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Energy budgeting and economics of weed management in dry direct-seeded rice

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ABSTRACT

A field experiment was conducted at Main Research Station, Hebbal, Bengaluru during *Kharif* 2016 and *Kharif* 2017 to study the effect of different herbicide combinations and weed management methods on yield, energetics and economics of dry direct-seeded rice. The experiment consisted of 12 treatments and replicated thrice in RCBD design. Among various weed management treatments hand weeding at 20, 40 and 60 DAS recorded significantly highest paddy grain and straw yield in hand weeding at 20, 40 and 60 DAS (5.50 and 7.22 t/ha, respectively) and found at par with application of bensulfuron-methyl + pretilachlor as pre-emergence *fb* bispyribac-sodium (5.39 and 7.16 t/ha, respectively). Weedy check recorded significantly lowest yield (1.40 and 2.32 t/ha, respectively). Among the various herbicide combinations, sequential application of bensulfuron-methyl + pretilachlor as pre-emergence *fb* bispyribac-sodium was found to be the most energy and economically efficient weed management strategy in dry direct-seeded rice and had maximum value of total output energy (169090 MJ/ha), net energy returns (157444 MJ/ha), energy use efficiency (14.52), net returns (` 59,276/ha) and benefit cost ratio (2.93).

INTRODUCTION

The weed flora of direct-seeded rice crop is entirely different from that of transplanted crop due to maintenance of saturation moisture at sowing and shallow depths of water up to 3 weeks after sowing. As weeds emerge almost at the same time as that of the crop in wet direct-seeded rice and weed competition with rice crop is greater, hence weed management by herbicide is more crucial (Singh and Singh 2010). Weeds pose a serious threat in DSR by competing for nutrients, light, space and moisture just from the time of emergence and throughout the growing season, whereas, weed seeds germinate after rice transplanting in transplanted rice and compete with the well-established rice seedlings. Energy budgeting of weed management is also important because energy and economics are mutually dependent. There is a close relationship between agriculture, economics and energy. Very scanty information is available on this aspect. Therefore, the present study was undertaken to assess the energy budgeting and economics of weed management in dry direct-seeded rice.

MATERIAL AND METHODS

The field experiment was conducted during *Kharif*, 2016 and 2017 to study the effect of combination of herbicides against complex weed flora, and their effect on growth and yield of dry direct-seeded rice (upland condition). The field study was conducted at the Main Research Station, Hebbal, Bengaluru. The experiment consisted 12 treatments, *viz.* bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (RM) (60 + 600 *fb* 60 g/ha), oxadiargyl *fb* triafamone + ethoxysulfuron (RM) (100/ *fb* 60 g/ha), pendimethalin *fb* triafamone + ethoxysulfuron (RM) (1000 *fb* 60 g/ha), pyrazo-sulfuron-ethyl *fb* triafamone + ethoxysulfuron (RM) (20 + 60 g/ha), bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (60 + 600 *fb* 25 g/ha), oxadiargyl *fb* bispyribac-sodium (100 *fb* 25 g/ha), pendimethalin (38.7% CS) *fb* bispyribac-sodium (1000 *fb* 25 g/ha), pyrazo-sulfuron-ethyl *fb* bispyribac-sodium (20 *fb* 25 g/ha), pendimethalin *fb* penoxsulam + cyhalofop-butyl (RM) (1000 *fb* 135 g/ha), three mechanical weedings (at 20, 40, 60 DAS), hand weedings (at 20, 40, 60 DAS) and weedy check were tested in a randomized block design with three replications. Rice variety '*MAS 946*' was sown at a spacing of 30 cm between rows and seeds were placed closely between plants and fertilizer level of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha was applied. The pre-emergence and post–emergence herbicides were applied using spray volume of 750 liters/ha and 500 liters/ha with knapsack sprayer having water foam nozzle (WFN). All the agricultural inputs, *viz.* seeds, fertilizers, labour, animals, electricity, machinery, organic manures, chemicals, *etc.* and all the agricultural outputs such as grain and straw will have their own equivalent energy (Mega Joules) values (**Table 1**). Energy balance was calculated by using data on input and output energy. From these, the net energy returns, energy productivity, specific energy and energy use efficiency, were calculated by using the following formulae suggested by Alipour *et al.* (2012).

Net energy returns (MJ/ha) = Output energy – input energy

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Input energy (MJ/ha)}}$$

$$\text{Specific energy (MJ/kg)} = \frac{\text{Input energy (MJ/ha)}}{\text{Grain yield (kg/ha)}}$$

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

The price of inputs that were prevailing at the time of their use was considered to work out the cost of cultivation. The cost of cultivation was worked out considering the material input like the seed, manure, fertilizer, herbicides, plant protection chemicals, *etc.* and labour input for all the operations. Treatment wise cost of cultivation was worked out. The prevailing market prices of the paddy at university after harvest was obtained from the Senior Farm Superintendent Office, MRS, Hebbal, Bengaluru, was used for the calculation of gross returns.

RESULTS AND DICUSSION

Weed flora

Predominant category of weed was broad leaved followed by grasses and sedges. Among the weed species, the densities of *Cyperus rotundus, Cynodon dactylon, Digitaria marginata, Ageratum conyzoides, Commelina benghalensis* and *Alternenthra sessilis* were more than other weed species.

Weed density and dry weight

Among different category of weeds, in unweeded control the density and dry weight of broad-leaf weeds (128.5/m^2 and 23.7 g/m^2, respectively) was higher followed by grasses (56.3/m^2 and 11.9 g/m^2, respectively) and sedges (56.3/m^2 and 4.9 g/m^2, respectively) at 90 DAS (**Table 2**). Effective control of weeds was noticed at 90 DAS with application of bensulfuron-methyl + pretilachlor (60 + 600 g/ha) as pre-emergence *fb* bispyribac-sodium (25 g/ha) at 25 DAS followed by bensulfuron-methyl + pretilachlor (60 + 600 g/ha) as pre-emergence *fb* triafamone + ethoxysulfurn (60 g/ha at 25 DAS) as evident from the reduced weed density and dry weight due to broader spectrum of effective herbicides on major weed flora apart from hand weeding. All these herbicide mixtures were superior to weedy control in reducing the weeds' density and dry weight. The results were in conformity with the results obtained by Kumaran *et al.* 2015.

Productivity

The data pertaining to grain and straw yield of dry direct-seeded rice as influenced by different weed management practices has been presented (**Table 1**). The grain and straw yield of dry direct-seeded rice were significantly influenced by different weed management practices. Hand weeding at 20, 40 and 60 DAS recorded highest grain (5.50 t/ha) and straw yield (7.22 t/ha) compared to all the treatments. However, it was statistically at par with bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium, (5.39 and 7.16 t/ha, respectively) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (5.29 and 7.03 t/ha, respectively). It is mainly due to effective management of weeds, which lead to improve the growth and yield parameters of dry direct-seeded rice. These results were in conformity with Singh *et al.* (2016) and Yogananda *et al.* (2017). Whereas, significantly lowest gain yield (1.40 t/ha) and straw yield (2.32 t/ha) was noticed in weedy check due to sever completion by weeds, which affected the growth, nutrient uptake and yield parameters of the crop drastically.

Energetics

The different weed management practices varied in terms of input energy, output energy, net energy returns, energy productivity, specific energy and energy use efficiency. Unweeded check required minimum total input energy (10,600 MJ/ha) because neither hand weeding nor herbicide application was done in this treatment. Among the herbicidal treatments, maximum total input energy (11,682 MJ/ha) was required in plot treated bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn, while minimum total input energy (10,639 MJ/ha) was required in plot treated with oxadiargyl *fb* bispyribac-

Table 1. Equivalent energy (mega joules) values

Inputs	Units	Equivalent energy (mega joules)	Remarks
1. Human labour			
a. Adult man	Man hour	1.96	1 adult woman= 0.8 Adult man
b. Woman	Woman hour	1.57	
2. Bullocks	Pair hour	10.10	Body weight 351-450
3. diesel	1 L	56.31	Includes cost of lubricants
4. Petrol	1 L	46.23	Includes cost of lubricants
5. Electricity	1 HP hr	8.90	
6. Machinary			
a. Electric motor	kg	64.80	
b. Farm machinery (excluding self-propelled machines)	kg	62.70	Weight of the machinery was distributed equally over the total life span of the machinery for the particular operation or crop was worked out
7. Inorganic fertilizer			
a. Nitrogen	kg	60.6	Based on the quantity of N, P_2O_5 and K_2O in the fertilizer, energy input was estimated
b. P_2O_5	kg	11.1	
c. K_2O	kg	6.7	
8. Chemicals	kg	120	
9. Irrigation	Ha-cm	46.02	
10. Rice seeds	kg	14.70	
Outputs			
a. Rice grain	kg	14.70	
b. Rice straw	Kg (dry mass)	12.5	

Source: Mittal *et al.* (1985) and Binning *et al.* (1983).

sodium. Three hand weeded treatment required total input energy of 10789 MJ/ha. Based on the paddy grain and straw yield, treatment wise output energy production was calculated. Hand weeding at 20, 40 and 60 DAS recorded higher output energy (171614 MJ/ha). Whereas, among herbicide treatments, higher total energy output put was noticed in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (169090 MJ/ha) and it was closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (164999 MJ/ha) due to higher grain and straw yield compared to other treatments. Weedy check recorded lowest grain and straw yield resulted minimum energy output (49692 MJ/ha) compared to all the treatments.

Net energy returns

Among the various weed management treatments, hand weeding at 20, 40 and 60 DAS recorded higher net energy returns (160825 MJ/ha). Among herbicide combinations higher net energy returns was noticed in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (157444 MJ/ha) and it was closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (153317 MJ/ha) due to higher output energy compared to other treatments. Weedy check recoded lowest grain and straw yield hence resulted minimum energy output in obtaining lower net energy returns (39092 MJ/ha) compared to all the treatments.

Energy productivity

The minimum energy productivity was noticed in weedy check (0.13 kg MJ/ha) due to lowest grain yield. Maximum energy productivity was observed in hand weeding at 20, 40 and 60 DAS (0.51 kg MJ/ha). Among the herbicide treatments maximum energy productivity is obtained in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (0.46 kg MJ/ha) and it is closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (0.45 kg MJ/ha). Higher paddy grain in these treatments reflected on the energy productivity of dry direct-seeded rice.

Specific energy

Unweeded check recorded maximum specific energy (7.57 MJ/kg) due to lower grain yield. Minimum specific energy was noticed in hand weeding at 20, 40 and 60 DAS (1.96 MJ/kg). Among the herbicidal treatments, bensulfuron methyl + pretilachlor *fb* bispyribac sodium recoded minimum specific energy (2.16 MJ/kg).

Energy use efficiency

The higher energy use efficiency was observed in hand weeding at 20, 40 and 60 DAS (15.91). Among herbicide combinations higher energy use efficiency was noticed bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (14.52) and it is closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone +

ethoxysulfurn (14.12) due to higher output energy as a result of higher yield compared to other treatments. Whereas, weedy check recoded lower energy use efficiency (4.69) due to very low yield. Similar results are being observed by Shyam Lal *et al.* 2016.

Economics

The main aim of any agricultural technology is to obtain maximum economic returns per rupee invested. The highest mean cost of cultivation was recorded with hand weeding at 20, 40 and 60 DAS (` 35,010/ha) as compared to all other treatments. This was mainly due to the higter cost of labour and number of labours required for weeding is also more thus increased the cost of production. Hand weeding at 20, 40 and 60 DAS recorded highest gross returns (` 92,052/ha) closely followed by bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (` 90,158/ha) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (` 88,282/ha). Whereas, lowest gross returns were observed with weedy check (` 24,870/ha) due to poor yield. The highest

Table 2. Weeds density and weeds dry weight as influenced by different herbicide combinations in dry direct-seeded rice at 90 DAS (pooled data of 2 years)

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	Sedges	Grasses	Broad-leaf	Total	Sedges	Grasses	Broad-leaf	Total
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn	2.58(5.7)	1.13(11.7)	1.28(17.0)	1.56(34.3)	1.45(1.1)	1.74(2.0)	2.02(3.1)	0.91(6.2)
Oxadiargyl *fb* triafamone + ethoxysulfuron	4.08(15.7)	1.50(30.0)	1.73(52.0)	2.00(97.7)	1.99(3.0)	2.53(5.4)	3.21(9.3)	1.29(17.7)
Pendimetalin *fb* triafamone + ethoxysulfuron	4.24(17.0)	1.65(42.3)	1.93(83.7)	2.16(143.0)	2.05(3.2)	2.95(7.7)	4.02(15.2)	1.45(26.1)
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	4.00(15.0)	1.62(40.0)	1.79(60.0)	2.07(115.0)	1.96(2.9)	2.86(7.2)	3.42(10.7)	1.36(20.7)
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	2.45(5.0)	1.10(10.7)	1.24(15.7)	1.52(31.3)	1.40(1.0)	1.70(1.9)	1.97(2.9)	0.89(5.8)
Oxadiargyl *fb* bispyribac-sodium	3.41(10.7)	1.42(25.0)	1.62(39.7)	1.89(75.3)	1.74(2.0)	2.30(4.3)	2.90(7.5)	1.20(13.8)
Pendimethalin (38.7% CS) *fb* bispyribac-sodium	3.70(12.7)	1.47(27.7)	1.69(47.7)	1.95(88.0)	1.85(2.4)	2.43(4.9)	3.13(8.8)	1.26(16.2)
Pyrazosulfuron-ethyl *fb* bispyribac-sodium	3.36(10.3)	1.37(21.7)	1.62(39.7)	1.87(71.7)	1.73(2.0)	2.20(3.9)	2.88(7.3)	1.18(13.2)
Pendimethalin (38.7% CS) *fb* penoxsulam + cyhalofop-butyl	4.47(19.0)	1.63(41.0)	1.93(84.7)	2.16(144.7)	2.19(3.8)	2.92(7.5)	4.05(15.4)	1.46(26.7)
Three mechanical weedings	4.20(16.7)	1.61(38.7)	1.89(76.0)	2.12(131.3)	2.05(3.2)	2.81(6.9)	3.85(13.8)	1.41(23.9)
Hand weedings	2.38(4.7)	1.05(9.3)	1.22(14.7)	1.49(28.7)	1.38(0.9)	1.64(1.7)	1.92(2.7)	0.86(5.3)
Weedy check	4.54(19.7)	1.77(56.3)	2.12(128.5)	2.31(204.5)	2.43(4.9)	3.58(11.9)	4.96(23.7)	1.63(40.5)
LSD(p=0.05)	0.33	0.14	0.15	0.21	0.21	0.24	0.31	0.16

Data within the parentheses are original values; Transformed values - - # = log (X+2), + = square root of (X+1); DAS = Days after sowing

Table 3. Yield and energetics of dry direct-seeded rice as influenced by different weed management practices (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy productivity (Kg/MJ)	Specific energy (MJ/kg)	Energy use efficiency
Bensulfuron methyl + pretilachlor *fb* triafamone + ethoxysulfurn	5.29	7.03	11682	164999	153317	0.45	2.21	14.12
Oxadiagyl *fb* triafamone + ethoxysulfuron	4.39	6.14	10675	141646	130971	0.41	2.43	13.27
Pendimetalin *fb* triafamone + ethoxysulfuron	4.15	6.09	10925	137473	126548	0.38	2.63	12.58
Pyrazosulfuron ethyl *fb* triafamone + ethoxysulfuron	4.32	6.15	10687	140787	130100	0.40	2.47	13.17
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	5.39	7.16	11646	169090	157445	0.46	2.16	14.52
Oxadiargyl*fb* bispyribac-sodium	4.42	6.11	10639	141765	131127	0.42	2.41	13.33
Pendimethalin (38.7% CS) *fb* bispyribac sodium	4.43	6.11	10889	141913	131024	0.41	2.46	13.03
Pyrazosulfuron ethyl *fb* bispyribac sodium	4.48	6.20	10651	143777	133126	0.42	2.38	13.50
Pendimethalin(38.7% CS) *fb* penoxsulam + cyhalofop-butyl	4.15	6.13	10869	138098	127229	0.38	2.62	12.71
Mechanical weedings	4.38	6.19	10977	141975	130998	0.40	2.51	12.93
Hand weedings	5.50	7.22	10789	171614	160825	0.51	1.96	15.91
Weedy check	1.40	2.32	10600	49692	39092	0.13	7.57	4.69
LSD (p=0.05)	0.62	0.97	NA	NA	NA	NA	NA	NA

NA: Not Analyzed

Table 4. Economics of dry direct-seeded rice as influenced by different weed management practices (pooled data of 2 years)

Treatment	Cost of cultivation ($x10^3$ `/ha)	Gross returns ($x10^3$ `/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn	30.75	88.28	57.53	2.88
Oxadiagyl *fb* triafamone + ethoxysulfuron	29.58	74.48	44.90	2.52
Pendimetalin *fb* triafamone + ethoxysulfuron	29.48	71.24	41.76	2.42
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	30.01	73.55	43.54	2.45
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	30.88	90.16	59.28	2.93
Oxadiargyl *fb* bispyribac-sodium	30.58	74.86	44.28	2.45
Pendimethalin (38.7% CS) *fb* bispyribac-sodium	30.67	75.01	44.34	2.45
Pyrazosulfuron-ethyl *fb* bispyribac-sodium	29.56	75.94	46.38	2.58
Pendimethalin (38.7% CS) *fb* penoxsulam + cyhalofop-butyl	30.69	71.55	40.86	2.33
Mechanical weedings	31.94	74.58	42.64	2.34
Hand weedings	35.01	92.05	57.04	2.63
Weedy check	26.78	24.87	-1.91	0.93

net returns and B:C ratio was obtained in application of bensulfuron-methyl + pretilachlor as PE *fb* bispyribac-sodium at 25 DAS (` 59,276/ha and 2.93, respectively) and closely followed by PE application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron at 25 DAS (` 57,533/ha and 2.88) due to improved yield and reduced cost of weed management while it was ` 57,042/ha and 2.63, respectively in hand weeding plots due to increased cost of cultivation. The lowest B:C ratio (0.93) was obtained in the weedy check plots along with negative net returns (` -1,912/ha). Herbicide technology offered an alternative method of selective and economical control of weeds right from the beginning, giving crop an advantage of good start and competitive superiority and found to be cheaper than hand weeding for effective management of weeds and economic returns in dry direct-seeded rice. These results are in harmony with the findings of Vijay Singh *et al.* (2016), Prameela *et al.* (2014) and Yogananda *et al.* (2017).

From this study, it was revealed that pre-emergence application of bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium found to be the best herbicide combination for higher productivity, energy and economically efficient weed management strategy in dry direct-seeded rice cultivation.

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