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Labor-Saving Weed Technologies for Lowland Rice Farmers in sub-Saharan Africa

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Time requirements, weed control efficacy, and yield effects of three labor-saving weed technologies were tested against hand weeding during three seasons in 2012 and 2013. The technologies included two hand-operated mechanical weeders, the straight-spike and the twisted-spike floating weeder, and the PRE application of oxadiazon. The straight-spike floating weeder reduced weeding time by 32 to 49%, the twisted-spike floating weeder reduced weeding time by 32 to 56%, and the application of herbicide required 88 to 97% less time than hand weeding. Herbicide application provided the best weed control in two of the three seasons. No differences in weed control efficacy were observed between mechanical and hand weeding. Yield differences were only observed in season 3 with higher rice yields after PRE application of oxadiazon compared with other weed management treatments.
Nomenclature: Oxadiazon; rice, *Oryza sativa* L.
Key words: Chemical weed control, hand weeding, irrigated lowland, mechanical weed control, small-scale farming.

Los requisitos de tiempo, la eficacia del control de malezas, y los efectos en el rendimiento de tres tecnologías para reducir las labores manual fueron evaluados en comparación con la deshierba manual durante tres temporadas productivas en 2012 y 2013. Las tecnologías incluyeron dos cultivadores mecánicos operados manualmente, el cultivador flotante de picos rectos, el cultivador flotante de picos curvados, y la aplicación PRE de oxadiazon. El cultivador flotante de picos rectos redujo el tiempo de deshierba de 32 a 49%, el cultivador flotante de picos curvados redujo el tiempo de deshierba de 32 a 56%, y la aplicación de herbicidas requirió 88 a 97% menos tiempo de deshierba manual. La aplicación de herbicidas brindó el mejor control de malezas en dos de las tres temporadas. No se observaron diferencia en la eficacia en el control de malezas entre la deshierba mecánica y la manual. Las diferencias en el rendimiento fueron solamente observadas en la tercera temporada con mayores rendimientos del arroz después de la aplicación PRE de oxadiazon al compararse con los otros tratamientos de manejo de malezas.

Rice is a widely grown crop in sub-Saharan Africa (SSA), and a staple food with an increasing importance for food security (Seck et al. 2012). The crop is grown under rain-fed upland, rain-fed lowland, and irrigated lowland conditions. Rain-fed and irrigated lowlands comprise 64% of the total area under rice in SSA and cover 73% of the total production (Diagne et al. 2013).

Average rice yields obtained in SSA are estimated at 1.9 t ha^{-1} in rain-fed and 2.2 t ha^{-1} in irrigated lowlands (Diagne et al. 2013). Weeds are the most important biotic factors reducing lowland rice yields in SSA (Nhamo et al. 2014; Seck et al. 2012). Weed competition reduces the total annual rice production in SSA by an estimated 2.2 million tons, costing these economies approximately 1.5 billion U.S. dollars per year (Rodenburg and Johnson 2009). In rain-fed and irrigated lowland rice in Africa, the estimated yield loss despite control is 15 to 23% (Becker and Johnson 2001; Becker et al. 2003; Haefele et al. 2000). This is because of the weak competitiveness of rice (van Heemst 1985) and suboptimal weed management practices. The most common weed management practice in small-scale rice farming in SSA is hand weeding. Manual weed control is, however, extremely energy and time consuming (Akobundu 1987; Akobundu and Fagade 1978; Lodin-Bergman et al. 2012; Ogwuike et al. 2014). Small-scale farmers often lack such

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time, or external labor, to perform weeding adequately (Kremer and Lock 1993). Although herbicides are known to be labor saving (Lawrence and Dijkman 1997), the relative high costs limit their use. Herbicides cost around U.S. \$22 ha^{-1} $season^{-1}$. Efficient, affordable and labor-saving weed management technologies are a necessity for rice farmers in Africa (Rodenburg and Johnson, 2009).

One such labor-saving option for lowland rice is the use of mechanical weeders, also known as rotary weeders. The most common types in SSA are the straight-spike and the twisted-spike floating weeders. The straight-spike floating weeder is an Asian model introduced in a few countries in SSA like Burkina Faso (Gongotchame et al. 2014), and the twisted-spike floating weeder is widely used in Madagascar. In Madagascar it costs approximately U.S. \$23 $unit^{-1}$. Rotary weeders are not widely and reliably available at markets in SSA outside Madagascar yet (Ndiiri et al. 2013).

Although such weeders were favorably assessed in terms of weed management and rice yields in Senegal (Krupnik et al. 2012) and India (Senthilkumar et al. 2008, 2011), they are still a novelty in most countries in SSA (Gongotchame et al. 2014). The time savings of rotary weeders have not been thoroughly researched.

The objective of this study was to evaluate the efficacy and time requirement of three labor-saving weed technologies for lowland rice. The technologies included two mechanical weeders and one PRE herbicide, and were tested against hand weeding.

Materials and Methods

A field study was conducted at the IRRI-AfricaRice experimental irrigated lowland rice farm in Bagamoyo, Tanzania (6.47°S, 38.83°E) for three consecutive seasons. The first season is April 13 to July 31, 2012, the second is August 24 to December 31, 2012, and the third is March 1 to June 10, 2013. Each season represented a repeat of the same experiment.

The experiment comprised a randomized complete block design with four replications and an individual plot size of 6 by 8 m for each of the four treatments. The four treatments were: (1) hand-weeding at 21 and 42 d after transplanting (DAT); (2) weeding with the twisted-spike floating weeder at 21 and 42 DAT (Figure 1A); (3) weeding with the straight-spike floating weeder at 21 and 42 DAT (Figure 1B); and (4) PRE application of oxadiazon (Ronstar 25 EC, 250 g ai L^{-1}, Bayer Ltd.) at 4 DAT at a rate of 0.65 kg ai ha^{-1}, followed by hand-weeding at 42 DAT.

The rotary weeders passed in one direction, hence only between the crop rows. Each time a plot was weeded with one of the rotary weeders, it was followed by hand-weeding within the crop rows to remove the weeds that were missed by the weeder. The herbicide was applied with a 16-L hand-pumped knapsack sprayer at an equivalent of 220–L ha^{-1} spray solution, with the use of a 14-mm flat-fan nozzle with a spray pressure of 140 kPa.

Land preparation, including moldboard plowing to a depth of 10 to 15 cm and peg tooth harrowing of the top 5 to 10 cm, was done with a 6.5 HP power tiller. This was followed by wet leveling, whereby a wooden plank loaded with weights was manually pulled over the saturated soil in two directions. At transplanting all the plots were weed free. Rice seed was planted in a 3 by 6–m nursery bed in a field adjacent to the study site, at a rate of 200 kg ha^{-1}. At 21 d after emergence, seedlings were transplanted into 25-cm spaced rows. Within each row two rice plants were planted on 15-cm spacing. The rice variety was TXD 306, known as SARO-5 (Nhamo et al., 2014).

Continuous flooding started at 2 DAT in the manual and mechanical weeding treatments and at 8 DAT in the herbicide treatment, 4 d after herbicide application. The targeted flood layer depth was 5 to 10 cm. Because of regular pump breakdowns during season 1 and 2, the flood layer frequently dropped below 5 cm. A compound fertilizer (17 : 17 : 17 of $N : P_2O_5 : K_2O$) was applied at a rate of 200 kg ha^{-1} at 4 to 5 DAT. An additional 60 kg N ha^{-1} was top dressed as urea (46% N) at a rate of 130 kg ha^{-1}, in equal splits of 65 kg ha^{-1} at 21 and 42 DAT, following the weeding operations.

At 21 and 42 DAT, all aboveground weed biomass was sampled from two 1.25 by 1.5 m sampling areas in each plot. The sampled weed biomass was oven dried at 70 C for 48 h for dry-weight assessments. This destructive weed sampling was always done prior to manual or mechanical weeding operations. In addition, based on visual coverage assessments, weed species were ranked and

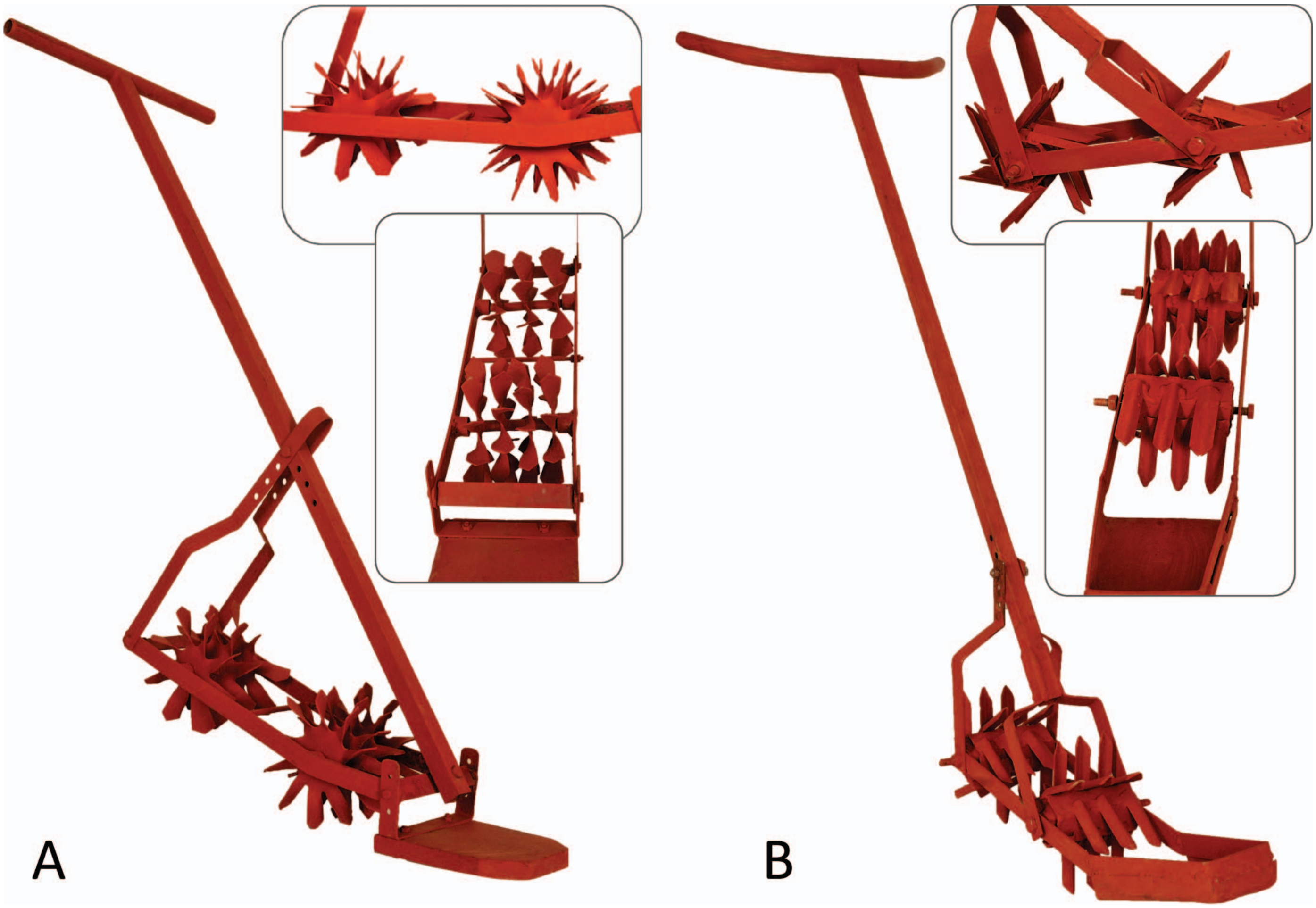

Figure 1. View of the twisted-spike floating weeder, with details of the weeder drum in the right-hand upper corner (A) and the straight-spike floating weeder, with details of the weeder drum in the right-hand upper corner (B). Source: AfricaRice. (Color for this figure is available in the online version of this article.)

the names of the five most abundant species were recorded. This was done just prior to destructive sampling at 42 DAT, from the same two 1.25 by 1.5–m weed sampling areas, and just prior to rice harvest, from the central 3.0 by 3.75–m rice yield assessment areas, in each plot.

For each plot area of 48 m^2, the labor requirements for all weed management operations were timed with the use of stopwatches. This included follow-up hand-weeding after rotary-weeder interventions and herbicide application and any time lost by cleaning of clogged weeder teeth and overcoming other impediments during the operations. Any handling prior to and after the weeding operations, like herbicide mixing and cleaning of material, was not timed. Herbicide application was performed by one person, weeding by hand and by the rotary weeders was performed by two persons. For each weeding operation the same person was assigned for the whole study, in order to avoid a bias due to differences in individual efficiencies.

At rice grain maturity, all rice panicles belonging to plants from the central 3 by 3.75–m area in each plot were hand cut for yield assessment. Panicles were air-dried for a week, then threshed and sorted, removing chaff and empty grains. Grain weights and grain moisture contents were assessed with the use of a digital grain moisture meter (SATAKE, Moistex Model SS-7, Satake Eng. Co., Tokyo, Japan), to enable correction of grain yield weights to 14% moisture content. The second season's experiment failed due to a heavy rice yellow mottle Virus (RYMV) outbreak, and therefore only data from the first weed sampling and weeding were collected.

Table 1. Frequency of appearance of weed species in the top five most dominant species, per weed management treatment (hand-weeding, straight-spike floating weeder, twisted-spike floating weeder, and PRE oxadiazon) based on observations in an experiment at Bagamoyo, Tanzania from April to July 2012 (season 1) and March to June 2013 (season 3). Values represent the percent of appearance of a species in the top five most abundant species, based on visual assessments, whereby observations from all four replicates at 42 d after transplanting and at harvest were combined.[a]

	Frequency of appearance in top five most dominant species							
	Season 1				Season 3			
Weed management treatment	Hand weeding	Straight-spike floating weeder	Twisted-spike floating weeder	PRE oxadiazon	Hand weeding	Straight-spike floating weeder	Twisted-spike floating weeder	PRE oxadiazon
Weed species	%							
CYPDI	88	100	88	0	100	100	88	0
SPSSE	100	63	75	13	100	75	88	13
ECLAL	13	38	25	38	88	25	50	38
ECHCO	50	38	50	0	63	38	50	0
SPDZE	38	38	63	0	0	38	25	0
AMMAU	38	13	25	0	38	50	38	0
IPOAQ	25	0	13	13	25	50	25	0
ORYBA	13	25	25	0	25	38	25	0
OCIPO	13	50	25	0	0	0	0	13
LUDLI	25	13	25	0	13	0	13	0
COMDI	13	0	25	13	13	0	0	25
FIMLI	0	50	0	0	0	0	0	0
ALRSE	13	13	13	0	0	0	0	0
CYPHP	13	0	25	0	0	0	0	0
LEFCA	0	0	0	0	13	0	13	13
LIDNU	13	0	0	0	0	13	0	0
BRALA	13	0	0	0	0	13	0	0
PYCTR	0	0	13	0	0	0	13	0

[a] Abbreviations: CYPDI: smallflower umbrella-sedge, *Cyperus difformis* L.; SPSSE: *Sphaeranthus senegalensis* DC.; ECLAL: eclipta, *Eclipta prostrata* (L.) L.; ECHCO: jungle rice, *Echinochloa colona* L. Link.; SPDZE: gooseweed, *Sphenoclea zeylanica* Gaertn.; AMMAU: eared redstem, *Ammania auriculata* Willd.; IPOAQ: swamp morningglory, *Ipomoea aquatica* Forsk.; ORYBA: Barth's rice, *Oryza barthii* A. Chev.; OCIPO: musk basil, *Basilicum polystachyon* (L.) Moench.; LUDLI: seedbox, *Ludwigia hyssopifolia* (G.Don) Exell; COMDI: *Commelina diffusa* Burm. f.; FIMLI: lesser fimbristylis, *Fimbristylis littoralis* Gaudich.; ALRSE: sessile joyweed, *Alternanthera sessilis* (L.) R.Br. ex Roth; CYPHP: haspan flatsedge, *Cyperus halpan* L.; LEFCA: *Leptochloa caerulescens* Steud.; LIDNU: *Lindernia nummulariifolia* (D. Don) Wettst.; BRALA: signalgrass, *Brachiaria lata* (Schumach.) CE Hubbard; PYCTR: white-edge flatsedge, *Pycreus macrostachyos* (Lam.) Raynal.

Total weed management time, weed-biomass dry weight at 21 and 42 DAT, and rice-grain yield data were subjected to ANOVA followed by a comparison of means with Fisher's protected LSD test at 5%, with the use of Genstat 16th Edition, SP1 (VSN-International, 2013). Prior to analyses, data distributions were checked for normality and homogeneity as described by Sokal and Rohlf (1995). Because of a lack of homogeneity of variance between seasons, data were analyzed and presented for each season separately. Measured times were converted in h ha^{-1} person^{-1} for the purpose of statistical analyses as well as for reporting. The data on weed species abundance were analyzed descriptively. The frequency of appearance of weed species in the top five most dominant species, expressed in percent, was calculated for each species and sorted from high to low, with the use of Excel (Microsoft Office 2013).

Results and Discussion

The weed community of the study consisted of 18 weed species across the seasons (Table 1). The five most frequent weed species were smallflower umbrella sedge (*Cyperus difformis* L.), *Sphaeranthus senegalensis* DC., junglerice [*Echinochloa colona* (L.) Link], eclipta [*Eclipta prostrata* (L.) L.], and gooseweed (*Sphenoclea zeylanica* Gaertn.). Compared with the other weed interventions, oxadiazon

Table 2. Weed biomass dry weight at 21 and 42 d after transplanting (DAT) following four weed management treatments, tested in a three-season experiment at Bagamoyo, Tanzania from April to July 2012 (season 1), August to December 2012 (season 2), and March to June 2013 (season 3).[a]

	Weed biomass dry weights				
	Season 1		Season 2[b]	Season 3	
Weed management treatment	21 DAT	42 DAT	21 DAT	21 DAT	42 DAT
	$g\ m^{-2}$				
Hand-weeding	3.0	8.1	0.3	3.1	16.4
Straight-spike floating weeder	3.2	5.1	0.8	3.0	17.5
Twisted-spike floating weeder	3.2	4.7	0.5	3.7	14.3
PRE oxadiazon	0.4	3.6	0.2	< 0.05	< 0.05
P	< 0.001	ns	ns	0.026	< 0.001
$LSD_{0.05}$	1.3			2.5	6.7

[a] Abbreviations: ns, not significant; LSD0.05, least significant difference at P = 0.05.

[b] The second season was interrupted soon after the first sampling, because of a serious rice yellow mottle virus outbreak. Data of this season were therefore only from the first sampling at 21 DAT.

applied PRE was successful for the control of junglerice, gooseweed, eared redstem (*Ammania auriculata* Willd.), seedbox [*Ludwigia hyssopifolia* (G.Don) Exell] and musk basil [*Basilicum polystachyon* (L.) Moench.], confirming previous studies (Chauhan and Johnson, 2011), and also smallflower umbrella sedge was diminished, in particular in the second and third season (Table 1). Oxadiazon was less successful for the control of *Sphaeranthus senegalensis,* eclipta and swamp morningglory (*Ipomoea aquatica* Forsk.), in the first season. The moderate tolerance of eclipta to oxadiazon was previously reported by Johnson (1997).

There were no differences in weed biomass dry weights among the manual and mechanical weeding treatments at any season and time (Table 2). Compared with these treatments, weed biomass at 21 DAT in season 1 and at 21 and 42 DAT in season 3 was lower following oxadiazon applied PRE. The lower weed biomass at 21 DAT in the rice treated with oxadiazon compared with the mechanical or hand-weeded rice was caused by the different timings of the weed interventions; while the herbicide was applied at 4 DAT, the first manual and mechanical weeding operations were performed at 21 DAT, just after this first destructive sampling. No differences were observed among the four treatments in season 2 at 21 DAT. This could be due to overall lower weed pressure compared with season 1 and 3 (Table 2). Low weed pressure may have masked the effect of oxadiazon on weed biomass.

In all three seasons, weeding time was shorter with the rotary weeders and the herbicide application, compared with hand weeding (Table 3). In season 1, hand weeding required 253 h ha^{-1} $person^{-1}$, whereas the straight-spike floating weeder required 172 h ha^{-1} $person^{-1}$, 32% reduction, the twisted-spike floating weeder 150 h ha^{-1} $person^{-1}$, 40% reduction, and the application of herbicide with follow-up hand weeding took only 31 h ha^{-1} $person^{-1}$, hence an 88% reduction. In season 2, with only data until 21 DAT, the time savings compared with hand weeding were 35, 32, and 91%, and in the third season 49, 56, and 97%, respectively. Comparing the two types of rotary weeder, the labor requirements were not different in the first two seasons. In season 3 the twisted-spike floating weeder required less time than the straight-spike floating weeder. The twisted-spike floating weeder appeared easier to operate in season 3 when, by the time of weeding, the flood layer was sufficiently high.

In season 1, there were no yield differences between the weed management treatments, whereas in season 3, the rice treated with oxadiazon had higher yields than any of the other weed management treatments (Table 4). Imeokparia (1994) reported no yield increase with rice treated with oxadiazon, compared with hand weeding. Observed yield increases following PRE application of oxadiazon in season 3 compared with season 1 can be explained with the weed control results presented in Table 2; i.e., in season 3, at 42 DAT the weed

Table 3. Total seasonal time requirements of four weed management treatments, tested in a three-season study at Bagamoyo, Tanzania, from April to July 2012 (season 1), August to December 2012 (season 2) and March to June 2013 (season 3). Weeding times at 4 (herbicide application), 21, and 42 d after treatment (manual and mechanical weeding) were totaled for each weed management treatment and analyzed per season.

Weed management treatment	Season 1		Season 2[a]		Season 3	
	Time	% Reduction[b]	Time	% Reduction	Time	% Reduction
	h ha^{-1} person^{-1}					
Hand-weeding	253	(–)	97	(–)	517	(–)
Straight-spike floating weeder	172	(32)	64	(35)	261	(49)
Twisted-spike floating weeder	150	(40)	67	(32)	233	(56)
PRE oxadiazon	31	(88)	8	(91)	14	(97)
P	< 0.001		< 0.001		< 0.001	
$LSD_{0.05}$[c]	54		9		26	

[a] The second season was interrupted soon after the first weed sampling because of a serious rice yellow mottle virus outbreak. Data of this season were therefore only available up to the first sampling at 21 d after transplanting.

[b] Values in parentheses represent percentage of reduction in time relative to the control treatment, hand weeding.

[c] Abbreviation: $LSD_{0.05}$, least significant difference at $P = 0.05$.

biomass dry weight in the herbicide treatment was still lower than in the manual and mechanical weeding treatments.

The use of rotary weeders for weed control did not show any yield advantage over hand weeding. This result is contrary to the yield advantages following rotary weeding reported by Senthilkumar et al. (2008) in Tamil Nadu, India. However, in that study, rotary weeding was performed five times, at 10-d intervals starting from 10 DAT, and on highly fertile and anaerobic soils.

The correct use of herbicides applied PRE can reduce farmers' time for weed management. However, herbicides are expensive, and costs need to be borne seasonally by the farmer and increase with farm size. Alternatively, weed control can be carried out by using rotary weeders. Such tools can reduce the weeding time by at least a third compared with hand weeding. Although the use of rotary weeders is more time- and energy-demanding than the use of herbicides, the costs for weed control can be considerably reduced as, once purchased, the rotary weeder can serve the farmer for multiple seasons and on multiple farms without any area restrictions. Between the two rotary weeders studied, there can be local differences in ease of operation, related to the water management or the shape, length, arrangement, and number of spikes. The type of rotary weeder should therefore be adapted to local conditions or be selected through local farmer participatory test sessions. The use of a rotary weeder can be combined with any other weed management practices and fits well in integrated crop management strategies. Rotary weeders offer a cost-effective and environmentally benign alternative to herbicides as a labor-saving weed management technology in rice production systems in sub-Saharan Africa.

Table 4. Rice yields following four weed management treatments, tested in a repeated experiment at Bagamoyo, Tanzania from April to July 2012 (season 1), and March to June 2013 (season 3).[a,b]

Weed management treatment	Rice yield	
	Season 1	Season 3
	t ha^{-1}	
Hand weeding	2.0	5.9
Straight-spike floating weeder	1.7	5.7
Twisted-spike floating weeder	1.9	6.1
PRE oxadiazon	2.1	6.8
P	ns[b]	0.021
$LSD_{0.05}$[c]		0.66

[a] The second season was interrupted soon after the first weed sampling at 21 d after transplantingbecause of an outbreak of rice yellow mottle virus.

[b] Abbreviations: ns, not significant; $LSD_{0.05}$, least significant difference at $P = 0.05$.

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