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Economic evaluation of weed management through herbicides in transplanted rice

G Manisankar, T Ramesh, S Rathika, P Balasubramaniam and P Janaki

Abstract
The experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu during *Rabi* (2018-19) to analyse the economic impact of herbicidal weed management in transplanted rice. The experiment was laid out in split plot design with four main plot, five sub plot treatments and replicated thrice. Main plot treatments were pre plant application of herbicides namely glyphosate 2.5 kg ha^{-1}, glufosinate ammonium 1.0 kg ha^{-1}, halosulfuron methyl 67.5 g ha^{-1} and control. Sub plot treatments consisted of different weed management practices in transplanted rice namely pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + one hand weeding on 45 DAT, post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT, pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + post emergence application of bispyribac sodium 25 g ha^{-1} on 25 DAT, hand weeding twice at 25 and 45 DAT and unweeded control. The pre plant herbicides are sprayed at 15 days before puddling. Economic analysis was carried out by working of gross return, net return, benefit cost ratio and partial budgeting in relation to each weed control treatments. Pre plant application of glyphosate 2.5 kg ha^{-1} recorded significantly higher weed control efficiency (88.3%), grain yield (4232 kg ha^{-1}), gross return (₹ 90154 ha^{-1}), net return (₹ 54391 ha^{-1}) and B:C ratio (2.51) than halosulfuron methyl and control. These results are closely followed by application of glufosinate ammonium 1.0 kg ha^{-1}. Among the weed management practices followed in rice, hand weeding twice at 25 and 45 DAT registered higher weed control efficiency (96.4%) at 60 DAT. This was on par with application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + bispyribac sodium 25 g ha^{-1} on 25 DAT, post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT. Post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT registered significantly higher grain yield (4327 kg ha^{-1}), gross return (₹ 91550 ha^{-1}), net return (₹ 53298 ha^{-1}) and B:C ratio (2.40) than unweeded control. Partial budgeting revealed that pre plant application of glyphosate 2.5 kg ha^{-1} gave additional benefit of ₹ 9885 ha^{-1} over existing practice of control. Pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + bispyribac sodium 25 g ha^{-1} on 25 DAT gave additional benefit of ₹ 5640 ha^{-1} over existing practice of two hand weeding. Pre plant application of glyphosate 2.5 kg ha^{-1} at 15 days before puddling followed by post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT not only reduced the cost of weeding (₹ 2975 ha^{-1}) but also gave higher net returns (₹ 3945 ha^{-1}) and additional benefit (₹ 5640 ha^{-1}) over existing practice of two manual weeding. Considering the present scenario of labour scarcity and higher rate of wages, herbicidal weed management in transplanted rice could be an economically viable option. Hence, it could be concluded from the field study, pre plant application of glyphosate 2.5 kg ha^{-1} at 15 days before puddling followed by post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + hand weeding on 45 DAT found better weed control efficiency, higher productivity, gross return, net return, benefit cost ratio and additional benefit in transplanted rice under sodic soil ecosystem.

Keywords: Economics of weed management, glyphosate, glufosinate ammonium, halosulfuron methyl, transplanted rice

Introduction
Rice (*Oryza sativa* L.) is the stable food for more than 60% of the world population and its cultivation secures a livelihood for more than two billion people. In India, rice is grown in an area of 43.79 million hectare with a production of 112.91 million tonnes and an average productivity of 2.5 t ha^{-1} (GoI, 2018) [4]. The productivity of rice is influenced by different internal and external factors. Among those factors, weeds are the major biotic constraint. In transplanted rice, about 60% of the weeds emerge in the period between one week to one month after transplanting. These emerging weeds are competing with rice during effective tillering stage and decline the quantity of panicles leads to reduction in grain yield (Soe thura, 2010) [17]. In transplanted rice, 45-51% yield reduction caused by weeds (Veeraputhiran and

Balasubramanian, 2013) [21].

In *Rabi* season rice (Sep - Jan), where one rice crop is being grown per year and rest of the period, the fields are left as fallow, weeds grown enormously during this off season and poses serious threat to reducing the grain yield of rice. Rainfall during August-September months and soaking of crop main field during nursery period causes more weeds infestation and multiplication. *Cyperus rotundus* is one of the dominant weeds of sodic soil causes difficulty during land preparation for rice cultivation (Revathi *et al*., 2017) [16]. In addition to that, regeneration of *Cyperus* rhizomes and weeds infestation occur during early growth stages of rice due to improper land levelling and alternate wetting and drying irrigation pattern causes more weeds growth, which leads to reduction in yield of rice.

Effective weed management can be achieved by either application of pre emergence herbicide or post emergence herbicide or combination of both or manual weeding. Among these methods, hand weeding is an effective method of weed management in transplanted rice. Because during manual weeding all the crop associated weeds and weeds resembles the crop morphology (Mimicry weed) are efficiently removed. But at the same time, manual weeding of *Cyperus rotundus* is laborious and increases the cost of weeding. This might be due to the strong morphological stature and regeneration potential of *Cyperus.* However, increasing labourer cost and scarcity of labourer during peak period of agricultural operation led to the search for alternative methods. This constraint forces he farming community to move forward towards a next viable option. Among the other options, chemical method was most effective and economical way of weed management (Sureshkumar and Durairaj, 2016) [18]. Hence, pre plant application of herbicide can be used for controlling the emerged weeds particularly *Cyperus* before transplanting which facilitate easy land preparation and less weed infestation in the rice field. Few studies are available on the use of glyphosate as pre plant herbicide to control weeds in transplanted rice. Prakash *et al.* (2013) [13] found that, application of glyphosate at 15 days before crop establishment was gave effective weed control and higher yield in rice.

Similarly, glufosinate ammonium also used to effectively manage the grasses, sedges and broad leaved weeds at before crop establishment (Coetzer and Al Khatib, 2001) [1]. According to Kumar (2018), foliar application of halosulfuron methyl 75% WG at 3-4 leaf stage of *Cyperus* for effective option to good control. It is also necessary to study the economic impact of pre plant application of herbicides on subsequent weed management in transplanted rice.

Pre emergence herbicide provides weed free condition during initial stage because it arrest the germination of weeds. Pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} at 3 DAT effectively controlled the weeds and gave higher grain yield (Nivetha *et al*., 2017) [9]. In transplanted rice, later emerged weed makes serious problem during critical period of crop weed competition. Recently post emergence herbicide bispyribac sodium getting popular in controlling of weeds in transplanted rice. Post emergence application of bispyribac sodium 25 g ha^{-1} followed by one hand weeding on 45 DAT can be recommended for effective weed management in rice (Parthipan and Ravi, 2016) [11].

The efficiency of sequential application of herbicides including pre plant, pre emergence and post emergence herbicides on weed management and its subsequent effect in grain yield of rice needs thorough investigation particularly in economic aspects. Any technology that reaches the farmers needs to be economically analysed. Very few studies have been carried out on the economics of sequential herbicide application in transplanted rice. Hence, present experiment has been carried out to evaluate the economic analysis of herbicidal weed management in transplanted rice.

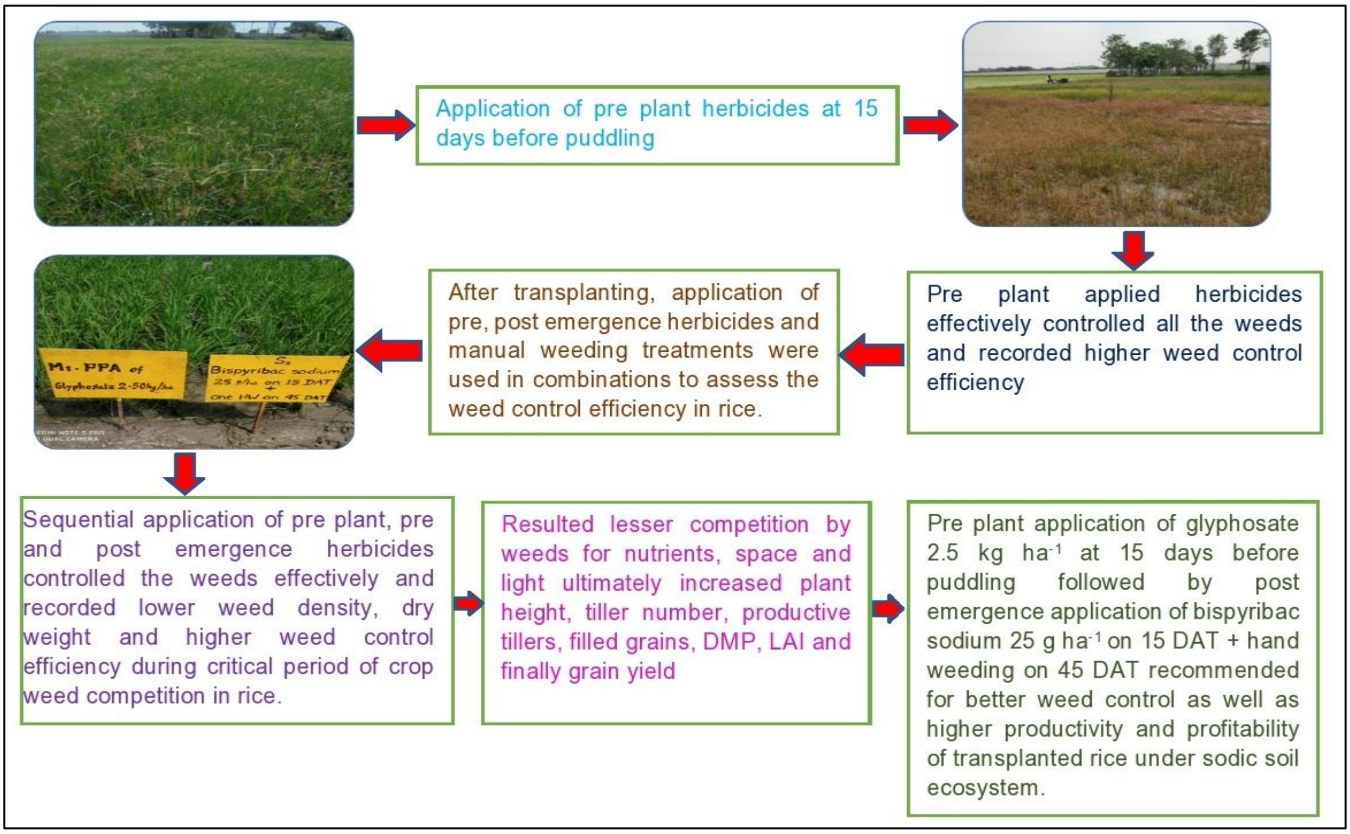

Fig 1: Graphical abstract

Materials and Methods

(i) Experimental site

A field experiment was conducted at Department of Agronomy, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli during *Rabi*, 2018-19.

(ii) Weather parameters

The total rainfall received during cropping season was 234 mm in 12 rainy days. The mean maximum and minimum temperature prevailed during the cropping period were 31.8 °C and 22.7 °C, respectively. The mean relative humidity was 87 and 61% during forenoon and afternoon, respectively. The mean bright sunshine hours, evaporation and wind velocity were 6.3 hours day^{-1}, 3.3 mm day^{-1} and 3.8 km hr^{-1}, respectively.

(iii) Soil characters

The soil of the experimental field was alkaline in nature (pH-9.1), sandy clay loam in texture, moderately drained and classified as Vertic Ustropepts. The experimental soil was low in available nitrogen (112.9 kg ha^{-1}), medium in available phosphorus (14.2 kg ha^{-1}) and high in available potassium (288.4 kg ha^{-1}).

(iv) Experimental design and treatment details

The experiment was laid out in split plot design with four main plot, five sub plot treatments and replicated thrice. The experimental plot size was 20 m^2. Main plot treatments were pre plant application of herbicides namely glyphosate 2.5 kg ha^{-1}, glufosinate ammonium 1.0 kg ha^{-1} and halosulfuron methyl 67.5 g ha^{-1} and control. Sub plot treatments consisted of different weed management practices in transplanted rice namely pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + one hand weeding on 45 DAT, post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT, application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + bispyribac sodium 25 g ha^{-1} on 25 DAT, hand weeding twice at 25 and 45 DAT and unweeded control. Pre plant herbicides are sprayed at 15 days before puddling. The rice variety TRY 3 was grown during the course of investigation. All the agronomic practises and plant protection measures were adopted as per the recommended package of Tamil Nadu Agricultural University, Coimbatore (CPG, 2012) [2].

(v) Weed control efficiency (WCE)

Weed control efficiency was calculated at 60 DAT by adopting the formula (Mani *et al.*, 1973).

$$\text{WCE (\%)} = \frac{\text{Total weed dry weight in unweeded control (g ha}^{-1}) - \text{Total weed dry weight in treated (g ha}^{-1})}{\text{Total weed dry weight in unweeded control (g ha}^{-1})} \times 100$$

(vi) Economic analysis

Cost of cultivation and gross returns were calculated by using prevailing input cost and market price of the grain. The expenditure incurred was expressed in ₹ ha^{-1}. The cost of inputs and market price of outputs were furnished in Table 1.

$$\text{Net return (₹. ha}^{-1}) = \text{Gross return (₹. ha}^{-1}) - \text{Cost of cultivation (₹. ha}^{-1})$$

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

(vii) Partial budgeting

A partial budget is used to calculate the expected change in profit for a proposed change in the farm activities. Only the changes in income and expenses of proposed treatments are included and not the total values. In the present investigation, partial budget was worked out by using the cost of herbicides, manual weeding, spraying cost, land preparation charges of the respective treatments and its gross return by keeping control in main plot and two manual weeding in sub plot as base or existing practice (Table 1).

Table 1: Details of inputs cost and outputs price

S. No.	Particulars	Unit	Cost / price (₹)
	Inputs		
1.	Glyphosate	1 lit	420.00
2.	Glufosinate ammonium	1 lit	470.00
3.	Halosulfuron methyl	18 g	980.00
4.	Bensulfuron methyl + pretilachlor	4 kg	930.00
5.	Bispyribac sodium	10 ml	136.00
6.	Men / Women labour	Man day	300.00
	Produce		
7.	Grain (Rice-TRY 3)	1 kg	18.00
8.	Straw	1 ton	2000.00

(viii) Statistical analysis

The data were statistically analysed following the procedure given by Panse and Sukhatme (1954) [10] for split plot design. Data on weed density and dry weight showed high variation and were subjected to square root transformation ($\sqrt{X + 0.5}$) and analyzed statistically. CD at 5% probability was calculated.

Results and Discussion

Weed flora

Common weed species observed in the field during the course of investigation were *Echinochloa colona* (L.), *Cynodon dactylon* (L.) in grasses, *Cyperus rotundus* (L.) in sedges and *Eclipta alba* (L.), *Euphorbia prostrata* (L.), *Lippia nodiflora* (L.) in broad leaved weeds (BLW). Before spraying of pre plant herbicides, sedges (71%) were found to be the predominant category followed by grasses (18%) and BLW (11%). *Cyperus rotundus* is one of the dominant weed in sodic soil environment and similar weed species have been found in transplanted rice under sodic soil (Revathi *et al.*, 2017) [16]. In transplanted rice, grasses (65.4%) were the dominant weed, followed by sedges (30.1%) and BLW (4.5%) at 60 DAT in absolute control (Table 2). This might be due to pre plant application of glyphosate and glufosinate ammonium completely destroyed the weeds before transplanting and also reduced the weeds germination as well as re-growth of *Cyperus* in rice field.

Table 2: Weed density per cent at 15 days before puddling and 60 days after transplanting.

Weed species	Percentage of weed density	
	15 days before puddling	60 days after transplanting
(i) Grasses		
Echinochloa colona (L.)	17.5	59.6
Cynodon dactylon (L.)	0.5	5.8
Total	18	65.4
(ii) Sedges		
Cyperus rotundus (L.)	71	30.1
(iii) Broad leaved weeds		
Eclipta alba (L.)	8.1	4.3
Euphorbia prostrata (L.)	0.6	0.2
Lippia nodiflora (L.)	2.3	0.0
Total	11	4.5
Grand total	100	100

Total weed density, dry weight and weed control efficiency

Among the pre plant application of herbicides, lower total weed density (5.0 m^{-2}), dry weight (7.1 g m^{-2}) and higher WCE (99.3%) registered with glufosinate ammonium 1.0 kg ha^{-1} over other pre plant application of herbicides at 15 days after application. This was on par with application of glyphosate 2.5 kg ha^{-1}. Fifteen days after application, glyphosate and glufosinate ammonium caused complete drying of all weeds including *Cyperus* through inhibition of 5-enol pyruvyl shikimate-3-phosphate (EPSP) synthase by glyphosate (Konlan *et al.*, 2019) [5] and activity of glutamine synthase by glufosinate ammonium (Takano and Dayan, 2020) [19] which led lower weed density, dry weight and higher WCE over halosulfuron methyl and control. Halosulfuron methyl 67.5 g ha^{-1} registered significantly higher total weed density than glyphosate and glufosinate. Halosulfuron methyl did not control the *Cyperus* as it was in flowering to maturity stage. Halosulfuron control the sedges especially *Cyperus* efficiently at 3-4 leaf stage (Kumar, 2018). Higher total weed density and dry weight recorded with control plot (Table 3).

At 60 days after transplanting, pre plant application of glyphosate 2.5 kg ha^{-1} registered significantly lower total weed density (16.7 m^{-2}), dry weight (15.0 g m^{-2}) and higher weed control efficiency (88.3%) than others. Glyphosate 2.5 kg ha^{-1} at 15 days before puddling effectively controlled all the weeds including *Cyperus* by inhibiting 5-enol pyruvyl shikimate-3-phosphate (EPSP) synthase pathway that required for protein synthesis. Further complete drying and incorporation of weeds during puddling would have reduced the weed germination. Such beneficial effect of glyphosate on weed control in transplanted rice has been reported by Ramachandra *et al.* (2014) [14]. This was followed by application of glufosinate ammonium 1.0 kg ha^{-1} which recorded the total weed density (25 m^{-2}), dry weight (17.2 g m^{-2}) and higher weed control efficiency (86.6%) on 60 DAT. Glufosinate inhibited the activity of glutamine synthase led to destroy cells directly by inhibited photosystem I and photosystem II reactions caused complete drying of weeds including *Cyperus*, which resulted in less weed density in transplanted rice (Ellis *et al.*, 2003) [3]. Application of halosulfuron methyl 67.5 g ha^{-1} registered significantly higher total weed density (48.5 m^{-2}), dry weight (29.3 g m^{-2}) and lower weed control efficiency (77.1%) than glyphosate and glufosinate ammonium on 60 DAT. The control plot registered significantly higher total weed density (75.7 m^{-2}), dry weight (128.3 g m^{-2}) on 60 DAT as compared to other treatments (Table 4).

Among the weed management practices fallowed in transplanted rice, hand weeding twice at 25 and 45 DAT registered significantly lower total weed density (9.4 m^{-2}), dry weight (6.9 g m^{-2}) and higher weed control efficiency (96.4%) on 60 DAT. Manual weeding removed all type of weeds including sedges and rice mimicry weeds which had grown along with rice, was the reason behind less weed population, dry weight and higher WCE in sodic soil environment (Revathi *et al.*, 2017) [16]. This was on par with application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + bispyribac sodium 25 g ha^{-1} on 25 DAT and post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT. Pre emergence application of bensulfuron methyl + pretilachlor and post emergence application of bispyribac sodium controlled broad spectrum of weeds including grasses, sedges and broad-leaved weeds through acetolactate synthase mode of action respectively during critical period of crop weed competition (Mishra, 2019) [8]. Hence it recorded lesser weed density, dry weight and higher weed control efficiency. This finding was close conformity with that of Nivetha *et al.* (2017) [9] who reported the lesser weed density, dry weight and higher weed control efficiency on 60 DAT in transplanted rice with pre emergence application of bensulfuron methyl + pretilachlor followed by early post emergence application of bispyribac sodium. In general, all the sub plot weed management treatments having herbicides and manual weeding produced higher WCE of more than 90 per cent than control at 60 DAT.

Table 3: Effect of pre plant applied herbicides on weed density (m^{-2}), dry weight (g m^{-2}) and WCE (%) at 15 days after spraying.

Treatments	Total density	Dry weight	WCE*
M_1 - Glyphosate 2.5 kg ha^{-1}	3.92 (15)	3.58 (12.5)	98.7
M_2 - Glufosinate ammonium 1.0 kg ha^{-1}	2.32 (5)	2.72 (7.1)	99.3
M_3 - Halosulfuron methyl 67.5 g ha^{-1}	22.18 (492)	24.42 (596.4)	42.6
M_4 – Control	29.25 (856)	32.22 (1040)	-
SEd	0.42	0.19	-
CD (P=0.05)	1.78	1.05	-

*Data not statistically analysed.

The figures in the parenthesis are original values. The data were transformed to $\sqrt{X+0.5}$.

Grain yield

Grain yield of rice varied significantly with different weed control methods (Table 4). Among the pre plant herbicides, glyphosate 2.5 kg ha^{-1} produced significantly higher grain yield (4232 kg ha^{-1}) over halosulfuron methyl and control. The increment in grain yields is mainly due to that application of glyphosate 2.5 kg ha^{-1} at 15 days before puddling controlled all the weeds including *Cyperus* by inhibiting 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase pathway that required for protein synthesis. These conditions favoured better crop growth and yield parameters which ultimately increased the grain yield of rice. These results are similar with findings of Veeraputhiran and Balasubramanian (2010) [22] who reported that application of glyphosate at 15 days before transplanting registered higher grain yield of rice. However, this was comparable with glufosinate ammonium 1.0 kg ha^{-1} (4145 kg ha^{-1}). Glufosinate inhibited the activity of glutamine synthase, the enzyme that essential for conversion of glutamate plus ammonium to glutamine. Accumulation of ammonia in the plant, that leads to destroys cells directly and inhibits photosystem I and II reactions, caused complete drying of weeds including *Cyperus* within 5 days after application, resulted in less weed density and competition favoured better crop growth and yield.

Among the post plant weed management practices, POE bispyribac sodium 25 g ha^{-1} + HW on 45 DAT registered significantly more grain yield (4327 kg ha^{-1}) over control. However, this was comparable with bensulfuron methyl + pretilachlor 660 g ha^{-1} + bispyribac sodium 25 g ha^{-1} on 25 DAT (4299 kg ha^{-1}), HW on 25 and 45 DAT (4187 kg ha^{-1}) and PE bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + HW on 45 DAT (4143 kg ha^{-1}). The combination of two herbicides or one herbicide followed by one manual weeding controlled the weeds both first flush as well as later emerged weeds. This corroborates with the findings of Sureshkumar and Durairaj (2016) [18]. Bispyribac sodium 25 g ha^{-1} interfered with production of a plant enzyme necessary for growth and development named acetolactate synthase (ALS) led to effectively controlled the emerged weeds during critical stages and maintain the crop free from crop weed competition resulted in lesser competition by weeds for nutrients, space and light ultimately increased plant height, tiller number, productive tillers, filled grains, DMP, LAI and finally grain yield. These results are in line with findings of Prashanth *et al.* (2015) [14] who reported that POE bispyribac sodium at 25 g ha^{-1} at 15 DAT recorded significantly higher grain yield in transplanted rice. Lesser grain yield (2923 kg ha^{-1}) was recorded under unweeded control. This is mainly because of severe crop weed competition during throughout the crop period. Similar findings were reported by Parthipan and Subramanian (2013) [12].

Economics

Application of glyphosate 2.5 kg ha^{-1} registered higher gross return (₹ 90154 ha^{-1}), net return (₹ 54391 ha^{-1}) and B:C ratio (2.51) than other treatments (Table 4). This was followed by glufosinate ammonium 1.0 kg ha^{-1} which gave higher gross return (₹ 88032 ha^{-1}), net return (₹ 51198 ha^{-1}) and B:C ratio of 2.39. This might be due to pre plant application of glyphosate and glufosinate ammonium killed all the weeds including *Cyprus* within 5-7 days. After drying, the field required one puddling lesser than halosulfuron methyl and control plots. In addition to that, the both herbicides improved the growth and yield attributes of rice and final yield, which ultimately increased the economics of rice. It has been observed that preplant application of glyphosate increased the net returns of rice cultivation (Ramachandra *et al.*, 2014) [15]. Halosulfuron methyl 67.5 g ha^{-1} registered lesser B:C ratio (2.10) than control, mainly because of poor weed control as well as need one extra puddling, higher herbicide cost and more labour required for manual weeding led higher cost of cultivation and lower profit.

Among the weed management practices in rice, post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT recorded higher gross return (₹ 91550 ha^{-1}), net return (₹ 53298 ha^{-1}) and B:C ratio (2.40). This was followed by application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + bispyribac sodium 25 g ha^{-1}on 25 DAT. This might be due to that application of herbicides effectively controlled the emerged weeds during critical stages and maintain the crop free from crop weed competition resulted in lesser competition by weeds for nutrients, space and light ultimately increased plant height, tiller number, productive tillers, filled grains, DMP, LAI, grain yield and finally economics. Similar to present study, in earlier Yogananda *et al.* (2017) [23] reported the economic benefits of bensulfuron methyl + pretilachlor and Veeraputhiran and Balasubramanian (2013) [21] found the benefit of bispyribac sodium in transplanted rice. The lower gross return (₹ 63437 ha^{-1}), net return (₹ 31585 ha^{-1}) and B:C ratio (2.00) obtained with unweeded control. Occurrence of weed competition throughout the crop period in unweeded control resulted poor net return and B:C ratio.

Partial budgeting

Partial budgeting of weed management indicated that pre plant application of glyphosate 2.5 kg ha^{-1} incurred added cost of ₹ 3420 ha^{-1}, added return of ₹ 13305 ha^{-1} and additional benefit of ₹ 9885 ha^{-1} over existing practice of control (Table 5). This was followed by glufosinate ammonium 1.0 kg ha^{-1}, which gave added cost of ₹ 4378 ha^{-1} and additional benefit of ₹ 6805 ha^{-1}. Halosulfuron methyl 67.5 g ha^{-1} registered reduced returns of ₹ 98.00 ha^{-1} and also noted lower additional benefit (₹ 2866 ha^{-1}) compared to glyphosate and glufosinate ammonium.

Among the post plant weed management practices, pre emergence application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + post emergence application of bispyribac sodium 25 g ha^{-1} on 25 DAT recorded higher added return (₹ 2665 ha^{-1}) and additional benefit (₹ 5640 ha^{-1}) over existing practice of manual weeding twice. This was followed by post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + one hand weeding on 45 DAT, which registered added return and additional benefit of ₹ 2490 ha^{-1}, ₹ 4790 ha^{-1}, respectively. These findings are in harmony with findings of (Teja *et al*., 2015) [20]. The lower additional benefit (₹ 3929 ha^{-1}) was incurred with application of bensulfuron methyl + pretilachlor 660 g ha^{-1} on 3 DAT + one hand weeding on 45 DAT.

Table 4: Effect of sequential herbicides application on total weed density (m^{-2}), total weed dry weight ($g\ m^{-2}$), weed control efficiency (%), grain yield ($kg\ ha^{-1}$), gross return (₹ ha^{-1}), net return (₹ ha^{-1}) and B:C ratio of transplanted rice

Treatments	At 60 DAT			Grain yield	Gross return*	Net return*	B:C Ratio*
	Total Weed density	Total weed dry weight	Weed control efficiency*				
Main plots (Pre plant herbicides)							
M_1 - Glyphosate 2.5 kg ha^{-1}	3.68 (16.7)	3.49 (15.0)	88.3	4232	90154	54391	2.51
M_2 - Glufosinate ammonium 1.0 kg ha^{-1}	4.61 (25.0)	3.77 (17.2)	86.6	4145	88032	51198	2.39
M_3 - Halosulfuron methyl 67.5 g ha^{-1}	6.09 (48.5)	4.91 (29.3)	77.1	3959	84388	44399	2.10
M_4 – Control	7.09 (75.7)	8.04 (128.3)	-	3565	76849	40665	2.11
SEd	0.23	0.26	-	110	-	-	-
CD (P=0.05)	0.57	0.64	-	269	-	-	-
Sub plots (Weed management in rice)							
S_1 - PE bensulfuron methyl + pretilachlor 660 g ha^{-1} + HW on 45 DAT	4.49 (21.0)	3.70 (13.8)	92.9	4143	88506	51179	2.37
S_2 - POE bispyribac sodium 25 g ha^{-1} + HW on 45 DAT	3.66 (13.5)	3.46 (12.0)	93.9	4327	91550	53298	2.40
S_3 - PE bensulfuron methyl + pretilachlor 660 g ha^{-1} + POE bispyribac sodium 25 g ha^{-1}	4.24 (18.7)	3.01 (9.0)	95.4	4299	91725	53100	2.37
S_4 - HW on 25 and 45 DAT	3.07 (9.4)	2.60 (6.9)	96.4	4187	89059	49155	2.25
S_5 - Unweeded control	11.37 (144.9)	12.13 (195.4)	-	2923	63437	31585	2.00
SEd	0.31	0.27	-	101	-	-	-
CD (P=0.05)	0.63	0.55	-	206	-	-	-

Interaction non-significant. The figures in the parenthesis are original values. The data were transformed to $\sqrt{X+0.5}$. *Data not statistically analysed

Table 5: Effect of sequential application of herbicides on partial budgeting of transplanted rice

Treatments	Reduced cost (₹) (A)	Added returns (₹) (B)	Added cost (₹) (C)	Reduced returns (₹) (D)	Additional benefit (₹) (A+B) - (C+D)
Main plots (Pre plant herbicides)					
M_1 - Glyphosate 2.5 kg ha^{-1}	-	13305	3420	-	9885
M_2 - Glufosinate ammonium 1.0 kg ha^{-1}	-	11183	4378	-	6805
M_3 - Halosulfuron methyl 67.5 g ha^{-1}	-	7539	4575	98.00	2866
M_4 – Control	-	-	-	-	-
Sub plots (Weed management in rice)					
S_1 - PE bensulfuron methyl + pretilachlor 660 g ha^{-1} + HW on 45 DAT	3375	554.0	-	-	3929
S_2 - POE bispyribac sodium 25 g ha^{-1} + HW on 45 DAT	2300	2490	-	-	4790
S_3 - PE bensulfuron methyl + pretilachlor 660 g ha^{-1} + POE bispyribac sodium 25 g ha^{-1}	2975	2665	-	-	5640
S_4 - HW on 25 and 45 DAT	-	-	-	-	-
S_5 - Unweeded control	-	-	-	-	-

Data not statistically analysed

Conclusion

From this field study, it could be concluded that, pre plant application of glyphosate 2.5 kg ha^{-1} at 15 days before puddling followed by post emergence application of bispyribac sodium 25 g ha^{-1} on 15 DAT + hand weeding on 45 DAT found better weed control efficiency, higher productivity, gross return, net return, benefit cost ratio and additional benefit in transplanted rice under sodic soil ecosystem.

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