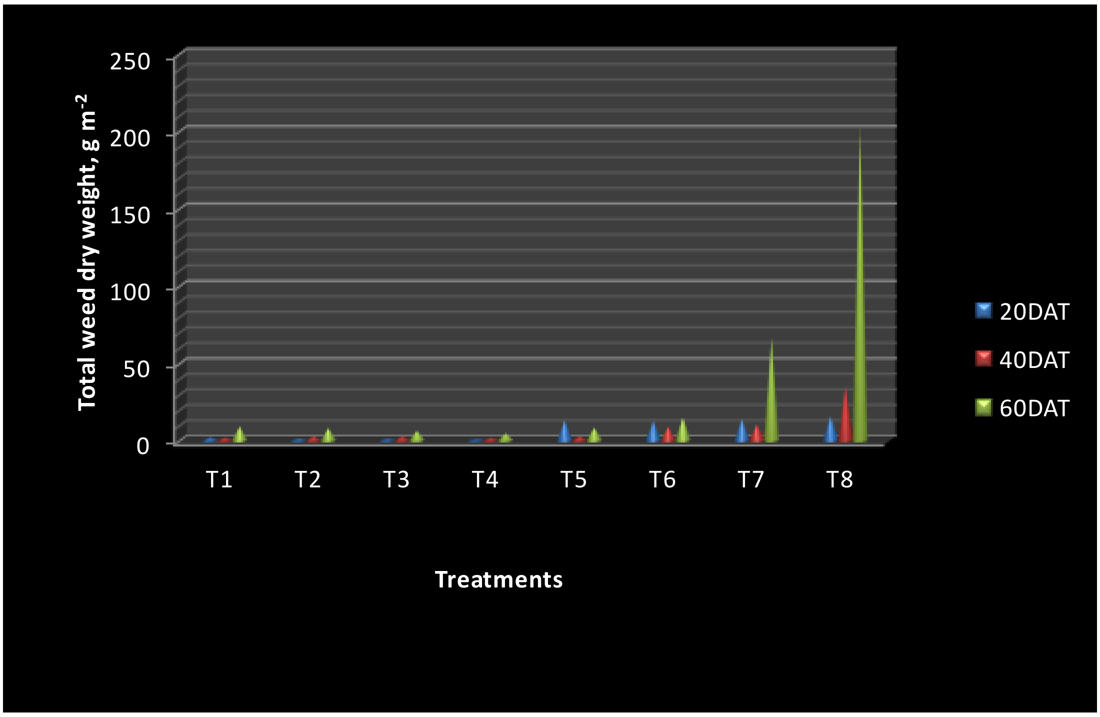

Fig 5. Effect of weed management practices on total weed dry weight

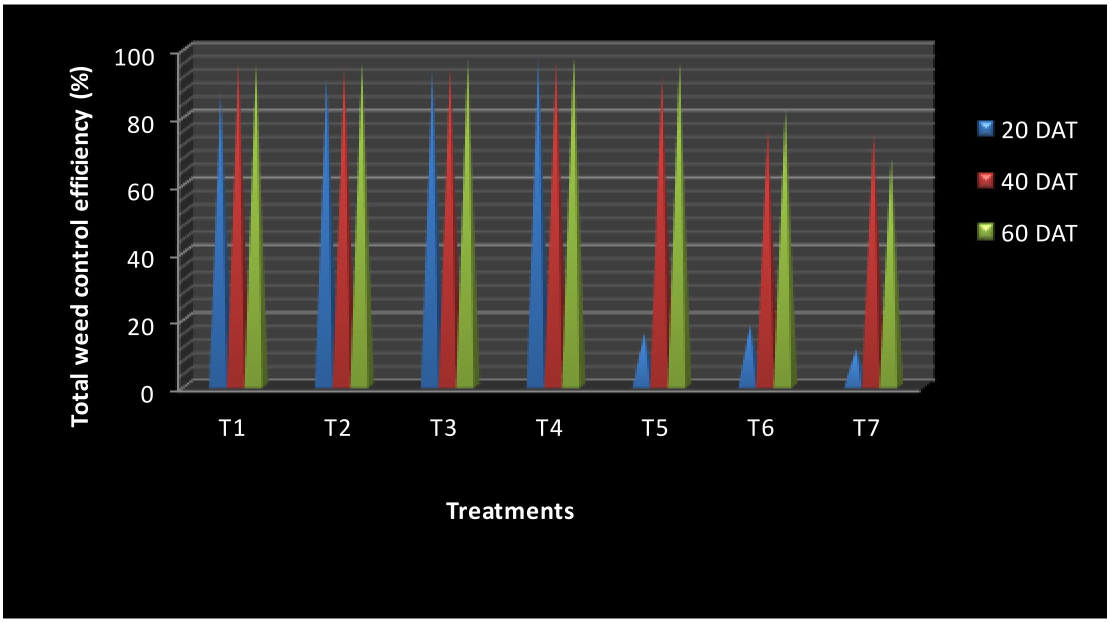

Fig 6. Effect of weed management practices on total weed control efficiency

Reduced weed dry weight as well as density of weeds observed in the plots treated with penoxsulam @ 25.0 and 22.5 g a.i ha^{-1} resulted in low total absolute frequency of weeds. This index is indicative of frequency of different categories of weeds per unit area. Present study revealed that the penoxsulam applied @ 25.0 g a.i ha^{-1} and 22.5 g a.i ha^{-1} reduced the number of occurrence of all three groups of weeds in the treated plots. The effectiveness of bispyribac sodium inreducing the density of all the three morphological groups of weeds has been well documented (Yadav *et al.,* 2007; Walia *et al.,* 2008; Walia *et al.,* 2008a ; Yadav *et al.*, 2009; Rathod, 2013).

The data on summed dominance ratio and importance value also affirms the above results.

The total weed control efficiency of penoxsualam @ 25 g a.i ha^{-1} was 96.2 percent at 40 DAT, which was comparable with its lower doses and bispyribac sodium. Effective weed control reduced the biomass accumulation in weeds which in turn resulted in high weed control efficiency for these treatments. These findings are in line with the results of Pal *et al.* (2009). The treatments comprising traditional herbicide, *i.e.* 2, 4-D sodium salt @ 1 kg a.i ha^{-1} and hand weeding twice were significantly less effective than the new generation herbicides with regard to weed control efficiency. Weed control efficiency was recorded for different morphological classes of weeds and the results also indicated that hand weeding twice was less effective in controlling all the groups of weeds especially perennial weeds. This was earlier reported by Rao (2000).

Better weed control efficiency of penoxsulam was reported by several earlier workers (Prakash *et al.,* 2013 and Pal *et al.,* 2009). Veeraputhiran and Balasubramanian (2010) reported significant reduction in total weed dry weight and high weed control efficiency of more than 90 percent with application of bispyribac sodium. Corroboratory result is reported by Mehta *et al.* (2010).

5.1.3 Nutrient Removal by Weeds

The present study indicated that the removal of N, P and K by weeds was the highest (14.16 N, 3.14 P and 19.4 K kg ha^{-1}) under weedy check. Weeds grow faster than the crop and absorb added nutrients more rapidly and in large quantities (Rao, 2000). Similar observation on the significantly higher nutrient removal by weeds in weedy check was reported by Punyia *et al.* (2007) and Rajagopal (2013). An estimate showed that weeds could deprive the crops of 47 per cent N, 42 per cent P, 50 per cent K, 39 per cent Ca and 24 per cent Mg of their nutrient uptake (Balasubramaniyam and Palaniappan, 2001). Unchecked weed growth in rice depleted 59.3 kg N, 10.5 kg P_2O_5 and 35.0 kg K_2O on per hectare basis (Raju and Gangwar, 2004).

Nitrogen removal by weeds at harvest was the lowest under penoxsulam @ 25.0 g a.i ha^{-1} (T4). Penoxsulam @ 22.5 g a.i ha^{-1} (T3) and 2, 4- D sodium salt @ 1 kg a.i ha^{-1} (T6) also showed comparatively low N uptake. With respect to potassium uptake also these treatments registered very low uptake values along with bispyribac sodium and penoxsulam @ 20.0 g a.i ha^{-1}. However with regard to phosphorus uptake, only bispyribac sodium and penoxsulam @ 22.5 g a.i ha^{-1} showed significantly lower values. The reduced weed growth and lesser dry matter accumulation by weeds in these treatments might have resulted in reduced nutrient uptake by weeds. The nutrient uptake by weeds is directly related to weed population and dry matter accumulation of weeds and inversely related to rice grain yield (Raju and Reddy, 1986).

Reduction in the uptake of nutrients by weeds due to weed control treatments reported earlier by Lakhsmi (1983), Singh *et al.* (1999), Jacob (2002), Yadav (2006) and Puniya *et al.* (2007) conforming the fact that initial weed free treatment for 45 days or longer resulted in significantly higher yield and lower dry weight and nutrient uptake by weeds.

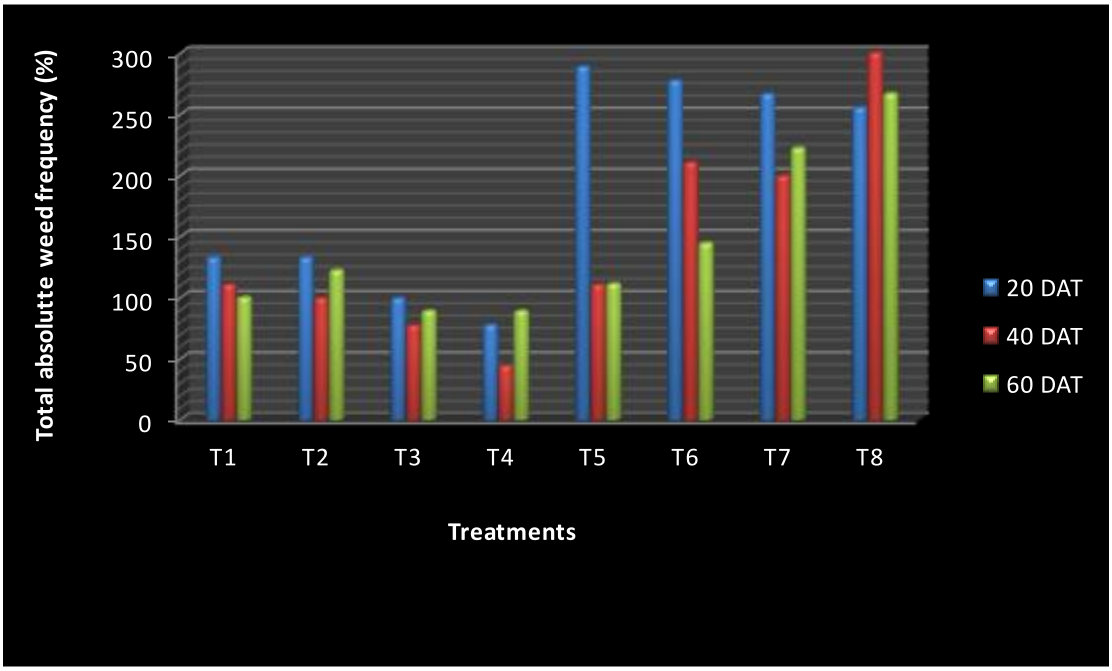

Fig 7. Effect of weed management practices on total absolute weed frequency

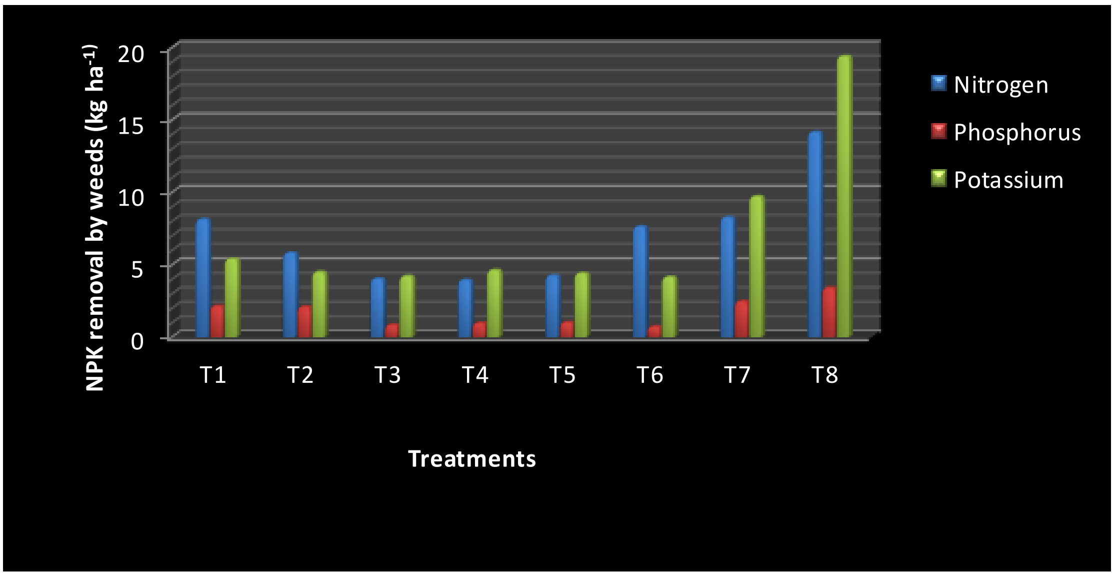

Fig 8. Effect of weed management practices on NPK removal by weeds

The present study revealed that the unchecked weed growth caused significantly higher nutrient drain in weedy check as evident from the high nutrient uptake values (14.16, 3.41 and 19.40 kg N, P and K ha^{-1} respectively) which might otherwise be available to the crop. Similar result was already reported by Balasubramanian (1996).

5.2 OBSERVATIONS ON CROP

5.2.1 Phytotoxicity

The data on visual phytotoxicity rating, recorded seven days after herbicide spraying, using 1-10 scale, indicated no phytotoxicity on rice crop. Application of different doses of penoxsulam under test did not show any phytotoxic symptoms on rice plant. These findings in close conformity with the findings of Mishra *et al.* (2007) ; Bond *et al.* (2007) ; Pal *et al.* (2009), Malik *et al.* (2011) and Praksh *et al.*(2013).

The present study also revealed that bispyribac sodium had no phytotoxic effect on the rice crop. Similar view was expressed by earlier workers also (Yadav *et al.*, 2009; Ghosh *et al.*, 2013).

5.2.2 Crop Growth Characters

Various weed management practices did have a significant role in deciding the growth characters like plant height, tiller number and dry matter production (DMP). In general, penoxsulam applied @ 25.0 and 22.5 g a.i ha^{-1} recorded comparatively higher values for all the growth characters. All the weed management practices including different doses of penoxsulam, bispyribac sodium, 2,4 – D sodium salt and hand weeding twice at 20 and 40 DAT (HWT) recorded better crop growth characters than weedy check, which recorded the lowest value for all growth characters. The superiority of weed control treatments may be due to comparatively low competition from weeds (Jacob, 2002; Moorthy, 2002; Chopra and Chopra, 2003). Timely weed control at early stage is imperative for realizing desired level of productivity from transplanted rice.

Plant height remained statistically unchanged due to different treatments at 20, 40 and 60 DAT. At harvest both the penoxsulam as well as bispyribac sodium having low weed density recorded comparatively higher plant height. Corroboratory results on the positive effect of weed control treatments on height of rice plants was reported by Jacob (2002) and Yadav (2006).

Among herbicide treatments, penoxsulam @ 22.5 g a.i ha^{-1} recorded highest value for plant height at harvest and it was on par with other two doses of the same herbicide *viz.*, 20.0 and 25.0 g a.i ha^{-1}. Early post emergence application of the herbicide at 10 DAT could have resulted in early weed control leading to better expression of this growth attribute. Plant height was lower in plots which were hand weeded twice (T7). This could be because manual weeding allowed unchecked weed growth during the early growth stages of the crop *i.e.* up to 20 DAT, depleting valuable resources from the soil at a time when it is highly essential for the crop to put forth proper growth.

The present study revealed that plots with low weed population where penoxsulam was applied @ 25.0 g a.i ha^{-1} recorded highest number of tillers per unit area at all the stages of observation. This may be attributed to the reduction in weed vegetation analysis parameters like density, dry matter production and nutrient uptake by weeds which might have enabled rice to put forth better growth resulting in enhanced tiller number in this treatment. However at 60 DAT, this treatment was statistically on par with penoxsulam @ 22.5 g a.i ha^{-1} and bispyribac sodium @ 30.0 g a.i ha^{-1} indicating the superiority of the new generation herbicides. Many scientists reported that weed control by herbicides at early stages enabled better rice growth (Ali and Sankaran, 1975; Sumner *et al.*, 1981; Mabbayad and Moody, 1992; Balasubramaniyan, 1996). The lowest tiller number was registered by weedy check at all the stages of observation.

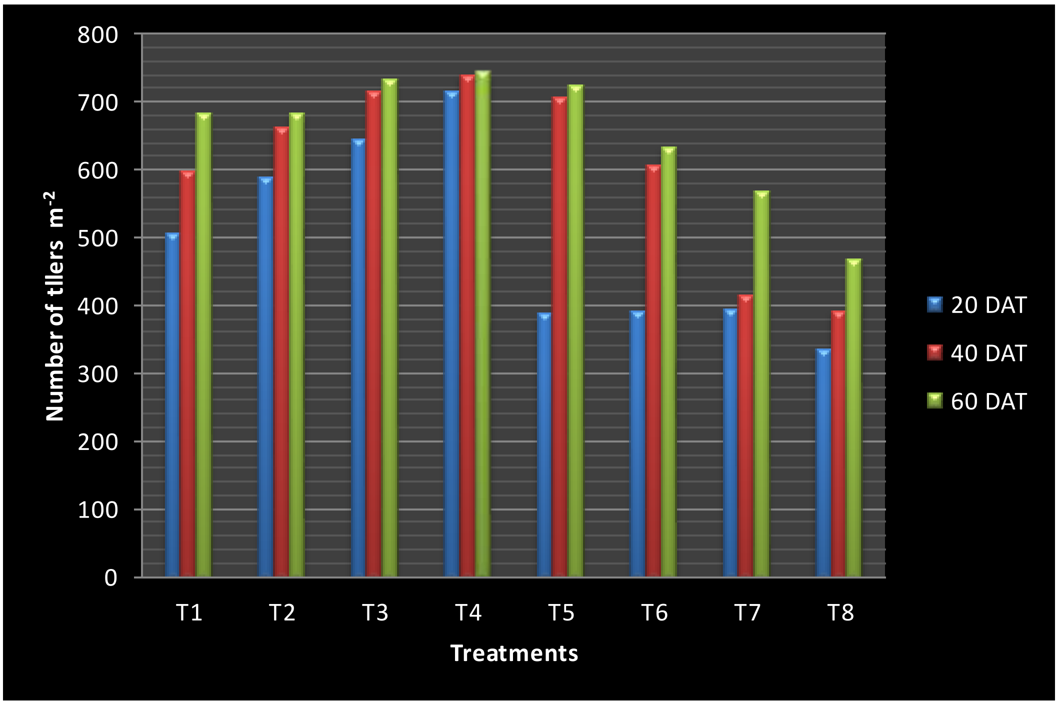

Fig 9. Effect of weed management practices on number of tillers

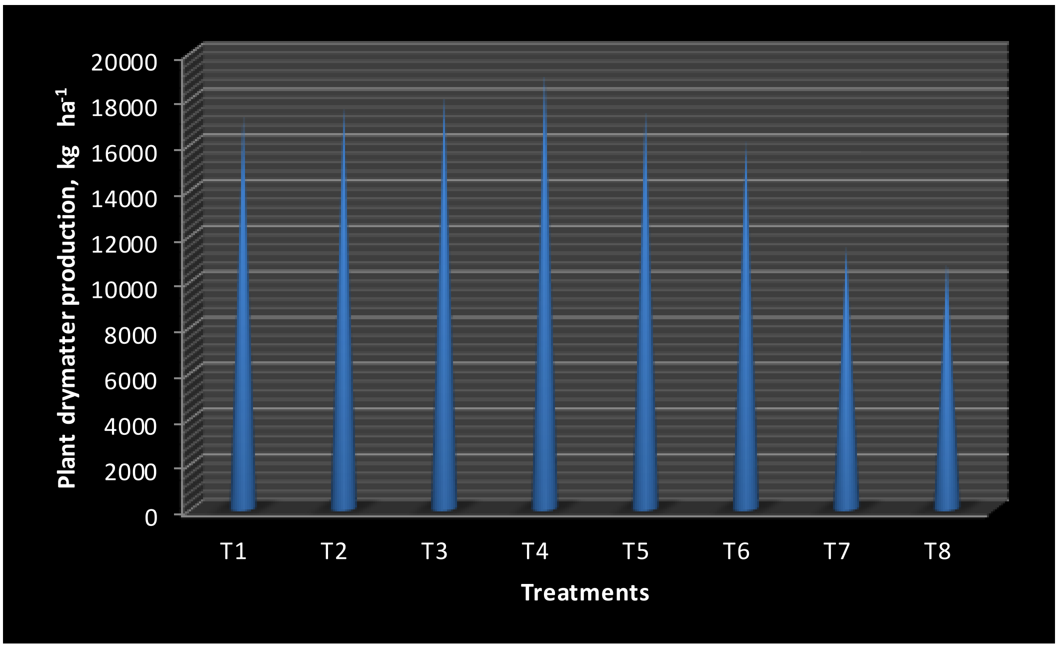

Fig 10 .Effect of weed management practices on plant dry matter production at harvest

The adverse effect on tiller production of rice due to weed competition at critical growth stages of crop was reported by Sankaran and Thiagarajan (1982) and Mabbayad and Moody (1992) also. This result is in conformity with the observations of Rao (2000) that for every unit of weed growth, there will be one unit less of crop growth.

The present study estimated plant dry matter production at harvest and revealed the favorable influence of weed management practices on this character. All the doses of the tested new generation herbicide penoxsulam as well as the standard new generation herbicide bispyribac sodium @ 30.0 g a.i ha^{-1} included in the trial for comparison were equally effective in increasing this growth attribute compared to other treatments. The lowest value was registered by T8 (weedy check). Effective weed control measures reduce the crop weed competitions which in turn result in better utilization of resources ultimately leading to higher crop dry matter production. This is in conformity with the findings of Balasubramaniyan (1996), Jacob (2002), Seema (2004), Yadav (2006), Yadav *et al.* (2009) and Rathod (2013) in rice. The antagonistic effect of weeds on rice dry matter production was earlier reported by Rathod (2013) and Yadav (2006).

The stimulatory effect of the new generation herbicides on plant height, tiller number and dry matter production was due to their favorable effect in reducing weed growth substantially. The reduced weed growth in these plots might have enabled rice plants to put forth better growth resulting in enhanced plant height, tiller number, dry matter production etc.

5.2.3 Crop Yield Attributes and Yield

From the data on yield attributing characters it is clear that effective weed management practices did have a positive role in determining the yield attributes and yield of rice. Penoxsulam @ 22.5 g a.i ha^{-1} (T3) registered highest value for the yield attributes *viz.*, number of productive tillers m^{-2}, filled grains per panicle and the lowest value for percentage sterility. This is mainly due to the comparatively low competition from weeds, which allowed the crop to express its full genetic potential in this treatment. With respect to number of productive tillers m^{-2}, the highest dose of penoxsulam and bispyribac sodium was also equally effective. A similar result on the favorable effect of penoxsulam @ 25.0 g a.i ha^{-1} and 22.5 g a.i ha^{-1} on number of productive tillers was reported by Singh *et al.* (2007). Thesetreatments and 2, 4 – D sodium salt also recorded comparable values with respect to filled grains per panicle. With respect to weed vegetation analysis parameters also these treatments exhibited comparable performance as that of T4.

The lowest value for all the yield attributes was registered by weedy check. Weed competition might have severely reduced the availability of moisture, sunlight and nutrients to the rice plants in weedy check resulting in poor expression of yield attributes. Yield can be limited either by the supply of assimilates (source) during grain filling or by the number and capacity of kernels to be filled (sink) or by source and sink simultaneously (Fischer, 1983; Venkateswaralu and Visperas, 1987; Evans, 1993). In the present investigation, both source and sink were limited due to competition of weeds in weedy check (T8) resulting in significantly low grain yield in this treatment. Corroboratory results were reported by Jacob (2002), Seema (2004), Yadav (2006) and Rathod (2013). According to Jacob and Syriac (2005) weeds are important competitiors in their early growth stages than later and hence the growth of crops slows down and finally grain yield decreases.

Prakash *et al.* (2013) reported significant negative influence of weed growth on the filled grains $panicle^{-1}$. The control of weeds promoted the yield and yield attributes including productive tillers m^{-2} and number of filled grains per panicle in rice (Raju *et al.,* 2002). Positive influence of herbicide application on yield attributes of rice was reported by Yadav (2006) and Rajagopal (2013).

All the weed control treatments significantly influenced the grain yield and the highest yield (5404 kg ha^{-1}) was obtained for penoxsulam applied @ 22.5 g a.i ha^{-1} (T3). Performance of other doses of penoxsulam, bispyribac sodium,

2, 4-D sodium salt and hand weeding twice were also statistically on par. The higher grain yield in the herbicide treated as well as hand weeded plots might be due to the increased production and translocation of photosynthates to grain, owing to adequate availability of growth resources, as a result of less competition offered by weeds. The traditional herbicide 2, 4-D sodium salt is effective in controlling broad leaved weeds and sedges alone, was found effective in the present study because the experimental field was dominated by broad leaved weeds (58.33%) and sedges (25%). At the same time on vegetation analysis, it was found less effective to control grassy weeds. In rice, grain yield is a function of number of productive tillers $hill^{-1}$, number of grains per panicle and sterility percentage. The higher values for these yield attributes recorded under the treatment involving penoxsulam 22.5 g a.i ha^{-1} (T3) might have resulted in highest grain yield (5.4 t ha^{-1}) for this treatment. Other doses of penoxsulam and bispyribac sodium also gave comparable yield (> 5 t ha^{-1}). Corroboratory results on the favourable effect of penoxsulam on grain yield was reported by Mishra *et al.* (2007); Yadav *et al.* (2008); Pal *et al.* (2009); Singh *et al.* (2009); Khaliq *et al.* (2011) and Bhat *et al.* (2013) and that of bispyribac sodium by Walia *et al.* (2008) and Khaliq *et al.*(2011).

Weedy check recorded the lowest grain yield of 4208 kg ha^{-1} indicating an yield reduction of 22.13% due to season long crop weed competition as compared to the best treatment *i.e.* penoxsulam @ 22.5 g a.i ha^{-1} (T3). Corroboratory results on yield reduction due to uncontrolled weed growth were reported earlier too (Mishra *et al.*, 2007; Singh *et al.*, 2007 ; Yadav *et al.*, 2008 ; Pal *et al.*, 2009 ; Mehta *et al.*, 2011). Sultana (2000) observed that weed density of 100-200 m^{-2} reduced paddy yield by 51-64% compared to weed free condition. In the present study also absolute density of weeds was very high in weedy check

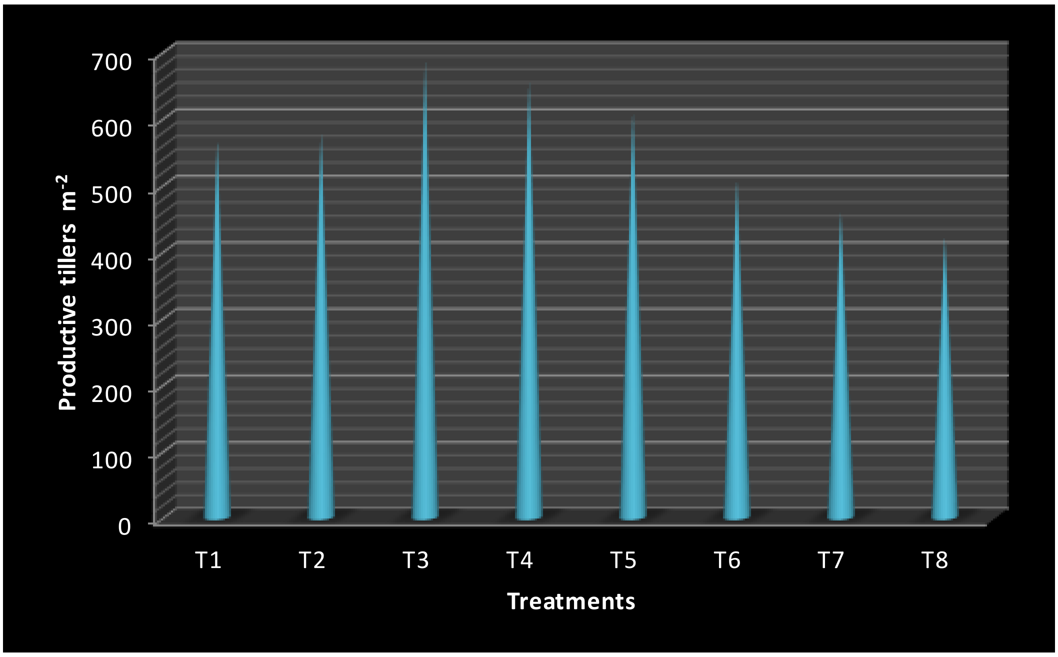

Fig 11. Effect of weed management practices on productive tillers

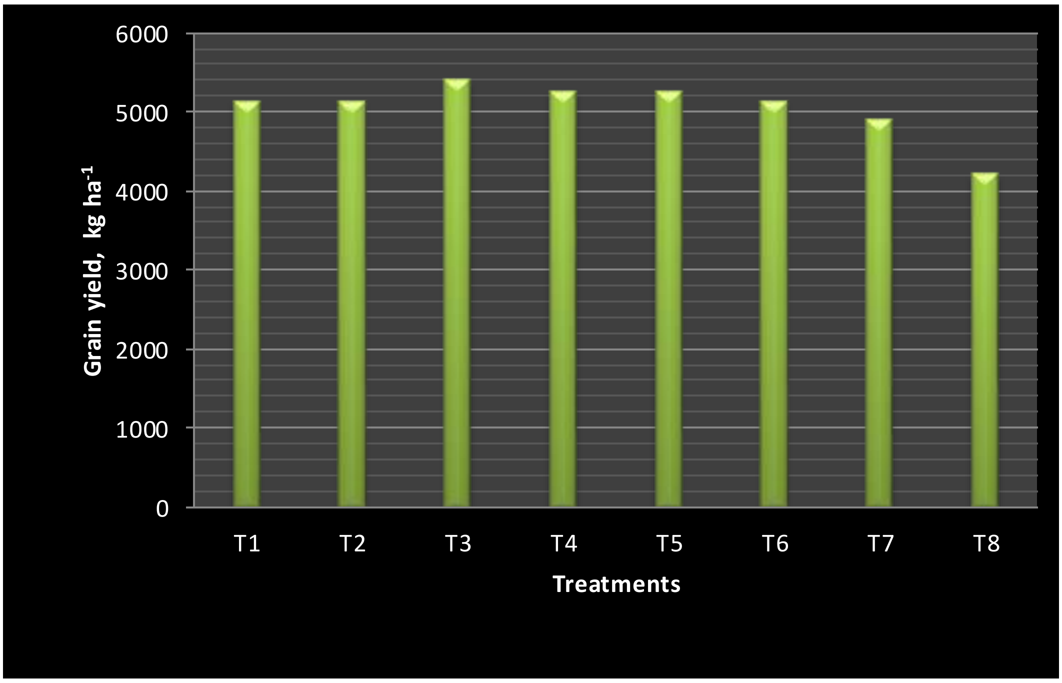

Fig 12. Effect of weed management practices on grain yield

i.e. (209.66, 310.66 and 354.00 m^{-2}). This could be the probable reason for substantial yield reduction in weedy check

5.2.4 Nutrient Uptake by Crop

A critical analysis of the data on nutrient uptake of the crop indicated that the uptake of all the three major nutrients *viz.,* N, P and K were significantly higher in the herbicide treated plots compared to weedy check. This could be the probable reason for the better expression of growth characters, yield attributes and yield in these treatments. However the nutrient uptake was comparatively less in hand weeded plots, probably because the uninterrupted growth of weeds up to initial 20 DAT *i.e.* first hand weeding and from 20 to 40 DAT, *i.e.* up to second hand weeding deprived the availability of nutrients to crop plants at its most critical growth period. Nutrient uptake is a product of nutrient content and plant dry matter production. The reduced competition from weeds in these treatments might have enhanced dry matter production which resulted in high nutrient uptake by crop. Similar finding was reported by Jacob and Syriac (2005).

But the rice plants in weedy check recorded the lowest nutrient uptake. This might be due to the depletion of nutrients by weeds in higher amounts resulting in limited nutrient availability to the crop. Similar observations were made earlier by several workers (Rajan, 2000; Jacob, 2002 and Sajith babu, 2010).

5.3 POST HARVEST NUTRIENT STATUS OF SOIL

Post harvest nutrient status of the soil was appreciably influenced by the weed management practices. The results on post experiment nutrient status indicated a marginal decrease in the nitrogen, phosphorus and potassium content over the initial status. The treatment which recorded comparatively low values for the density and dry weight of weeds *viz.,* T4 (penoxsulam @ 25.0 g a.i ha^{-1}), T3 (penoxsulam @ 22.5 g a.i ha^{-1}), T5 (bispyribac sodium @ 30.0 g a.i ha^{-1}), and T6 (2, 4 – D sodium salt @ 1 kg

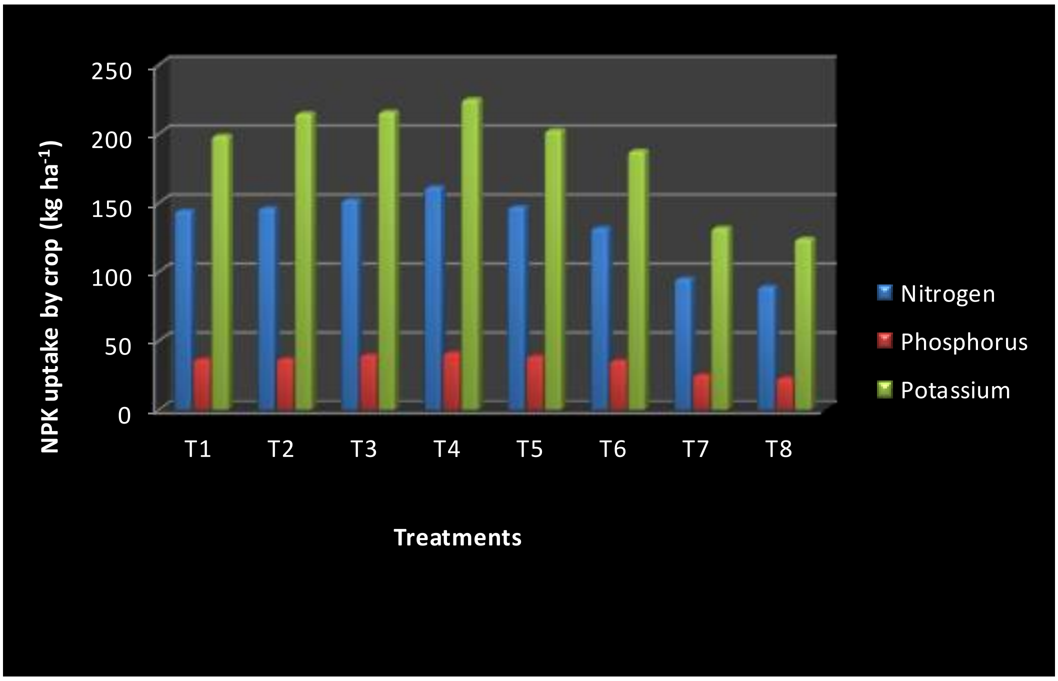

Fig 13. Effect of weed management practices on NPK uptake by crop

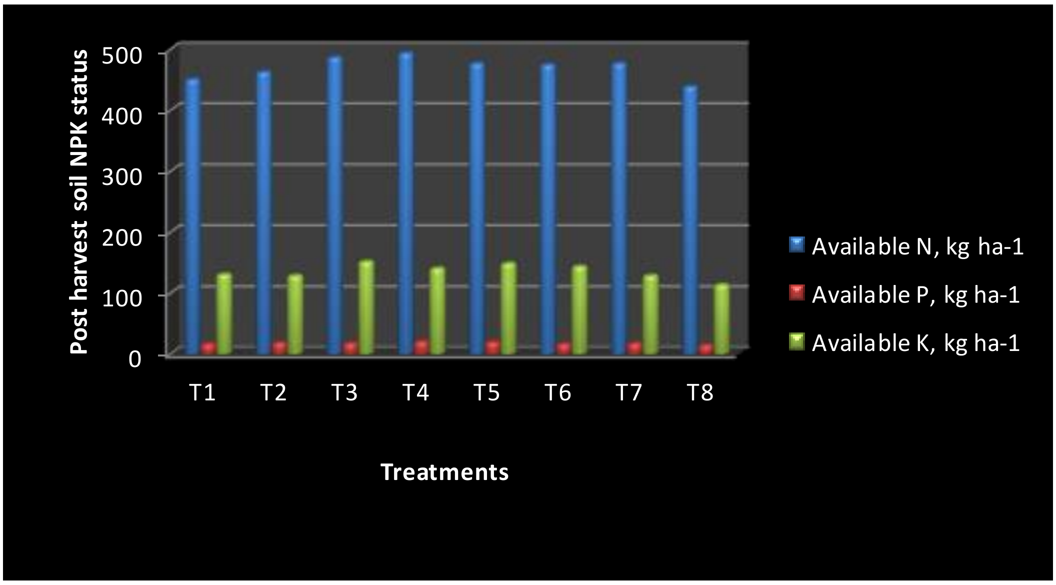

Fig 14. Effect of weed management practices on post harvest NPK status in soil

a.i ha^{-1}) recorded the higher available nutrient status in the post experiment soil, because there was less nutrient removal by weeds in these treatments. The post experiment nutrient status was the lowest in weedy check. Lowest N, P and K status in weedy check was due to the high nutrient removal by weeds along with crop from these plots. These finding are in conformity with that of Rajkhowa *et al.* (2001) ; Jacob (2002) ; Seema (2004) ; Yadav, 2006 and Rathod (2013). Sajith babu (2010) who studied rice weed competition in rice has reported decline in the available N and K status of post experiment soil compared to the initial status.

5.4 ECONOMICS

The present study indicated that all the herbicides used in the trial registered significantly higher net income and B:C ratio than hand weeding treatment. The new generation herbicide penoxsulam at all the tested doses registered comparatively higher net income and benefit cost ratio. Among these doses, penoxsulam @ 22.5 g a.i ha^{-1} (T3) was found to be the best one which gave a net income and benefit cost ratio of Rs.49065/- ha^{-1} and 1.67 respectively. T4 (penoxsulam @ 25 g a.i ha^{-1}) was the next best treatment with a net income and B:C ratio of Rs.45833/- ha^{-1} and 1.63 respectively. Malik *et al.* (2011) also reported highest B:C ratio for penoxsulam @ 25.0 g a.i ha^{-1} applied at 3 or 10 DAT. Bispyribac sodium and 2, 4 – D sodium salt also registered comparable net income and B: C ratio. Eventhough yield was comparatively high for the hand weeding twice (HWT) treatment, net income and benefit cost ratio were significantly low (Rs.35011/- ha^{-1} and 1.46 respectively) for this treatment compared to all the herbicide treatments owing to the huge expenditure incurred for manual weeding. The data on vegetation analysis parameters also indicate the effectiveness of this treatment for weed control. Thus, this result on economics also favours chemical weed control. Another interesting observation is that even though bispyribac sodium recorded comparatively higher grain yield than 2, 4 – D sodium salt (T6), net income was high for 2, 4 – D sodium salt owing to the

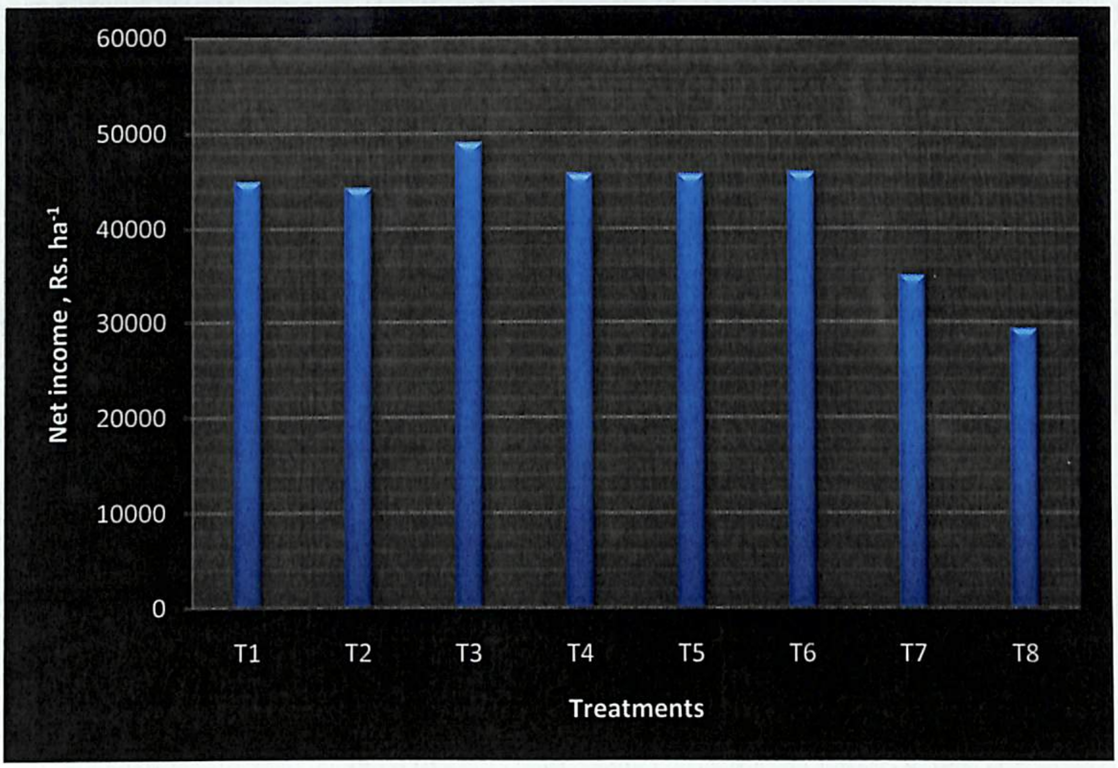

Fig 15. Effect of weed management practices on net income

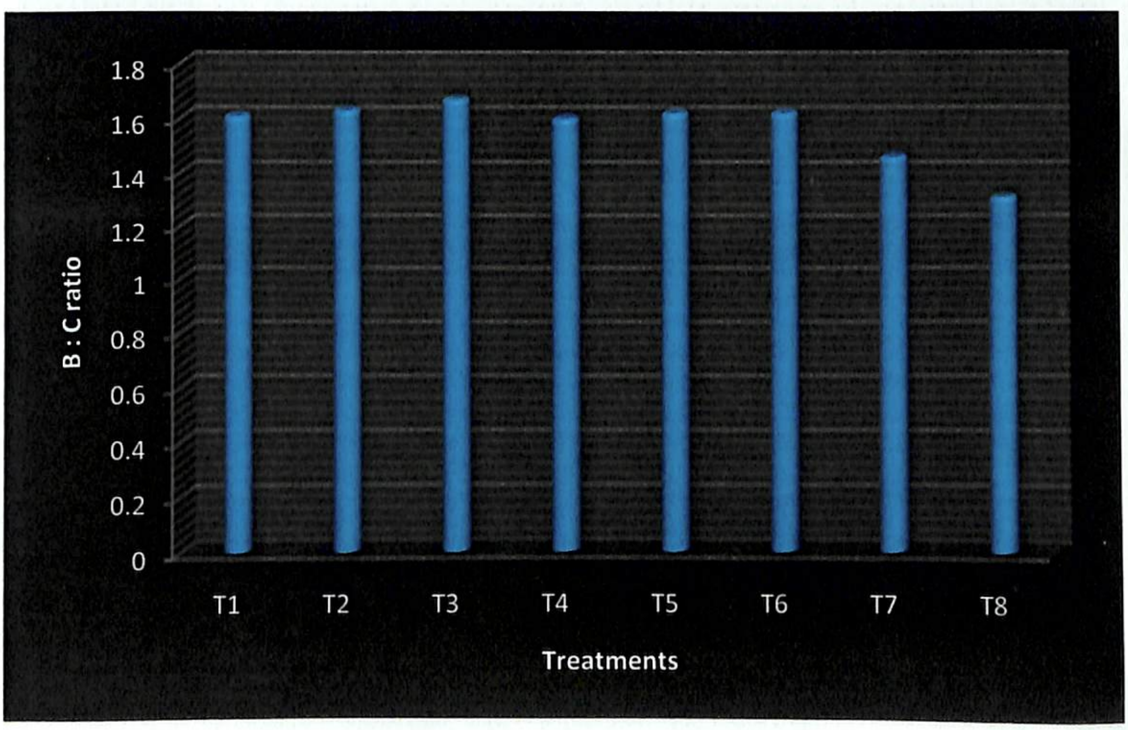

Fig 16. Effect of weed management practices on B:C ratio

fact that it is comparatively a cheap herbicide. However new generation herbicide penoxsulam is green labeled indicating its safety to the environment compared to the yellow labeled traditional herbicide 2, 4 – D sodium salt.

Singh *et al.* (2003), Jacob (2002), Seema (2004), Yadav (2006) and Kiran *et al.* (2010) reported that herbicide application resulted in higher net income and benefit cost ratio compared to manual weeding. Herbicides offer economic and efficient weed control if applied at proper dose and stage (Kumar and Sharma, 2005). Economic benefit of herbicide application over manual weed control was reported earlier too (Rangiah *et al.*, 1975; Versteeg and Maldonado, 1978; Lakshmi, 1983). Many earlier studies using new generation herbicide also confirmed the findings of this study (Khaliq *et al.*, 2011 and Malik *et al.*, 2011).

5.5 EFFECT OF WEED CONTROL TREATMENTS ON POPULATION OF SOIL MICRO ORGANISMS

Total microbial population in a soil is the direct measurement of qualitative change appearing after herbicide treatment.

5.5.1 Effect on Soil Fungi

The results revealed that the population of fungi in the soil was not significantly influenced by any of the herbicide treatment. Similar result was reported earlier by Kalyanasundaram and Kavitha (2012). Application of herbicides at above field dose *i.e.* at higher concentrations affected the population of fungi (Chauhan *et al.*, 1994; Allievi and Gigliotti, 2001). In the present study the population of fungi in the experimental field was not influenced by the herbicide spraying, may be because the herbicides were applied at the recommended rate.

5.5.2 Effect on Soil Bacteria

The results indicated that there was a decline in the population of bacteria at 6 DAS (days after spraying) in all herbicide treatments, compared to weedy check and HWT. After the application of the new generation herbicide, pyrazo sulfuron-ethyl there was significant reduction in the population of bacteria at 3, 6 and 15 DAS; from 15 DAS onwards the bacterial count started to increase (Yadav, 2006). Similar observation was made by Devi (2002) for 2, 4 – D sodium salt. According to her though 2, 4-D sodium salt had a negative influence on soil bacteria, their population was restored within 30 DAS. This type of short term inhibitory effect of herbicides on the population of soil bacteria was reported earlier by several workers (Mukhopadhyay, 1980; Nalayini and Sankaran, 1992; AICRPWC, 1994). Post emergence herbicide 2, 4–D sodium salt significantly influenced bacterial population, but these effects were transient, being detectable only within the first 1-5 days of herbicide addition (Subhani *et al.*, 2000). In general in the present study there was an initial reduction in the population of bacteria when observed at 6 DAS. This kind of initial setback in microbial population and restitution after certain period of time was reported earlier also (Anderson and Domsch, 1983).

5.5.3 Effect on Soil Actinomycetes

The actinomycetes population was not affected by any of the herbicides or its concentration when observed at 6 DAS. Similar findings were reported by Devi (2002); Lekshmi (1984) and Kalyanasundaram and Kavitha (2012). The population of actinomycetes at different days after herbicide application showed significant difference; the highest population being recorded at 30 days after application and the lowest at 7 days after application of the herbicide butachlor, pretilachlor, 2, 4- D EE and pyrazosulfuron ethyl (Latha and Gopal, 2010).

SUMMARY

6. SUMMARY

The present study entitled "Evaluation of the new generation herbicide penoxsulam in transplanted rice (*Oryza sativa* L.)" was undertaken during the third crop / summer season of 2012 – 13. The field experiment was conducted in farmer's field in Nemom block, Thiruvananthapuram, Kerala. The objective of the study was to assess the bio efficacy of the post emergence micro herbicide penoxsulam in transplanted rice and to work out the economics.

The experiment was laid out in RBD with eight treatments and three replications. The treatments included penoxsulam at four doses *viz.*, 17.5 (T1), 20.0 (T2), 22.5 (T3) and 25.0 (T4) g a.i ha^{-1} applied at 10 DAT, bispyribac sodium @ 30.0 g a.i ha^{-1} (T5), 2,4 – D sodium salt @ 1 kg a.i ha^{-1} (T6) applied at 20 DAT, hand weeding at 20 and 40 days after transplanting (DAT) (T7) *i.e.* farmer's practice and weedy check (T8).

The salient results emanating from the study are summarized in this chapter.

Results of the study revealed that the floristic composition of the experimental field included, *Echinochloa colona* (L.) Link., *Panicum repens, Cyperus difformis, Fimbristylis dichotoma (L.)* Vahl., *Scirpus grossus* L.f., *Limnocharis flava* (L.) Buchenau., *Monochoria vaginalis* (Burm. f.) Presl. Ex Kunth., *Ludwigia parviflora* Roxb., *Lindernia rotundifolia* blanc vert ., *Salvinia molesta* D.S. Mitch., *Marsilea quadrifolia* Linn. and *Pistia stratiotes* L.Royle. The results indicated the predominance of broad leaved weeds (7 *sp*.) and sedges (3 *sp*.) compared to grasses (2 *sp*.) in the experimental field.

The study indicated that the dry matter accumulation by weeds could be substantially reduced by all weed management treatments. At all the growth stages, highest dose of penoxsulam *i.e*. (T4) 25.0 g a.i ha^{-1} recorded the lowest total dry matter production of weeds. However this treatment was comparable with the next higher dose of penoxsulam too. At 40 DAT, the most critical time of crop weed competition, dry matter accumulation by weeds in this treatment was comparable with bispyribac sodium (T5), 2, 4- D sodium salt (T6). Weedy check registered maximum weed growth throughout the crop growth period. Total dry weight of weeds in this treatment was significantly higher than that in all the weed control treatments.

With respect to weed control efficiency, new generation herbicides performed well compared to other treatments. At 40 DAT, *i.e.* the most critical time of crop - weed competition, the highest total weed control efficiency (96.24 %) was recorded by the highest dose of penoxsulam (T4), which was on par with lower doses of penoxsulam and bispyribac sodium. At later stages also T4 registered highest value. WCE of treatments with respect to different categories of weeds *viz.,* grasses, sedges and broad leaved weeds also emphasized the superiority of the new generation herbicide penoxsulam. However, HWT was less effective in controlling all the three types of weeds.

In general, penoxsulam @ 25.0 g a.i ha^{-1} (T4) recorded lowest absolute density of weeds at all the growth stages, and it was comparable to its lower dose. The weedy check registered the highest weed density during all stages of observation and was significantly inferior to all other treatments. Penoxsulam was found effective in controlling all the three morphological classes of weeds identified in the field as evident by the lowest absolute density values recorded for grasses, sedges and broad leaved weeds in this experiment. The data on summed dominance ratio and importance value also affirms the above results.

With respect to nutrient removal by weeds, all the weed management treatments registered significantly lower values compared to weedy check, which recorded the highest nutrient removal of 14.16 kg N, 3.14 kg P and 19.40 kg K ha^{-1}. However, nutrient removal by weeds was comparatively low for new generation herbicides (bispyribac sodium and penoxsulam) as well as traditional herbicide 2, 4 –D sodium salt.

In the present study, traditional herbicide 2, 4 –D sodium salt was found effective because the experimental field was dominated by broad leaved weeds (58.33%) and sedges (25%). So in vegetation analysis, comparable effect was observed for 2, 4 –D sodium salt and new generation herbicides. None of the tested herbicides showed any phytotoxic symptom on rice plants.

Weedy check registered the lowest values for all growth characters *viz.,* plant height, tiller number m^{-2} and dry matter production at all the stages of observation. At harvest, the highest plant height was recorded by T3 penoxsulam @ 22.5 g a.i ha^{-1} which was on par with T2 (penoxsulam @ 20.0 g a.i ha^{-1}) and T4 (penoxsulam @ 25.0 g a.i ha^{-1}). The highest value for number of tillers (40 and 60 DAT) was recorded by T4 and it was comparable with T3 (penoxsulam @ 22.5 g a.i ha^{-1}) *i.e.* the next highest dose of penoxsulam. With respect to number of tillers the proven standard new generation herbicide bispyribac sodium also recorded comparable values as that of penoxsulam at 60 DAT. In the case of plant dry matter production all the doses of penoxsulam as well as bispyribac sodium were significantly superior to traditional herbicide 2,4 – D sodium salt and hand weeding treatments.

Penoxsulam @ 22.5 g a.i ha^{-1} (T3) registered the highest value for the yield attributing characters *viz.*, number of productive tillers per m^{-2}, number of filled grains $panicle^{-1}$ and this treatment recorded the lowest sterility percent also. However, with regard to number of productive tillers m^{-2}, penoxsulam @ 25.0 g a.i ha^{-1} (T4) and bispyribac sodium @ 30.0 g a.i ha^{-1}also registered comparable values. With respect to number of filled grains per panicle along with these treatments 2, 4 - D sodium salt @ 1 kg a.i ha^{-1} also recorded comparable values.

There was significant increase in grain yield in all the weed control treatments over weedy check. Among the different treatments, penoxsulam @ 22.5 g a.i ha^{-1} (T3) recorded the highest yield (5404 kg ha^{-1}) and it was statistically on par with all the herbicide treatments and hand weeding. The higher yield was in accordance with the growth characters and yield attributes, recorded in these treatments. The weedy check recorded the lowest grain yield of 4912 kg ha^{-1}.

The yield loss due to weeds was highest in weedy check. The percentage yield reduction due to uninterrupted weed growth in this treatment was 22.13. Straw yield and harvest index were not significantly influenced by the weed control treatments.

Uptake of nitrogen, phosphorus and potassium by rice plants at harvest was the highest in T4 (penoxsulam @ 25.0 g a.i ha^{-1}). With respect to N and K uptake, T4 was found to be statistically on par with all the lower doses of penoxsulam as well as T5 (bispyribac @ 30.0 g a.i ha^{-1}). As far as P uptake is concerned, along with the above treatments, 2, 4 – D sodium salt also recorded comparable uptake values.

Economic analysis revealed that all the herbicide treatments gave significantly higher net income and B:C ratio compared to hand weeding treatments (T7). The highest net income and B:C ratio of Rs. 49065/- ha^{-1} and 1.67 respectively, were realized by penoxsulam @ 22.5 g a.i ha^{-1} and it was statistically on par with other doses of penoxsulam, bispyribac sodium and 2, 4 - D sodium salt. Even though hand weeding twice (T7) recorded grain yield comparable to that of herbicides, net income and benefit cost ratio were comparatively low for this treatment due to the huge expenditure incurred for manual weeding. The weedy check registered the lowest net income and B:C ratio implying the essentiality for weed management in transplanted rice for realizing economic returns.

Enumeration of soil microbial population consequent to the application of the herbicides, revealed that the herbicides caused an inhibitory effect on the growth of bacteria at the initial stages *i.e.* 6 days after herbicide spraying (DAS), but there was no change in actinomycetes and fungi population compared to weedy check where the rhizosphere was undisturbed.

The present investigation directed towards finding out the optimum concentration of the new generation herbicide penoxsulam for weed management in transplanted rice revealed the superiority of both the higher doses of penoxsulam *i.e.* 22.5 and 25.0 g a.i ha^{-1} based on vegetation analysis. However, based on economic analysis penoxsulam @ 22.5 g a.i ha^{-1} could be adjudged as the best treatment for effective and economic weed management in transplanted lowland rice.

Hence, considering weed control efficiency, yield, economics and the minimal application rate, the new generation green labeled herbicide penoxsulam @ 22.5 g a.i ha^{-1} at 10 DAT can be recommended for weed management in transplanted rice.

FUTURE LINE OF WORK

- The present study needs multi locational trials to verify the results.
- A detailed investigation on the dynamics of soil microbial population at varying time intervals, consequent to the use of this new herbicide is needed.
- A detailed investigation to assess the residue level of penoxsulam in rice plant, grain and soil should be conducted.
- Effect of penoxsulam on soil macro fauna and soil reaction should be assessed.

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EVALUATION OF THE NEW GENERATION HERBICIDE PENOXSULAM IN TRANSPLANTED RICE (*Oryza sativa* L.)

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ABSTRACT

The study entitled "Evaluation of the new generation herbicide penoxsulam in transplanted rice (*Oryza sativa* L.)" was conducted during the period, December 2012 to April 2013 at farmer's field in Nemom block, Thiruvananthapuram district. The objective of the study was to assess the bio-efficacy of the post emergence micro herbicide penoxsulam in transplanted rice and to work out the economics. The experiment was laid out in randomised block design with eight treatments and three replications. Four doses of penoxsulam *i.e.* 17.5, 20.0, 22.5 and 25.0 g a.i ha^{-1} (T1 - T4), bispyribac sodium @ 30.0 g a.i ha^{-1} (T5), 2, 4 – D sodium salt @ 1 kg a.i ha^{-1} (T6), hand weeding twice (T7) and weedy check (T8) constituted the treatments.

Study of the weed flora dynamics of experimental field indicated the dominance of broad leaved weeds (7 *sp*.), followed by sedges (3 *sp*.) and grasses (2 *sp*.) All the herbicide treatments reduced the population and biomass of weeds substantially over weedy check. The lowest density and dry weight of weeds and highest weed control efficiency was recorded with penoxsulam @ 25.0 g a.i ha^{-1} (T4) at all the stages of observation, *viz*., 20 DAT, 40 DAT and 60 DAT. With respect to density of weeds, T4 was found to be on par with T3 at 20, 40 and 60 DAT. Regarding dry weight of weeds, at 20 DAT, T4 was on par with T3 ; however, at 40 DAT, all other herbicide treatments were on par with T4. None of the herbicides produced any phytotoxic symptom on rice plant.

Critical analysis of the growth factors indicated the favourable effect of weed control treatments especially penoxsulam @ 25.0 and 22.5 g a.i ha^{-1} on plant height at harvest, number of tillers at 40 and 60 DAT and dry matter production at harvest. All the weed control treatments significantly improved the yield attributes *viz*., number of productive tillers m^{-2}, grain weight $panicle^{-1}$ and significantly lowered the sterility percentage as compared to weedy check.

Penoxsulam @ 22.5 g a.i ha^{-1}(T3) registered highest grain yield (5404 kg ha^{-1}), net income (Rs 49065 /- ha^{-1}) and B:C ratio (1.67) which was on par with other doses of penoxsulam(T4 , T2 and T1) as well as bispyribac sodium @ 30.0 g a.i ha^{-1} (T5) and 2,4 - D sodium salt (T6). Even though hand weeding twice

registered grain yield comparable to herbicide treatments, due to very high labour cost involved, net income and B:C ratio were significantly low for this treatment. The weedy check recorded significantly lower values for grain yield, net income and B:C ratio compared to herbicide treatments and the yield loss due to weeds in this treatment was 22.13 per cent.

Enumeration of soil microbial population 6 days after herbicide spraying revealed that the herbicides caused an initial reduction in the population of bacteria; but, there was no significant variation in the population of fungi and actinomycets , compared to weedy check where the rhizosphere was undisturbed.

Considering weed control efficiency, grain yield, net income and B:C ratio, the new generation herbicide penoxsulam @ 22.5 g a.i ha^{-1} at 10 DAT can be adjudged as the best treatment for weed management in transplanted rice.

APPENDIX

APPENDIX – II

Media composition for Microbial study

1. Nutrient Agar Medium

Sl.No:	Reagents	Quantity
1.	Peptone	5 g
2.	Sodium chloride	5 g
3.	Beef extract	3 g
4.	Agar	20 g
5.	Distlled water	1000 ml
6.	pH	7

2. Kenknight's Agar medium

Sl.No:	Reagents	Quantity
1.	Dextrose	1. 0 g
2.	KH_2PO_4	0. 1 g
3.	$NaNO_3$	0. 1 g
4.	Kcl	0. 1 g
5.	$MgSO_4.7\ H_2O$	0. 1 g
6.	Agar	15. 0 g
7.	Distlled water	1000 ml

3. Martin's Rose Bengal Agar medium

Sl.No:	Reagents	Quantity
1.	Glucose	10 g
2.	Peptone	5 g
3.	KH_2PO_4	1 g
4.	$MgSO_4.7\ H_2O$	0.5 g
5.	Streptomycin	30 mg
6.	Agar	15 g
7	Rose Bengal	35 mg
8.	Distlled water	1000 ml

APPENDIX – I

Weather parameters during the experimental period (December 2012-April 2013)

Standard weeks	Maximum temperature (^0C)	Minimum temperature (^0C)	Max. R.H (%)	Min R.H (%)	Sun shine hours	Rain fall(mm)
48	28.2	23.5	98.0	79.3	8.2	110
49	31.7	22.7	97	64.1	9.4	0.5
50	30	22.8	96.4	68.7	9	10.5
51	31.5	22.7	93.7	59.1	8.4	0.5
52	28.6	20.8	99	65.3	9.3	36
1	30.7	20.8	99	60.4	9.2	0
2	30.3	23.5	98.6	67.6	9.2	0
3	29.4	19.2	98.1	55.3	9.3	5
4	30.3	19.9	98.7	57.4	9.4	0
5	31.3	22.2	97.1	55.9	9.2	0
6	30.8	23.5	97.6	71.6	8.9	0
7	30.8	22.9	97.7	65.3	9.4	0
8	30.6	21.6	96.4	51.7	9.4	0
9	30.5	23.2	94.3	62.1	9.2	0
10	30.2	23.7	88.6	66.3	9.2	9
11	30.4	21.3	98.3	69.1	8.9	4
12	30.2	24.6	93.7	63.6	8.6	0
13	30.2	22.6	95.7	63.1	8.6	9
14	30.4	23.0	95.2	64.2	8.6	1.5
15	30.4	22.9	95.0	63.0	8.9	11
16	30.5	23.0	95.6	63.9	9.5	8