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Research Paper

Effect of irrigation schedule and weed-management practices on productivity and profitability of direct-seeded rice (*Oryza sativa*) in South-eastern Rajasthan

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ABSTRACT

A field experiment was carried out at Agricultural Research Station, Kota, Rajasthan during the rainy (*Kharif*) season of 2011 and 2012, to evaluate the productivity and profitability of rice (*Oryza sativa* L.) grown under direct-seeded condition as influenced by irrigation scheduling and weed-management practices in South-eastern Rajasthan. Treatments comparised irrigation schedules in main plots, viz. 75, 100 and 150% cumulative pan evaporation (CPE), and weed-management practices in sub-plots, viz. pendimethalin @ 1.0 kg/ha, bispyribac sodium @ 35 g/ha, pendimethalin @ 1.0 kg/ha followed by (fb) bispyribac sodium @ 35 g/ha, brown manuring + 2, 4-D @ 0.8 kg/ha and weedy check, was laid out in split-plot design with 3 replications. The pooled data of 2 years revealed that application of irrigation at 100% CPE resulted in significantly higher plant height and dry-matter accumulation at harvest, tillers/m^2, panicle length and weight, filled spikelets/panicle, test weight, dry weight of weeds at harvest, N, P and K uptake by weeds at harvest, grain and straw yield, net returns and benefit: cost ratio, water-use efficiency (WUE) and water productivity than irrigation at 75% CPE. However, plant height and dry-matter accumulation were maximum at harvest with the irrigation at 150% CPE. Among weed-management practices, pre-emergence application of pendimethalin @1.0 kg/ha fb bispyribac sodium @ 35 g/ha showed the highest growth and yield attributes, yields, net returns, benefit: cost ratio, WUE and water productivity, weed-control efficiency (WCE) and low NPK uptake by weeds at 45 days after sowing (DAS) and at harvest.

Key words : Crop production, Direct-seeded rice, Irrigation schedule, Weed-management practices, Water productivity

Rice is grown in different agro-ecosystems and physical conditions of soil. Cultivation of transplanted rice in north India and South-eastern (S-E) Rajasthan is most popular, but it is highly labour intensive and expensive method, requiring huge quantity of water for puddling, transplanting and establishment of rice seedlings. Irrigation plays a pivotal role in increasing the productivity of rice, though the efficiency and productivity of water is very low due to percolation losses and higher water requirement. Most of the farmers in S-E Rajasthan are small and marginal and face many problems in carrying out these operations. Besides these, unpredictable and insufficient monsoon rains greatly affect the rice productivity. In these situations, direct seeding of rice may be the next best alternative in S-E Rajasthan. (Maity and Mukherjee, 2008). Direct seeding in non-puddled condition eliminates the need of raising, maintaining and subsequent transplanting of seedlings. Besides, early maturity of rice crop also allows timely sowing of subsequent wheat (Singh and Singh, 2010). Direct-seeded rice crop is subjected to more weed competition for nutrient, light, water and space than transplanted rice because seeds of both crop and weed emerge almost at the same time, resulting in reduction of yield up to 50–90% (Rao *et al*., 2007). Hence, in direct-seeded rice, control of weeds is utmost important to reduce the weed competition as well as to maximize the water utilization to enhance water and crop productivity. Therefore, a field experiment was carried out to explore the profitability and possibility of direct-sown rice through irrigation scheduling and weed management in S-E Rajasthan.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*Kharif*) seasons of 2011 and 2012 at Agricultural Research Station, Kota (26º N, 76º-6' E and 260 m above

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mean sea-level), Rajasthan. The soil was Vertisols having bulk density 1.52 Mg/m^3, pH 7.78 and cation-exchange capacity (CEC) 35 C mol/kg. The soil had a very low infiltration rate (0.25 cm/hr) on surface but at deeper layers (1.2 to 1.5 m) was impermeable. The potential moisture-retention capacity of soil was 120 mm of water at 1 m soil depth. The soil of the experimental field was medium in organic carbon 5.6 g/kg, available nitrogen (322 kg/ha) and available phosphorus (23.8 kg/ha) and high in available potash (279 kg K_2O /ha). The experiment was laid out in split-plot design with 3 replications. The main plot treatments comprised 3 irrigation schedules, i.e. 75, 100 and 150% cumulative pan evaporation (CPE) and sub-plot treatments were weed management practices viz. pendimethalin @ 1.0 kg/ha at 3–4 days after sowing (DAS), bispyribac sodium @ 35 g/ha at 15–20 DAS, pendimethalin @ 1.0 kg/ha at 3-4 DAS followed by (fb) bispyribac sodium @ 35 g/ha at 15–20 DAS, brown manuring + 2,4-D @ 0.8 kg/ha at 20–25 DAS and weedy check. For brown manuring, *dhaincha* (*Sesbania rostrata* Brem) @ 30 kg/ha was grown at the time of sowing and burned by spray of 2,4-D @ 0.8 kg/ha at 25 DAS followed by its mulching with the help of paddy weeder at 35 DAS. High-yielding variety 'Pusa sugandha 4' was grown with the recommended package of practices i.e crop geometry (20 cm × 10 cm), seed rate (30 kg/ha), seed treatment by sodium hypoclorite and streptocycline and recommended dose of fertilizer (120, 60, 40 kg/ha of NPK) were applied. Irrespective of irrigation treatments, 2 comman irrigations were applied for establishment the crop in the early stage and rest irrigations were applied on the basis of cumulative pan evaporation (CPE) as per treatments. Seed was sown directly in unpuddled conditions on 15 and 18 July and harvested on 20 and 22 October in 2011 and 2012 respectively. Water requirement of the crop as per the treatments was fulfilled by rainfall and irrigation. Supplemental irrigation was given in case of less rainfall at scheduled irrigation treatment. Measurement of irrigation water was done by velocity-area method. Year-wise consumptive use of water was worked out using the formula described by Dastane (1972) and then mean of 2 years was used for calculating water-use efficiency (WUE). The effective rainfall observed was 531 mm and 431 mm and evapotranpiration 400 mm and 430 mm during growing seasons of 2011 and 2012 respectively. All the plant-protection measures were adopted to ensure healthy crop. The herbicides were applied with hand-operated knapsack sprayer using spray volume of 500 liters water/ha. For counting weed density (No./m^2) and weed dry weight (g/m^2) of the plots were sampled randomly at 2 places in each plot with the help of 1.0 m^2 quadrates 45 days after sowing and at harvest. Weed-control efficiency (WCE) was calculated on the basis of dry-matter production of weeds at harvest.

Weed data were subjected to square-root transformation $\{\sqrt{X+0.5}\}$ and analysed statistically. Samples were oven dried at 70^{0}C for 72 hrs and dry weight was recorded. The sun-dried bundles were threshed and winnowed and seed obtained was weighed. The straw yield was obtained by subtracting the seed yield from the biological yield. Nutrient uptake by weeds was estimated by multiplying the dry weight of weeds at 45 DAS and at harvesting by their respective percentages. All the observations were analysed statistically for their test of significance of the individual years, and pooled analysis was done over the years. Weed-control efficiency (WCE), water-use efficiency (WUE) and water productivity (WP) were worked out as per standard procedures (Devasenapathy *et al*., 2008; Singh and Kumar, 2011). Economics of the treatments was carried out on the basis of prevailing market price of inputs and output.

RESULTS AND DISCUSSION

Weeds

The dominant weed species present in the experimental field during 2011 and 2012 were *Echinochloa crus-galli* L., *Echinochloa colonum* Link. and *Cynadon dactylon* Pers. among the grasses; *Cyperus rotundus* and *Cyperus iria* in sedges; and *Phyllanthus niruri* Hook.f., *Commelina benghalensis* L., *Euphorbia hirta* L. and *Eclipta alba* Hassk. among broad leaved weeds. The grasses, sedges and broad-leaf weeds constituted 32.5, 42.7 and 24.8% of the total weed flora respectively. Emergence of broad-leaf weeds was noticed earlier than that of sedges and grasses. Weed density and weed dry weight 45 days after sowing were higher than at harvest. This was perhaps due to death of some weeds and shading effect of the tall weeds like *Echinochloa crus-galli* and crop plants on short-stature weeds. At both the stages of observation, unweeded check recorded significantly higher weed population and weed dry weight than any other treatment (Table 1).

Irrigation schedules did not influence the weed density at 45 DAS, at harvesting, and dry weight of weed at 45 DAS significantly (Table 1). This shows that germination of the weeds was not influenced by the irrigation schedules because the first two irrigations were applied common for establishment of the crop. However, dry weight of weeds increased significantly up to irrigation at 100% CPE at harvesting. Increase in dry weight of weeds beyond the irrigation applied at 100 CPE was non-significant at harvesting. This may be attributed to vigorous growth and development of weeds owing to higher uptake of nutrients by weeds with the irrigation at 100% CPE as compared to 75% CPE. The maximum weed-control efficiency was also found in irrigation at 150 % CPE. Nitrogen, phosphorus and potassium uptake by weeds at harvest was significantly influenced by irrigation schedules. However, N, P and K uptake by weeds at 45 DAS was non-significant. The lowest uptake of these nutrients by weeds was recorded at 75% CPE, while the uptake by weeds with irrigation schedule at 150% and 100% CPE were comparable with each other. Weeds grow faster than crop plants and thus absorb the available nutrients quickly, leading to inadequate supply of nutrients to the crop. Increased soil moisture through the irrigation at 100% CPE provided better environment for availability to crop and weeds and, thereby lower dry-matter accumulation of weeds resulted in lesser nutrient uptake by weeds. Jayprakash and Wahab, (1995), Ramakrishna *et al*. (2007) and Murthy and Reddy (2013) reported similar results.

All the weed-control practices resulted in lower weed density and weed dry weight at 45 DAS and at harvesting than weedy check (Table 1). Application of pendimethalin @ 1.0 kg/ha fb bispyribac sodium @ 35 g/ha was significantly superior in respect of minimizing weed density and weed dry weight at 45 DAS and at harvesting. Maximum weed-control efficiency was also observed with pendimethalin @1.0 kg/ha fb bispyribac sodium @ 35 g/ha. The lowest uptake of NP and K by weeds was recorded with the pendimethalin @1.0 kg/ha fb bispyribac sodium @ 35 g/ha. This may be attributed due to earlier control of weeds by pendimethalin and subsequent flushes of weeds were controlled by bispyribac sodium efficiently. Sole applications of herbicides were found least effective in minimizing the density of weeds due to low weed control. The results confirm the findings of Maity and Mukherjee (2008).

Crop

Growth and yield attributes: Irrigation schedules had significant effect on growth and yield attributes, viz. plant height at harvesting, tillers/m^2 at 60 DAS, dry-matter accumulation/m^2 at harvesting, panicle weight, length of panicle, filled spikelets/panicle and test weight. The growth and yield attributes increased significantly up to the irrigation applied at 100% CPE except plant height at harvesting. Irrigation applied beyond this level improved the growth and yield attributes of the crop non-significantly. This might be due adequate availability of water and better conductive rhizosphere environment for higher uptake of nutrients and in turn boost the

Table 1. Effect of irrigation regimes and weed-management practices on weed dry weight, weed-control efficiency and N, P and K uptake by weeds of rice (pooled data of 2 years)

Treatment	Weed density at 45 DAS (No./m^2)	Weed density at harvesting (No./m^2)	Dry weight of weed at 45 DAS (g/m^2)	Dry weight of weed at harvesting (g/m^2)	WCE	Nutrient uptake by weeds (kg/ha)					
						N		P		K	
						45 DAS	At harvest	45 DAS	At harvest	45 DAS	At harvest
Irrigation regimes											
Irrigation at 75% CPE	9.4(92.6)	8.9(84.5)	7.3(72.2)	7.0(57.0)	62.4	13.1	13.1	2.30	2.71	13.0	12.0
Irrigation at 100% CPE	9.9(101)	9.4(93.1)	8.2(74.3)	8.0(71)	59.8	13.5	16.4	2.34	3.37	13.4	14.9
Irrigation at 150% CPE	9.8(100)	9.3(91.8)	8.4(77.8)	8.2(73.9)	57.6	14.2	17.0	2.45	3.51	14.0	15.5
SEm±	0.15	0.15	0.08	0.09		0.22	0.31	0.04	0.06	0.22	0.28
CD (P=0.05)	NS	NS	NS	0.31		NS	1.02	NS	0.21	NS	0.93
Weed management practices											
Pendimethalin @ 1.0 kg/ha	10.8(116)	10.4(107)	7.2(67.5)	7.0(47.8)	71.6	10.1	11.0	1.74	2.27	10.0	10.1
Bispyribac sodium @ 35 g/ha	8.6(73.8)	8.1(66.2)	8.0(55.3)	7.8(60.2)	64.1	12.3	13.9	2.13	2.86	12.2	12.7
Pendimethalin @ 1.0 kg/ha fb Bispyribac sodium @ 35 g/ha	6.9(47.7)	6.3(39.6)	5.2(31.3)	4.7(23.7)	85.9	5.7	5.45	0.99	1.12	5.6	4.98
Brown manuring + 2, 4-D @ 0.8 kg/ha	9.4(87.3)	8.9(79.3)	6.4(44.5)	6.2(37.3)	77.9	8.1	8.59	1.40	1.77	8.0	7.85
Control	12.8(164)	12.5(157)	13.1(175.2)	14.0(167)	0.0	31.9	38.6	5.52	7.96	31.6	35.2
SEm±	0.135	0.145	0.08	0.09		0.25	0.33	0.04	0.07	0.24	0.30
CD (P=0.05)	0.38	0.41	0.24	0.26		0.70	0.93	0.12	0.19	0.69	0.85

Original values in parentheses; CPE, cumulative pan evaporation; WCE, weed-control efficiency; DAS, days after sowing growth leading to the development of higher yield attributes through supply of more photosynthates towards the sink. Stress during the reproductive phase might have hampered the supply of photosynthates towards the sink, resulting in poor yield attributes obtained in irrigation at 75% CPE. However, stress during the post-panicle initiation reduced the spikelets/panicle and during later stage reduced the grain filling, resulting in increased unfilled grain percentage and reduced test weight (Ramakrishna *et al*., 2007). The irrigation at 75% CPE probably caused stress to rice plant, resulting in reduced growth and yield attributes. Higher growth and yield attributes owing to irrigation at IW: CPE of 0.8 in aerobic rice were also reported by Murthy and Reddy (2013).

All the weed-management practices significantly increased the growth and yield attributes as compared to weedy check (Table 2). Application of pendimethalin @ 1.0 kg/ha fb bispyribac sodium @ 35 g/ha resulted 16.5% higher plant height, 137.2% higher dry matter at harvesting, 36.9% higher tillers/m^2, 26.0 and 25.6% higher panicle length and weight, 26.5% higher filled spikelets/panicle as well as 13.1% higher test weight than the weedy check. However, alone application of pendimethalin @ 1.0 kg/ha and brown manuring of *dhaincha* fb its mulching both were found at par with each other to increase growth and yield attributes but significantly superior to the weedy check. This might be owing to significant reduction in weed density and weed dry weight. Effective control of weeds with pre-and post-emergence application of herbicides might have resulted in increased growth and yield attributes of the crop, which reduces water and the nutrients uptake by weeds. Severe weed infestation decreased the growth and yield attributes in weedy check. These results are in accordance with the findings of Singh and Singh (2010).

Yields: Irrigation schedules had significant influence on grain and straw yields of rice. Maximum grain and straw yields were obtained under irrigation at 150% CPE. However, significant increase in these parameters was recorded with irrigation applied at 100% CPE. Thus, application of irrigation at 100% CPE increased grain and straw yields by 10.2 and 10.3% over the irrigation applied at 75% CPE. Irrigation schedules did not have significant effect on harvest index. These results confirm the findings of Murthy and Reddy (2013) and Maheswari and James (2007).

The highest grain and straw yields were recorded with the pendimethalin 1.0 kg/ha fb bispyribac sodium 35 g/ha (Table 3). Single application of pendimethalin 1.0 kg/ha, bispyribac sodium 35 g/ha and brown manuring fb its mulching were found significantly superior in enhancing grain and straw yields of the crop as compared to the unweeded control. However, pendimethalin 1.0 kg/ha and brown manuring fb its mulching remained statistically at par with each other in relation to enhance yields of rice. Weed-management practices did not influence the harvest index. The increased grain and straw yields by pendimethalin 1.0 kg/ha fb bispyribac sodium 35 g/ha were owing to reduced weed density, weed dry weight and higher weed-control efficiency resulted in higher panicles/

Table 2. Effect of irrigation regimes and weed-management practices on growth and yield attributes of rice (pooled data of 2 years)

Treatment	Plant height at harvesting (cm)	Dry matter accumulation at harvesting (g/m^2)	Tillers/m^2	Panicle length (cm)	Panicle weight (g)	Filled spikelets/ panicle	Test weight (g)
Irrigation regimes							
Irrigation at 75% CPE	99	567	311	26.1	2.41	89.5	21.7
Irrigation at 100% CPE	104	624	323	27.3	2.55	95.7	22.5
Irrigation at 150% CPE	114	658	341	28.3	2.67	102	23.1
SEm±	1.8	10.2	5.5	0.36	0.04	1.93	0.18
CD (P=0.05)	5.94	33.5	18.1	1.2	0.14	6.30	0.60
Weed management practices							
Pendimethalin @ 1.0 kg/ha	105	549	319	26.5	2.44	92.8	22.1
Bispyribac sodium @ 35 g/ha	105	650	344	27.8	2.61	98.3	22.9
Pendimethalin @ 1.0 kg/ha fb Bispyribac sodium @ 35 g/ha	115	925	375	30.5	2.89	109	23.7
Brown manuring + 2, 4-D @ 0.8 kg/ha	104	567	313	27.1	2.47	92.7	22.4
Control	99	390	274	24.2	2.30	86.0	21.0
SEm±	1.6	10.6	6.6	0.45	0.05	1.7	0.23
CD (P=0.05)	4.5	30.2	18.8	1.3	0.15	4.7	0.66

CPE, cumulative pan evaporation

Table 3. Effect of irrigation regimes and weed-management practices on productivity, economics and water-use efficiency of rice (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Net returns (×10³₹ /ha)	Benefit: cost ratio	Total water applied (mm)	WR (mm)	CU (mm)	Water-use efficiency (kg/ha-cm)	Water productivity (₹/m³ water)
Irrigation regimes										
Irrigation at 75% CPE	2.25	3.39	40.1	48.9	1.82	726	1,219	399	57.6	6.8
Irrigation at 100% CPE	2.48	3.74	39.9	56.4	2.10	787	1,282	415	60.8	7.2
Irrigation at 150% CPE	2.62	3.93	40.1	61.0	2.27	921	1,418	436	61.2	6.7
SEm±	0.04	0.07	0.59	1.52	0.06				0.74	0.19
CD (P=0.05)	0.15	0.25	NS	4.97	0.19				2.90	0.64
Weed management practices										
Pendimethalin @ 1.0 kg/ha	2.18	3.29	39.8	47.5	1.89	811	1,306	424	51.3	5.9
Bispyribac sodium @ 35 g/ha	2.59	3.89	40.0	58.5	2.10	811	1,306	406	63.8	7.3
Pendimethalin @ 1.0 kg/ha fb Bispyirbac sodium @ 35 g/ha	3.67	5.55	39.8	92.2	3.12	811	1,306	387	94.7	11.5
Brown manuring + 2, 4-D @ 0.8 kg/ha	2.25	3.40	39.7	49.4	1.93	811	1,306	409	54.9	6.1
Control	1.57	2.30	40.7	29.6	1.26	811	1,306	457	34.5	3.6
SEm±	0.05	0.07	0.78	1.67	0.06				1.15	0.22
CD (P=0.05)	0.15	0.21	NS	4.74	0.18				3.37	0.63

Price of paddy (average): ₹31,000/t; WR, water requirement; CU, Consumptive use; CPE, cumulative pan evaporation

unit area (Table 2). The minimum yield and yield attributes in unweeded check were the result of severe weed competition. Maity and Mukherjee (2008) and Sharma *et al*. (2007) also reported similar results.

Economics: Maximum net returns and benefit: cost (B:C) ratio were recorded under irrigation applied at 150% CPE (Table 3), being significantly higher than that of 75% CPE and remained statistically at par with irrigation at 100% CPE. The higher net returns might be owing to higher yield. Among the weed-management practices, application of pendimethalin 1.0 kg/ha fb bispyribac sodium 35 g/ha resulted in the maximum net returns and benefit: cost ratio than other treatments of weed-management practices. The lowest net returns and benefit: cost ratio obtained in weedy check were due to high infestation of weeds resulting in low weed-control efficiency. These results are in conformity with those reported by Sharma *et al.* (2007) and Jayprakash and Wahab (1995).

Water-use efficiency: The consumptive use (CU) of water and water requirement (WR) were found increased with increasing level of water application but significantly higher water-use efficiency was noticed at 100% CPE (Table 3), being at par with irrigation at 150% CPE. However, maximum water productivity was registered at 100% CPE. This indicated that application of water at 100% CPE was sufficient for obtaining maximum yield of rice grown in direct-seeded conditions. Maheswari *et al*. (2007) reported similar results in rice.

Consumptive use of water, water-use efficiency and water productivity were positively influenced by weed-management practices (Table 3). Maximum WUE, water productivity and minimum CU of water were recorded with pendimethalin 1.0 kg/ha fb bispyribac sodium 35 g/ha. However, pendimethalin 1.0 kg/ha and brown manuring remained on a par with each other. This was mainly owing to higher grain production and ultimately net returns/unit of water applied. The results confirm the findings of Rao *et al*. (2007).

It was concluded that direct-seeded rice can be successfully grown in South-Eastern Rajasthan by scheduling of irrigation at 100% cumulative pan evaporation, which resulted in the best performance of rice in terms of productivity and profitability. For efficient weed-management, pendimethalin @1.0 kg/ha fb bispyribac sodium @ 35 g/ha was found effective in controlling weed in direct-seeded rice.

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