Journal of Tropical Agriculture 56 (1): 17-26, 2018

Management of blood grass (*Isachne miliacea* Roth ex Roem et Schult) in wetland rice

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Received 7 February 2018; received in revised form 2 June 2018; accepted 04 June 2018

Abstract

Field experiments were conducted during *Kharif* and *Rabi* seasons of 2015 at the State seed farm, Kottarakkara, Kerala in a wetland field heavily infested with blood grass (*Isachne milacea* Roth ex Roem et Schult) to develop an effective strategy for managing the weed. The experiment was laid out in a split plot design with combinations of tillage and water regimes as main plot treatments and weed management practices as sub-plot treatments. The results revealed that an integrated strategy involving intensive tillage (three ploughings *fb* puddling), deep water ponding (i.e., > 7.5 cm up to panicle initiation and saturation thereafter) and application of azimsulfuron @ 35 g ha^{-1} at 3-5 leaf stage of the weed was the most efficient treatment for managing the weed in terms of weed control efficiency (WCE), crop performance and net income. Combining these modified cultural practices with either (bispyribac sodium + metamifop) @ 70 g ha^{-1} or fenoxaprop-*p*-ethyl @ 60 g ha^{-1} were alternate strategies for management of this noxious wetland weed. Pre-plant application of oxyflourfen @ 0.15 kg ha^{-1} *fb* hand weeding when combined with deep water ponding and intensive tillage recorded high WCE, but was inferior in terms of economics. Combinations with manual weeding though uneconomic, were efficient in managing the weed, and recorded higher yield and hence could be an option for organic rice cultivation.

Key words: Blood grass, Grain yield, Tillage, Water regime, Weed management

Introduction

Blood grass (*Isahcne miliacea*), locally known as v*alari/changalipullu/naringa,* is a very troublesome wetland weed belonging to Poaceae family which has infested vast tracts of rice fields in Kerala state. According to Babu et al. (2014), the relative density of blood grass was > 65 per cent in many of the wetland fields in Kerala. The highly competitive nature of the weed potentially reduces rice yields when significant populations exist. The weed is resistant to the prevalent farmers' practice of tillage and hand pulling and it's mat forming roots interfere with the movement of simple implements like rotary weeder, restricting their efficient use. Though herbicides are considered as the most practical, effective and economical means of weed management in rice (De Datta, 1981), most of the conventional herbicides fail to manage the perennial grass.

According to Clements et al. (1994), integrated weed management (IWM) strategies alone can reduce the dominance of specific noxious weeds in any agro–ecosystem. Studies from the tropical regions on possible effects of tillage and water control on weed emergence and growth in the presence and absence of herbicides have yielded conflicting results due to site specificity. Interactions among water, tillage and weed management practices are complex, and are further complicated by soil and climatic variability and heterogeneities (Bhagat et al.*,*1996). Most of the past studies have been confined to evaluation of the independent

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effects of these management practices without consideration of their interactions (Baltazar and De Datta, 1992). The present study was therefore undertaken to investigate the effect of tillage, water regimes and some of the recently registered safer herbicide molecules on blood grass infestation and to develop an effective integrated strategy for managing the weed.

Materials and Methods

The field experiments were conducted during *Kharif* and *Rabi* seasons of 2016 at the State Seed Farm, Kottarakkara, Kollam district, Kerala in a wetland field heavily infested with blood grass. An initial observation on the infestation intensity of the weed in the selected site indicated that the relative density (Philips, 1969) was about 83 per cent. The soil was sandy clay loam in texture with acidic pH (4.52), high organic carbon (1.69%), medium NPK i.e, available N (303.34 kg ha^{-1}), available P (13.52 kg ha^{-1}) and available K (153.42 kg ha^{-1}). The experiment was laid out in a split plot design with three replications and the crop variety used was *Sreyas* released from Rice Research station Moncombu, Kerala. Combinations of tillage (P) and water regimes (W) were the main plot treatments and weed management practices (M) were the sub-plot treatments. The tillage practices included were: P_1- intensive tillage (three ploughings followed by (*fb*) puddling) and P_2- farmers' practice (two ploughings *fb* puddling). The water regimes tried were W_1- continuous deep water ponding *i.e.*, > 7.5cm from 7 days after transplanting (DAT) till grain filling stage, W_2- >7.5cm water from 7 DAT till panicle initiation stage and saturation thereafter, W_3- maintaining about 5cm water level with intermittent drainage (KAU, 2011). The weed management practices in the sub-plots were M_1 - oxyfluofen @ 0.15 kg ha^{-1} *fb* one hand weeding (HW) at 20 DAT, M_2- azimsulfuron @ 35 g ha^{-1}, M_3- (bispyribac sodium + metamifop) @ 70 g ha^{-1}, M_4- fenoxaprop- *p*-ethyl @ 60 g ha^{-1}, M_5- HW twice at 20 and 40 DAT and M_6 - unweeded control.

The *Kharif* crop was transplanted on 04-08-2016 and harvested on 15-11-2016 and the *Rabi* crop was began immediately thereafter without disturbing the field layout. The water regimes as per the treatments were maintained by providing 50 cm bunds to avoid seepage between plots. As the experimental site was part of a large block of paddy field away from natural streams and main canals, the water regime was assumed to be influenced only by the treatments. Similarly the site was given minor land shaping before laying out the plots to facilitate the construction of channels and bunds for managing the water regime. Application of manures and fertilizers as well as all the other management practices were done as per the Package of Practices Recommendations (POP) of KAU (2011). Among the herbicides, oxyfluorfen (M_1) was applied as pre-plant, three days before transplanting, and the others (M_2 to M_4) were applied as post emergence spray at 15 DAT. The weeds were sampled at 15, 30, 45 and 60 DAT by quadrat method and yield attributes were recorded at harvest. The weed dry weight was recorded and the weed control efficiency (WCE) was worked out using the equation developed by Mani et al. (1973).

$$WCE = \frac{WDWC - WDWT}{WDWC} \times 100$$

WDWC= weed dry weight in unweeded control
WDWT= weed dry weight in treated plot
Weed index was worked out as follows (Gill and Vijayakumar, 1969):

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

X = Yield from treatment which recorded the minimum dry weight of weeds
Y = Yield from the plot for which weed index is to be computed

Results and Discussion

Effect on the weed

The data on weed dry weight and weed control efficiency (Table 1 and 2) revealed that intensive tillage involving three ploughings (P_1) suppressed the growth of blood grass more efficiently than the

Table 1. Effect of tillage, water regimes and weed management on weed dry weight of blood grass (g m^{-2})

Treatments	First crop				Second crop			
	15 DAT #	30 DAT #	45 DAT *	60 DAT *	15 DAT #	30 DAT #	45 DAT *	60 DAT *
Main plot treatments								
I-Tillage (P)								
Intensive tillage (P_1)	3.17	3.10	1.15	1.41	2.92	2.78	1.07	1.35
	(9.55)	(12.07)	(24.60)	(39.69)	(8.07)	(9.67)	(20.52)	(33.49)
Farmers practice (P_2)	3.69	3.69	1.26	1.49	3.55	3.32	1.20	1.44
	(12.92)	(16.35)	(29.66)	(48.36)	(11.96)	(13.23)	(26.40)	(42.95)
CD (0.05)	0.08	0.12	0.02	0.02	0.05	0.06	0.02	0.02
II-Water regimes (W)								
>7.5 cm till grain filling stage (W_1)	3.31	3.15	1.15	1.39	3.04	2.82	1.07	1.33
	(10.37)	(12.32)	(24.00)	(37.54)	(8.66)	(9.91)	(20.28)	(32.24)
>7.5 cm till PI stage (W_2)	3.35	3.20	1.16	1.43	3.06	2.91	1.07	1.37
	(10.58)	(12.62)	(24.71)	(40.85)	(8.79)	(10.33)	(20.43)	(34.90)
POP recommendation (W_3)	3.64	3.82	1.31	1.54	3.61	3.41	1.26	1.49
	(12.76)	(17.69)	(32.69)	(53.68)	(12.59)	(14.10)	(29.67)	(54.80)
CD (0.05)	0.09	0.15	0.02	0.03	0.06	0.07	0.03	0.03
Subplot treatments								
Weed management (M)								
Oxyflourfen @ 0.15 kg ha^{-1} *fb* HW (M_1)	2.13	2.10	1.05	1.26	1.96	1.89	0.99	1.21
	(3.74)	(3.58)	(11.78)	(19.65)	(3.10)	(2.65)	(10.33)	(17.80)
Azimsulfuron @ 35 g ha^{-1}(M_2)	3.70	1.55	0.60	0.82	3.37	1.41	0.43	0.72
	(12.79)	(1.49)	(4.21)	(6.86)	(10.51)	(1.05)	(2.98)	(5.49)
Bispyribac Na + metamifop@ 70 g ha^{-1} (M_3)	3.68	3.03	1.22	1.51	3.40	3.36	1.19	1.48
	(12.65)	(8.56)	(16.84)	(32.66)	(10.71)	(6.84)	(15.66)	(30.29)
Fenoxaprop- *p*-ethyl @60 g ha^{-1} (M_4)	3.65	3.61	1.31	1.56	3.55	3.51	1.28	1.54
	(12.41)	(12.38)	(20.63)	(36.83)	(11.84)	(9.27)	(19.61)	(35.00)
HW at 20 and 40 DAT (M_5)	3.70	2.76	1.07	1.44	3.52	2.60	1.01	1.41
	(12.80)	(6.89)	(11.91)	(28.18)	(11.57)	(5.00)	(10.59)	(26.01)
Unweeded control(M_6)	3.73	7.29	1.98	2.14	3.62	7.21	1.90	2.05
	(13.01)	(52.38)	(97.42)	(139.97)	(12.37)	(43.88)	(81.60)	(114.73)
CD (0.05)	0.09	0.14	0.02	0.04	0.09	0.13	0.03	0.05

DAT- Days after transplanting HW- Hand weeding PI – Panicle initiation

\# Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

conventional farmers' practice of land preparation with two ploughings (P_2). During both seasons as well as at all the stages of observation, the weed dry weight recorded was significantly lower under P_1 and had higher WCE also. According to Chauhan et al. (2014) tillage influences weed growth by altering the soil conditions for germination and emergence through several means such as uprooting, dismembering and burying them deep enough to prevent emergence. It is likely that in the present study the weed propagules in the soil seed bank which emerged after the initial tillage operation were destroyed during the second and third ploughing, which justifies the higher WCE under intensive tillage. Those seedlings which emerged later might have got suppressed by the crop canopy.

The results of the present study also indicated that water depth had significant influence on the control of blood grass. Irrespective of the season, the weed dry weight was lower under deep water ponding at all the growth stages. Between the two higher water regimes, weed suppression was more under continuous flooding up to grain filling stage (W_1), but the variation was not statistically significant. There are reports that weed species differ in their

Table 2. Effect of tillage, water regimes and weed management on weed control efficiency (%)

Treatments	First crop				Second crop			
	15 DAT	30 DAT	45 DAT	60 DAT	15 DAT	30 DAT	45 DAT	60 DAT
Main plot treatments								
I-Tillage (P)								
Intensive tillage (P_1)	6.35	8.97	8.77	8.80	7.52	8.97	8.99	8.94
	(49.3)	(82.2)	(79.4)	(78.9)	(57.4)	(82.5)	(81.8)	(80.3)
Farmers practice (P_2)	4.30	4.62	8.39	8.39	5.87	8.45	8.52	8.44
	(22.0)	(75.9)	(75.2)	(74.3)	(37.0)	(76.1)	(76.6)	(74.7)
CD (0.05)	0.35	0.08	0.06	0.05	0.17	0.05	0.06	0.05
II-Water regimes (W)								
>7.5 cm till grain filling stage (W_1)	5.88	8.96	8.84	8.91	7.34	8.96	9.01	8.99
	(37.3)	(81.8)	(79.9)	(80.0)	(54.5)	(82.01)	(82.0)	(81.0)
>7.5 cm till PI stage (W_2)	5.86	8.93	8.79	8.79	7.29	8.91	9.00	8.90
	(36.2)	(81.4)	(79.3)	(78.3)	(53.6)	(81.3)	(81.9)	(79.4)
POP recommendation (W_3)	4.24	8.25	8.11	8.09	5.48	8.26	8.24	8.18
	(23.0)	(73.9)	(72.7)	(71.5)	(33.6)	(74.5)	(73.7)	(72.1)
CD (0.05)	0.42	0.10	0.06	0.06	0.21	0.07	0.07	0.06
Subplot treatments								
Weed management (M)								
Oxyflourfen @ 0.15 kg ha^{-1} *fb* HW (M_1)	8.82	9.78	9.54	9.51	9.18	9.81	9.58	9.51
	(77.3)	(94.7)	(90.1)	(89.6)	(83.7)	(95.2)	(90.8)	(89.5)
Azimsulfuron @ 35 g ha^{-1}(M_2)	4.56	9.94	9.87	9.87	6.67	9.96	9.92	9.89
	(22.8)	(97.8)	(96.5)	(96.4)	(44.6)	(98.1)	(97.4)	(96.8)
Bispyribac Na + metamifop@ 70 g ha^{-1} (M_3)	4.71	9.39	9.32	9.14	6.58	9.41	9.33	9.12
	(23.7)	(87.4)	(85.9)	(82.6)	(43.5)	(87.6)	(86.1)	(82.2)
Fenoxaprop- *p*-ethyl @60 g ha^{-1} (M_4)	4.93	9.09	9.15	9.02	6.07	9.17	9.14	8.97
	(25.2)	(81.7)	(82.8)	(80.4)	(37.6)	(83.3)	(82.6)	(79.4)
HW at 20 and 40 DAT (M_5)	4.60	9.53	9.54	9.27	6.18	9.59	9.57	9.26
	(22.7)	(8.98)	(90.0)	(85.0)	(38.9)	(91.0)	(90.6)	(84.7)
Unweeded control(M_6)	-	-	-	-	-	-	-	-
CD (0.05)	0.44	0.13	0.14	0.10	0.62	0.12	0.08	0.06

DAT- Days after transplanting PI – Panicle initiation
Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

response to different water depths and that grass species in general are sensitive to deep water ponding (Kent and Johnson, 2001). From the present study it could be inferred that blood grass was sensitive to higher water regimes and could be suppressed by deep water ponding. The lower WCE recorded under the POP recommendation (W_3) was probably because the growth of blood grass, being a marginal wetland weed, was favoured by the intermittent drainage in this practice.

Among the herbicides, azimsulfuron @ 35g ha^{-1} (M_2) provided excellent control of blood grass during both seasons throughout the growing season. Suada (2015) who studied the response of blood grass to herbicides using bioassay techniques also reported that the highest WCE was obtained for azimsulfuron @ 35g ha^{-1}. At 15 DAT the weed dry matter recorded by pre-plant application of oxyfluorfen @ 0.15 kg ha^{-1} fb hand weeding (M_1) was found significantly lower which indicated that the herbicide could be recommended for early season weed control. The treatment registered satisfactoy weed control throughout crop growth period probably because the herbicide application was followed by hand weeding at 20 DAT. When compared to the weedy check, the other two herbicides, i.e., (bispyribac sodium + metamifop) and fenoxaprop- *p*-ethyl (M_3 and M_4) also recorded significantly lower weed dry weight but they were inferior to hand weeding twice (M_5), suggesting

Table 3. Interaction effect of tillage, water regimes and weed management on dry matter production of blood grass during *Kharif* (g m^{-2})

Treatments	15 DAT		30 DAT		45 DAT		60 DAT	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
W_1M_1	1.74 (2.04)	2.39 (4.74)	1.72 (2.03)	2.10 (3.42)	0.91 (8.15)	1.06 (11.71)	1.13 (13.50)	1.22 (16.78)
W_1M_2	3.34 (10.16)	3.80 (13.42)	1.33 (0.79)	1.48 (1.18)	0.45 (2.80)	0.59 (3.89)	0.76 (5.89)	0.76 (6.12)
W_1M_3	3.28 (9.76)	3.93 (14.43)	2.48 (5.17)	3.00 (8.01)	1.13 (13.43)	1.22 (16.48)	1.44 (27.59)	1.48 (30.16)
W_1M_4	3.16 (9.02)	3.81 (13.51)	3.15 (8.96)	3.42 (10.68)	1.22 (16.73)	1.31 (20.60)	1.55 (35.66)	1.44 (27.61)
W_1M_5	3.29 (9.85)	3.82 (13.63)	2.21 (4.16)	3.00 (8.00)	0.96 (9.16)	1.05 (11.30)	1.32 (21.18)	1.44 (27.46)
W_1M_6	3.25 (9.59)	3.91 (14.32)	6.78 (44.95)	7.18 (50.54)	1.90 (79.11)	1.98 (94.63)	2.03 (106.13)	2.12 (132.41)
W_2M_1	1.75 (2.06)	2.55 (5.54)	1.76 (2.17)	2.19 (3.81)	0.88 (7.66)	1.07 (11.82)	1.15 (14.15)	1.20 (15.90)
W_2M_2	3.45 (10.94)	3.94 (14.53)	1.30 (0.70)	1.58 (1.54)	0.46 (2.91)	0.62 (4.17)	0.78 (6.16)	0.78 (6.12)
W_2M_3	3.32 (10.04)	3.73 (12.95)	2.50 (5.27)	3.16 (8.99)	1.13 (13.60)	1.23 (17.03)	1.47 (29.45)	1.55 (36.07)
W_2M_4	3.38 (10.46)	3.69 (12.59)	3.20 (9.25)	3.48 (11.09)	1.24 (17.50)	1.31 (20.54)	1.56 (36.29)	1.60 (39.69)
W_2M_5	3.34 (10.15)	3.83 (13.63)	2.11 (3.47)	3.06 (8.34)	0.98 (9.72)	1.05 (11.22)	1.42 (26.53)	1.49 (31.37)
W_2M_6	3.36 (10.27)	3.84 (13.75)	6.83 (45.67)	7.22 (51.21)	1.91 (80.98)	2.00 (99.39)	2.03 (106.68)	2.15 (141.77)
W_3M_1	1.61 (1.64)	2.73 (6.46)	2.19 (3.81)	2.69 (6.27)	1.09 (12.30)	1.28 (19.02)	1.24 (17.47)	1.60 (40.09)
W_3M_2	3.54 (11.52)	4.14 (16.16)	1.61 (1.61)	2.01 (3.09)	0.65 (4.48)	0.85 (7.01)	0.83 (6.85)	0.99 (10.01)
W_3M_3	3.77 (13.26)	4.05 (15.46)	2.86 (7.19)	4.21 (16.73)	1.27 (18.51)	1.34 (22.00)	1.53 (34.10)	1.58 (38.61)
W_3M_4	3.84 (13.79)	4.02 (15.13)	3.59 (11.89)	4.84 (22.41)	1.33 (21.53)	1.43 (26.89)	1.53 (34.20)	1.67 (47.54)
W_3M_5	3.85 (13.82)	4.08 (15.72)	2.67 (6.21)	3.48 (11.18)	1.13 (13.50)	1.22 (16.58)	1.44 (28.01)	1.53 (34.50)
W_3M_6	3.81 (13.51)	4.20 (16.62)	7.41 (54.02)	8.30 (67.88)	2.04 (110.78)	2.08 (119.65)	2.22 (164.53)	2.27 (188.29)
CD (0.05)	0.22		0.33		NS		0.10	

P_1 : Intensive ploughing , P_2 : Farmer's practice W_1 : >7.5 cm till grain filling stage, W_2 : >7.5 cm till PI stage, W_3 : 5 cm with intermittent drainage M_1: Oxyfluorfen @0.15 kg ha^{-1} *fb* HW, M_2: Azimsulfuron @35 g ha^{-1}, M_3: Bisptribac Na+ metamifop @70 g ha^{-1} M_4 :Fenoxaprop – p- ethyl @ 60 g ha-^{1},M_5 :HW at 20 and 40 DAT, M_6 :Unweeded control
Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

Table 4. Interaction effect of tillage, water regimes and weed management on dry matter production of blood grass during *Rabi* (g m^{-2})

Treatments	15 DAT		30 DAT		45 DAT		60 DAT	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
W_1M_1	1.44 (1.08)	2.22 (3.96)	1.56 (1.46)	1.89 (2.59)	0.85 (7.08)	0.99 (10.17)	1.07 (11.96)	1.18 (15.04)
W_1M_2	2.94 (7.66)	3.47 (11.04)	1.18 (0.40)	1.34 (0.81)	0.19 (1.59)	0.46 (2.90)	0.65 (4.58)	0.64 (4.75)
W_1M_3	2.84 (7.11)	3.65 (12.38)	1.94 (2.79)	2.58 (5.70)	1.08 (12.09)	1.18 (15.32)	1.41 (25.42)	1.44 (27.90)
W_1M_4	2.91 (7.53)	3.67 (12.48)	2.59 (5.78)	3.29 (9.83)	1.20 (15.89)	1.27 (18.77)	1.52 (33.68)	1.40 (25.57)
W_1M_5	2.96 (7.78)	3.66 (12.41)	2.02 (3.10)	2.59 (5.74)	0.89 (7.86)	1.01 (10.31)	1.28 (19.28)	1.40 (25.47)
W_1M_6	3.10 (8.58)	3.58 (11.88)	6.23 (37.86)	6.62 (42.88)	1.79 (61.64)	1.90 (79.69)	1.91 (80.91)	2.05 (112.42)
W_2M_1	1.42 (1.03)	2.42 (4.93)	1.59 (1.54)	1.93 (2.77)	0.81 (6.38)	1.00 (10.01)	1.10 (12.57)	1.15 (14.25)
W_2M_2	2.92 (7.50)	3.68 (12.55)	1.21 (0.45)	1.54 (1.41)	0.22 (1.70)	0.45 (2.87)	0.67 (4.84)	0.68 (4.81)
W_2M_3	2.92 (7.53)	3.41 (10.66)	2.22 (3.95)	2.81 (6.96)	1.09 (12.24)	1.20 (15.74)	1.43 (27.08)	1.53 (33.58)
W_2M_4	3.02 (8.16)	3.76 (13.14)	2.78 (6.76)	3.31 (10.01)	1.21 (16.11)	1.28 (18.88)	1.54 (34.75)	1.57 (37.12)
W_2M_5	2.93 (7.59)	3.66 (12.46)	2.00 (3.01)	2.73 (6.53)	0.92 (8.41)	1.01 (10.16)	1.38 (24.46)	1.46 (29.11)
W_2M_6	3.02 (8.16)	3.56 (11.80)	6.14 (36.66)	6.70 (43.85)	1.79 (61.98)	1.91 (80.63)	1.91 (81.88)	2.06 (114.34)
W_3M_1	1.66 (1.79)	2.60 (5.80)	2.06 (3.27)	2.28 (4.26)	1.04 (10.98)	1.24 (17.25)	1.19 (15.75)	1.57 (37.26)
W_3M_2	3.33 (10.07)	3.90 (14.22)	1.41 (1.03)	1.78 (2.17)	0.50 (3.25)	0.74 (5.56)	0.73 (5.50)	0.92 (8.49)
W_3M_3	3.60 (12.00)	3.95 (14.58)	2.65 (6.08)	4.07 (15.54)	1.23 (17.09)	1.33(21.50)	1.50 (31.58)	1.56 (36.17)
W_3M_4	3.85 (13.82)	4.11 (15.87)	2.95 (7.58)	4.06 (15.48)	1.30 (20.06)	1.44 (27.94)	1.53 (34.22)	1.65 (44.66)
W_3M_5	3.75 (13.10)	4.12 (16.07)	2.51 (5.29)	2.68 (6.33)	1.09 (12.15)	1.16 (14.63)	1.40 (25.71)	1.51 (32.15)
W_3M_6	3.98 (14.85)	4.47 (18.96)	6.91 (46.80)	7.50 (55.21)	1.97 (92.88)	2.05 (112.80)	2.11 (128.72)	2.23 (170.08)
CD (0.05)	NS		0.31		NS		0.12	

P_1 : Intensive ploughing , P_2 : Farmer's practice W_1 : >7.5 cm till grain filling stage, W_2 : >7.5 cm till PI stage, W_3 : 5 cm with intermittent drainage M_1: Oxyfluorfen @0.15 kg ha^{-1} *fb* HW, M_2: Azimsulfuron @35 g ha^{-1}, M_3: Bisptribac Na+ metamifop @ 70 g ha^{-1} M_4 :Fenoxaprop – p- ethyl @ 60 g ha-^{1}, M_5 :HW at 20 and 40 DAT, M_6 :Unweeded control
Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

Table 5. Interaction effect of tillage, water regimes and weed management on weed control efficiency during *Kharif* (%)

Treatments	15 DAT		30 DAT		45 DAT		60 DAT	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
W_1M_1	9.42 (87.8)	8.48 (71.1)	9.90 (97.0)	9.79 (94.9)	9.71 (93.2)	9.55 (90.3)	9.68 (92.8)	9.60 (91.1)
W_1M_2	6.25 (38.4)	4.31 (18.6)	9.99 (98.8)	9.96 (98.3)	9.93 (97.7)	9.89 (96.7)	9.89 (96.9)	9.89 (96.8)
W_1M_3	6.49 (41.1)	3.51 (12.8)	9.66 (92.4)	9.44 (88.2)	9.48 (88.8)	9.34 (86.2)	9.29 (85.3)	9.22 (84.0)
W_1M_4	6.82 (45.6)	4.43 (18.7)	9.37 (86.8)	9.23 (84.2)	9.33 (86.0)	9.15 (82.8)	9.06 (81.0)	9.29 (85.3)
W_1M_5	6.37 (40.2)	4.10 (17.4)	9.73 (93.7)	9.44 (88.2)	9.66 (92.3)	9.57 (90.6)	9.47 (88.7)	9.29 (85.3)
W_1M_6	6.56 (42.1)	3.80 (13.6)	5.86 (33.5)	5.13 (25.4)	5.87 (33.1)	4.65 (20.8)	6.68 (43.6)	5.53 (29.6)
W_2M_1	9.41 (87.6)	8.20 (66.4)	9.88 (96.7)	9.77 (94.4)	9.73 (93.6)	9.54 (90.1)	9.67 (92.5)	9.62 (91.6)
W_2M_2	5.93 (34.2)	3.44 (12.2)	10.0 (99.0)	9.34 (97.7)	9.93 (97.6)	9.88 (96.5)	9.88 (96.7)	9.89 (96.8)
W_2M_3	6.31 (39.2)	4.75 (22.1)	9.66 (92.2)	9.37 (86.7)	9.47 (88.6)	9.31 (85.7)	9.24 (84.4)	9.05 (80.9)
W_2M_4	6.17 (37.2)	4.99 (24.1)	9.34 (86.3)	9.20 (83.7)	9.29 (85.4)	9.15 (82.8)	9.04 (80.7)	8.94 (78.9)
W_2M_5	6.32 (39.1)	4.31 (17.7)	9.79 (94.9)	9.42 (87.7)	9.64 (91.9)	9.57 (90.6)	9.32 (85.8)	9.18 (83.4)
W_2M_6	6.24 (38.1)	4.19 (17.0)	5.78 (32.6)	5.04 (24.5)	5.75 (32.3)	4.22 (16.9)	6.53 (43.3)	5.06 (24.7
W_3M_1	9.54 (90.0)	7.85 (60.8)	9.76 (94.3)	9.58 (90.7)	9.52 (89.7)	9.22 (84.0)	9.58 (90.7)	8.93 (78.8)
W_3M_2	5.59 (30.4)	1.85 (2.8)	9.93 (97.6)	9.82 (95.5)	9.86 (96.3)	9.75 (94.1)	9.87 (96.4)	9.78 (94.7)
W_3M_3	4.44 (19.8)	2.75 (8.7)	9.51 (89.4)	8.73 (75.3)	9.25 (84.5)	9.09 (81.6)	9.10 (81.9)	8.97 (79.4)
W_3M_4	4.16 (16.7)	2.99 (8.7)	9.14 (82.5)	8.24 (66.9)	9.11 (82.0)	8.86 (77.5)	9.10 (81.8)	8.70 (74.7)
W_3M_5	3.95 (16.4)	2.53 (5.5)	9.58 (90.8)	9.20 (83.6)	9.47 (88.7)	9.33 (86.1)	9.27 (85.1)	9.09 (81.6)
W_3M_6	4.26 (18.2)	1.00 (0.0)	4.58 (20.2)	1.00 (0.00)	2.82 (7.30)	1.00 (0.0)	3.64 (12.5)	1.00 (0.00)
CD (0.05)	NS		0.32		NS		0.25	

P_1: Intensive ploughing , P_2: Farmer's practice W_1 : >7.5 cm till grain filling stage, W_2 : >7.5 cm till PI stage, W_3 : 5 cm with intermittent drainage M_1: Oxyfluorfen @0.15 kg ha^{-1} *fb* HW, M_2: Azimsulfuron @35 g ha^{-1}, M_3: Bisptribac Na+ metamifop @70 g ha^{-1} M_4 :Fenoxaprop – p- ethyl @ 60 g ha-^{1}, M_5 :HW at 20 and 40 DAT, M_6 :Unweeded control

[#] Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

Table 6. Interaction effect of tillage, water regimes and weed management on weed control efficiency during *Rabi* (%)

Treatments	15 DAT		30 DAT		45 DAT		60 DAT	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
W_1M_1	9.76 (94.32)	8.94 (79.08)	9.92 (97.37)	9.81 (95.31)	9.73 (93.72)	9.59 (91.01)	9.69 (92.99)	9.60 (91.14)
W_1M_2	7.78 (59.59)	6.53 (41.74)	10.01 (99.28)	9.98 (98.53)	9.98 (98.60)	9.92 (97.42)	9.92 (97.30)	9.91 (97.18)
W_1M_3	7.97 (62.56)	597 (34.78)	9.79 (94.94)	9.52 (89.66)	9.50 (89.28)	9.35 (86.43)	9.28 (85.07)	9.20 (83.58)
W_1M_4	7.83 (60.34)	5.92 (34.24)	9.51 (89.49)	9.12 (82.18)	9.32 (85.89)	9.19 (83.37)	9.01 (80.20)	9.27 (84.99)
W_1M_5	7.74 (58.96)	5.96 (34.54)	9.77 (94.38)	9.52 (89.64)	9.70 (93.02)	9.59 (90.87)	9.47 (88.68)	9.28 (85.06)
W_1M_6	7.46 (54.73)	6.19 (37.39)	5.68 (31.51)	4.82 (22.41)	6.81 (45.36)	5.50 (29.35)	7.31 (52.43)	5.90 (33.86)
W_2M_1	9.78 (94.56)	8.66 (74.06)	9.91 (97.22)	9.80 (94.99)	9.77 (94.35)	9.59 (91.05)	9.68 (92.63)	9.62 (91.62)
W_2M_2	7.84 (60.43)	5.89 (33.86)	10.01 (99.17)	9.92 (97.47)	9.98 (98.49)	9.92 (97.46)	9.91 (97.14)	9.91 (97.16)
W_2M_3	7.83 (60.32)	6.67 (43.70)	9.69 (92.86)	9.41 (87.43)	9.49 (89.16)	9.33 (86.04)	9.22 (84.05)	9.01 (80.23)
W_2M_4	7.60 (56.99)	5.63 (30.71)	9.42 (87.79)	9.10 (81.89)	9.31 (85.73)	9.18 (83.27)	8.98 (79.56)	8.90 (78.17)
W_2M_5	7.80 (59.98)	5.92 (34.21)	9.77 (94.55)	9.44 (88.20)	9.67 (92.56)	9.59 (90.99)	9.31 (85.65)	9.16 (82.88)
W_2M_6	7.61 (57.02)	6.22 (37.72)	5.87 (33.58)	4.62 (20.52)	6.79 (45.05)	5.43 (28.52)	7.27 (51.84)	5.81 (32.77)
W_3M_1	9.57 (90.59)	8.39 (69.48)	9.75 (94.08)	9.66 (92.27)	9.55 (90.26)	9.26 (84.69)	9.58 (90.76)	8.89 (78.02)
W_3M_2	6.92 (46.89)	5.06 (25.07)	9.96 (98.15)	9.85 (96.05)	9.91 (97.13)	9.80 (95.07)	9.88 (96.76)	9.80 (94.98)
W_3M_3	6.14 (36.73)	4.91 (23.1)	9.49 (89.02)	8.54 (71.87)	9.27 (84.86)	9.05 (80.95)	9.08 (81.43)	8.93 (78.76)
W_3M_4	5.29 (27.17)	4.14 (16.29)	9.32 (85.97)	8.54 (71.99)	9.12 (82.22)	8.73 (75.22)	8.99 (79.88)	8.65 (73.74)
W_3M_5	5.64 (30.88)	3.98 (15.32)	9.56 (90.41)	9.46 (88.59)	9.50 (89.22)	9.38 (87.03)	9.27 (84.87)	9.06 (81.10)
W_3M_6	4.74 (21.64)	1.00 (0.00)	4.02 (15.23)	1.00 (0.00)	4.30 (17.69)	1.00 (0.00)	5.03 (24.31)	1.00 (0.00)
CD (0.05)	0.62		0.28		0.19		0.15	

P_1: Intensive ploughing , P_2: Farmer's practice W_1 : >7.5 cm till grain filling stage, W_2 : >7.5 cm till PI stage, W_3 : 5 cm with intermittent drainage M_1: Oxyfluorfen @0.15 kg ha^{-1} *fb* HW, M_2: Azimsulfuron @35 g ha^{-1}, M_3: Bisptribac Na+ metamifop @70 g ha^{-1} M_4 :Fenoxaprop – p- ethyl @ 60 g ha-^{1}, M_5 :HW at 20 and 40 DAT, M_6 :Unweeded control

[#] Original figures in parentheses were subjected to $\sqrt{x+1}$ transformation

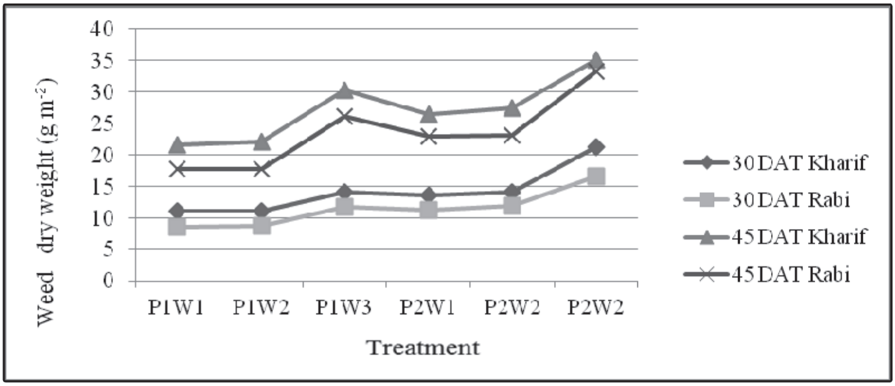

Figure 1. Weed dynamics as influenced by tillage (P) x water regimes (W)

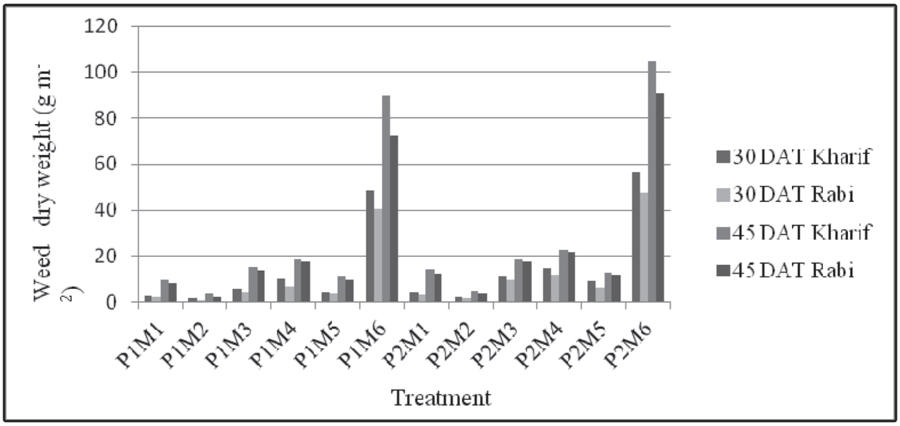

Figure 2. Weed dynamics as influenced by tillage (P) x weed management (M)

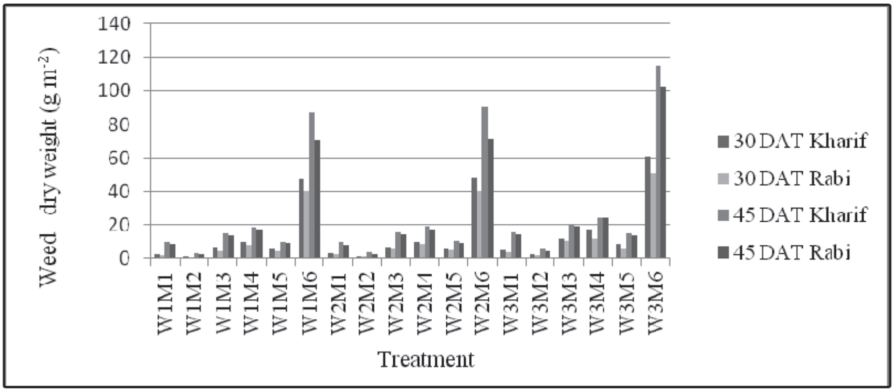

Figure 3. Weed dynamics as influenced by water regimes (W) x weed management (M)

that for controlling blood grass, application of these two herbicides needed to be combined with alternate weeding strategies also.

The interaction effects of the different management practices on weed dry weight and WCE were statistically significant at most of the observation stages (Fig. 1 to 3 & Table 3 to 6). Evidently the WCE of the herbicides was enhanced when combined with the modified cultural practices. The weed dry weight was the lowest under intensive tillage combined with deep water ponding and application of azimsulfuron. Combining these cultural practices with oxyfluorfen *fb* hand weeding was the next best treatment in suppressing the weed. Combinations with hand weeding twice as well as the other two herbicides also gave significantly better WCE than the weedy check. It was clear that the cultural practices alone were ineffective. The very high weed dry weight recorded under all the weedy check combinations emphasized the need for managing the weed through direct weed control practices like hand weeding or herbicides.

From the results it was evident that the weed dry weight during *Rabi* was much lower than that during *Kharif* which could be partly attributed to the carry over effect of the treatments, since the second crop was taken soon after the first without disturbing the field lay out. During the experiment, it was also observed that the integrated strategies were effective for managing the other weed species such as *Cyperus difformis* L., *Fimbristylis miliacea* (L.) Vahl., *Ludwigia perennis* L., and *Monochoria vaginalis* (Burm, f.) C. Presl ex Kunth. which were found growing associated with blood grass.

Tillage x water regimes x weed management interaction effect on crop performance

The results of the present study were indicative of the importance and significance of an efficient weed management strategy for enhancing crop yield from blood grass infested field (Table 7). During both seasons, the growth and yield attributes were higher in treatments involving intensive tillage and deep water regimes up to panicle initiation stage. This in turn was reflected in the grain and straw yield also. The grain yield recorded was the highest (6.15 and 6.96 t ha^{-1} respectively) when these cultural practices were combined with application of azimsulfuron @ 35 g ha^{-1} wherein the weed dry weight was also consistently lower as discussed earlier. However during the *Kharif* season, the grain yield was statistically on par with many of the other treatments except those involving weedy check. The combinations with conventional tillage and POP water management were also comparatively inferior during *Rabi*. The variations in straw yield was non significant except in those treatments involving weedy check.

From the weed index values (Table 7) it was found that under the weedy check in combination with farmer's practice of tillage and POP water management ($P_2W_3M_6$) the crop loss due to blood grass infestation was as high as 61.83 and 62.98 per cent during *Kharif* and *Rabi* respectively (Table 7). This is line with the findings of Varughese (1996) who reported that blood grass alone could cause up to 61 per cent reduction in rice production. It was evident that the crop loss could be reduced substantially by following the modified practices of tillage, water regime and weed management. Interestingly, the crop loss recorded was not always directly proportional to the weed dry weight ($P_1W_2M_5$ during *Kharif* and $P_1W_2M_2$ during *Rabi* recorded negative weed index), which suggested that blood grass was a competitor with the crop only when the infestation intensity was above a threshold level.

In line with the reports of earlier workers like Mukherjee and Karmakar (2015), the grain and straw yields recorded under combinations with manual weeding were found better than that of many of the herbicide treatments. This was arguably because hand weeding at 20 and 40 DAT gave little chance for the weed to flourish and compete with the crop especially during the critical stages of crop weed competition. However, it must be mentioned that vast areas of blood grass infested fields are often left partially weeded or even uncultivated due to labour scarcity and high cost of labour, which results in heavy crop loss and low income for the rice farmer. In the present study also, the yield from the unweeded control plots was found very poor irrespective of the land preparation and water management strateigies.

Economics

Among the two seasons, the net income and benefit-cost ratio was found higher for the *Rabi* crop owing

Table 7. Interaction effect of tillage, water regimes and weed management on tiller number, grain, straw yield and weed index of rice

Treatments	Tiller number (No m-²)				Grain yield (t ha⁻¹)				Straw yield (t ha⁻¹)				Weed index			
	Kharif		*Rabi*		*Kharif*		*Rabi*		*Kharif*		*Rabi*		*Kharif* #		*Rabi**	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
W_1M_1	564.7	494.7	683.0	605.3	5.78	5.34	6.54	6.20	6.81	6.53	7.28	7.81	4.43 (4.87)	5.06 (11.26)	3.69 (3.98)	4.31 (8.94)
W_1M_2	588.0	558.7	709.3	679.0	6.03	5.91	6.82	6.79	6.74	6.91	7.00	7.30	3.70 (0.76)	4.10 (2.98)	3.16 (0.00)	3.19 (0.43)
W_1M_3	500.3	477.7	641.6	605.7	5.66	5.61	6.52	6.30	7.22	6.93	7.58	7.63	4.44 (6.21)	4.69 (7.47)	3.74 (4.32)	4.18 (7.60)
W_1M_4	511.7	481.3	601.0	601.3	5.59	5.39	6.40	6.10	6.92	6.76	7.85	7.58	4.71 (7.75)	5.12 (11.28)	3.95 (6.08)	4.49 (10.41)
W_1M_5	487.0	470.7	606.3	577.0	5.64	5.54	6.52	6.30	6.13	6.85	7.45	7.93	4.73 (7.52)	4.64 (8.03)	3.70 (4.31)	4.19 (7.63)
W_1M_6	232.3	184.7	297.3	245.0	2.45	2.43	2.97	2.87	3.27	3.55	4.00	4.13	8.36 (54.86)	8.40 (55.52)	8.15(56.46)	8.24 (57.91)
W_2M_1	578.7	547.0	699.3	584.3	5.98	5.34	6.81	6.08	6.83	6.55	7.30	7.44	3.56 (1.34)	4.90 (11.0)	3.11 (0.03)	4.54 (1081)
W_2M_2	593.0	556.0	715.7	644.0	6.15	5.88	6.96	6.62	6.47	6.97	6.96	7.48	3.80 (0.00)	4.32 (3.57)	2.32 (-2.25)	3.51 (2.78)
W_2M_3	496.3	544.3	603.7	624.3	5.81	5.42	6.59	6.13	6.84	6.95	7.54	7.83	4.25 (4.23)	4.91 (10.09)	3.65 (3.33)	4.44 (9.99)
W_2M_4	491.3	509.0	597.0	621.7	5.78	5.37	6.15	6.08	6.42	7.07	6.85	7.13	4.50 (5.16)	5.02 (10.81)	4.44 (9.83)	4.49 (10.66)
W_2M_5	504.3	517.7	612.3	631.7	6.13	5.56	6.47	6.39	6.57	6.71	6.91	7.82	3.82 (-0.18)	4.82 (8.32)	3.83 (5.06)	4.01 (6.21)
W_2M_6	267.7	222.3	338.7	288.7	2.65	2.28	3.11	2.67	3.46	3.32	4.29	3.84	8.17 (51.79)	8.52 (57.65)	8.02(54.33)	8.41 (60.75)
W_3M_1	500.7	456.7	608.7	561.3	5.69	5.32	6.49	5.66	6.56	7.01	7.56	7.88	4.61 (6.58)	5.00 (11.34)	3.70 (4.63)	5.11 (16.75)
W_3M_2	559.0	481.7	676.3	590.0	5.73	5.42	6.54	5.91	6.20	7 .08	7.19	7.51	4.39 (5.39)	5.00 (10.36)	3.72 (3.98)	4.81 (13.37)
W_3M_3	489.7	468.7	595.7	574.7	5.56	3.38	6.32	4.19	7.58	4.67	7.34	5.82	4.70 (7.94)	7.46 (40.72)	4.15 (7.25)	6.95 (38.42)
W_3M_4	486.3	451.3	592.0	479.0	5.59	3.16	6.27	3.65	7.42	4.31	7.76	5.24	4.59 (7.35)	7.71 (44.38)	4.14 (7.86)	7.51 (46.44)
W_3M_5	494.7	462.3	601.0	455.3	5.63	5.39	6.45	6.10	6.26	7.34	7.68	8.44	4.28 (6.41)	4.93 (10.32)	3.84 (5.30)	4.48 (10.36)
W_3M_6	210.3	171.3	272.0	230.0	2.26	2.01	2.62	2.52	2.98	2.93	3.53	3.81	8.53 (57.81)	8.77 (61.83)	8.46(61.53)	8.54 (62.98)
CD (0.05)	NS		41.8		0.83		0.56		1.45		0.99		NS		1.05	

Original figures in parentheses were subjected to $\sqrt{x+7}$ transformation *Original figures in parentheses were subjected to $\sqrt{x+10}$ transformation

Table 8. Interaction effect of tillage, water regimes and weed management on cost of cultivation, net income and benefit - cost ratio of rice

Treatments	Cost of cultivation (₹ha⁻¹)		Net income (₹ha⁻¹)				Benefit - cost ratio			
			Kharif		*Rabi*		*Kharif*		*Rabi*	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
W_1M_1	117411	114911	38114	29957	56329	54339	1.323	1.260	1.477	1.470
W_1M_2	105035	102535	55280	56075	73115	76485	1.527	1.547	1.697	1.747
W_1M_3	103975	101475	51030	51016	70792	68922	1.490	1.503	1.680	1.680
W_1M_4	103515	101015	48435	46003	70082	64968	1.074	1.457	1.677	1.643
W_1M_5	130375	127875	18640	22717	43708	44075	1.143	1.177	1.337	1.343
W_1M_6	100125	97625	-32315	-28918	-17808	-16791	0.677	0.703	0.820	0.827
W_2M_1	116111	113611	43614	31316	63452	51269	1.373	1.273	1.547	1.450
W_2M_2	103735	101235	57817	57112	77278	75185	1.557	1.563	1.743	1.740
W_2M_3	102675	100175	53517	48339	73415	67705	1.520	1.483	1.717	1.677
W_2M_4	102215	99715	51362	48368	61185	63632	1.500	1.483	1.597	1.640
W_2M_5	129075	126575	32447	23799	41415	46768	1.253	1.190	1.320	1.370
W_2M_6	98825	96325	-25954	-31864	-11995	-21055	0.737	0.667	0.880	0.783
W_3M_1	114811	112311	37414	34427	59366	46002	1.327	1.307	1.517	1.410
W_3M_2	102435	99935	48983	49192	70925	61638	1.480	1.490	1.693	1.617
W_3M_3	101375	98875	53377	-4511	68131	18215	1.527	0.957	1.670	1.187
W_3M_4	100915	98415	53527	-10479	69642	4505	1.533	1.893	1.690	1.047
W_3M_5	127775	125275	21902	24685	45988	45095	1.173	1.197	1.357	1.363
W_3M_6	97525	95025	-35244	-38165	-24768	-22968	0.640	0.597	0.747	0.760
CD (0.05)	-	-	23480		14915		0.218		0.140	

Labour charge for men: ₹ 650/day Labour charge for women: ₹ 550/day

Cost of herbicides ha⁻¹ : oxyfluorfen: ₹ 1586 azimsulfuron: ₹ 2960 bispyribac Na + metamifop: ₹ 1900fenoxaprop- *p*-ethyl: ₹ 1440 Price of grain: ₹ 21 kg⁻¹ straw: ₹ 5 kg⁻¹

to the better crop performance and yield. Irrespective of the season, the highest net profit was recorded under intensive tillage combined with deep water ponding upto panicle initiation stage and azimsulfuron application (Table 8) which in turn was the most efficient strategy for managing the weed as well as for realising higher crop yield. Between the two higher water regimes, the yield and economics were mostly comparable but considering the water use efficiency, flooding up to the PI stage must be considered better than continuous flooding throughout the crop growth. Because of the high cost of cultivation for manual labour, herbicides were found significantly more profitable than hand weeding. From the data it is clear that even though oxyfluorfen @ 0.15 kg ha^{-1} *fb* hand weeding recorded high level of WCE and good yield, the net profit obtained was less than that from the other herbicide treatments mainly because of the cost involved in hand weeding. It was also shown that irrespective of the tillage and water management practices, the net income and benefit-cost ratio from weedy check were always very poor or even negative, and that cultural methods alone were not sufficient for profitable rice cultivation in blood grass infested fields.

It was concluded that an integrated strategy involving intensive tillage, deep water ponding upto panicle initiation stage and application of azimsulfuron @ 35 g ha^{-1} was very effective and economic in managing blood grass in transplanted rice. Combining these modified cultural practices with either (bispyribac sodium + metamifop) @ 70 g ha^{-1} or fenoxaprop-*p*-ethyl @ 60 g ha^{-1} were alternate strategies for management of this noxious wetland weed. With the accelerating labour cost and labour scarcity, combining these cultural practices with manual weeding was uneconomic but could be an option for organic rice cultivation.

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