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Bio-efficacy of new herbicide combination (Bispyribac sodium 4% SE + Metamifop 10% SE) on weed control, economics and profitability of direct seeded rice

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Abstract
Direct seeded rice (DSR) is gaining momentum in India due to high demand of labour during peak season of transplanting and short period availability of water. Weed management is a major factor contributing a considerable share to the cost of production and deciding the final yield, especially in DSR as the crop and weeds emerge simultaneously due to which the crop suffers competition even from early stage of growth which in turn reduces the grain yield. Weeds are the main biological constraints to its success. Field experiments were conducted in the *rabi* season of 2013 and 2014 to study the new formulation of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE against weeds in DSR and their residual effect on succeeding crop. Results revealed that the post-emergence (POE) application of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} gave significantly lower total weed density (25.78 plants m^{-2} in 2013 and 24.19 plants m^{-2} in 2014), total weed biomass (24.89 g m^{-2} in 2013 and 34.56 g m^{-2} in 2014) and higher weed control efficiency (80.07% in 2013 and 81.68% in 2014) at 40 days after herbicide spray (DAHS). Application of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} as POE herbicide can keep the weed density and dry weight below the economic threshold level and increase the grain yield of 5676 and 6388 kg ha^{-1} in DSR. Economic analysis of weed management practices in DSR revealed that the higher gross and net return (` 68,112 $ha^{-1}$ and ` 43,662 ha^{-1}in 2013; ` 76,656 $ha^{-1}$ and ` 51,506 ha^{-1} in 2014) were realized in the treatment of new formulation bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1}. Similarly, the maximum benefit cost ratio of 2.79 in 2013 and 3.05 in 2014 were realized with the POE application of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1}. The results of this study are important for farmers growing DSR in making decisions regarding the application of POE herbicide combination, according to existing weed flora in the field.

Keywords: Herbicide combination, DSR, weed density, weed biomass, WCE, grain yield, economics

1. Introduction
Rice (*Oryza sativa* L.) is the leading cereal of the world and more than half of the human race for their daily sustenance (Chauhan and Johnson, 2011) [4]. Direct seeded rice cultivation is subjected to greater weed competition than transplanted rice because both weeds and crop seeds emerge at the same time and compete with each other for germination resulting in lesser grain yield. Crop competitiveness is the ability of the crop to produce desirable yields in the presence of weeds (Zhao, 2006) [25]. In tropic, average rice yield losses from weeds is 35% (Oerke and Dehne, 2004) [18]. Sunil *et al.* (2010) [24] as stated, season-long weed competition in DSR may cause yield reduction upto 80%. In DSR, weeds emerge simultaneously rice seedlings at the early growth stages when rice is highly susceptible to the weed competition (Khaliq and Matloob, 2011 [10]; Chauhan, 2012 [3]). Thus, an efficient and timely weed control is crucial for the success of DSR. Direct seeding can curtail water and labor inputs involved in rice production; nevertheless, its large-scale adoption is impeded by heavy weed infestation. However, for cultivation of DSR, weeds are a major hurdle as nearly all *rabi* season weeds depending upon seed bank in the field infest this crop. DSR is possible provided there is a good crop establishment as well as adequate weed control methods is available to keep the crop free from weeds (Rao and Nagamani, 2007) [20]. Efficient, cost-effective and timely weed management options remain pivotal to making DSR profitable and commercially acceptable. Such a strategy should help improve yield and reduce production costs as well as minimize the

negative effects of weeds on the quality of the produce. Timely and effective weed control has a positive correlation with good crop stand and higher grain yield of DSR. Manual weeding although is effective and the most common practice of weed control in direct seeded rice; these have several limitations particularly during peak period which makes it further problematic. In hand weeding, it is difficult to differentiate and remove the grassy weeds especially *Echinochloa crusgalli* and *Echinochloa colonum* due to the phenotypical similarities between weeds and rice seedlings in the early stages. Herbicides are considered to be an alternative supplement to hand weeding. The use of herbicides offers selective control of weeds right from beginning, giving crop an advantage of good start and competitive superiority over weeds. Hence, chemical weed control in direct seeded rice has gained importance because of the intensity of weed problem, coupled with the lack of labour for weeding and high cost. Chemical weed control has expanded manifold in DSR (Chauhan and Opena, 2013 a, b [5 & 6]) and is likely to increase further with the increased adoption of direct seeding.

In India, the high cost and scarcity of labour and cost effective as well as timely control of weeds have increased use of herbicides for weed control in almost all crops (Rao *et al*., 2014) [21]. In order to control weeds, farmers use both pre and post emergence herbicides (Mahajan and Timsina, 2011) [16]. Both pre and post emergence herbicides, if properly used, are quite effective in suppressing weeds in DSR (Chauhan, 2012) [3]. To the best of our understanding, a very few studies in this line have been conducted in DSR grown in Western Zone of Tamil Nadu, India. Moreover, the rice herbicides presently used in Tamil Nadu are mainly pre-emergence therefore; weeds coming at later stages of crop growth are not controlled as effectively as the weeds at emergence stage. This situation warranted for initiating research efforts to evaluate and identify suitable post-emergence herbicides. But sometimes continuous use of a single herbicide (pretilachlor) may lead the buildup of herbicide resistance in weeds. Nevertheless, indiscriminate use of herbicides is driving agro-ecosystem toward declining species diversity and in many situations, is leading to herbicide resistance (Powles and Yu, 2010) [19]. Singh (2008) [22] found that the continuous changes in weed community composition in just five years. Without any doubt, the development and availability of effective POE herbicides have encouraged farmers to try this new method of crop establishment (DSR) in Tamil Nadu. Currently available rice herbicide have a narrow spectrum of activity and their efficacy is further limited when they are used alone (Singh, 2008 [22]; Chauhan, 2012 [3]). This rarely provides season long weed control (Khaliq *et al*., 2011 a, b [11 & 12]). Control of complex weed flora with a single POE application is really a diffcult task for the DSR farmers (Mahajan and Chauhan, 2013) [14]. Therefore, the combined application of different herbicides with different mode of action is required for broad spectrum weed control in DSR and for delaying the development of herbicide resistance.

Hence, there is a need to focus attention on new herbicide combination to enhance the weed control efficiency, broadening the spectrum of weed control and saving the herbicide and labour requirements. Literatures suggest that the repeated use of the same herbicides encourages the problem of herbicide resistance in weeds (Kim, 1996) [13]. For a broad spectrum of weed control in DSR, applications of herbicides with different mode of action (chemistry) are needed. With changing scenario of weed management, farmers need new herbicides or new herbicide combination having with high efficacy, low phytotoxicity, there was no residual effect on succeeding crops and cost effective. Thus, it is essential to identify economic and effective herbicide combinations for managing complex weed flora in DSR. This study was conducted for general detailed information for managing a mixed population of grasses, sedges and broad leaved weeds in DSR effectively and economically with herbicide combination of newly available POE herbicides. The present work is intended to look out the broad spectrum weed control through new POE herbicide combination in *rabi* season DSR of Tamil Nadu.

2. Materials and Methods

2.1. Experimental site and initial soil characteristics

A field study was conducted for two years (*rabi* seasons of 2013 and 2014) at the research farm of Wetland Farm (Field No: N_1), Tamil Nadu Agricultural University, Coimbatore, India. The experimental farm was located in Western Zone of Tamil Nadu is at 11º29”N latitude and 77º08”E longitude with an altitude of 256 m above MSL. The climate is semi arid, with an average of 674.2 mm distributed over 47 rainy days (mean of past 50 years). The maximum rainfall received during the cropping period was 70 mm. During the cropping period, the maximum and minimum temperature ranged from 35.7 to 27.0ºC and 26.0 to 19.8ºC, respectively. Relative humidity ranged from 61 to 95% and 29 to 75% during forenoon and afternoon, respectively. The solar radiation received during the cropping period ranged from 224 to 462.6 cal/cm^2/day and the sunshine hours ranged from 1.4 to 9.0 hrs/day. The evaporation prevailing during the cropping period ranged from 2.4 to 9.2 mm. The soil was clay loam in texture with low in available nitrogen (238 kg ha^{-1}), medium in available phosphorus (16.8 kg ha^{-1}) and high in available potassium (518 kg ha^{-1}) with 0.5% organic matter with a pH of 7.4.

2.2 Experimental design and treatments

The treatments in each year were arranged in a randomized complete block design with three replication. Twelve weed control treatments were included with different herbicide combination options for weed control in DSR. Herbicides included in the study were bispyribac-sodium, metamifop, almix, clincher and wetter (isoxadifen, a safener).

2.3 Experimental details, selection of cultivar and sowing

In each year, rice (cv. ADT 43, a cultivar with the duration of 120 days) was seeded in the first week of September and the harvested in last week of December. Manually operated rice drum seeder developed by Tamil Nadu Agricultural University, Coimbatore was used for sowing the seeds. The seeder has two wheels at both the ends. It drops the seeds at 30 cm apart in continuous row. At a time, eight rows of rice seeds were sown. A seed rate of 40 kg ha^{-1} was adopted. Before sowing the field was drained to keep it under saturated condition to facilitate easy sowing and uniform establishment of seedlings. A thin film of water was maintained at the time of sowing. For the next 8-15 days, irrigation and drainage of water were alternated to facilitate aeration, adequate moisture for germination of seed and establishments of seedlings. Thereafter, the plots were irrigated to 2 cm depth uniformly in all the treatments after the appearance of hair line cracks, upto panicle initiation stage. After panicle initiation, the plots were irrigated to 5 cm depth on disappearance of ponded water. Irrigation was stopped 15 days prior to harvest.

2.4. Treatment details

New formlation of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE was applied as POE herbicide on 10 to 15 DAS. Bispyribac-sodium (Nominee gold) has been widely used for DSR with its excellent foliar efficacy against grasses, sedges and broad leaved weeds. Metamifop which was discovered by Dongbu Honnong Co., Ltd. is a novel grass herbicide with excellent foliar efficacy against grasses and crop safety. Hand operated knapsack sprayer fitted with a flat fan type nozzle (WFN 40) was used for spraying the herbicides adopting a spray volume of 500 litres ha^{-1} in DSR. The herbicides were sprayed by keeping a thin film of water in the field. The field was neither drained nor irrigated for 2 days after application of herbicides. The non-treated control plot was kept undisturbed for the entire cropping period.

Table 1: Herbicide treatments used in the study

Tr. No	Treatment details	Dose g.a.i/ha	Dose ml/gm/ha of Formulation	Time of Application
T_1	Bispyribac sodium 4% SE + Metamifop 10% SE + Wetter	42 g a.i. + 100 ml wetter	300 ml +100 ml wetter	10-15 DAS
T_2	Bispyribac sodium 4% SE + Metamifop 10% SE + Wetter	56 g a.i. + 100 ml wetter	400 ml +100 ml wetter	10-15 DAS
T_3	Bispyribac sodium 4% SE + Metamifop 10% SE + Wetter	70 g a.i. + 100 ml wetter	500 ml +100 ml wetter	10-15 DAS
T_4	Almix (Chlorimuron + Metsufuron 20% WP)	4 g a.i.	20 g	10-15 DAS
T_5	Clincher (Cyhalofop Buthyl 10% EC)	80 g a.i.	800 ml	10-15 DAS
T_6	Bispyribac sodium 10% SC + Wetter	20 g a.i. + 100 ml wetter	200 ml + 100 ml wetter	10-15 DAS
T_7	Metamifop 10% SE + Wetter	50 g a.i. + 100 ml wetter	500 ml +100 ml wetter	10-15 DAS
T_8	Bispyribac sodium 4% SE + Metamifop 10% SE	70 g a.i.	500 ml	10-15 DAS
T_9	Bispyribac sodium 10% SC	20 g a.i.	200 ml	10-15 DAS
T_{10}	Metamifop 10% SE	50 g a.i.	500 ml	10-15 DAS
T_{11}	Hand weeding twice on 25 and 45 DAS	---	---	---
T_{12}	Non-treated control	---	---	---

Abbreviation: DAS - Days after sowing

2.5 Observation on weeds

2.5.1 Weed flora of the experimental field

To account for the general weed flora of the experimental field, species wise weeds observed in the treatment plots were recorded during the period of maximum appearance of 20 and 40 days after herbicide spray (DAHS). The weed flora of the experimental site was recorded species wise.

2.5.2 Weed density

The weed count was recorded species wise using 0.5 m x 0.5 m quadrant from four randomly fixed places in each plot and the weeds falling within the frames of the quadrant were counted and the mean values were expressed in number m^{-2}. The density of grasses, sedges and broad leaved weeds and also the total weeds were recorded at 20 and 40 days after herbicide application (DAHS) and expressed in number m^{-2}.

2.5.3 Weed dry weight

The weeds falling within the frames of the quadrant were collected, categorized into grasses, sedges and broadleaved weeds, first shade dried and later dried in hot-air oven at 80°C for 72 hrs. The dry weight of grasses, sedges and broadleaved weeds were recorded separately at 20 and 40 DAHS and expressed in g m^{-2}.

2.5.4 Weed control efficiency

Weed control efficiency (WCE) was calculated as per the procedure given by Mani *et al*. (1973) [17].

$$\text{WCE \%} = \frac{WD_c - WD_t}{WD_c} \times 100$$

Where,
WCE - weed control efficiency (%)
WD_c - weed biomass (g m^{-2}) in control plot
WD_t - weed biomass (g m^{-2}) in treated plot

2.5.5 Weed index

Weed index (WI) was calculated as per the method suggested by Gill and Vijaya Kumar (1969) [8].

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

Where,
X = yield (kg ha^{-1}) from minimum weed competition plot
Y = yield (kg ha^{-1}) from the treatment plot for which WI is to be worked out.

2.6 Observation on crop

2.6.1 Grain yield

Grains from each net plot were cleaned, sun dried, weighed and adjusted to 14% moisture content and the grain yield was expressed in kg ha^{-1}.

2.7 Economic analysis

2.7.1 Gross return

Gross return was computed by multiplying the grain and straw yield in respective treatments with the unit market price of the produce and expressed as ` ha^{-1}.

2.7.2 Net return

The net return was worked out for all the treatments by subtracting the cost of cultivation from the gross return and expressed as ` ha^{-1}.

2.7.3 Benefit cost ratio

Benefit cost ratio of direct seeded rice was computed using the formula given below.

$$\text{Benefit cost ratio} = \frac{\text{Gross return (` ha}^{-1}\text{)}}{\text{Cost of cultivation (` ha}^{-1}\text{)}}$$

2.8. Statistical analysis

The data collected for direct seeded rice was statistically analyzed following the procedure given by Gomez and

Gomez (2010) [9] for randomized block design. The data pertaining to weeds and germination were transformed to square root scale of $\sqrt{(X+2)}$ and analyzed as suggested by Snedecor and Cochran (1967) [23]. Whenever significant difference existed, critical difference was constructed at five per cent probability level. Such of those treatments where the differences are not significant were denoted as NS.

3. Results and discussion
3.1 General weed flora of the experimental field
A critical analysis of relative proportion of grasses, sedges and broad leaved weeds to total weed population in non-treated control revealed that during the crop growth period, the population of sedges was higher than that of grasses and broad leaved weeds. Among the grasses, *Echinochloa crus-galli* (L.) Beauv. *Echinochloa colona* (L.) Link. *Dinebra retroflexa* (Vahl.) Panzer. and *Panicum repens* (L.) were the dominant species and major sedges were *Cyperus difformis* (L.), *Cyperus irria* (L.) and *Fimbristylis miliacea* (L.) Vahl. Among the broad leaved weeds M*arsilea quadrifoliata* (Linn.), *Ammania baccifera* (L.) and *Eclipta alba* (L.) Hassk. were the dominant species. However, a species-wise result was given for the first five weeds only, as they were the predominant weeds in the experimental trial.

3.2 Effect on weeds
3.2.1 Total weed density
Significant variation in total weed density was observed among the herbicidal weed control treatments. During both the years, lesser total weed density was observed with POE application of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} and bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} without wetter and it was closely followed by application of bispyribac sodium 4% SE + metamifop 10% SE at 56 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (16.80, 17.09, 22.50 in 2013 and 13.90, 15.43, 18.44 in 2014, respectively). At 40 DAHS also similar results were recorded. Bispyribac sodium is pyrimidinyl carboxate group which inhibits the biosynthesis of amino acids. Metamifop is aryloxyphenoxy propionate group which inhibits the activity of acetyl coenzyme-A carboxylase (ACCase) leading to growth retardation of weeds. However, the combined application of both herbicides induces chlorosis selectively in weeds and insufficient chlorophyll production makes it difficult for thrive of weeds. The combined application of these herbicides was better than their individual application in reducing the weed density, weed biomass and enhancing the productivity of rice yield. Total weed density was higher in individual application as POE application of clincher at 80 g a.i. ha^{-1} when compared to almix at 4 g a.i. ha^{-1} and it was similar in the both years of study. Clincher is a systemic POE herbicide and it is aryloxyphenoxy propionate group. In the present study, POE applications of clincher (alone) effectively control grassy weeds than compared to sedges and broad leaved weeds in direct seeded rice. Total weed density in the non-treated control were 105.20 and 156.13 plants m^{-2} in 2013; 85.93 and 1132.78 plants m^{-2} in 2014, respectively at 20 and 40 DAHS. All the herbicide treatments recorded lower total weed density significantly as compared to the non-treated control. Earlier, Mahajan and Chauhan (2013) [14] revealed that sequential applications of pre and post-emergence herbicides provided better weed control than the sole application pre or post-emergence herbicides in DSR.

3.2.2 Total weed biomass
With regard to the total weed biomass, significant variation was observed among the herbicidal weed management practices in DSR. During both the years, lower total weed biomass was observed in POE application of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (8.92 and 24.89 g m^{-2} in 2013 and 11.38 and 34.56 g m^{-2} in 2014, respectively), bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} without wetter (9.54 and 31.42 g m^{-2} in 2013 and 13.45 and 37.58 g m^{-2} in 2014, respectively) and it was closely followed by application of bispyribac sodium 4% SE + metamifop 10% SE at 56 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (16.77 and 36.76 g m^{-2} in 2013 and 18.56 and 52.62 g m^{-2} in 2014, respectively), bispyribac sodium 10% SC at 20 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (21.56 and 40.97 g m^{-2} in 2013 and 24.63 and 64.82 g m^{-2} in 2014, respectively) and individual application of almix at 4 g a.i./ha (24.41 and 44.91 g m^{-2} in 2013 and 28.44 and 65.89 g m^{-2} in 2014, respectively) as POE herbicides at 20 and 40 DAHS (Table 2). In the present study, herbicides differed in respect of their efficacy and bispyribac sodium emerged as promising one in averting both density and dry matter accumulation by weeds. The performance of this herbicide could be attributed to reasonable suppression of weeds and selectivity to rice crop as well. It is a member of pyrimidinyloxy benzoic chemical family and inhibits acetolactate synthase enzyme in susceptible plants thus retarding the synthesis of branch chain amino acids (Darren and Stephen, 2006) [7]. The effectiveness of bispyribac sodium as a post-emergence herbicide for DSR is also reported elsewhere (Mahajan *et al.*, 2009 [15]; Khaliq *et al*., 2011b [12]). At 20 and 40 DAHS, POE of bispyribac sodium 10% SC at 20 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} obtained lower weed biomass as compared with application of almix at 80 g a.i. ha^{-1} (24.41 and 44.91 g m^{-2} in 2013 and 28.44 and 65.89 g m^{-2} in 2014, respectively) and clincher at 80 g a.i. ha^{-1} (26.79 and 49.81 g m^{-2} in 2013 and 30.44 and 63.24 g m^{-2} in 2014, respectively). Total weed biomass in the non-treated control were 70.97 and 116.83 g m^{-2} in 2013; 110.56 and 188.67 g m^{-2} in 2014, respectively at 20 and 40 DAHS. All the herbicide treatments recorded lower total weed biomass significantly as compared to the non-treated control.

3.2.3 Weed control efficiency
Adoption of herbicide combination of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} treatment exhibited lowest weed infestation with higher weed control efficiency than sole herbicide application in the present study (Fig 1). During both the years, it was observed that POE application of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} resulted the higher weed control efficiency of 87.43 and 80.07% in 2013 and 88.45 and 81.68%, in 2014, respectively and it was followed by application of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} without wetter (86.55 and 73.10% in 2013 and 86.35 and 80.08%, in 2014, respectively). In the present study at 40 DAHS, weed control efficiency with ranged from 47.89 to 66.06% (single herbicide application); 60.22 to 80.07% (new herbicide combination) in 2013, respectively and WCE ranged from 55.67 to 66.48% (single herbicide application); 63.14 to 81.68% (new herbicide combination) in 2014, respectively (Table 2).

3.3 Effect on direct seeded rice

3.3.1 Grain yield

Rice grain yield following all herbicide treatments ranged from 4276 to 5676 kg ha^{-1} and 4658 to 6388 kg ha^{-1}, while the non-treated control plots yield of 2734 and 3012 kg ha^{-1} in 2013 and 2014, respectively (Table 2). Higher grain yield was recorded in the plots treated with the POE application of new formulation bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (5676 kg ha^{-1} in 2013 and 6388 kg ha^{-1} in 2014) and it was similar to the grain yield observed in the plots treated with the application of herbicide combination of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} without wetter (5488 kg ha^{-1} in 2013 and 6232 kg ha^{-1} in 2014), bispyribac sodium 10% SC at 20 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} (5442 kg ha^{-1} in 2013 and 6076 kg ha^{-1} in 2014) and hand weeding twice on 25 and 45 DAS (5256 kg ha^{-1} in 2013 and 5908 kg ha^{-1} in 2014). Bispyribac sodium 4% SE + metamifop 10% SE showed on par with hand weeding twice on 25 and 45 DAS for most of the yield parameters and grain yield (Fig 1). These treatments recorded lesser crop weed competition during the critical period of rice that was marked as more panicles per unit area, increased kernel number and kernel weight over non-treated control. Higher grain yield in response to efficient weed control are reported elsewhere (Mahajan *et al.*, 2009 [15]; Khaliq *et al.*, 2011a,b [11 & 12]; Akbar *et al.*, 2011) [1]. Our data showed effectiveness of manual weeding in limiting weed density and dry biomass merely owing to POE application of new herbicide combination as an effective tool for their weed management in direct seeded rice. Nonetheless, during later part of the growing season weeds were also suppressed by shading effect of rice in manually weeded plots due to quick and dense canopy closure (Baloch *et al.*, 2005) [2]. In both the years, grain yield in the plots treated with already existing molecule of almix at 4 g a.i. ha^{-1} (4948 kg ha^{-1} in 2013 and 5792 kg ha^{-1} in 2014) and clincher at 80 g a.i. ha^{-1} (4404 kg ha^{-1} in 2013 and 5248 kg ha^{-1} in 2014) was similar, but lower than grain yield recorded in the bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter. Though, the combined application of bispyribac sodium 4% SE + metamifop 10% SE + wetter with all different doses were very effective, provide broad spectrum weed control and subsequently increasing the productivity of direct seeded rice in this study.

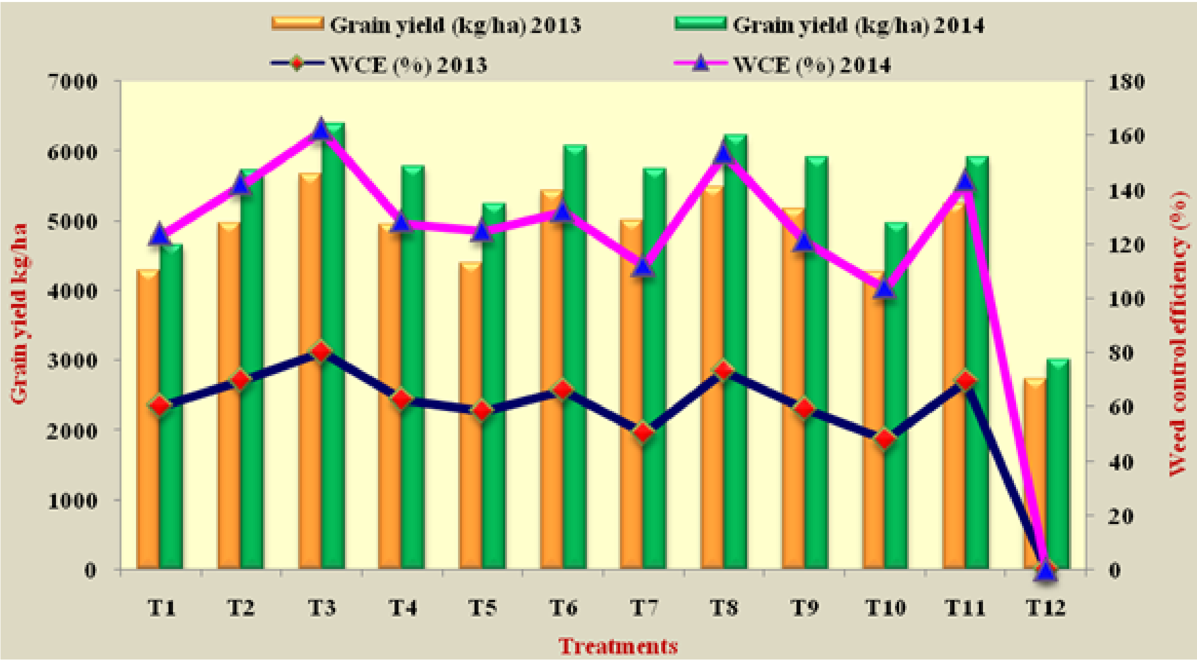

Fig 1: Effect of herbicide combination on grain yield and weed control efficiency of direct seeded rice (pooled mean data)

3.4. Economics of direct seeded rice Economic efficiency and viability of crop cultivation are mainly the outcome of yield of crops with larger management costs. Higher crop productivity with lesser cost of cultivation could result in better economic parameters like higher net returns and cost benefit ratio. Adoption of different weed management practices significantly influenced the gross returns, net returns and benefit cost ratio. Economic analysis of weed management practices in direct seeded rice revealed that the higher gross and net return of ` 68,112 ha$^{-1}$ and ` 43,662 ha^{-1} were realized in the treatment of new formulation bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1}. The untreated control and wetter alone realized a lower net return of ` 9,958 ha$^{-1}$ and ` 11,966 ha^{-1} during the cropping period. Similarly, the maximum benefit cost ratio of 2.79 was realized with the POE application of herbicide combination bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} while untreated control registered lowest benefit cost ratio of 1.44 during *rabi*, 2013 (Fig 2).

uring *rabi*, 2014, the economic analysis of weed management practices in DSR revealed that the higher gross and net return of ` 76,656 and ` 51,506 ha^{-1} were realized under application of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1}. The untreated control and wetter at 100 ml ha^{-1} alone realized the lower net return of ` 12,594 ha$^{-1}$ and ` 19,858 ha^{-1} during the cropping period. Similarly, the maximum benefit cost ratio of 3.05 was realized with POE herbicide combination bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} while the untreated check registered lower benefit cost ratio of 1.82.

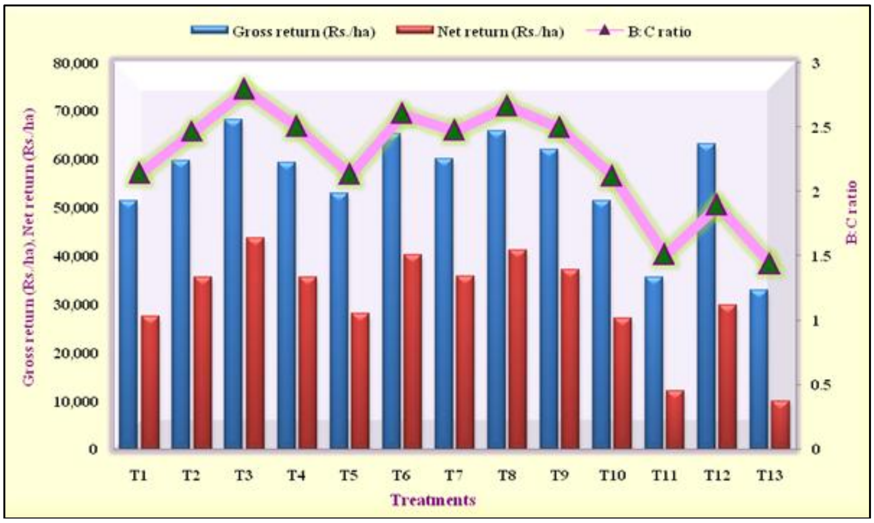

Fig 2: Effect of herbicide combination on economics of direct seeded rice during *rabi*, 2013

4. Conclusions

Results revealed that plots treated with herbicide combination of bispyribac sodium 4% SE + metamifop 10% SE at 70, 56 and 42 g a.i. ha^{-1} + wetter at 100 ml ha^{-1} at all different doses registered higher grain yield because of lower total weed density and weed biomass in these herbicide combination treated plots when compared to individual herbicide application. Herbicide combination of bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i.ha^{-1} + wetter at 100 ml ha^{-1} effectively control of *Echinochloa crus-galli* (L.) Beauv., *Dinebra retroflexa* (Vahl.) Panzer and *Panicum repens* L., among grasses; *Cyperus difformis* L. *and Cyperus irria* L. among sedges; *Marsilea quadrifolia* Linn and *Ammania baccifera* L. among broad leaved weeds with higher weed control efficiency of 80% at critical period of crop growth stage in DSR. Based on economics in DSR revealed that higher gross return, net return and benefit cost ratio were realized in bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i. ha^{-1} + wetter at 100 ml ha^{-1}. Thus a synergistic composition of bispyribac sodium 4% SE + metamifop 10% SE, when applied to DSR, allow a reduction in the amount of herbicide needed, greater flexibility in timing of the application besides offering broad spectrum weed control. Sometimes, if farmers missed the application of pre-emergence herbicide due to erratic rains or any other reasons, effective weed control and higher grain yield can still be obtained with this new herbicide combination of bispyribac sodium 4% SE + metamifop 10% SE + wetter.

Table 2: Total weed dry weight, weed control efficiency and grain yield as influenced by different weed management practices in DSR

Herbicide treatments	Total weed dry weight (g/m^2), WCE (%) & grain yield (kg/ha)									
	rabi, 2013					*rabi*, 2014				
	Total weed dry weight (g/m^2)		WCE (%)		Grain yield	Total weed dry weight (g/m^2)		WCE (%)		Grain yield
	20 DAHS	40 DAHS	20 DAHS	40 DAHS		20 DAHS	40 DAHS	20 DAHS	40 DAHS	
T_1 - Bispyribac sodium 4% SE + metamifop 10% SE at 42 g a.i.ha^{-1} + wetter	5.49 (23.18)	6.76 (47.68)	67.33	60.22	4286	5.40 (27.11)	8.34 (69.54)	72.49	63.14	4658
T_2 - Bispyribac sodium 4% SE + metamifop 10% SE at 56 g a.i.ha^{-1} + wetter	4.10 (16.77)	5.90 (36.76)	76.37	69.73	4978	4.53 (18.56)	7.39 (52.62)	81.17	72.11	5722
T_3 - Bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i.ha^{-1} + wetter	2.69 (8.92)	4.78 (24.89)	87.43	80.07	5676	3.66 (11.38)	6.05 (34.56)	88.45	81.68	6388
T_4 - Almix (Chlorimuron + Metsufuron 20% WP) at 4 g a.i.ha^{-1}	5.24 (24.41)	6.55 (44.91)	65.60	62.63	4948	5.52 (28.44)	8.12 (65.89)	71.14	65.08	5792
T_5 - Clincher (Cyhalofop Buthyl 10% EC) at 80 g a.i.ha^{-1}	5.27 (26.79)	6.91 (49.81)	62.25	58.36	4404	5.70 (30.44)	7.95 (63.24)	69.12	66.48	5248
T_6 - Bispyribac sodium 10% SC at 20 g a.i.ha^{-1} + wetter	4.64 (21.56)	6.24 (40.97)	69.62	66.06	5442	5.16 (24.63)	8.05 (64.82)	75.01	65.64	6076
T_7 - Metamifop 10% SE at 50 g a.i.ha^{-1} + wetter	5.39 (26.03)	7.56 (59.16)	63.32	50.22	5004	5.49 (28.19)	8.52 (72.61)	71.40	61.51	5748
T_8 - Bispyribac sodium 4% SE + metamifop 10% SE at 70 g a.i.ha^{-1}	2.92 (9.54)	5.68 (31.42)	86.55	73.10	5488	3.93 (13.45)	6.29 (37.58)	86.35	80.08	6232
T_9 - Bispyribac sodium 10% SC at 20 g a.i.ha^{-1}	5.28 (27.86)	7.08 (52.10)	60.74	59.00	5167	5.87 (32.51)	8.49 (72.15)	67.02	61.76	5911
T_{10} - Metamifop 10% SE at 50 g a.i.ha^{-1}	5.45 (29.70)	7.74 (61.84)	58.15	47.89	4276	6.18 (36.19)	9.15 (83.64)	63.28	55.67	4968
T_{11} - Hand weeding twice on 25 and 45 DAS	7.39 (52.55)	6.15 (35.84)	25.95	69.32	5256	10.33 (104.63)	7.20 (49.87)	5.36	73.56	5908
T_{12} - Unsprayed control	8.42 (70.97)	10.72 (116.83)	-	-	2734	10.03 (110.56)	13.81 (188.67)	-	-	3012
SEd	0.58	0.88	-	-	352	0.61	0.87	-	-	309
CD (P=0.05)	1.21	1.79	-	-	688	1.23	1.76	-	-	623

Figures in parenthesis are original values; Data subjected to square root transformation; DAHS: Days after herbicide spray

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