Crop Protection 61 (2014) 32–37

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Participatory evaluation of mechanical weeders in lowland rice production systems in Benin

Sylvestre Gongotchame [a,b], Ibnou Dieng [a], Kokou Ahouanton [a], Jean-Martial Johnson [a], Amakoe Delali Alognon [a], Atsuko Tanaka [a], Sanoussi Atta [b], Kazuki Saito [a,*]

[a] Africa Rice Center, 01 BP 2031 Cotonou, Benin
[b] AGRHYMET Regional Center, BP 11011 Niamey, Niger

A R T I C L E I N F O

Article history:
Received 11 February 2014
Received in revised form
6 March 2014
Accepted 8 March 2014

Keywords:
Gender
Mechanization
Rice
Water
Weeds

A B S T R A C T

Weeds are a major constraint to rice (*Oryza sativa*) production in sub-Saharan Africa. Use of mechanical hand weeders could reduce the labor required for weeding. This paper uses a participatory approach to examine the suitability of six mechanical weeders in Benin. A total of 157 farmers (93 male, 64 female) in 14 villages tested the mechanical weeders, ranked them in order of preference, and compared them with their own weed management practices. The ring hoe had the highest rank, followed by the straight-spike weeder; 97% of the farmers preferred the ring hoe to their own weed management practices, by hand or using traditional hoe, because of its easy operation and high efficiency. The ring hoe tended to be preferred especially in the fields with non-ponded water and relatively higher weed pressure. The straight-spike weeder tended to be preferred to ring hoe in the fields where weed pressure is less, whereas in ponded conditions, farmers liked these two weeders in equal proportion. The preference of weeders was not related to gender, rice field size, or years of experience of rice cultivation. Among 23 farmers who used herbicides, 17 farmers preferred herbicides to the ring hoe and have rice field of >0.5 ha. Mechanical weeders can offer an effective approach for weed management, especially for small-scale rice farmers, and different types of mechanical weeders should be introduced to farmers based on water regimes and weed pressure level.

1. Introduction

Lowland rice production in West Africa occurs in a wide range of hydrological environments—from permanently flooded to permanently non-flooded conditions (Defoer et al., 2004). Rice grown on the upper slopes of valleys frequently experiences drought. Rice grown on the lower slopes benefits from a shallow water table and occasional flooding during the rainy season, whereas rice in the valley bottoms is usually grown under flooded conditions (Defoer et al., 2004). In this production system, weeds are one of the most important biological constraints to rice production with yield reduction ranging from 28 to 54% in transplanted and from 28 to 89% in direct-seeded lowland rice (Akobundu, 1980; Becker et al., 2003; Johnson et al., 2004; Rodenburg and Johnson, 2009). Large reductions in yield are due mainly to the limited number of effective and affordable weed management practices available to farmers (Rodenburg and Johnson, 2009). Farmers rely mainly on manual weeding or traditional hoe-weeding and, to a lesser extent, on herbicides (Adesina et al., 1994). Hand- or hoe-weeding, which are labor-intensive and time consuming, often result in delays in completing weeding, and consequently rice yields are reduced (Saito et al., 2010), while use of herbicides requires local availability of suitable products, functional application and protection equipment, and knowledge of safe application procedures. It is often difficult to meet these requirements in the region (Rodenburg and Johnson, 2009). Thus, improved weed management practices are needed to help reduce yield losses from weed infestation.

The introduction or development of mechanical hand weeders may be a cost-effective and safe approach for weed-management, particularly for resource-poor farmers in sub-Saharan Africa. The ideal weeders are adapted to a wide range of hydrological conditions and outperform current weed control by farmers. More importantly, such mechanical weeders should be locally and easily manufactured and the price should be affordable for the resource-poor farmers. Although mechanical weeders for irrigated lowland rice, such as the Cono Weeder, are currently available in some sub-

* Corresponding author. Tel.: +229 64 18 13 13.
E-mail address: k.saito@cgiar.org (K. Saito).

http://dx.doi.org/10.1016/j.cropro.2014.03.009
0261-2194/© 2014 Published by Elsevier Ltd.

Saharan countries (e.g. Burkina Faso, Madagascar), there are no mechanical weeders in most others, apart from simple and traditional hoes. This is the case for Benin, where we conducted this study. There is also limited knowledge of the efficacy of mechanical weeders in the lowland rice fields with different water availability in West Africa. Therefore testing a wide range of mechanical weeders for their performance across environments differing in water availability may provide new and useful information.

The objectives of this study were to investigate farmers' preferences among six mechanical hand weeders and their own weed management practices, and test whether the preference is related to field conditions, experience of rice cultivation, or gender. As we include different types of mechanical weeders, we hypothesize that farmers' perceptions would be affected by water status and soil texture. Weed cover could also affect farmers' preference, as weeders have different mechanisms for removing weeds. Also, farmers' perception of weeders might be related to sociodemographic parameters such gender and field size. This study used a participatory approach to evaluate the suitability of the weeders in field conditions (Bellon, 2001). Information obtained from farmers can provide insights for further improvement or modification of the technologies.

2. Material and methods

2.1. Description of the study area

The study area is in Benin; it covers Guinea Savanna in the south and Sudan Savanna in the north (latitude, 6°45′N to 11°48′N, longitude, 1°01′E to 3°24′E) and includes important rice cultivation areas (Table 1; Saito et al., 2013; Adegbola and Sodjinou, 2003).

2.2. Description of mechanical weeders

Technical details of the six mechanical weeders tested are shown in Table 2. Pictures and technical drawings can be obtained from the authors or the website (http://www.ricehub.org/).

Three weeders were manufactured in Japan: the ring hoe ("Kezuttaro Slim" DK-801; Doukan Co. Ltd., Hyogo), the straight-spike weeder ("Tagayasu power" TP-90; Mukai Kogyo Co. Ltd., Osaka), the two-row spike-and-blade weeder ("Kabumatohru", KJW-Z1; Sasagawanouki Co. Ltd., Niigata). The curved-spike floating weeder, twisted-spike floating weeder, and fixed-spike weeder were manufactured in Bobo-Dioulasso, Burkina Faso, Antsirabe, Magadascar, and Kumasi, Ghana, respectively. Apart from the ring hoe and fixed-spike weeder, the test weeders have a rotary action. The ring hoe and straight-spike weeder were originally developed for upland crops, whereas the others are intended mainly for flooded lowland conditions. While all the traditional hoes found in farmers' fields in this study require the user to stoop for weeding, all the mechanical weeders tested can be used in an upright position.

2.3. Participatory testing of mechanical weeders

On-farm testing of weeders using a participatory approach was undertaken from July 29 to September 20 2012. Fourteen rice fields in 14 villages (one field per village) were selected in collaboration with local extension officers, based on uniform crop establishment which is required for testing of the weeders (e.g. row sowing, sowing in grid formation), and weed infestation in the fields. Information was collected at each rice field (village-level) on land preparation methods and dates of crop establishment (by transplanting or direct sowing) by interviewing participants. Water status (completely or partially ponded; not ponded, but soil is wet.) and weed cover (weed cover ≤10%; weed cover >10% and ≤60%.) were visually scored by field observation (Savary and Castilla, 2009) (Table 1). Soil texture at 0–20 cm depth was determined by the hydrometer method (Gee and Bauder, 1979) and classified into two levels using clay content (clay content >20% and ≤20%) for statistical analysis.

For each test field, information was collected at farmer-level on 10–12 participating farmers randomly selected in the chosen village, excluding the farmers who were growing rice in the field. Prior to the participant selection process in each village, the gender ratio of the farmers who do weeding was determined to establish the number of male and female participants required (e.g. if weeding is always done by women, all the participating farmers should be women).

In each test field, the participating village farmers were assembled. We explained how to use the mechanical weeders one by one, and then asked all the participating farmers to test each weeder in one or two rows in the field and to evaluate effectiveness and ease of operation. Once all the weeders had been tested,

Table 1
Rice-growing environment and date of crop establishment in 14 fields, Benin.

Field code	Village where test field was located	Latitude	Longitude	Rice-growing environment	Sowing date for direct seeded rice	Transplanting date for transplanted rice	Weed infestation below rice canopy	Dominant weed group	Water regime at testing time	Soil texture	Clay content (%)
F1	Allahe	7°11′N	2°16′E	Rainfed lowland		July 18th	1[a]	1[b]	1[c]	Sandy loam	19
F2	Za-Hla	7°11′N	2°16′E	Rainfed lowland		July 9th	1	1	1	Sandy clay loam	27
F3	Deve	6°45′N	1°39′E	Rainfed lowland	July 15th		2	1	2	Sandy loam	15
F4	Kinwedji	6°43′N	1°40′E	Irrigated lowland		July 17th	2	1	1	Sandy loam	19
F5	Hlodo	6°44′N	1°40′E	Rainfed lowland		Aug 15th	1	2	2	Sandy loam	15
F6	Vovokanmey	6°47′N	1°45′E	Irrigated lowland		July 5th	2	1	1	Clay	53
F7	Ouedeme	8°00′N	2°11′E	Rainfed lowland	July 27th		2	1	2	Loam	13
F8	Kpakpa-zoume	7°55′N	2°15′E	Rainfed lowland	July 19th		2	2	2	Sandy loam	13
F9	Dogue	9°06′N	1°56′E	Rainfed lowland	July 28th		2	1	1	Sandy loam	15
F10	Kodowari	9°11′N	1°34′E	Rainfed lowland	Aug 5th		2	2	2	Sandy loam	15
F11	Cobly	10°28′N	1°01′E	Rainfed lowland	Aug 19th		1	3	2	Sandy loam	15
F12	Bagapodi	10°31′N	1°03′E	Rainfed lowland	Aug 23rd		2	1	2	Sandy loam	15
F13	Monkassa	11°47′N	3°24′E	Rainfed lowland		July 20th	1	2	1	Sandy clay loam	25
F14	Bodjekali	11°48′N	3°23′E	Rainfed lowland		Aug 10th	2	2	2	Loam	19

[a] 1 = weed cover ≤10%; 2 = weed cover >10% and ≤60%.
[b] Broad-leaved species = 1; sedges = 2; grasses = 3.
[c] 1 = completely or partially ponded; 2 = not ponded, but soil is wet.

Table 2
Technical characteristics of six weeders tested in Benin.

Descriptive name	Technical characteristics					
	Weight (kg)	Number of rows weeded	Directional use	Type of tilling drums/rotary frame	Type of ground grasp (spikes/blade)	Presence or type of directional guides
Ring hoe	0.2	1	Pull forward or backward	No rotary frame	Small spikes in front of round plate	None
Fixed-spike weeder	2.4	1	Push-and-pull forward	No rotary frame	Big spikes under plate	None
Curved-spike floating weeder	3.8	1	Push-and-pull forward	2 cylindrical wheels	Curved and angled spikes	Front flat metallic float
Twisted-spike floating weeder	4.4	1	Push-and-pull forward	2 cylindrical wheels	Twisted spikes	Front flat wooden float
Straight-spike weeder	2.0	1	Push-and-pull forward	2 cylindrical wheels	Star-shaped spike & sharp blade	Back metallic keel
2-Row spike-and-blade weeder	5.0	2	Push-and-pull forward	Cylindrical wheels and round plate	Straight angled spike + blades	Front tilted metallic float

farmers were permitted to use them freely. We interviewed farmers to find out which they preferred and also asked about farmers' current crop management practices. The interviews were conducted individually to avoid farmers trying to reach a consensus among themselves. Farmers were asked to rank the six mechanical weeders in order of preference and to compare each mechanical weeder with their own weed management practices (i.e. hoe-weeding, herbicide application, hand-weeding). Information was also collected on their years of experience in rice cultivation and the size of rice fields (Table 3).

2.4. Statistical analysis

Results from descriptive analysis on farmers' preference on weeders showed that ring hoe was highly preferred, and all the farmers preferred ring hoe to the fixed-spike weeder (Table 4). Thus, farmers' ranking of six weeders were used to compute four binary response variables, each of which indicates whether ring hoe is preferred or not to straight-spike weeder, two-row spike-and-blade weeder, curved-spike floating weeder, or twisted-spike floating weeder. A two-level hierarchical logistic linear mixed model (Hox, 2010; Raudenbush and Bryk, 2002; Heck and Thomas, 2000), including a random intercept to compare farmers' preference after taking into account variation across villages and among farmers within the same village, was used for each response variable. Six competing models with three predictors have been stated for each of the four response variable based on finding in a previous study (Senthilkumar et al., 2008) and our research hypotheses. As in 12 out of 14 fields, there was no weed infestation above rice canopy, we do not use this parameter. Also, we include socio-demographic parameters including gender, field size and experience of rice farming. The following models to be tested are:

Table 3
Characteristics of the participating farmers who tested weeders in Benin 2012 ($n = 157$).

Characteristic	Number of farmers
Gender	
Male	93
Female	64
Field size for rice cultivation in 2012	
<0.5 ha	60
≥0.5 ha	97
Experience of rice farming	
≤3 years	39
≥4years ≤9 years	74
≥10 years	44
Weed management practice[a]	
Hand	86
Traditional hoe	116
Herbicide	23

[a] Number of farmers is more than 157 as farmers used more than one weed management practices in their fields.

Model 1: water status, soil texture, and field size
Model 2: water status, soil texture, and experience of rice farming
Model 3: water status, soil texture, and gender
Model 4: water status, weed infestation below rice canopy, and field size
Model 5: water status, weed infestation below rice canopy, and experience of rice farming
Model 6: water status, weed infestation below rice canopy, and gender.

Odds ratio of the predictors were estimated on the best fitted model selected based on the lowest AIC (Akaike, 1974). An odds ratio quantifies the chance for preferring ring hoe to another weeder comparing one level of the given predictor, as a reference, with another level (Tables 1 and 3). For example, we defined 'wet soil condition' as a reference for water status and 'weed cover ≤10%' as a reference for weed infestation below rice canopy. SAS GLIMMIX procedure was used (SAS, 2009) for the computation.

We did not use statistical models to compare farmers' preference between weeders tested and their own weed management practices. This is due to the fact that ring hoe (the best weeder) and straight-spike weeder (2nd one) were preferred by more than 90% to the practices using hand or traditional hoe, and sample size is too small to identify reasons why some farmers preferred their practices to newly introduced weeders (Table 5). Also, this is case for comparison between weeders and herbicide use for preference. We had only 23 farmers who used herbicide. Among them, 11 farmers were from Ouedeme village (F7 in Table 1) due to recommendation by the extension officer (Mr. Gildas Zodome, CeCPA, Glazoue, personal communication), and 5 farmers only out of 23 preferred the best two weeders to use of herbicide.

3. Results

Among 14 fields, two were irrigated lowland, and all others were rainfed lowland (Table 1). Neither irrigated lowland field was permanently ponded during the rice-growing season. Rice was transplanted in seven fields and directly sown in the other seven. At

Table 4
Distribution of ranking in preference for six mechanical weeders ($n = 157$).

Mechanical weeder	Distribution of ranking (%)					
	1st	2nd	3rd	4th	5th	6th
Ring hoe	56	25	8	8	3	0
Straight-spike weeder	25	35	22	15	3	0
Curved-spike floating weeder	7	20	39	27	7	0
Twisted-spike floating weeder	3	14	25	40	13	4
2-Row spike-and-blade weeder	9	4	4	9	59	15
Fixed-spike weeder	0	1	2	2	15	80

Table 5
Percentage of farmers preferring the tested weeder relative to their own weed management practices.

	vs. hand ($n = 86$)	vs. hoe ($n = 116$)	vs. herbicide ($n = 23$)
Ring hoe	97	98	26
Straight-spike weeder	94	91	26
Curved-spike floating weeder	92	84	13
Twisted-spike floating weeder	88	80	13
2-Row spike-and-blade weeder	83	66	13
Fixed-spike weeder	56	21	13

the time of testing, weed infestation below the rice canopy varied between score 1 (weed cover less than or equal to 10%) and score 2 (weed cover more than 10% and less than or equal to 60%) (Table 2). There was no weed infestation above rice canopy in 12 out of 14 fields (data not shown). Six fields were completely or partially ponded, and surface soil was wet without ponding water in eight fields. The dominant soil texture in the test fields was sandy loam. This result is compatible with a previous study in inland valley in West Africa, indicating that In general, lowland soils in West Africa have sandy texture (Abe et al., 2010).

Of the farmers, 59% were male and 41% were female (Table 3). Weed control with hands and traditional hoe were dominant practices. Among the 23 farmers who used herbicide, three were female. The ring hoe was the most preferred of the six mechanical weeders, followed by the straight-spike weeder (Table 4). 32% of farmers preferred the straight-spike weeder to the ring hoe. Only 20, 10 and 13% of farmers, respectively, preferred the curved-spike floating weeder, twisted-spike floating weeder, and two-row spike-and-blade weeder against the ring hoe, and none preferred the fixed-spike weeder (data not shown). Generally, farmers rated the mechanical weeders for ease of operation, high efficiency, light weight, and quickness. The ring hoe and straight-spike weighed less than others (Table 1).

Results from the six two-level hierarchical logistic linear mixed models for the comparing between ring hoe and others for farmers' preference revealed that best fitted models differed among different comparisons (Table 6). Model 4 (water status, weeds below rice canopy, field size) was selected, when comparison between ring hoe and straight-spike weeder and between ring hoe and twisted-spike floating weeder were taken. In other comparisons, other models were selected (Table 6). Water status and weed infestation scores are only variables which showed significant effects on preference in the best fitted models (Table 7). The effect of water status on preference was significant, when comparisons between ring hoe and straight-spike weeder and between ring hoe and curved-spike floating weeder were taken. For weed infestation, the effect was significant except for comparison between ring hoe and two-row spike-and-blade weeder. Thus, farmers' preference was not related to farmers' gender, size of field, or years of experience in rice cultivation.

The odds ratio estimates indicated that ring hoe tends to be more preferred by farmers to straight-spike weeder, curved-spike floating weeder and twisted-spike floating weeder in more weedy conditions than in less weedy conditions. In addition, farmers tend to more prefer ring hoe to straight-spike weeder, and curved-spike floating weeder in wet soil conditions than farmers in ponded conditions (Table 7). Table 8 shows % of farmers that preferred ring hoe to other weeders in different conditions in terms of water status and weed infestation level below rice capopy. Although tendency of farmers' preference differed between two levels of water status or weed infestation, majority of farmers (>60%) still preferred ring hoe to others except for straight-spike weeder in ponded conditions and less weedy conditions. The straight-spike weeder was preferred by 59% of farmers to ring hoe in the fields where weed pressure is less, whereas in ponded conditions, farmers liked these two weeders in equal proportion.

Except for the fixed-spike weeder, all the weeders were generally preferred to farmers' own manual weed management practices by hand or hoe (Table 5). This is especially evident for the ring hoe, as more than 95% of farmers preferred this to their own weed management practices. However, for those who use herbicides, only 21% preferred the ring hoe to herbicide application (5 out of 23 farmers).

4. Discussion

This is the first report to compare various types of mechanical weeders for weed management for rice in Africa. The ring hoe was identified as the most preferred mechanical weeder, followed by the straight-spike weeder. Water status and weed infestation level in the test fields were the characteristics identified for explaining changes in farmers' preferences for the mechanical weeders. Our finding of farmers' preference for the ring hoe in non-ponded conditions more than in ponded conditions is consistent with the development of the ring hoe for non-ponded conditions. Ring hoe was preferred especially in the fields, where weed pressure was high. This is due to the fact that this hoe can easily remove weeds around rice plants compared with other weeders as it is very small and light. It was difficult for other weeders to remove weeds around rice plants as they could also damage rice plants, if they were used operated to rice plants. These results indicate that for lowlands in West Africa, where water conditions as well as weed infestation levels vary over short distances, a wide range of mechanical weeders should be tested for their efficacy and appropriateness across different hydrological environments.

In India, Senthilkumar et al. (2008) found that farmers' perception of weeders was related to gender, soil texture and the weight of the weeder, and reported that women could not use a

Table 6
AIC values from the six two-level hierarchical logistic linear mixed models for the comparing between ring hoe and others for farmers' preference. For each comparison, the model having the lowest AIC (underlined) among 6 is the best fitted model.

	Ring hoe vs. straight-spike weeder	Ring hoe vs. curved-spike floating weeder	Ring hoe vs. twisted-spike floating weeder	Ring hoe vs. two-row spike-and-blade weeder[a]
Model 1 (water status, soil texture, field size)	169.0	128.8	106.2	93.1
Model 2 (water status, soil texture, experience)	172.5	137.0	110.7	93.5
Model 3 (water status, soil texture, gender)	171.0	132.7	108.3	<u>92.7</u>
Model 4 (water status, weeds below rice canopy, field size)	<u>161.8</u>	123.2	<u>99.3</u>	95.1
Model 5 (water status, weeds below rice canopy, experience)	166.3	130.5	104.3	95.5
Model 6 (water status, weeds below rice canopy, gender)	164.6	<u>122.9</u>	100.8	94.6

[a] Water status was included in each of the six models as all farmers in wet soil conditions preferred ring hoe to two-row spike-and-blade weeder.

Table 7
P values of fixed effects and dds ratio estimates from the two-level hierarchical logistic linear mixed models for the comparing between ring hoe and others for farmers' preference.

	P value	Odds ratio estimate	Lower 95% confidence limit	Upper 95% confidence limit
		Ring hoe vs. straight-spike weeder		
Water status[a]	0.03	0.18	0.04	0.83
Weeds below rice canopy[b]	0.02	6.91	1.56	30.62
Field size	0.13	–	–	–
		Ring hoe vs. curved-spike floating weeder		
Water status	<0.01	0.10	0.03	0.35
Weeds below rice canopy	0.01	4.48	1.54	13.04
Gender	0.06	–	–	–
		Ring hoe vs. twisted-spike floating weeder		
Weeds below rice canopy	0.0496	3.78[a]	1.00	14.25
Water status	0.17	–	–	–
Field size	0.12	–	–	–
		Ring hoe vs. two-row spike-and-blade weeder		
Soil texture	0.20	–	–	–
Gender	0.42	–	–	–

[a] Wet soil is the reference for water status: odds ratio estimate of <1 indicates that ring hoe tends to be more preferred by farmers to the given weeder in wet soil conditions than in ponded conditions.
[b] Weed cover $\leq 10\%$ is the reference for weeds below rice canopy: odds ratio estimate of >1 indicate that ring hoe tends to be more preferred by farmers to other weeders in more weedy conditions than in less weedy conditions.

heavy weeder in heavy clay soils. This is in contrast with our results showing that none of the socio-demographic information recorded (field size, experience, and gender) is related to difference in farmers' perceptions. The reason for the difference between two studies is probably due to the fact that we did not test the mechanical weeders in heavy clay soils, and both men and women generally selected smaller weeders (ring hoe and straight-spike weeder).

Although almost all the farmers preferred the ring hoe or straight-spike weeder against their own weed management practices, 74% of the farmers who used herbicides in this study preferred herbicides to the ring hoe or straight-spike weeder. This can be attributed to the ease and speed of application of herbicides compared with using the weeders. Rodenburg et al. (2013) showed that herbicide application was much less labor-intensive than using mechanical weeders, and the application of herbicide reduced weeding time by 86% compared with the twisted-spike floating weeder, which we also tested in this study. Although the number of farmers using herbicide was small in this study, the results suggest that dissemination of mechanical weeders is more successful in locations where most farmers do manual weeding than in areas where herbicide is commonly used. However, even in the latter case, a combination of herbicide and mechanical weeder use can be recommended to farmers.

In this study, we used a participatory approach to test mechanical weeders for technical feasibility (Bellon, 2001). However,

Table 8
% of farmers that prefer ring hoe to other weeders in different conditions with water status and weed infestation below rice canopy.

	% of farmers that prefer ring hoe to straight-spike weeder	% of farmers that prefer ring hoe to curved-spike floating weeder	% of farmers that prefer ring hoe to twisted-spike floating weeder
Water status			
Completely or partially ponded	49	61	ns[a]
Not ponded, but soil is wet	81	94	ns
Weed infestation below rice canopy			
Weed cover $\leq 10\%$	41	63	80
Weed cover $>10\%$ and $\leq 60\%$	82	90	95

[a] Data are not shown as the effect of water status was not significant (Table 8).

it is essential to test the mechanical weeders for the entire rice-growing season, to examine if farmers will adopt the weeders (Senthilkumar et al., 2008). For example, the use of ring hoe might have been easier for farmers than other weeders for short-term testing. Other mechanical weeders might have required more training or more time for farmers to become familiar with their use. Apart from the data reported in this paper, we also received farmers' suggestions to improve the mechanical weeders. The information has been used for developing new prototypes for further testing to be conducted in the entire rice-growing environments.

In conclusion, we identified mechanical weeders, which can present a viable alternative for reducing the labor required for weeding. Among six mechanical weeders tested, the lightest ring hoe was most preferred by farmers, followed by the straight-spike weeder. A wide range of mechanical weeders is required to suit farmers' preferences and the diversity of water and weedy conditions.

Acknowledgments

Sylvester wishes to thank the AGHRYMET Regional Center for his MSc degree scholarship.

References

Abe, S.S., Buri, M.M., Issaka, R.N., Kiepe, P., Wakatsuki, T., 2010. Soil fertility potential for rice production in West African lowlands. JARQ 44, 343–355.
Adegbola, P., Sodjinou, E., 2003. Analyse de la filière riz au Benin – Rapport technique. PAPA/INRAB/MAEP, PADSA, Benin.
Adesina, A.A., Johnson, D.E., Heinrichs, E.A., 1994. Rice pests in the Ivory Coast, West Africa farmers perceptions and management strategies. Int. J. Pest Manag. 40, 293–299.
Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Autom. Control 19, 716–723.
Akobundu, I.O., 1980. Weed science research at the International Institute of Tropical Agriculture and research needs in Africa. Weed Sci. 28, 439–445.
Becker, M., Johnson, D.E., Wopereis, M.C.S., Sow, A., 2003. Rice yield gaps in irrigated systems along an agro-ecological gradient in West Africa. J. Plant Nutr. Soil Sci. 166, 61–67.
Bellon, M.R., 2001. Participatory Research Methods for Technology Evaluation: a Manual for Scientists Working with Farmers. CIMMYT, Mexico, D.F.
Defoer, T., Wopereis, M.C.S., Jones, M.P., Lancon, F., Erenstein, O., Guei, R.G., 2004. Rice-based production systems for food security and poverty alleviation in sub-Saharan Africa. Int. Rice Comm. Newsl. 53, 85–96.
Gee, G.W., Bauder, J.W., 1979. Particle size analysis by hydrometer, a simplified method for routine textural analysis and a sensitivity test of measurement parameters. Soil Sci. Soc. Am. J. 43, 1004–1007.

Heck, R.H., Thomas, S.L., 2000. An Introduction to Multilevel Modeling Techniques. Erlbaum, Mahwah, NJ.
Hox, J.J., 2010. Multilevel Analysis: Techniques and Applications. Lawrence Erlbaum, Mahwah, NJ.
Johnson, D.E., Wopereis, M.C.S., Mbodj, D., Diallo, S., Powers, S., Haefele, S.M., 2004. Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. Field Crops Res. 85, 31–42.
Raudenbush, S.W., Bryk, A.S., 2002. Hierarchical Linear Models: Applications and Data Analysis Methods, second ed. Sage, Thousand Oaks, CA.
Rodenburg, J., Johnson, D.E., 2009. Weed management in rice-based cropping systems in Africa. Adv. Agron. 103, 150–218.
Rodenburg, J., Saito, K., Irakiza, R., Makokha, D., Senthilkumar, K., 2013. Labour-saving Weed Management Tools for Lowland Rice: Comparing the Use of a Pre-emergence Herbicide, Rotary Weeders and Hand Weeding. Presented at 3rd Africa Rice Congress at Yaoundé, Cameroon. 21–24 Oct.
Saito, K., Nelson, A., Zwart, S., Niang, A., Sow, A., Yoshida, H., Wopereis, M.C.S., 2013. Towards a better understanding of biophysical determinants of yield gaps and the potential for expansion of the rice area in Africa. In: Wopereis, M.C.S., Johnson, D.E., Ahmadi, N., Tollens, E., Jalloh, A. (Eds.), Realizing Africa's Rice Promise. CAB International, Wallingford, UK, pp. 188–203.
Saito, K., Phanthaboon, K., Shiraiwa, T., Horie, T., Futakuchi, K., 2010. Genotypic variation in ability to recover from weed competition at early vegetative stage in upland rice. Plant Prod. Sci. 13, 116–120.
SAS Institute Inc., 2009. SAS/STAT ® 9.2 User's Guide, second ed. SAS Institute Inc, Cary, NC.
Savary, S., Castilla, N.P., 2009. A Survey Portfolio to Characterize Yield-reducing Factors in Rice. IRRI, The Philippines.
Senthilkumar, K., Bindraban, P.S., Thiyagarajan, T.M., de Ridder, N., Giller, K.E., 2008. Modified rice cultivation in Tamil Nadu, India: yield gains and farmers' (lack of) acceptance. Agric. Syst. 98, 82–94.