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Research Paper

Energetics, productivity and weed control in different rice (*Oryza sativa*) establishment methods in North-Western Indo-Gangetic Plains

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ABSTRACT

A field experiment was conducted at Punjab Agricultural University, Ludhiana (Punjab) during the rainy (*kharif*) season of 2009 and 2010, to study the effect of various establishment methods and weed-control treatments on weeds, crop growth, yield attributes and yield of rice (*Oryza sativa* L.). The experiment was laid out in a split-plot design with 5 establishment methods, i.e. dry-seeding with 3 different drills–zero till drill, modified furrow drill, conventional seed-cum-fertilizer drill in unpuddled soil, wet–seeding or manual broadcast in puddled soil and manual transplanting in puddled soil, and 4 weed-control treatments, viz. pre-emergence application of pendimethalin 0.75 kg/ha, sequential application of pendimethalin 0.75 kg/ha and bispyribac 0.025 kg/ha or azimsulfuron 0.02 kg/ha and weed-free in 4 replications. Weed biomass at harvesting, effective tillers and grain yield did not vary significantly among different establishment methods. At 60 days after sowing, 27% more plant height, 5.6% more number of tillers and 49% more crop biomass were recorded under direct seeding methods than transplanting method. More net returns (₹36,660/ha) and energy output: input ratio (5.04) were recorded under dry seeding methods than wet seeding (₹28,792/ha and 4.24) and puddled transplanted method (₹27,305/ha and 4.47). The maximum grain yield (6.7 t/ha) was recorded under weed-free treatment which was statistically at par with sequential use of pendimethalin 0.75 kg/ha with bispyribac 0.025 kg (6.6 t/ha) or azimsulfuron 0.02 kg/ha (6.5 t/ha). Sequential application of pre- and post-emergence herbicides resulted in more benefit: cost ratio (1.66) and energy output: input ratio (5.32).

Key words : Direct-seeded rice, Energetics, Economics, Transplanted rice, Weed control

India has to increase its rice productivity by 3% per annum to sustain present food self-sufficiency and to meet future food requirements (Thiyagarajan and Selvaraju, 2001). Growing more food with the same production costs or even reduced costs and sustaining the quality of the natural resource base are the major concerns (Kumar and Ladha, 2011). Manual transplanting in standing water after puddling is the dominant method of rice establishment in the rice-wheat growing areas of the Indo-Gangetic Plains. Repeated puddling damaged the soil structure and health (Kukal and Aggarwal, 2003) which adversely affects the soil productivity (Singh *et al.,* 2005) and can negatively affect the growth and yield of succeeding upland crops in rotation (Tripathi *et al.,* 2005). Transplanting is labour intensive and labour shortage at the time of transplanting is of major concern. There is dire need for change in rice establishment methods to improve productivity, economics and long-term sustainability. Direct-seeded rice (DSR) is a cost effective alternative and it gives similar yields under good weed and water-management practices. The major forces driving the spread of direct-seeding are the availability of chemical methods of weed control, the increasing scarcity of water and its rising cost, and less availability of farm labour. According to Pandey and Velasco (2005), depending on water and labour scarcity, farmers are changing either their rice-establishment methods only (from transplanting to direct-seeding in puddled soil [Wet-DSR]) or both tillage and rice establishment methods (puddled transplanting to dry direct seeding in unpuddled soil [Dry-DSR]). Zero till drill is conventionally used for growing wheat in no-till system and this drill must be evaluated for sowing of rice also. Modified furrow drill is also used for sowing of direct-seeded rice on ridges. It drills the seeds on each slope of ridge (two rows per ridge) with alternate furrows and ridges and has inclined plate mechanism as seed metering system. Conven-

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tional seed-cum-fertilizer drill used for dry seeding of rice has inclined plate seed-metering device and it places seeds and fertilizer on flat surface. Rao *et al.* (2007) reported that in absence of weed control, rice yields are reduced by 35–100% in direct-seeded system. Use of various herbicides with wide-spectrum weed-control ability for efficient and economical weed management is also crucial for improving the potential of direct seeding of rice in the state. Keeping this in view, an experiment was conducted to study the effect of different establishment techniques with weed-control treatments on weeds, crop growth and productivity of rice.

MATERIALS AND METHODS

The field experiment was conducted at Department of Agronomy, Punjab Agricultural University, Ludhiana (India) during the rainy (*kharif*) season of 2009 and 2010. The experimental site is situated in Trans-Gangetic Agro-Climatic zone, representing the Indo-Gangetic Alluvial plains at (30°56' N, 75°52' E and 247 m above mean sea-level). The maximum temperature remained above 38°C during crop season. The total rainfall of 818 and 627.6 mm were received during 2009 and 2010 respectively. Most of the rainfall was received during vegetative phase from 23rd (sowing time) to 35th standard meteorological week (80 days after sowing). The soil was loamy sand (coarse loamy, mixed hyperthermic, Typic Ustipsamments) having normal soil reaction with *p*H of 7.5 and electrical conductivity of 0.16 dS/m. The soil was low in organic carbon (0.31%) and available nitrogen (251.7 kg/ha), medium in available phosphorus (13.5 kg/ha) and available potassium (164.1 kg/ha). The experiment was laid out in split-plot design with 4 replications comprising of 5 crop-establishment methods in main plots and 4 weed-control treatments in subplots. Rice was direct-seeded with zero till drill (ZTD–direct seeding with ZTD), direct seeded with modified furrow drill (MFD–direct seeding with MFD), direct seeded with conventional seed-cum-fertilizer drill (direct seeding with CD), i.e. 3 dry-DSR techniques along with wet-DSR, i.e. broadcasting seed in puddled soil and conventional manual transplanting of nursery in puddled field conditions. Weed-control treatments comprising pendimethalin 0.75 kg/ha as pre-emergence alone and with follow-up application of bispyribac 0.025 kg or azimsulfuron 0.02 kg/ha and weed-free. At the used seed rate of 35 kg/ha, problem of seed breakage (5–6%) was observed in zero-till drill which was taken care of while calibration of drill. The field was levelled with laser-land leveller to allow drills to place seeds at a uniform distance and depth. Rice cv. 'PAU 201' was dry-seeded in the first week of June by using seed rate of 35 kg/ha at 20-cm-row spacing with different drills. In wet-DSR, primed seed was broadcast in puddled field (wet seeding) and suspended mud is allowed to settle down and form a protective cover over the seeds sown. For puddled transplanted rice method, nursery was raised by sowing on the date of direct seeding and 30-day old seedlings were transplanted manually at 20 cm × 15 cm spacing in puddled field. Pendimethalin was sprayed within 2 days after sowing with knap-sack sprayer using 500 litres/ha water. Post-emergence herbicides, i.e. bispyribac sodium and azimsulfuron, were applied with knap-sack sprayer fitted with flat-fan nozzle using 375 litres/ha of water 30 days after sowing (DAS) in direct-seeded plots and 30 days after transplanting or 60 DAS in puddled transplanting method. Weed-free plots were kept free from weeds by hand-weeding as and when required. Nitrogen (187.5 kg/ha N) was applied as broadcast in 4 equal splits – 2, 4, 7 and 10 weeks after sowing. Full dose of phosphorus (30 kg/ha), potassium (30 kg/ha) and zinc sulphate heptahydrate (62.5 kg/ha) were applied at the time of seed-bed preparation by broadcasting. The direct-seeded rice were kept moist for first 2 weeks with light irrigation after sowing was completed and during these days irrigation was applied at 2 days interval. Thereafter, irrigation was applied at 3–5 days intervals to avoid water stress to the crop. Irrigation was stopped 15 days before harvesting of the crop. The data on weed population, weed biomass, plant height, number of tillers, crop biomass and number of grains/panicles were recorded. The crop was harvested manually from net plot of 8 m × 0.80 m (= 6.4 m^2) in the first week of November. On the basis of existing price of the inputs and outputs, variable cost of cultivation and gross returns was calculated. Benefit: cost ratio was worked out by dividing net returns with variable cost. All inputs in the form of labour, machinery, fuel, fertilizer, seed, pesticide, irrigation, harvesting and threshing were taken into consideration with use of energy-conversion factors for calculating the input energy. The grain yield was also converted into energy in terms of energy output (MJ). Energy equivalent of each parameter was calculated using the energy conversion factors as suggested by Devasenapathy *et al.* (2009). The data were statistically analyzed using statistical procedures as prescribed by Cochran and Cox (1967). Pooled analysis of 2 years was done and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Effect of establishment methods and weed control on weeds

Weed flora of the experimental field consisted of grasses, viz. *Echinochloa crus-galli* (L.) Beauv. and *Echinochloa colona* L., and sedges, viz. *Cyperus iria* L., *Cyperus difformis* L. At 60 DAS, weed data were recorded from dry-DSR and wet-DSR only, because in puddled transplanted rice-establishment method, post-emergence application of bispyribac 0.025 kg and azimsulfuron 0.02 kg/ha was done at that time. Similar number of *Cyperus* and *Echinochloa* was observed in dry-DSR and wet-DSR crop, resulting in statistically similar weed biomass accumulation at 60 DAS (Table 1). At the time of harvesting, weed biomass was not affected by the different establishment techniques (Table 2). *Cyperus* spp. was completely controlled with sequential application of pendimethalin 0.75 kg/ha as pre-emergence and post-emergence application of bispyribac 0.025 kg or azimsulfuron 0.02 kg/ha and weed-free treatment (Table 1). This showed that *Cyperus* spp. could not be controlled with pendimethalin which recorded 58 plants/m^2. Sequential application of bispyribac and azimsulfuron at 30 DAS effectively controlled the sedges. Weed-free and follow-up application of bispyribac 0.025 kg/ha controlled *Echinochloa* spp., whereas pre-emergence application of pendimethalin 0.75 kg/ha applied as alone or followed by azimsulfuron 0.02 kg/ha did not control this weed. This revealed that azimsulfuron herbicide could not control *Echinochloa* spp. Yadav *et al.* (2009) also reported that application of azimsulfuron @ 0.030 kg – 0.040 kg/ha at 15 and 25 DAS was not found effective against *Echinochloa* spp. but proved effective against sedges. Weed biomass was the maximum in alone application of pendimethalin 0.75 kg/ha applied as pre-emergence and was followed by sequential application of pendimethalin and azimsulfuron. At harvesting, weed biomass was found statistically similar with that reported with application of pendimethalin 0.75 kg applied as pre-emergence either alone or followed by azimsulfuron 0.02 kg/ha but was significantly more than that recorded with weed-free treatment and application of pendimethalin 0.75 kg as pre-emergence followed by post-emergence application of bispyribac 0.025 kg/ha (Tables 2, 3) in which weed biomass was nil at harvesting. This might be due to more weed pressure under these treatments.

Effect of establishment methods on crop growth and yield

At 60 DAS, rice crop was significantly taller with direct seeding (dry-DSR and wet-DSR methods) as compared with puddled transplanted method (Table 1), and more crop biomass was recorded. This was due to absence of transplanting shock in DSR methods, whereas it was experienced by the plants in puddled transplanted method. Dry-DSR produced significantly more tillers than wet-DSR followed by conventional puddled transplanted crop (Table 1). Gill *et al.* (2006) also reported that direct seeded rice produced significantly more biomass than that with the transplanted rice owing to more plants per unit area in

Table 1. Effect of crop-establishment methods and weed control on weeds and crop growth 60 days after sowing of rice (mean data of 2 years)

Treatment	Weed count/m^2		Weed biomass (g/m^2)	Plant height (cm)	Tillers/m^2	Crop biomass (g/m^2)
	Echinochloa spp.	*Cyperus* spp.				
Establishment methods						
Direct seeding with ZTD	1.6 (2)	2.5 (15)	5.7 (54)	61.9	278.0	509.8
Direct seeding with MFD	1.6 (2)	2.4 (14)	5.6 (53)	63.1	279.0	509.7
Direct seeding with CD	1.6 (2)	2.5 (14)	5.7 (54)	60.3	278.1	513.4
Puddled broadcast	1.6 (2)	2.5 (15)	5.8 (58)	61.1	259.7	468.8
Puddled transplanted	-	-	-	48.2	259.0	335.6
SEm±	0.03	0.03	0.2	1.2	5.8	16.5
CD (P=0.05)	NS	NS	NS	3.5	17.0	48.3
Weed control treatment						
Pendimethalin 0.75 kg/ha	2.2 (4)	6.9 (58)	11.2 (126)	58.4	180.2	335.5
Pendimethalin 0.75 kg/ha *fb* bispyribac 0.025 kg/ha	1.0 (0)	1.0 (0)	1.0 (0)	58.8	300.8	509.9
Pendimethalin 0.75 kg/ha *fb* azimsulfuron 0.02 kg/ha	2.2 (4)	1.0 (0)	9.6 (93)	59.2	297.1	510.3
Weed-free	1.0 (0)	1.0 (0)	1.0 (0)	59.2	304.9	514.1
SEm±	0.03	0.03	0.1	0.6	4.5	9.4
CD (P=0.05)	0.1	0.1	0.5	NS	12.6	26.4
Interaction	NS	NS	NS	NS	NS	NS

ZTD, Zero-till drill; MFD, modified furrow drill; CD, conventional seed-cum-fertilizer drillData were square root transformed and values in the parentheses are original values; *fb*, denotes followed

DSR as compared with transplanted rice. In wet-DSR, uneven crop stand due to broadcasting and lower emergence count (due to bird damage) might be the reason for 7.2% lower tiller count and 9.0% lower crop biomass than dry-DSR methods. However at harvesting, the number of tillers was at par with each other among different direct seeding methods (Table 2). Although 8.7% more tillers were observed in directly sown crop, higher number of tillers and vigorous plant growth resulted in intra-plant competition which ultimately resulted in to more tiller mortality and thus resulted in statistically similar number of effective tillers. Numerically, 6.4% more effective tillers were observed in dry-DSR than conventional transplanting method. Our results confirm the findings of Saharawat *et al.* (2010) who reported 9% higher effective tillers in direct drilled rice than transplanting method.

Grains/panicle in puddled transplanting rice was more than direct-seeded rice, as spikelet number is the linear function of plant nitrogen concentration at panicle-formation stage and a curvilinear function of crop biomass. The higher panicle density and excessive vegetative growth of direct-seeded rice might have influenced the nitrogen dilution during reproductive stage leading to hindrance in spikelet differentiation stage, resulting in 11% less grains/panicle in direct-seeding methods. These results are in line with those reported by Saharawat *et al.* (2010) that number of grains/panicle was 9% less in direct-seeded than with transplanted rice. The 8% more grain and 5% more straw yield were observed in dry-DSR than wet-DSR. Dry-DSR and wet-DSR methods resulted in significantly more straw yield than puddled transplanted method, but grain yield was similar under different crop-establishment methods (Table 3). This significant effect of different direct-seeding techniques on straw yield may be owing to the significantly more number of tillers and crop biomass in direct-seeding techniques than puddled transplanting method. These results confirm those of Bhullar *et al.* (2012), who reported that rice drilled directly in moist seed bed or in dry soil followed by irrigation and broadcast with or without puddling recorded grain yield at par to puddled transplanting method. However, in contrary, Walia *et al.* (2009) reported that broadcasting dry seed in puddled field recorded the highest yield as compared with direct seeding using conventional drill and zero drill and broadcasting seeds without puddling and transplanting paddy with nursery sown at the time of direct sowing of the crop.

Effect of weed control on crop growth and yield

Significantly lower number of tillers was recorded with pendimethalin 0.75 kg/ha as compared with all the other weed control treatments. Pendimethalin provided effective control of weeds for initial 15–20 days only and afterwards crop suffered huge competition thereby resulting in 67.0% lower tiller number at 60 DAS. More number of

Table 2. Effect of crop-establishment methods and weed control on weeds, yield attributes and yield of rice (mean data of 2 years)

Treatment	Final plant height (cm)	Tillers/m^2	Effective tillers/m^2	Weed biomass (g/m^2) at harvest	Grains/ panicle (Nos.)	Grain yield (t/ha)	Straw yield (t/ha)
Establishment method							
Direct seeding with ZTD	94.0	296.0	276.0	13.0 (320)	89.3	5.90	13.42
Direct seeding with MFD	97.7	299.1	278.4	12.9 (318)	92.0	5.98	13.47
Direct seeding with CD	93.0	296.9	281.0	13.0 (319)	89.0	6.03	13.41
Puddled broadcast	92.7	281.6	260.6	13.2 (332)	90.1	5.49	12.82
Puddled transplanted	93.3	269.9	261.6	12.8 (311)	100.4	6.05	9.68
SEm±	2.2	6.7	6.5	0.2	3.7	0.15	0.20
CD (P=0.05)	NS	19.7	NS	NS	NS	NS	0.60
Weed control treatment							
Pendimethalin 0.75 kg/ha	92.3	238.9	219.7	24.8 (631)	82.5	3.80	8.91
Pendimethalin 0.75 kg/ha *fb* bispyribac 0.025 kg/ha	96.0	303.9	286.6	1.0 (0)	95.0	6.60	13.66
Pendimethalin 0.75 kg/ha *fb* azimsulfuron 0.02 kg/ha	93.9	302.5	283.5	25.1 (649)	94.3	6.47	13.70
Weed-free	94.5	309.4	296.4	1.0 (0)	96.9	6.69	13.96
SEm±	1.0	5.1	5.5	0.2	1.6	0.10	0.17
CD (P=0.05)	NS	14.4	15.5	0.7	5.3	0.28	0.50
Interaction	NS	NS	NS	NS	NS	NS	S

ZTD, Zero-till drill; MFD, modified furrow drill; CD, conventional seed-cum-fertilizer drill

Data were square root transformed and values in the parentheses are original values; *fb*, denotes followed tillers were reported under weed-free and sequential application of pre- and post-emergence herbicides than alone pre-emergence herbicide application (Table 1), resulting in 52.4% more crop biomass. Sequential application of pendimethalin and bispyribac or azimsulfuron and weed-free treatments created favourable environment for crop to grow and resulted in 29.7% more number of effective tillers and 15.6% more grains/panicle than alone application of pendimethalin. The maximum number of effective tillers and grains/panicle were obtained under weed-free treatment and was found at par with sequential application of pendimethalin 0.75 kg/ha applied as pre-emergence followed by bispyribac 0.025 kg or azimsulfuron 0.02 kg/ha. The maximum grain yield was obtained where sequential application of pre- and post-emergence herbicides were done or under weed-free treatment and increase was to the magnitude of 73.7% than single application of pre-emergence herbicide. Straw yield also followed the similar pattern. These results are in conformity with the findings of Mahajan *et al.* (2009), Walia *et al.* (2009) and Kaur and Singh (2015), where they used either pre- and post-emergence herbicides or used integrated weed-management methods, and rice grain yield was significantly more than that of single use of herbicide.

Economics and energetics

The benefit accrued was more in case of dry-DSR methods than that wet-DSR method and manual transplanting in puddled field (Table 4). The lower benefit: cost ratio in conventional puddled transplanted was due to higher variable cost (labour charges) incurred in this practice which resulted in lower net returns than that in direct-seeded rice. The gross returns were more or less similar in all crop establishment methods. Amongst the weed-control methods, sequential application of pre- and post-emergence herbicides resulted in more benefit: cost ratio (1.62 and 1.71 for bispyribac and azimsulfuron respectively) as compared to weed-free (1.11) and alone application of pre-emergence herbicide (0.61). These results confirm the findings of Kaur and Singh (2015). The lower benefit: cost ratio under weed-free treatment was due to more variable cost (labour charges because of repeated hand-weedings) involved, whereas in alone application of pendimethalin, low gross returns obtained were the reason for lower benefit: cost ratio. Energy output: input ratio or energy-use efficiency (EUE) and energy productivity of dry-DSR establishment methods were more than wet-DSR and PTR, may be owing to less energy used in dry-DSR production system. To produce 1 tonne of grain yield, more energy was required in under DSR and PTR leading to high specific energy than dry-DSR methods. Both DSR production systems (dry-DSR and wet-DSR) appeared to be more energy intensive compared to PTR and results were contrary to EUE. The EUE and energy productivity were more when sequential application of pendimethalin 0.75 kg/ha with bispyribac 0.025 kg or azimsulfuron 0.02 kg/ha

Table 3. Interaction effect of crop-establishment methods and weed control on weeds and yield of rice (mean data of 2 years)

Weed-control treatment	Establishment methods				
	Direct seeding with ZTD	Direct seeding with MFD	Direct seeding with CD	Puddled broadcast	Puddled transplanted
			Weed biomass at harvest (g/m^2)		
Pendimethalin 0.75 kg/ha	24.8 (626)	24.8 (630)	24.7 (624)	25.3 (654)	24.6 (622)
Pendimethalin 0.75 kg/ha *fb* bispyribac 0.025 kg/ha	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Pendimethalin 0.75 kg/ha *fb* azimsulfuron 0.02 kg/ha	25.2 (655)	24.9 (641)	25.1 (652)	25.2 (675)	24.6 (622)
Weed free	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
CD (P=0.05)			NS		
			Grain yield (t/ha)		
Pendimethalin 0.75 kg/ha	3.818	3.936	3.801	3.422	4.064
Pendimethalin 0.75 kg/ha *fb* bispyribac 0.025 kg/ha	6.557	6.617	6.840	6.258	6.743
Pendimethalin 0.75 kg/ha *fb* azimsulfuron 0.02 kg/ha	6.415	6.553	6.677	6.053	6.684
Weed free	6.814	6.840	6.831	6.260	6.712
CD (P=0.05)			NS		
			Straw yield (t/ha)		
Pendimethalin 0.75 kg/ha	9.406	9.742	9.667	8.401	7.372
Pendimethalin 0.75 kg/ha *f.b.* bispyribac 0.025 kg/ha	15.031	14.667	14.500	14.120	9.992
Pendimethalin 0.75 kg/ha *f.b.* azimsulfuron 0.02 kg/ha	14.818	14.768	14.672	14.276	10.005
Weed-free	14.432	14.724	14.802	14.484	11.385
CD (P=0.05)		1.121			

Weed data was square root transformed and values in parenthesis are original values; fb denotes followed by.

Table 4. Effect of crop-establishment methods and weed control on economics and and energy use in rice (mean data of 2 years)

Treatment	Net returns (₹/ha)	Benefit: cost ratio	Energy output-input ratio	Energy productivity (kg/MJ)	Specific energy (MJ/t)	Energy intensiveness (MJ/₹)
Establishment method						
Direct seeding with ZTD	35,898	1.45	4.98	0.34	3,138.8	0.71
Direct seeding with MFD	36,780	1.49	5.05	0.34	3,077.6	0.71
Direct seeding with CD	37,300	1.51	5.09	0.35	3,080.4	0.71
Puddled broadcast	28,792	1.07	4.24	0.29	3,756.4	0.71
Puddled transplanted	27,305	0.78	4.47	0.30	3,459.6	0.57
Weed control treatment						
Pendimethalin 0.75 kg/ha	14,169	0.61	3.08	0.21	4,834.9	0.75
Pendimethalin 0.75 kg/ha *fb* bispyribac 0.025 kg/ha	41,567	1.62	5.37	0.37	2,768.1	0.69
Pendimethalin 0.75 kg/ha *fb* azimsulfuron 0.02 kg/ha	41,350	1.70	5.27	0.36	2,817.8	0.74
Weed-free	35,774	1.11	5.33	0.36	2,789.4	0.56

ZTD, Zero-till drill; MFD, modified furrow drill; CD, conventional seed-cum-fertilizer drill
Data were square root transformed and values in the parentheses are original values; *fb*, denotes followed

was done for weed control compared to single use of pre-emergence herbicide. Sequential application of pre- and post-emergence herbicides led to lesser specific energy and energy intensiveness than single pre-emergence herbicide application.

Thus, labour-intensive and costly method of transplanting could be substituted by direct-seeding with no sacrifice in productivity if effective weed control is possible. Rice can be direct seeded with zero-till drill, modified furrow drill- and conventional drill fitted with inclined plate metering device as seed-metering mechanism. Pre-emergence application of pendimethalin 0.75 kg/ha provides effective control of most of annual grasses and broad-leaf weeds for initial 15–20 days. Weeds that emerge later can be effectively controlled with application of post-emergence herbicides (bispyribac 0.025 kg or azimsulfuron 0.02 kg/ha, depending on weed flora) 30 days after sowing. There is need to identify niche areas where DSR technology will work well such as medium-textured soils with assured water availability.

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