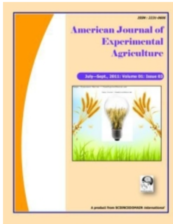

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Evaluation of the Efficacy of Different Rates of Herbicides on Weed Growth and Grain Yield of Two Rice Varieties in Two Rice Ecologies in Sierra Leone

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Authors' contributions

This work was carried out in collaboration between all authors. SSH designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. DRT assisted in the designed and ABJ in selection and description of rice varieties. NM managed the economic analyses of the study. CAD was involved in sites selection and description whilst SDJ managed the literature searches. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Two rice varieties, NERICA L19 (weed competitive) and ROK10 (high yielding) were subjected to two pre-emergence (RiceForce and ButaForce) and two post-emergence (Stam and RiceForce) with different active ingredients and rates of application during the wet seasons of 2009 and 2010 at Rokupr Mangrove Associated Swamp and at Gbomsamba in the Boliland to determine (i) the effectiveness of different rates of application of pre-and post emergence herbicides on weed growth and yield of rice

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varieties, (ii) identify suitable herbicides for the two ecologies and (iii) the cost benefit of herbicides application. The results showed significantly reduction in weed population with herbicides application (*P*=.05). Percentage reductions over control ranged from 65 to 91 percent in 2009 and from 68 to 87 percent in 2010. The herbicides Stam (PE), RiceForce (Pe) and ButaForce (Pe) were the most effective in reducing weed population (*P*=.05). All herbicides treatments gave significantly higher grain yields than control plots. Grain yields increased with increased rates of application but yields from full and three-quarter doses were similar. Yields of the two varieties at Rokupr were similar to Gbomsamba. The three-quarter doses for the herbicides RiceForce (Pe) and ButaForce (Pe) could be considered for higher marginal returns. The herbicide, Stam (PE) though effective in reducing weed population gave low marginal returns. The results suggest that growing a weed competitive variety and a high yielding variety in conjunction with reduce herbicide rates of RiceForce (Pe) and ButaForce (Pe) could be an effective and economical weed management strategy for rice in the Mangrove Associated Swamp and Boliland ecologies in Sierra Leone.

Keywords: Rice varieties; efficacy; herbicide rates; yield; ecologies; MRRs.

ABBREVIATIONS

***MRRs**: marginal Rate of Returns; **PE**: post-emergence; **Pe:** pre-emergence; **CV**: coefficient of variation; **LSD:** least significant difference.*

1. INTRODUCTION

Continuous rice cropping in the lowlands has resulted in serious weed problems. Weeding by hand is the common practice of controlling weeds in the Sub-Saharan African. This method is tedious due to shortage of labour and as such is usually curtailed and inadequately executed resulting in yield reductions (Rodenburg et al., 2006b).

Common agronomic factors that contribute to weed problems are inadequate land preparation (soil tillage, soil leveling in lowland areas), inadequate water management, labor shortages for hand weeding, delayed and incorrect use of herbicide applications, non use of weed competitive varieties and other interventions (Becker and Johnson, 1999a, 2001b; de Vries et al., 2010).

The use of herbicides have been effective in controlling weeds but because of the high rates normally recommended by manufacturers and cost involved in the purchase of herbicides, farmers hardly apply them.

In addition, African farmers often lack sufficient financial means for the purchase of the product and application and protection equipment (Balasubramanian et al., 2007). The incorrect use of herbicides, caused by the above cited problems, may accelerate the evolution of herbicide resistance in weeds (Johnson, 1995).

Effective weed management involves the integration of many practices. Herbicides are undeniably the most effective, reliable technology available today for weed control in rice (Marwat et al., 2004). However, an integrated approach involving the minimal use of chemicals with proper use of other cultural weed control and management techniques such as good land preparation and/or use of weed suppressive varieties will reduce the farmer's dependence on a heavy application of herbicides and thus offers the best hope for increasing food production (Shakoor et al., 2000).

In Sub-Saharan, five main rice ecosystems can be distinguished based on water supply and topography (Windmeijer et al., 1994). Unlike other countries in the Sub-Saharan Africa, all five ecologies are available for rice cultivation in Sierra Leone. They are: (1) rain-fed upland rice on plateaus and hydromorphic slopes, (2) lowland rain-fed rice in valley bottoms, old river basins and floodplains, (3) irrigated rice in deltas and floodplains, (4) deep-water floating rice along major rivers and (5) mangrove-swamp rice in lagoons and deltas (Balasubramanian et al., 2007).

In Sierra Leone, However, rice cultivation in the Mangrove Associated Swamps and Bolilands (lowland rain-fed rice in valley bottoms and floodplains) is difficult and yields are low due to their topography, soil nutrient status and heavy weed infestation (MAFFS, 2005).

The Mangrove Associated Swamps are located on the upper reaches of the Mangrove Swamp catena and grade into the adjacent uplands in which the soil fertility status is low with nitrogen and phosphorus being the major nutrient deficiencies for crop growth. As a result weed infestation is high, posing a major bottleneck for increasing rice productivity whilst the Bolilands are poorly drained saucer-shaped depressions lying on old river basins and normally carry a hard pan making drainage very slow and weed infestation extremely high. Yields in these ecologies ranged from 0.4 - 1 ton ha^{-1} (MAFFS, 2005).

Studies were therefore carried out at Rokupr in the Mangrove Associated Swamp and at Gbomsamba in the Boliland ecologies to determine (i) the effectiveness of different rates of application of Pre- and post-emergence herbicides on weed growth and yield of rice varieties (ii) identify suitable herbicides for the two ecologies and (iii) the cost benefit of herbicides application.

2. MATERIALS AND METHODS

Two rice varieties NERICA L19, a weed competitive variety and ROK10 a non-competitive but high yielding variety (RARC, 2011) were subjected to four different herbicides (two pre- and two post-emergence) at four different rates with different active ingredients. The studies were carried out at the Mangrove Associated Swamp at Rokupr and the Boliland at Gbomsamba during the raining season of 2009 and 2010 cropping seasons. The variety ROK10 is the Centre release variety. It was selected because it is the most widely preferred variety well adapted to both ecologies. It is high yielding but however, susceptible to weeds. It is intermediate in height (125-130 cm) and highly tillered with duration of 170-180 days. The variety NERICA L19 was developed at the West African Rice Development Association (WARDA, 2001) now called Africa Rice centre (ARC). It is high yielding, weed competitive and is short (85–100 cm) with a duration of 120-125 days.

The herbicide, RiceForce which acts as pre-emergence and post-emergence was taken as two different herbicides with active ingredient oxadiazon at 0.25 kg ha^{-1} (ai). This herbicide was applied at two weeks before transplanting (Pe) and four (4) weeks after transplanting (PE). It is a selective contact herbicide used to control annual grasses, sedges and broadleaf weeds in rice. ButaForce (Pe) with active ingredient butachlor at 0.5 kg ha^{-1} (ai) was applied as pre-emergence four days after transplanting. It is a selective systemic pre-emergence herbicide for the control of annual grasses and certain broadleaf weeds while Stam (PE) with active ingredient propanil at 0.36 kg ha^{-1} (ai) was applied four weeks after transplanting. Four rates of applications (Full dose, Three-quarter dose, Half dose and zero dose (Control)) for each of the herbicides evaluated were obtained from manufacturers' recommended labeled rates of application which are, 5 and 2 l ha^{-1} for RiceForce and ButaForce, respectively and 18 l ha^{-1} for Stam (Table 1 below). The MRRs was computed from series of calculations based on variable cost components which included seeds, fertilizers, herbicides, land preparation, planting, fertilizer application, herbicide application, harvesting, threshing and bags (sacks). The farm gate price of paddy rice at the time the studies were under taken were Le4000/kg and Le2400/kg for NERICA L19 and ROK10, respectively. These farm gate prices were used in estimating the revenue and comparing with the total variable costs to obtain the gross margin which measured the economic performance of the four herbicides.

Table 1. Active ingredient and rates of application (l ha^{-1}) obtained from manufacturers' label

Herbicide	Active ingredient	Herbicide rate of application (l ha^{-1})		
		Half dose	Three-quarter dose	Full dose
RiceForce (Pe)	Oxadiazon @ 0.25 kg ha^{-1}	2.5	3.8	5
ButaForce (Pe)	Butachlor @ 0.5 kg ha^{-1}	1	1.5	2
RiceForce (PE)	Oxadiazon @ 0.25 kg ha^{-1}	2.5	3.8	5
Stam (PE)	Propanil @ 0.36 kg ha^{-1}	9	13.5	18

Two varieties, four herbicides and four rates of application (2×4^2) were main factor treatments within a randomized complete block design with three replications. Three weeks old seedlings of the rice varieties were transplanted on the 25th July and 27th July, 2009 and 2010, respectively, in the Mangrove Associated Swamp at Rokupr and on the 6th September and 10th September, 2009 and 2010, respectively, in the Boliland at Gbomsamba into gross plots of $15m^2$ at spacing of 20cm x 20cm apart. Fertilization at the rate of 60-40-40 $NP_2O_5K_2O$ in the form NPK 15-15-15 compound fertilizer was broadcast two weeks after transplanting. At 40 days after transplanting 20 kg $ha-^1$ N (nitrogen) was topdressed (RARC, 2011).

Two sample quadrants of $1m^2$ each were used to collect data on weed count at harvest. Rice grain was hand-harvested at maturity and grain yield of rice in kg ha^{-1} was calculated at 14% moisture content. The MSTAT-C software package was used to carry out combined analysis of variance (ANOVAR) for grain yield and weed count. The analysis for main factors over sites was done separately for each year. Mean values from ANOVAR were then summarized and presented in tables 2-5. Partial budget and marginal analysis were done to determine the economic cost benefit of herbicide application.

2.1 Description of Study Site and Choice of Varieties

Two rice ecologies selected for the studies were the Mangrove Associated Swamp and the Boliland.

The Mangrove Associated Swamp was at the upper reaches of the main Mangrove Swamp catena and grade into the adjacent uplands. The Mangrove Associated Swamp has a salt free period of at least six months. ROK10 which is high yielding, longer in duration and is well adapted to this ecology is the main variety grown by farmers. The ecology is influenced by seasonal flooding through seepage and/or runoff from the surrounding uplands; as well as by tidal water during spring tides at the peak of the rainy season in August. The annual rainfalls recorded were 3000mm and 3500mm for 2009 and 2010, respectively.

The soils of the Mangrove Associated are sufic tropaquept (cat clays) with a massive structural consistence. Soil reaction is acidic with pH range of 4.5-5.5; and is characterized by toxic levels of iron and aluminium (RARC, 2011). The soil fertility status is low with nitrogen and phosphorus being the major nutrient deficiencies. The Boliland is poorly drained with saucer-shaped depressions lying on old river basins and in addition to high phosphorus adsorption capacity and high acidity; the soils are deficient in nitrogen (RARC, 2011).

3. RESULTS AND DISCUSSION

The results presented in tables 2-5 are summaries of data from analysis of variance of the main factors in randomized complete block, combined over sites for each year. The results show that application of herbicides at different rates significantly reduced weed population (P=.05). Percentage reduction in weed population over control ranged from 65 to as high as 91 percent in 2009 for RiceForce (PE) and Stam (PE), respectively (Table 2). In 2010 percentage weed reductions ranged from 68 to 87 for RiceForce (PE) and ButaForce (Pe), respectively. These ranges in reductions suggest that herbicides differ in their efficacy to control weeds (Table 2). The herbicides RiceForce, ButaForce and Stam with active ingredients oxadiazon, butachlor and propanil, respectively, were effective in controlling weeds. Work done by Adeosun et al. (2009) reported herbicides containing oxadiazon as equally effective as pendimethalin in combating weeds in upland rice in Katsina State of Nigeria. However, with increase in rates of application of herbicides, there were corresponding increases in percent reductions in weed population but these increases were not significantly different for rates of application (P=.05) but were significant for herbicides (Table 2). Similar work done by Akobundu (1981) reported propanil, thiobencarb, oxadiazon and fluorodifen as effective in reducing weed population in lowland rice.

Table 2. Effect of herbicide x rates interaction on percentage reduction in weed population over control across sites in 2009 and 2010

Herbicide	Rate of application							
	2009				2010			
	½ dose	¾ dose	Full dose	Control	½ dose	¾ dose	Full dose	Control
RiceForce (Pe)	77	59	57	369	95	66	70	404
	79	84	85	-	76	84	83	-
ButaForce (Pe)	92	61	61	410	100	65	61	473
	78	85	85	-	79	86	87	-
RiceForce (PE)	172	157	142	495	190	173	185	590
	65	68	71	-	68	71	67	-
Stam (PE)	60	36	37	418	127	110	100	608
	86	91	91	-	79	82	84	-
	CV (%) = 8.9; LSD (0.05) = 9.3				*CV (%) = 14.1; LSD (0.05) = 10.2*			

Numbers in black denote weed population/m^2
Numbers in red denote percentage reduction in weed population over control

Herbicide by rate interaction effects were significant for both years at *P*=.01 (Table 3). Different rates for the different herbicides gave significantly higher grain yields than control plots (*P*=.01). Grain yields of plots increased with the increased in treatments from half to full dose in both years (Table 3). In similar studies undertaken by Babiker (1982), reported that for effective and safe herbicide use, the appropriate product and application rates are important.

Table 3. The effect of herbicide x rate interaction on mean grain yield (kg ha^{-1}) of rice varieties across sites in 2009 and 2010

Herbicide	Rate of application							
	2009				2010			
	½ dose	¾ dose	Full dose	Control	½ dose	¾ dose	Full dose	Control
RiceForce (Pe)	2940	3376	3532	1990	2466	3194	3260	1813
ButaForce (Pe)	2642	2760	2996	1538	2518	3200	3210	1511
RiceForce (PE)	1351	1788	1896	1128	1212	1562	1619	987
Stam (PE)	2958	3416	3511	1034	2396	3299	3444	1171
	CV (%) = 3.1; LSD (0.05) = 240.4				*CV (%) = 11.6; LSD (0.05) = 213.6*			

Table 4 shows summary of the interaction effect of herbicide by variety on grain yield in 2009 and 2010. The variety NERICA L19 was not significantly different from ROK10 as both varieties gave similar yields with the application of herbicides (Table 4). The results suggest that irrespective of the nature of the variety, herbicide application of the right type reduces weed pressure and increases yields. These findings have been documented by Babiker, (1982) who worked on chemical weed control in irrigated direct-seeded rice in the Sudan Gezira and reported increased yields on rice varieties by over 50%.

However, the effect of the herbicide RiceForce (PE) on the two varieties was poor as low yields were recorded both in 2009 and 2010 (Table 4).

Table 4. The effect of herbicide x variety interaction on mean grain yield of rice varieties across sites in 2009 and 2010

Herbicide	2009		2010	
	Variety		Variety	
	NERICA L19	ROK10	NERICAL19	ROK10
RiceForce (Pe)	2883	3037	2680	2611
ButaForce (Pe)	2262	2480	2354	2467
RiceForce (PE)	1879	1428	1260	994
Stam (PE)	3075	2869	2516	2412
	CV (%) = 3.1; LSD (0.05) = 240.0		*CV (%) =15.8; LSD (0.05) = 110.7*	

The interaction effect between rate and variety in both years illustrates no significant difference between varieties for each rate of application at *P*=.05 (Table 5). However, significant yield differences were observed with increase in treatment dose from half to three-quarter dose. The three-quarter dose was similar to full dose application of the herbicides for both varieties. Yields of ROK10 were significantly reduced than NERICA L19 in control plots (Table 5). The significant reductions in yields of ROK10 could be attributed to the inability of the variety to compete with weeds. The variety NERICA L19 was able to out compete weeds and hence less reduction in yields was recorded in control plots. Work done by Rodenburg et al. (2009) reported differences in weed competitiveness of the lowland rice varieties of NERICA in the southern Guinea Savanna.

Rice is an inherently weak competitor with most weeds and consequently, yield losses due to weed competition can be high. Smallholder rice farmers in Africa have a limited number of options for preventing weed infestations and concomitant crop losses due to changing environmental conditions may result in reduced efficiencies of existing weed control practices (Rodenburg et al., 2011). If so, this requires the use of rice varieties that could compete or tolerate weeds, identification of the right types of herbicides for different ecologies and some integrated approaches to prevent species invasion (Rodenburg et al., 2011).

Table 5. The effect of rate x variety interaction on mean grain yield of rice varieties across sites in 2009 and 2010

Rate	2009		2010	
	Variety		Variety	
	NERICA L19	ROK10	NERICAL19	ROK10
½ dose	2347	2583	2119	2113
¾ dose	2778	2893	2465	2437
Full dose	2978	2989	2400	2371
Control	1996	1349	1826	1563
	CV (%) = 3.1; LSD (0.05) = 244.0		*CV (%) =15.8; LSD (0.05)=110.7*	

The effectiveness of oxadiazon as pre-emergence, butachlor and propanil in controlling weeds (Table 2) was reflected in the high yields obtained (Tables 3 and 4). Similar observations have been made by several authors that oxadiazon and propanil are effective in controlling weeds and also in increasing yields of rice in the lowlands and direct seeded upland rice (Adeosun et al., 2009; Ikuenobe et al., 2005; Rao et al., 2007).

Site effect and its interactions were not significant at *P*=.05 (data not presented). This suggests that the performances of the varieties and herbicides across sites were similar. High MRRs were obtained for RiceForce (Pe) with oxadiazon as active ingredient and ButaForce (Pe) with butachlor as active ingredient. However, the MRRs was low (Table 6) for Stam due to its high rate of application (Table1) which affected the gross and net benefits.

Table 6. Marginal rate of returns from rice varieties and herbicides

Herbicide	2009		2010	
	MRRs		MRRs	
	NERICA L19	ROK10	NERICA L19	ROK10
RiceForce (Pe)	1762	1955	1591	1599
ButaForce (Pe)	1407	1574	1248	1326
RiceForce (PE)	88	96	71	76
Stam (PE)	75	85	69	98

In 2009, MRRs from no application to three-quarter dose application of RiceForce (Pe) were 1762% and 1955% and for ButaForce (Pe) were 1407% and 1574% for the varieties NERICA L19 and ROK10, respectively whilst for Stam (PE) from no application to three-quarter dose application were 75% and 85% and for RiceForce (Pe) were 88% and 96% for NERICA L19 and ROK10, respectively. Similar trend was also observed in 2010 (Table 6).

4. CONCLUSIONS

Weed population significantly reduced with herbicides application. The herbicides Stam, RiceForce and ButaForce were more effective in reducing weed population in both ecologies. Grain yields of plots treated with herbicides increased with the increased in their rates of application but yields from full and three-quarter doses were similar. Yields of the two varieties at Rokupr were similar to those at Gbomsamba. The three-quarter doses which were similar to full doses could be considered for higher returns. These results suggest that growing weed competitive and high yielding non-competitive varieties in conjunction with reduced herbicide rates of RiceForce and ButaForce as pre-emergence herbicides could be an effective and economical weed management strategy for rice in the Mangrove Associated swamps and Bolilands ecologies in Sierra Leone.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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