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Efficacy of *Sesbania* brown manuring and weed management approaches to improve the production and weed control efficiency in transplanted rice

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ABSTRACT

In Central India, rice is the important crop and occupies maximum area. However, the favorable environment for the growth of wide spectrum of weeds is the main reason of reduced productivity of crop. Therefore, effective weed management approaches is essential for higher productivity in rice. Keeping this in view, a field experiment was conducted to find out the efficacy of Sesbania brown manuring and weed management efficacy in suppression of weed dynamics and improvement of production and control efficiency under transplanted rice. The experiment was conducted at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh during kharif season for two consecutive kharif seasons of 2013 and 2014. The experiment was laid out in split plot design with two crop establishment techniques [Transplanted Rice, Transplanted Rice + brown manuring (Sesbania)] in main plots and four treatments of weed management practices (weedy check, Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1}, Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT and two hand weeding at 20 DAT and 45 DAT) in sub-plots with three replication. Among the crop establishment methods, weed density and weed biomass at 30 and 90 DAS was recorded minimum in transplanted rice (TPR) with brown manuring (BM) as compared to TPR without BM. Similarly, among weed control approaches, the minimum weed density and weed biomass was recorded under two hand weeding at 20 DAT and 45 DAT followed by Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding. Consequently, weed control efficiency, yield, production efficiency were maximum under the same treatment.

Keywords: Brown manuring, crop establishment techniques, production efficiency, transplanted rice, weed control efficiency

Asia produces and consumes 90 per cent of world's rice. Among the rice growing countries, India ranks first in area followed by China and Bangladesh. Rice is a major cereal crop of India occupied an area of 42.10 million hectare and production of 90.6 million tonnes with average productivity of 2180 kg ha^{-1}. In Uttar Pradesh, rice is cultivated in an area of 5.93 million hectares with an annual production of 11.90 million tonnes with average productivity of 2129 kg ha^{-1} (Anonymous, 2015-16). Among the various factors responsible for low rice production, weeds are considered to be as one of the major limiting factors due to manifold harmful effects (Kalyanasundaram *et al*., 2006). Weed infestation reduces the grain yield by 70-80% in aus rice (early summer), 30-40 per cent for transplanted aman rice (late summer) and 22-36 per cent for modern boro rice cultivars (winter rice) (BRRI, 2006). Maity and Mukherjee (2008) reported that uncontrolled weeds reduce the grain yield by 40 per cent in transplanted rice. The longer weed-free periods, up to 70 days, after the emergence of seeds contributes increasing rice yield. The growth of weeds emerged thereafter is suppressed by the crop (Fischer *et al*., 1993). The favorable environment for the growth of wide spectrum of weeds is the main reason of reduced productivity of crop. Therefore, effective weed management is essential for higher productivity in rice. Hand weeding is the most popular method of removing weeds in India and in the developing world. Besides hand weeding, a number of herbicides have been developed and tested for rice around the world. The effects of many herbicides have been tested in rice. Brown manuring with sesbania is another technique to reduce weed problems in transplanted rice. It aimed at suppressing the weeds without affecting the soil physico and chemical properties and its associated microbes. It can be achieved through raising green manure crops as inter crop and killing the same by application of post-emergence herbicides. Weeds are controlled by many means. However, in the current scenario of agriculture, evolving ecofreindly approach of weed control is more advisable so as to protect the natural resources such as soil flora and fauna including human being and animals in a holistic manner. Given the post-emergence spray on green manure leaves resulting in loss of chlorophyll in leaves showing brown in colour is referred to as brown manuring (Tanwar *et al*., 2010). Keeping these points in view, a study was undertaken to find out the efficacy of sesbania brown manuring and weed management approaches to improve the production and weed control efficiency in transplanted rice.

MATERIALS AND METHODS

A field experiment was conducted at the student's instructional farm at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh

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during kharif season for two consecutive *kharif* seasons of 2013 and 2014. This location has a typical sub-tropical climate characterized by hot & dry summers and cool winters. The mean annual rainfall of Kanpur is 893 mm. The rainfall received during the crop growing period from June to December was 1104.4 mm in 2013 and 505.7 mm in 2014. Maximum temperature during kharif season of 2013 and 2014 ranged from 24.5 to 38.6°C and 21.7 to 45.0°C, respectively. The minimum temperature during kharif season of 2013 and 2014 varied from 7.1°C to 25.8°C and 9.7°C to 26.8^0 C. The soil was sandy loam in texture with pH 8.1, organic C 0.61 per cent, available N 217.5 kg ha^{-1}, available P 21.0 kg ha^{-1} and available K 201.5 kg ha^{-1}. The experiment was laid out in split plot design with two crop establishment techniques [Transplanted Rice, Transplanted Rice + brown manuring (*Sesbania*)] in main plots and four treatments of weed management practices (weedy check, Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1}, Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT and two hand weeding at 20 DAT and 45 DAT) in sub-plots with three replication.

Crops were grown as per recommended package of practices. Transplanted field was prepared by one deep ploughing followed by two cross harrowing and leveling. Two days before transplanting, the layout was shaped and bunds were prepared. The seedlings were transplanted at 20 cm apart. *Sesbania rostrata* with the seed rate of 30 kg ha^{-1} was grown for brown manuring between the rice rows. *S. rostrata* was then knock down by the application of 2, 4-D 0.5 kg ha^{-1} at 25 DAT followed by its mulching with the help of rotary paddy weeder. Pant 12 cultivar of was used for experimental purpose. Sowing of the crop was done on first fortnight of June and harvesting in October.

RESULTS AND DISCUSSION

Effect of crop establishment and weed management approaches on weed dynamics

The predominant weeds observed in the experimental plot among grasses were *Echinochloa crusgalli* and *Echinochloa colonum* (L.), *Leptochloa chinensis* (L.); *C. benghalensis, Eclipta alba* among broad leaves; C. species among sedges and other weeds in both years of experimentation. The significant differences were found among the rice establishment techniques for the grasses, broad leaved weeds, sedges and other weeds density at 30 DAT (Table 1) and 90 DAT (Table 2) in 2013 and 2014. Our results showed that the density of *Echinochloa spp., L. chinensis, C. benghalensis*, *Eclipta alba*, *Cyprus spp* and other weeds under TPR + BM were significantly less (2.78, 0.97, 0.91, 0.85, 2.16 and1.45 plants m^{-2}) in 2013 and in 2014 (6.62, 0.63, 2.88, 2.61, 3.11 and 5.53 plants m^{-2}) respectively as compared to without BM (7.83, 3.44, 1.82, 2.57, 4.24 and 4.24 plants m^{-2} in 2013) and (12.96, 3.71, 5.76, 7.31, 6.71 and 11.71 plants m^{-2} in 2014) at 30 DAT. In transplanted rice, there is an advantage of seedling size. These rice seedlings are more competitive against the emerging weed seedlings. There is also standing water in the field at the time of transplanting and standing water is known to suppress the emergence of several weeds especially brown manuring with cono weeder (Chauhan and Johnson, 2010 and Maity and Mukherjee, 2011).

Weed control treatments significantly affected grasses, sedges, and broadleaved weed densities at 30 DAT (Table 1) and 90 DAT (Table 2) in 2013. A similar trend was observed in 2014 (Table 1 and 2). The maximum grass, sedge broadleaved and other weed densities were recorded in the weedy check plots while the application of herbicides and hand weeding reduced the density of all the weed groups in both years. Among the wed control treatments, two hand weeding at 20 DAT and 45 DAT followed by Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding were provided control of grasses, broadleaves weed and sedges during both years. Similarly, in a previous study, herbicide combinations or herbicide plus hand weeding provided excellent control of weeds than the single application of herbicides (Sangeetha *et al*., 2011).

Effect of crop establishment and weed management approaches on weed biomass

The effects of different rice establishment techniques on grass biomass were significant at 30 DAT and 90 DAT in the 2013 and 2014, while the effects were non significant only for sedges at 30 DAT and 90 DAT during both the years (Table 3 and Table 4). The highest grass weed biomass was recorded in TPR without BM as compared to TPR with BM. These results of different weed groups being dominant in different rice establishment methods were similar to the findings, in which land preparation methods for brown manuring effective in limiting weed growth (Mishra *et al*, 2012).

All the weed control treatments resulted in significant reduction in the biomass of *Echinochloa species, Leptochloa chinensis, C. benghalensis, Eclipta alba*, *C. species* and other weeds as compared to weedy check at 30 and 90 DAT of crop growth. Two hand weeding at 20 DAT and 45 DAT caused significantly higher reduction in the weed biomass of *Echinochloa species, Leptochloa chinensis, C. benghalensis, Eclipta*

Table 1: Effect of crop establishment techniques and weed management approaches on weed dynamics (m^{-2}) at 30 DAS

Treatment	*Echinochloa spp.*		*L. chinensis*		*C. benghalensis*		*Eclipta alba*		*Cyprus spp*		Other weeds	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment techniques (CE)												
TPR	2.89	3.67	1.99	2.05	1.52	2.50	1.75	2.79	2.18	2.69	2.18	3.49
	(7.83)	(12.96)	(3.44)	(3.71)	(1.82)	(5.76)	(2.57)	(7.31)	(4.24)	(6.71)	(4.24)	(11.71)
TPR + BM	1.81	2.67	1.21	1.06	1.19	1.84	1.16	1.76	1.63	1.90	1.40	2.46
	(2.78)	(6.62)	(0.97)	(0.63)	(0.91)	(2.88)	(0.85)	(2.61)	(2.16)	(3.11)	(1.45)	(5.53)
SEm(±)	**0.18**	**0.21**	**0.07**	**0.10**	**0.03**	**0.06**	**0.13**	**0.22**	**0.14**	**0.25**	**0.09**	**0.26**
LSD (0.05)	**0.57**	**0.70**	**0.23**	**0.32**	**0.10**	**0.19**	**0.40**	**0.67**	**0.42**	**0.80**	**0.28**	**0.80**
Weed management approaches (WM)												
W0	4.20	5.85	3.22	2.92	2.53	4.03	2.60	4.08	3.67	4.55	3.48	5.70
	(17.14)	(33.72)	(9.85)	(8.01)	(5.92)	(15.77)	(6.26)	(16.17)	(12.95)	(20.20)	(11.63)	(31.99)
W1	2.83	4.33	1.62	1.32	1.47	2.77	1.55	2.75	2.15	2.60	1.80	3.90
	(7.53)	(18.27)	(2.11)	(1.23)	(1.65)	(7.16)	(1.90)	(7.06)	(4.12)	(6.26)	(2.74)	(14.71
W2	1.65	1.78	0.86	1.29	0.71	1.17	0.97	1.57	1.09	1.31	1.16	1.59
	(2.22)	(2.68)	(0.23)	(1.16)	(0.00)	(0.87)	(0.44)	(1.97)	(0.68)	(1.22)	(0.83)	(2.02)
W3	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SEm(±)	**0.11**	**0.15**	**0.06**	**0.05**	**0.07**	**0.10**	**0.06**	**0.09**	**0.14**	**0.17**	**0.08**	**0.18**
LSD (0.05)	**0.26**	**0.44**	**0.15**	**0.14**	**0.17**	**0.28**	**0.16**	**0.23**	**0.33**	**0.45**	**0.20**	**0.50**
CE X WM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: *Data were subjected to "x+0.5 transformations before statistical analysis. Figures in parentheses are the original values.*

Table 2:Effect of crop establishment techniques and weed management approaches on weed dynamics (m^{-2}) at 90 DAS

Treatment	*Echinochloa spp.*		*L. chinensis*		*C. benghalensis*		*Eclipta alba*		*Cyprus spp*		Other weeds	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment techniques												
TPR	5.00	5.77	3.36	3.01	2.46	3.33	2.95	3.49	3.97	4.41	3.94	6.16
	(24.46)	(32.83)	(10.81)	(8.53)	(5.53)	(10.56)	(8.17)	(11.67)	(15.24)	(18.97)	(15.02)	(37.45)
TPR + BM	3.28	4.17	1.92	1.52	1.75	2.42	1.64	2.14	2.68	2.96	2.31	4.14
	(10.28)	(16.91)	(3.19)	(1.80)	(2.56)	(5.38)	(2.17)	(4.06)	(6.67)	(8.29)	(4.84)	(16.66)
SEm(±)	**0.11**	**0.36**	**0.02**	**0.14**	**0.03**	**0.08**	**0.19**	**0.27**	**0.07**	**0.42**	**0.21**	**0.46**
LSD (0.05)	**0.36**	**1.13**	**0.07**	**0.48**	**0.11**	**0.26**	**0.61**	**0.85**	**0.19**	**1.35**	**0.70**	**1.44**
Weed management approaches												
W0	7.75	9.38	5.53	4.40	4.27	5.46	4.35	5.17	6.66	7.68	6.42	10.28
	(59.61)	(87.39)	(30.11)	(18.86)	(17.69)	(29.29)	(18.38)	(26.20)	(43.83)	(58.48)	(40.72)	(105.18)
W1	5.00	6.94	2.97	1.99	2.73	3.75	2.64	3.48	3.97	4.39	3.47	7.04
	(24.48)	(47.71)	(8.34)	(3.45)	(6.94)	(13.53)	(6.49)	(11.60)	(15.25)	(18.77)	(11.52)	(48.99)
W2	3.10	2.87	1.35	1.94	0.71	1.59	1.46	1.90	1.95	1.97	1.90	2.58
	(9.08)	(7.71)	(1.33)	(3.28)	(0.00)	(2.01)	(1.64)	(3.09)	(3.30)	(3.39)	(3.12)	(6.16)
W3	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SEm(±)	**0.12**	**0.27**	**0.07**	**0.08**	**0.09**	**0.13**	**0.10**	**0.11**	**0.14**	**0.25**	**0.16**	**0.34**
LSD (0.05)	**0.32**	**0.70**	**0.20**	**0.22**	**0.24**	**0.38**	**0.32**	**0.29**	**0.36**	**0.76**	**0.43**	**0.89**
CE X WM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Data were subjected to “x+0.5 transformations before statistical analysis. Figures in parentheses are the original values.

Table 3:Effect of crop establishment techniques and weed management approaches on weed biomass (g m^{-2}) at 30 DAS

Treatment	*Echinochloa spp.*		*L. chinensis*		*C. benghalensis*		*Eclipta alba*		*Cyprus spp*		Other weeds	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment techniques												
TPR	1.53	2.10	1.27	1.28	0.97	1.19	0.99	1.38	1.08	1.16	1.00	1.60
	(1.85)	(3.91)	(1.12)	(1.13)	(0.44)	(0.92)	(0.48)	(1.40)	(0.67)	(0.84)	(0.50)	(2.07)
TPR + BM	0.99	1.55	0.87	0.94	0.78	1.01	0.79	1.00	0.87	0.96	0.80	1.26
	(0.49)	(1.91)	(0.26)	(0.38)	(0.11)	(0.53)	(0.12)	(0.50)	(0.25)	(0.42)	(0.14)	(1.09)
SEm±	**0.09**	**0.12**	**0.06**	**0.07**	**0.03**	**0.03**	**0.04**	**0.11**	**0.08**	**0.09**	**0.03**	**0.10**
LSD (P=0.05)	**0.29**	**0.39**	**0.18**	**0.22**	**0.08**	**0.08**	**0.14**	**0.31**	**NS**	**NS**	**0.10**	**0.34**
Weed management approaches												
W0	2.10	3.22	1.93	1.80	1.14	1.70	1.17	1.88	1.47	1.78	1.22	2.45
	(3.91)	(9.88)	(3.22)	(2.73)	(0.80)	(2.37)	(0.87)	(3.02)	(1.65)	(2.65)	(0.99)	(5.51)
W1	1.42	2.39	0.97	1.09	0.75	1.17	0.75	1.26	0.86	1.02	0.73	1.68
	(1.51)	(5.19)	(0.44)	(0.68)	(0.06)	(0.86)	(0.06)	(1.10)	(0.24)	(0.53)	(0.03)	(2.32)
W2	0.83	0.99	0.67	0.83	0.71	0.84	0.75	0.91	0.75	0.73	0.75	0.89
	(0.18)	(0.47)	(-0.05)	(0.18)	(0.00)	(0.21)	(0.06)	(0.33)	(0.06)	(0.03)	(0.06)	(0.28)
W3	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SEm(±)	**0.05**	**0.09**	**0.03**	**0.05**	**0.04**	**0.04**	**0.02**	**0.04**	**0.05**	**0.06**	**0.02**	**0.07**
LSD (0.05)	**0.13**	**0.24**	**0.09**	**0.18**	**0.12**	**0.12**	**0.07**	**0.11**	**0.13**	**0.18**	**0.07**	**0.21**
CE X WM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Data were subjected to “x+0.5 transformations before statistical analysis. Figures in parentheses are the original values.

Table 4: Effect of crop establishment techniques and weed management approaches on weed biomass (g m^{-2}) at 90 DAS

Treatment	*Echinochloa spp.*		*L. chinensis*		*C. benghalensis*		*Eclipta alba*		*Cyprus spp*		Other weeds	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment techniques												
TPR	2.27	2.98	1.77	1.51	1.39	1.53	1.56	1.70	1.82	2.04	2.21	3.29
	(4.67)	(8.36)	(2.63)	(1.77)	(1.42)	(1.84)	(1.94)	(2.39)	(3.34)	(3.66)	(4.38)	(10.32)
TPR + BM	1.58	2.18	1.14	1.15	1.04	1.25	1.00	1.17	1.59	1.50	1.41	2.33
	(1.98)	(4.24)	(0.80)	(0.83)	(0.58)	(1.05)	(0.49)	(0.88)	(1.59)	(1.76)	(1.50)	(4.91)
SEm(±)	**0.05**	**0.20**	**0.01**	**0.07**	**0.02**	**0.03**	**0.11**	**0.12**	**0.09**	**0.18**	**0.12**	**0.26**
LSD (0.05)	**0.14**	**0.56**	**0.04**	**0.24**	**0.05**	**0.08**	**0.30**	**0.39**	**NS**	**NS**	**0.38**	**0.75**
Weed management approaches												
W0	3.49	4.69	2.77	2.07	2.09	2.35	2.17	2.38	3.13	3.38	3.47	5.35
	(11.68)	(21.50)	(7.15)	(3.78)	(3.88)	(5.01)	(4.22)	(5.14)	(9.30)	(10.91)	(11.53)	(28.09)
W1	2.25	3.48	1.49	1.45	1.34	1.61	1.32	1.60	1.87	1.93	1.87	3.66
	(4.56)	(11.58)	(1.71)	(1.61)	(1.29)	(2.09)	(1.25)	(2.06)	(2.98)	(3.22)	(3.01)	(12.88)
W2	1.39	1.43	0.85	1.09	0.71	0.88	0.91	1.06	1.11	1.07	1.19	1.51
	(1.44)	(1.55)	(0.23)	(0.69)	(0.00)	(0.28)	(0.32)	(0.63)	(0.72)	(0.64)	(0.92)	(1.79)
W3	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
SEm(±)	**0.07**	**0.11**	**0.04**	**0.03**	**0.04**	**0.06**	**0.05**	**0.05**	**0.06**	**0.12**	**0.08**	**0.07**
LSD (0.05)	**0.18**	**0.35**	**0.10**	**0.09**	**0.12**	**0.17**	**0.16**	**0.13**	**0.17**	**0.34**	**0.23**	**0.47**
CE X WM	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Data were subjected to “x+0.5 transformations before statistical analysis. Figures in parentheses are the original values.

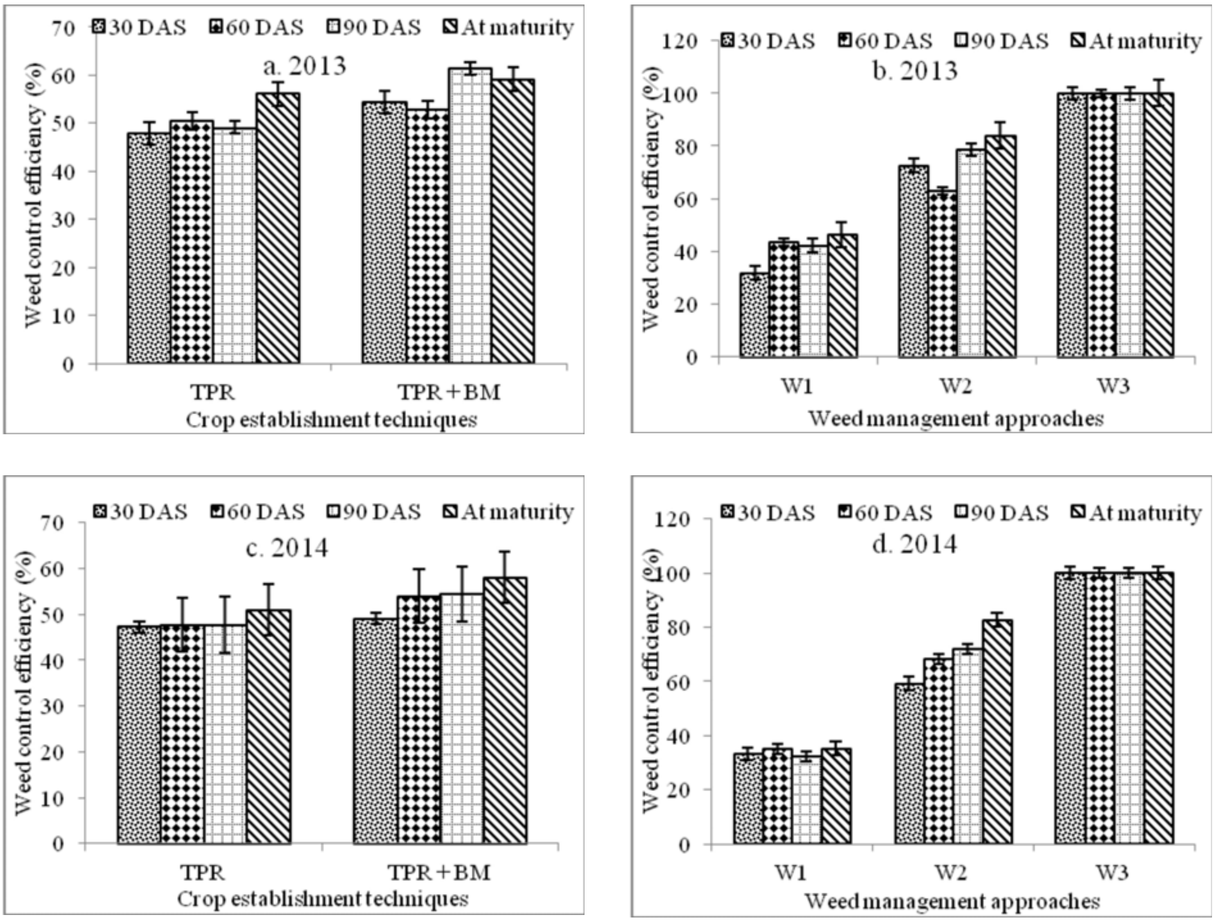

Fig. 1:Effect of weed management practices on weed control efficiency (%)

Table 5: Effect of crop establishment techniques and weed management approaches on grain yield, production efficiency and net returns

Treatment	Grain yield (t ha^{-1})		Production efficiency (kg ha^{-1}day^{-1})		Net returns (Rs ha^{-1})		B : C ratio	
	2013	2014	2013	2014	2013	2014	2013	2014
Crop establishment techniques								
TPR	4.76	4.64	31.3	30.5	49882	48007	3.25	3.17
TPR + BM	5.14	5.01	33.8	33.0	53926	51922	3.33	3.25
LSD (0.05)	**0.15**	**0.37**	**0.9**	**2.4**	**2195**	**2150**	**NS**	**NS**
Weed management approaches								
W0	3.94	4.19	25.90	27.59	38,587	42,037	2.85	3.02
W1	4.91	4.70	32.29	30.91	52,028	48,885	3.41	3.26
W2	5.25	5.03	34.54	33.06	55,494	52,124	3.37	3.22
W3	5.72	5.40	37.61	35.51	61,508	56,812	3.52	3.33
LSD (0.05)	**0.50**	**0.45**	**3.29**	**2.97**	**6,790**	**6,183**	**0.28**	**0.19**

alba, C. species and other weeds recorded at 30 DAS, which, followed with application of Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT amongst the weed management treatments (Table 3 and 4). With the advancement of crop growth, the weed density of *Echinochloa species, Leptochloa chinensis, C. benghalensis, Eclipta alba, C. species* and other weeds were also increased at 30 days onwards in all the treatments except two hand weeding at 20 DAT and 45 DAT and application of Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT. Population and dry weight was significantly reduced due to herbicidal treatment at all stages of observation. This may be attributed to the inhibition of germination of weeds owing to paralysis of vital metabolic process viz. Cell division, protein synthesis etc and subsequently drying of susceptible weed species (Kumar and Ladha, 2011).

Effect of crop establishment and weed management approaches on weed control efficiency

The highest weed control efficiency was found in the transplanted rice with brown manuring (TPR + BM) treatment (54.40, 52.79, 61.35 and 59.13% in 2013 as well as 49.03, 54.06, 54.4 and 58.03% in 2014) at 30, 60, 90 DAS and at maturity stage, respectively. The weed control efficiency was the lowest in TPR without brown manuring (47.8, 50.45, 49.05 and 56.11% in 2013 as well as 47.27, 44.7, 47.68 and 51.0% in 2014), respectively (Figure 1).

Amongst weed management treatments the highest weed control efficiency were achieved at 30, 60, 90 DAS and at maturity stage under two hand weeding at 20 DAT and 45 DAT. The second best treatment in increasing weed control efficiency was with the application of Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT (72.56, 62.87, 78.5 and 84.17% in 2013 as well as 59.28, 68.25, 71.94 and 82.87% in 2014), respectively (Figure 1). Similar results were reported in a previous study, in which plots treated with the combination of one herbicide application plus a single hand weeding provided effective weed control and consequently increased the weed control efficiency (Timsina *et al*., 2010 and Teja *et al*., 2015).

Effect of crop establishment and weed management approaches on production efficiency

The significantly higher grain yield of rice was recorded when rice was sown as under TPR with BM of sesbania (5.14 and 5.01 t ha^{-1} in 2013 and 2014, respectively) as compared to TPR without BM (4.76 and 4.64 t ha^{-1} in 2013 and 2014, respectively) during both the years of experimentation. Consequently, the production efficiency was significantly higher under TPR with BM 33.8 and 33.0 kg ha^{-1}day^{-1} in 2013 and 2014, respectively as compared to TPR without BM (31.3 and 30.5 kg ha^{-1}day^{-1} in 2013 and 2014) (Table 5). Similarly, the net return was also increased due to more production (Rs 53926 and Rs 51922 ha^{-1}) as compared to without BM (Rs 49882^{-1} and Rs 48007 ha^{-1}) in 2013 and 2014, respectively. Our results were similar with Mishra and Singh (2012) who stated that yield attributes and yield was observed higher due to brown manuring. Transplanted rice with brown manuring provide congenial environment for growth and development due to less weeded plot during the critical period, which increase rice grain yield significantly (Cabangon *et al.,* 2000 and Jayadeva, 2010).

The maximum grain yield (5.72 and 5.40 t ha^{-1} in 2013 and 2014, respectively) was obtained with two hand weeding at 20 DAT and 45 DAT followed by Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT (4.78 and 4.58 t ha^{-1} in 2013 and 2014, respectively) and lowest was observed in control treatment (5.25 and 5.03 t ha^{-1} in 2013 and 2014, respectively). Similarly, two hand weeding at 20 DAT and 45 DAT (37.61 and 35.51 kg ha^{-1}day^{-1}) followed by Bispyribac sodium 25 g ha^{-1} + (Chlorimuron + metsulfuron) 4 g ha^{-1} followed by one hand weeding at 45 DAT (34.54 and 33.06 kg ha^{-1}day^{-1}) enhanced the production efficiency as compared to control treatment (25.90 and 27.59 kg ha^{-1} day^{-1}) in 2013 and 2014, respectively (Table 5). Consequently, two hand weeding at 20 DAT and 45 DAT fetched the highest net returns (Rs 61,508 and 56,812 ha^{-1}) as compared to control (Rs 38,587 and 42,037 ha^{-1}) in 2013 and 2014, respectively. The B: C ratio was also highest in same treatment (3.52 and 3.33) than control (2.85 and 3.02) in respective years 2013 and 2014 of experimentation (Table 5). The better performance of these treatments in term of grain yield could be attributed to better expression of their yield attributes due to reduction in crop weed competition as evidenced by higher weed control efficiency and lower weed index. This could be attributed to their selectivity to crop and significant reduction in the weed growth.

Transplanted rice with brown manuring of sesbania significantly reduces the weed dynamics (density), weeds biomass and found highest weed control efficiency as well as enhanced the production efficiency as compared to without BM. Among weed management practices, two hand weeding at 20 and 45 DAT significantly reduces the weed dynamics (density), weed dry biomass with highest weed control efficiency as compared to control treatment. Consequently, the same treatment was enhanced the production efficiency, net returns and B: C ratio.

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