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Research Paper

Integrated weed management in direct-seeded rainfed rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted for three years during rainy (*kharif*) season of 2006-2008 at Almora, Uttarakhand to study the effect of different weed control methods on weed infestation, energy use efficiency, productivity and profitability of direct seeded rice (*Oryza sativa* L.) under rainfed conditions. On an average, a weed population of 627/m^2 was recorded in the weedy check plots. The grain yield decreased by 78.5-94.8% due to season-long weed-crop competition as compared with hand weeding (20 and 40 DAS). The highest weed-control efficiency and loweet nutrient uptake by weeds was recorded with butachlor + hand weeding (40 DAS) closely followed by hand weeding twice (20 and 40 DAS). Both these treatments recorded higher grain yield (2.21-2.36 t/ha) compared to other treatments. Butachlor + weeding with wheel-hoe (40 DAS) was the next best treatment. This treatment required less energy input compared with all other weed control treatments. Butachlor + hand weeding and butachlor + wheel- hoe registered the highest energy use efficiency (10.23 and 9.75, respectively) and net returns (₹11,868 and 11,299/ha, respectively) compared with other treatments. The benefit: cost ratio was the highest (1.90) with butachlor + weeding with wheel-hoe closely followed by butachlor + hand weeding and butachlor + long-handled *khurpi*.

Key words : Direct-seeded rice, Energy use, Integrated weed management, Weed control efficiency

Rice with an area of 0.29 million ha, is the most widely cultivated cereal during rainy season in Uttarakhand. Owing to favourable weather conditions, severe weed infestation is a major biotic constraint to rice production. Uncontrolled weeds cause up to 80% reduction in grain yield and sometimes result in complete failure of crop (Pandey *et al*., 2000; Gopinath and Kundu, 2008). Manual weeding with '*kutla'* (a local small hand tool) is a common practice in Uttarakhand hills. *Kutla* has a sharp single pointed tip and therefore, required more time, cost and energy for weeding to cover unit area than *khurpi* or other intercultural tools. Further, manual weeding is often not done on time due to adverse soil and weather conditions. Long-handled *khurpi* and wheel-hoe are two improved intercultural tools which may enhance the working efficiency of farmers in the region (Kumar *et al*., 2010). Inter-row weeds can be removed by inter-row cultivation relatively easily although intra-row weeds constitute a major challenge (Melander *et al*., 2005). Hence, the present study was conducted to evaluate the efficacy of weeding implements either alone or in combination with herbicide use and to develop suitable integrated weed management practices for upland rice.

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MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) season of 2006-2008 at the Experimental Farm (29^0 56' N latitude, 79^0 40' E longitude and located at 1250 m above mean sea level) of Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand. The soil was sandy clay loam with pH 6.4, organic C 1.02%, available P and K 15.5 and 181.0 kg/ha respectively. The bulk density of the soil was 1.23 Mg/m^3. The crop received 513, 401 and 558 mm rainfall during 2006, 2007 and 2008, respectively. The rainfall was low and its distribution was uneven during the crop season in 2007. The mean weekly minimum and maximum temperature was 15.4 and 32.3^{o}C, respectively during 2006, 17.1 and 34.0^{o}C during 2007 and 18.6 and 29.9^{o}C during 2008. The experiment comprised eight treatments, viz. hand weeding (20 and 40 DAS); weeding with long-handled *khurpi* (20 and 40 DAS); use of wheel-hoe (20 and 40 DAS); hand weeding (20 DAS) + wheel-hoe (40 DAS); butachlor + hand weeding (40 DAS); butachlor + long-handled *khurpi* (40 DAS); butachlor + wheel-hoe (40 DAS), and weedy check. The treatments were arranged in a randomized block design with three replications.

The 'VL 154' rice was sown 20 cm apart in rows in the first fortnight of June, depending upon the onset of monsoon, during the three years. The crop was fertilized with 60, 40 and 30 kg/ha of N, P_2O_5 and K_2O, respectively. Half the dose of N and full dose of P_2O_5 and K_2O was applied at sowing, while the remaining N was applied 40-50 days after sowing. Butachlor (1.5 kg a.i./ha) was applied one day after sowing with a manually operated knapsack sprayer delivering a spray volume of 600 liters/ha through a flat fan nozzle. In the plots under hand weeding, weeds were removed manually using *kutla*. The wheel-hoe is operated by repeated push-pull action, which allows the soil-working component (V-blade) to penetrate into the soil and cut or uproot the weeds in between the crop rows (Gopinath *et al.*, 2009). Similarly, long-handled *khurpi* consisted of a V-blade (7.5 cm width) attached to a wooden handle of 1.2-1.5 m length. The time used to carry out weeding under different practices was recorded and used for calculating energy use efficiency.

Data on weed density and biomass were recorded 60 days after rice sowing in each plot in two quadrants, each measuring 50 × 50 cm. Weeds were counted species-wise and were removed for recording their biomass. Weed samples were sun-dried and later oven dried at 70°C until constant weight was attained. Crop was manually harvested during the last week of October in all the three years. The grain yield data were recorded and adjusted to 14% of the moisture content. Economics were computed using the prevailing market prices for inputs and outputs such as rice grains (₹ 8,500/tonne), rice straw (₹ 1,500/tonne) and manual labour (₹ 80/day). The primary data on various inputs and management practices were used for computation of energy consumption. For estimation of energy inputs and outputs, the energy equivalents were worked out as suggested by Singh *et al.* (2008a). Data on weeds were subjected to square-root transformation ($\sqrt{X + 1.0}$) before statistical analysis.

RESULTS AND DISCUSSION

Weed flora and weed-control efficiency

On an average, a weed population of 627/m^2 was recorded in the weedy check plots. The field was dominated by jungle rice [*Echinochloa colona* (L.) Link.], bahia grass (*Paspalum notatum* Flugge), goat weed (*Ageratum conyzoides* L.), and wood sorrel (*Oxalis latifolia* H.B.K). Besides these, day flower (*Commelina benghalensis* L.), gallant soldier (*Galinsoga parviflora* Cav.), spurges (*Euphorbia geniculata* Forsk.), signal grass [*Brachiaria ramosa* (L.) Stapf.], crab grass [*Digitaria sanguinalis* (L.) Scops.], purple nutsedge (*Cyperus rotundus* L.) and bermuda grass [*Cynodon dactylon* (L.) Pers.] were also observed in low densities.

All the treatments recorded significant reduction in density of both grassy and broadleaf weeds compared with weedy check (Table 1). Butachlor + hand weeding (40 DAS) being at par with hand weeding (20 and 40 DAS) and butachlor + wheel-hoe (40 DAS) resulted in significantly lower density of grassy weeds compared with other treatments. Similarly, Butachlor + hand weeding was most effective in reducing the density of broadleaf weeds. It was significantly superior to all other treatments except hand weeding twice (20 and 40 DAS). Butachlor + wheel-hoe was the next best treatment.

All the treatments significantly reduced biomass of both grass and broadleaf weeds compared with weedy check. Butachlor + hand weeding was superior to all other treatments in reducing the biomass of grassy weeds. Hand weeding (20 and 40 DAS) was the next best treatment. Similarly, these two treatments recorded similar but significantly lower biomass of broadleaf weeds compared to other treatments. Mechanical weed control by using either wheel-hoe or long-handled *khurpi* after butachlor application also resulted in significantly lower biomass of both grass and broadleaf weeds compared with treatments involving mechanical weeding alone. The weed-control efficiency of different weed control measures ranged from 72.2–96.0%. The highest weed-control efficiency was achieved with butachlor + hand weeding (40 DAS) closely followed by hand weeding twice (20 and 40 DAS). However, the lowest weed-control efficiency (72-77%) was recorded for the treatments involving mechanical weed control alone. This was mainly due to poor efficacy of weeding implements against intra-row weeds (Gopinath *et al.*, 2009). However, butachlor application coupled with mechanical weeding (40 DAS) gave a weed-control efficiency of 80-86%.

In general, nutrient uptake by weeds under different treatments had direct relationship with weed biomass. The nutrient uptake by weeds decreased under different weed management practices compared with weedy check (Table 1). Butachlor + hand weeding (40 DAS) and hand weeding twice (20 and 40 DAS) registered similar but significantly lower uptake of N, P and K by weeds compared to other treatments. However, treatments involving mechanical weeding alone resulted in higher N (21-26 kg/ha), P (6-8 kg/ha) and K (18-20 kg/ha) uptake by weeds compared to other weed control treatments. Kumar *et al.* (2010) also reported that mechanical weed control resulted in higher nutrient uptake by weeds compared with herbicide treatment.

Crop growth and yield

All the treatments recorded significantly higher plant height compared with weedy check (Table 2). Butachlor +

hand weeding (40 DAS) resulted in the maximum plant height. However, it was at par with other treatments except mechanical weeding treatments (use of long-handled *khurpi* or wheel-hoe alone). All the weed control treatments resulted in significant increase in tillers/m^2, panicle length and 1,000-grain weight compared to weedy check. Butachlor + hand weeding (40 DAS) being at par with hand weeding twice (20 and 40 DAS) recorded significantly higher number of tillers/m^2 compared with all other treatments. Integration of wheel-hoe (40 DAS) with either butachlor application or hand weeding (20 DAS) was the next best treatment. Butachlor + hand weeding resulted in significantly higher panicle length compared to other treatments. Hand weeding twice (20 and 40 DAS) being at par with butachlor + wheel-hoe (40 DAS) also registered significantly higher panicle length compared to other treatments. Butachlor + hand weeding (40 DAS) gave the highest 1,000-grain weight. It was at par with hand weeding twice (20 and 40 DAS) and butachlor + wheel-hoe (40 DAS) but significantly superior to other treatments. Among the different weed control measures, the lowest 1,000-grain weight (24.0-24.5 g) was recorded with treatments involving mechanical weeding alone.

The grain yield decreased by 78.5% in 2006 due to season-long weed-crop competition in weedy check plots as compared with Butachlor + hand weeding (40 DAS) treatment (Table 2). In our earlier study, uncontrolled weeds resulted in about 80% reduction in grain yield of direct-seeded rice (Gopinath and Kundu, 2008). In the subsequent two years, however, more weed pressure coupled with luxurious growth of weeds severely affected the crop and decreased the grain yield in weedy check plots by 94.8% in 2007 and 93.4% in 2008. Butachlor + hand weeding (40 DAS) gave the highest grain yield in 2006. It was at par with hand weeding twice (20 and 40 DAS), butachlor + wheel-hoe (40 DAS) and hand weeding (20 DAS) + wheel-hoe (40 DAS) but significantly superior to other treatments. Similar results have been reported by Singh *et al.* (2008b). Increase in grain yield in these treatments may be attributed to effective control of weeds (Table 1) and marked improvement in crop growth and yield attributes (Table 2). In 2007 and 2008, butachlor + hand weeding (40 DAS) being at par with hand weeding twice (20 and 40 DAS) recorded significantly higher grain yield compared to all other treatments. Butachlor + wheel-hoe (40 DAS) was the next best treatment. Among the weed control measures, treatments involving mechanical weeding alone either with long-handled *khurpi* or wheel-hoe were least effective in improving the grain yield mainly due to poor control of intra-row weeds. Among the two weeding implements, wheel-hoe was found significantly better than long-handled *khurpi* in terms of better weed control and grain yield. However, Kumar *et al.* (2010) reported that long-handled *khurpi* can help to remove weeds in both inter-and intra-row spaces of wheat, whereas wheel hoe from inter-rows only, which resulted in lower crop-weed competition and higher grain yield.

Energy use

Application of butachlor followed by weeding with wheel-hoe (40 DAS) required less energy input compared with all other weed control treatments (Table 2). The highest energy input was required for the treatment involving hand weeding twice (20 and 40 DAS). This was mainly due to more labour requirement for weeding with *kutla* (a small hand tool), which covers less area/unit time. On contrary, mechanical weeding twice with either long-handled *khurpi* or wheel-hoe recorded less energy input as these treatments required about 58 and 74% less labour, respectively compared with hand weeding twice (20 and 40 DAS). The energy output had direct relation with the total biomass (grain and straw) produced in each treatment. Butachlor + hand weeding (40 DAS) recorded the highest energy output followed by hand weeding twice (20 and 40

Table 1. Effect of treatments on density and dry weight of weeds and nutrient uptake by weeds in rice at 60 DAS, (Mean of 3 crop seasons)

Treatment	Weed density (No./m^2)		Weed biomass (g/m^2)		WCE[2] (%)	Nutrient uptake (kg/ha)		
	Grass	Broadleaf	Grass	Broadleaf		N	P	K
Hand weeding (20 and 40 DAS[1])	6.5 (41)*	6.0 (36)	6.4 (40.5)	4.1 (15.7)	91.6	8.6	2.2	5.8
Long-handled *khurpi* (20 and 40 DAS)	13.6 (195)	12.1 (147)	12.0 (146.0)	6.4 (40.3)	72.2	25.7	7.5	20.3
Wheel-hoe (20 and 40 DAS)	12.6 (165)	10.0 (99)	11.1 (121.3)	6.0 (35.0)	76.7	20.8	5.9	17.5
Hand weeding (20 DAS) + wheel-hoe (40 DAS)	10.0 (100)	8.6 (75)	10.0 (99.0)	4.9 (23.2)	81.8	17.4	5.0	12.8
Butachlor + hand weeding (40 DAS)	5.8 (33)	5.2 (27)	4.3 (17.2)	3.2 (9.5)	96.0	4.0	1.1	3.0
Butachlor + long-handled *khurpi* (40 DAS)	11.2 (125)	9.3 (87)	10.5 (109.6)	5.3 (27.0)	79.6	19.0	5.1	14.6
Butachlor + wheel-hoe (40 DAS)	8.8 (76)	7.9 (61)	8.8 (77.0)	4.4 (19.7)	85.6	12.5	3.2	10.6
Weedy check	19.3 (372)	16.0 (255)	24.1 (584.5)	9.3 (86.4)	-	88.6	24.2	61.7
SEm ±	1.14	0.44	0.52	0.37	-	1.82	0.43	1.39
CD (P=0.05)	3.5	1.3	1.6	1.1	-	5.5	1.3	4.2

*Figures in parentheses indicate original values; [1]DAS, days after sowing; [2]WCE, weed control efficiency

Table 2. Effect of treatments on the growth, yield attributes, grain yield, energy-use efficiency and economics of rice cultivation, (Mean of 3 crop seasons)

Treatment	Plant height (cm)	Tillers/ m^2	Panicle length (cm)	1,000-grain weight (g)	Grain yield (t/ha)				Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Energy use efficiency	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	B:C ratio
					2006	2007	2008	Mean						
Hand weeding (20 and 40 DAS[1])	96.2	49.8	15.9	25.7	2.51	1.98	2.13	2.21	11.0	88.3	8.05	25.0	0.5	0.02
Long-handled *khurpi* (20 and 40 DAS)	89.4	36.0	14.1	24.0	1.76	1.01	1.14	1.30	9.3	53.6	5.79	16.5	-1.2	-0.08
Wheel-hoe (20 and 40 DAS)	91.6	41.6	14.8	24.5	2.11	1.32	1.52	1.65	8.8	61.6	7.02	15.2	3.3	0.22
Hand weeding (20 DAS) + wheel-hoe (40 DAS)	95.0	46.2	15.3	25.0	2.34	1.51	1.74	1.86	10.0	77.3	7.70	20.7	1.44	0.07
Butachlor + hand weeding (40 DAS)	98.0	52.1	16.6	26.1	2.62	2.11	2.34	2.36	9.1	92.6	10.23	15.1	11.8	0.79
Butachlor + long-handled *khurpi* (40 DAS)	93.6	45.6	15.1	24.8	2.18	1.64	1.73	1.85	8.8	75.9	8.58	13.6	7.9	0.59
Butachlor + wheel-hoe (40 DAS)	96.1	47.8	15.5	25.5	2.49	1.83	1.82	2.05	8.6	84.0	9.75	12.6	11.3	0.90
Weedy check	78.0	4.8	12.5	22.2	0.36	0.11	0.15	0.27	8.0	15.7	1.75	9.6	-5.8	0.39
SEm ±	1.69	0.97	0.15	0.28	0.13	0.06	0.08	-	-	1.55	0.1	-	0.7	-0.61
CD (P=0.05)	5.0	2.9	0.4	0.8	0.31	0.17	0.25	-	-	4.7	0.3	-	-	-

DAS) and butachlor + wheel-hoe (40 DAS). Similarly, butachlor + hand weeding and butachlor + wheel-hoe registered the highest energy use efficiency (10.23 and 9.75, respectively) compared with other treatments. The higher energy use efficiency coupled with less energy requirement under these treatments may help in reducing the human drudgery for weed management. Kumar *et al.* (2010) reported similar results in wheat.

Economics

In general, the cost of rice cultivation was lower in all the treatments involving herbicide use. It was lowest with butachlor + weeding with wheel-hoe (40 DAS). Application of butachlor followed by weed removal either by hand weeding or long-handled *khurpi* were the next best treatments (Table 2). The cost of cultivation was highest (25,000/ha) with hand weeding twice (20 and 40 DAS) closely followed by hand weeding (20 DAS) + wheel-hoe (40 DAS). About 190 man-days/ha were required to manually remove the weeds at two stages (20 and 40 DAS). Owing to higher yield and low cost of herbicides and labour requirement, Butachlor + hand weeding (40 DAS) gave the highest net return closely followed by butachlor + wheel-hoe (40 DAS). Gopinath and Kundu (2008) have also reported similar results. Treatments involving either manual or mechanical weeding alone gave lower net returns. However, Moorthy and Mishra (2004) reported that mechanical weeding at 15 and 30 DAS using finger weeder and wheel-hoe supplemented with one hand weeding gave effective and economical weed control. All the three treatments involving herbicide use recorded higher benefit:cost ratio compared to other treatments. It was highest (0.90) with butachlor + weeding with wheel-hoe (40 DAS) closely followed by butachlor + hand weeding (40 DAS) and butachlor + long-handled *khurpi* (40 DAS).

The present study suggests that integrated weed management involving pre-emergence application of butachlor (1.5 kg a.i. /ha) followed by removal of weeds at 40 days after sowing through manual or mechanical methods (wheel-hoe) was most effective in terms of weed control efficiency, energy use efficiency, higher grain yield and economic returns.

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