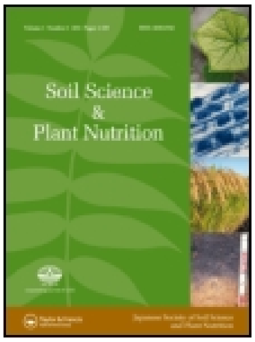

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Performance of Rice Cultivars in Various Sawah Ecosystems Developed in Inland Valleys, Ashanti Region, Ghana

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Experiments were conducted in 2001 and 2002 to evaluate the agronomic responses of 23 rice cultivars with various growth traits in order to select suitable cultivars based on the ecosystems and local farming systems, in the Ashanti region of Ghana. The ecosystems included irrigated sawah※ (IS), rainfed sawah (RS) and unbunded and unleveled lowland (UBLL). Two input levels consisted of a high input level (HIL—90 kg N + 45 kg P_2O_5 + 45 kg K_2O ha^{-1} + herbicide application at 21 d after transplanting (DAT) + hand weeding at 42 DAT) and a low input level (LIL—20 kg N + farmers' weed control practices). The results showed that the adoption of the high input level resulted in the increase of the rice grain yield by 100% with a mean yield of 4.2 Mg ha^{-1}, compared with 2.1 Mg ha^{-1} for the low input level. Rice yield in IS exceeded that in UBLL by 323%, whereas the yield in RS exceeded that in UBLL by 130%. Under the rainfed systems (RS and UBLL), the early maturing cultivars, WAB 208-5-HB, Emokokoo, Bouake189, PSBRC 34 and PSBRC 66 were less affected by the terminal drought that characterized the end of the rainy season, compared with the medium maturing ones such as WITA 1, WITA 3 and IR58088-16-2-2. Interspecific WAB208-5-HB (*O. glaberrima*×*O. sativa*) out-yielded most of the improved *Oryza sativa* cultivars in the UBLL ecosystem under both high and low input regimes.

Key Words: **ecosystem, farming system, input regimes, interspecific, sawah.**

Rice (*Oryza sativa* L.) is the most important food grain for one-third of the world's population (Crosson 1995). In developing countries, it accounts for 29% of the total calorie intake of the population (Johnson 1996). In Ghana and in West Africa, the gap between the supply of and demand for rice has been widening because of a shift in the diet from the traditional coarse grains, caused by urbanization (WARDA 1997a). Rice imports rank second after wheat among cereal imports to Ghana. About 42% of the country's rice requirement amounting to 300,000 metric t is imported (PPMED/MOFA 1999). It is estimated that within 10 years, the consumption of rice will reach 400,000 to 480,000 metric t. This will require an increase in local rice production of over 600,000 metric t, if self-sufficiency is to be achieved. Although the production in Ghana and West Africa has increased over the past few years, it is still far below consumption needs. Decrease of fallow periods and expansion of cultivation into marginal lands, mainly in fragile uplands, have been responsible for more than two-thirds of the increase in production (WARDA 1997b). Inland valley ecosystems in West Africa offer a large potential for expansion and intensification of rice cultivation (Windmeijer and Andriesse 1993; Sakurai 2002). About 44% of the rice area is located in lowland areas (Maclean et al. 2002), which cover about 20–50 million ha in West Africa (WARDA 1998), with Ghana accounting for about one million ha (Wakatsuki et al. 1998).

During the Green Revolution, rice yields increased at an average rate of 2.5% per year from 1967 to 1984 (Dawe and Dobermann 1999). This was mainly due to the introduction of high-yielding varieties and the use of high inputs such as fertilizers, under good water management conditions.

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※Sawah: The term sawah refers to a leveled rice field surrounded by a bund with inlet and outlet for irrigation and drainage.

Therefore, for intensive rice farming in the West African sub-region, the adoption of modern cultivars and water control technologies is essential (Sakurai 2002). Farmers in Ghana and sub-Saharan Africa cultivate rice mostly under rain-fed conditions with little or no bunding. Since the field conditions alternate between flooding and drought, added inputs, particularly nitrogen, are prone to leaching and surface run-off, resulting in the reduction of N-use efficiency (Fashola et al. 2001). Average rice yield is therefore 1.6 Mg ha^{-1}—the lowest in the world. Traditional low-yielding, non- responsive varieties are being replaced in West Africa (IITA 1992).

Since 1997, the Japan International Cooperation Agency (JICA) and the Crops Research Institute of Ghana (CRI), using a farmer-participatory approach in three towns of the Ahafo-Ano district in the Ashanti Region, Ghana, have tested a technology popularly called "Sawah" (Wakatsuki et al. 1998; Asubonteng et al. 2001a, b; Hirose and Wakatsuki 2002). The lack of suitable improved rice cultivars to fit into the various rice ecosystems created by the JICA-CRI project necessitated the present study. The objective was to evaluate the agronomic responses of 23 rice cultivars with various growth traits in the irrigated sawah (IS) and rainfed sawah (RS) ecosystems compared with the natural unbunded, unleveled lowland (UBLL) ecosystem under high and low input regimes.

MATERIALS AND METHODS

Field experiments were conducted in the Ashanti region of Ghana at Biemso No. 1 and 2 project sites (6°55′N, and 1°55′W) during the 2001 and 2002 growing seasons. The soil was a Haplic Gleysol with the properties previously characterized by Asubonteng et al. (2001a). Fertility characteristics are shown in Table 1. The site was located in a semi-deciduous forest agro-ecological zone characterized by a bimodal rainfall pattern, the major rainy season starting from mid-March to the end of July and the minor season beginning in September and ending in mid-November, followed by a long dry spell, which ended by mid-March.

Twenty-three rice cultivars with various growth traits (Table 2), some of which being modern, improved cultivars cultivated in many parts of the West African sub-region, were planted in three rice-growing ecosystems in the lowland area under low and high input regimes. The characteristics of the ecosystems, production treatments and agronomic practices are presented in Table 3. The experimental design for each ecosystem was a split-plot randomized complete block design. The main plot (size: 5 m×3 m) factor included the rice cultivars tested, while the inputs levels were assigned to the sub-plots, 5 m× 1.2 m in size with 0.6 m wide bunds between them. Treatments were applied with three replications.

The ecosystems included irrigated sawah (IS), consisting of a bunded and leveled field irrigated by a weir and canal system, rainfed sawah (RS) which was also bunded and leveled with water supplied by rainfall only, and an unbunded, unleveled lowland ecosystem (UBLL). Land preparation in UBLL was performed by slash and burn, as practiced in traditional lowland farming systems. In UBLL, sowing was performed by dibbling at the rate of 6 seeds, 3 cm deep at each position with a spacing of 20×20 cm. Fourteen days later, the seedlings were thinned to 2 plants per hill. In the irrigated and rainfed sawah farming systems, land was ploughed and harrowed wet (puddled), after which 21 d-old seedlings were transplanted at 20×20 cm intervals with two seedlings per hill. In the rainfed sawah system, irrigation was applied only during land preparation and transplanting. Basal application of fertilizers at the rates of 45 kg N, 45 kg P_2O_5 and 45 kg K_2O using NPK (15-15-15) was conducted just after transplanting under the high input regime. Top dressing was performed 30 d afterwards at the rate of 45 kg N per hectare. A mixture of 5 L ha^{-1} Propanyl (360 g L^{-1} propanil) and 1.0 L ha^{-1} Weedone (480 g L^{-1} 2,4 D-amine) was applied at 21 d after transplanting (DAT) and 21 d after sowing (DAS) in the case of UBLL followed by hand weeding at 42 DAT (51 DAS in UBLL). Under the low input regime, nitrogen at the rate of 20 kg N per hectare (based on average farmer's practice) was the only nutrient applied at 40 DAS for UBLL and at 30 DAT for the IS and the RS systems. Weed management under the

Table 1. Soil fertility characteristics of irrigated sawah (IS), rainfed sawah (RS) and unbunded and unleveled lowland (UBLL) systems compared with mean values in lowland topsoil of West Africa (IVS).

Site	pH (H_2O)	Total C (%)	Total N (%)	Avail. P (mg kg^{-1})	Exchangeable cations ($cmol_c$ kg^{-1})			
					Ca	Mg	K	Na
IS	5.9	1.53	0.17	4.9	3.94	1.17	0.13	5.9
RS	5.3	1.60	0.15	4.1	3.51	1.60	0.30	5.3
UBLL	5.7	1.79	0.20	4.4	5.13	1.81	0.27	5.7
IVs[a]	5.3	1.3	0.11	8.7	1.89	0.88	0.25	3.3

[a]Inland valleys (Hirose and Wakatsuki 2002).

Table 2. Rice cultivars used for the experiments in 2001 and 2002 in Ashanti region, Ghana.

Entry number	Cultivar	Maturity groups
1	WAB208-5-HB[a]	EM
2	Emokokoo[b]	EM
3	PSBRC34	EM
4	PSBRC54	EM
5	PSBRC66	EM
6	BOUAKE189	EM
7	WITA 8	EM
8	Tox3108-56-4-2-2-2	INT
9	IR5558-50-2-3-3-2	INT
10	IR58088-16-2-2	INT
11	IR54742-31-9-26-15-2	INT
12	C123CU83-1CU-5CU-6CU-3CU-1CU	INT
13	CT9737-6-11-6-3P-M	INT
14	CT8003-1-2A-M-1P	INT
15	CT9737-6-1-1-6-1P	INT
16	WITA 1	INT
17	WITA 3	INT
18	WITA 4	INT
19	WITA 6	INT
20	WITA 7	INT
21	WITA 9	INT
22	WITA 12	INT
23	GK88	INT

Early maturing cultivars: 80–130 d. Medium-maturing cultivars: 130–160 d. [a]*Oryza glaberrima*×*Oryza sativa*. [b]*Oryza glaberrima*.

low input regime involved hand weeding at 30 DAS for UBLL (30 DAT for the IS and the RS systems).

The date of anthesis of each cultivar was determined by visual observation when the full panicle was exserted in 50% of the plants. Before harvest, plant height was measured in 5 hills per plot. Yield components; namely number of panicles per square meter, number of spikelets per panicle, percentage of filled grains and 1,000-grain weight were determined in 25 plants sampled randomly. The percentage of filled grains was defined as the number of grains that sank in salt water with a specific gravity of 1.06 as a percentage of total spikelets. Plant samples from twenty-five hills were taken in each plot to determine the grain yield at a 14% moisture content.

Data were analyzed using a mixed model procedure (SAS/STATVIEW 1999). Combined analysis of variance across growing seasons was computed, with growing seasons, ecosystems, input levels and cultivars being fixed.

RESULTS AND DISCUSSION

The soil data of the three ecosystems (IS, RS and UBLL) (Table 1) were similar to those of the top soils of the inland valleys (IVs) of West Africa, revealing a very low content of plant nutrients, actually the lowest in the

Table 3. Summary of agronomic practices for rice cultivar experiments under three growing conditions and at two input levels.

	Ecosystems		
Agronomic practices	Irrigated sawah (IS)	Rainfed sawah (RS)	Unbunded/unleveled lowland (UBLL)
1. Soil and water management	Bunded and leveled field with inlet and outlet for irrigation and drainage	Bunded and leveled field with outlet for drainage	Field neither bunded nor leveled
2. Source of water	Dyke and canal	Rainfall	Rainfall
3. Water management	Submergence after transplanting	Duration of ponding of water depends on amount of rainfall	Field not ponded by water for more than 24 h after rainfall
4. Method of land preparation	Ploughed and puddled	Ploughed and puddled	Slash and burn
5. Planting method	Transplanting	Transplanting	Direct sowing by dibbling
	High input level (HIL)	Low input level (LIL)	
6. Fertilizer rate ($kg\ ha^{-1}$) N-P-K	90-45-45	20-0-0	Under the sawah systems, low input fertilization was conducted at 30 DAT
7. Fertilizer application ($kg\ ha^{-1}$)	45-45-45 as basal application at planting. 45 kg N at panicle initiation stage (PI)	20 kg N after manual weeding (approx. 40 DAS)	
8. Weed management	Herbicide: Propanil (360 $g\ L^{-1}$) and Weedone (2,4 D-amine 480 $g\ L^{-1}$) Herbicide application at 21 DAT+ manual weeding at 42 DAT	Manual weeding: Approximately at 30 DAS	Under UBLL, high input weed management was as follows: Herbicide at 21 DAS+manual weeding at 51 DAS

DAT, days after transplanting; DAS, days after sowing.

world (Hirose and Wakatsuki 2002). The pH indicated that the soils were slightly acidic in nature. Although the potassium content was low, the phosphorus level was similar to the level in IVs of West Africa. However, the Ca and Mg contents at the study site were relatively higher than those in IVs. Sodium content was slightly higher in the rainfed sawah ecosystem but lower than the average value in West Africa Inland valleys. The soil fertility data indicated that for sustainable rice production in the inland valley systems of West Africa, nutrient-replenishing farming systems would be essential.

Grain yield averaged across the growing seasons and input levels (Table 4) was 3.2 Mg ha^{-1}, a value above the national average of 1.9 Mg ha^{-1}, but slightly below the world average of 3.9 Mg ha^{-1} (FAOSTAT 2004). The high input level (HIL) led to a significant increase of the grain yield of rice by 100%, with a mean yield of 4.2 Mg ha^{-1} compared with 2.1 Mg ha^{-1} for the low input level (LIL) (Table 4). These results were mainly due to the increase in the spikelet number per unit area under the HIL regime, which was 76% higher than that under the LIL regime, underscoring the importance of this yield parameter for determining the grain yield (Pathnaik et al. 1991). Nitrogen fertilization and optimum weed control could also enhance the number of grains per unit area (Wada and Matsushima 1962; Norman et al. 2002; Kendig et al. 2003). However the 1,000-grain weight increased by only 5.6% for HIL compared with LIL. According to Yoshida (1981), 1,000-grain weight is a stable varietal character because the grain size is rigidly controlled by the size of the hull. Singh et al. (1999) observed that the N rate and soil type did not affect the 1,000-grain weight despite its large impact on grain yield, yield components and harvest index.

Rice growing in the lowland area significantly influenced the yield and all the yield components (Table 6).

Table 4. Mean grain yield and yield components of 23 lowland rice cultivars at high input level (HIL) and low input level (LIL) in Ashanti, Ghana, 2001 and 2002.

	HIL	LIL
Grain yield (Mg ha^{-1})	4.2***	2.1
Panicles (m^{-2})	266***	201
Spikelets ($panicle^{-1}$)	85***	61
Spikelets ($m^{-2}\times 1,000$)	22.7***	12.9
% Filled grain	66***	56
1,000-grain weight (g)	26.4***	25

***Significant at 0.001 level.

Table 5. Mean grain yield and yield components of 23 lowland rice cultivars grown under irrigated sawah (IS), rainfed sawah (RS) and unbunded, unleveled lowland (UBLL) systems.

	Grain yield (Mg ha^{-1})	No. of panicle (m^{-2})	No. of spikelets ($panicle^{-1}$)	No. of spikelets ($m^{-2}\times 1,000$)	% Filled grain	1,000-grain weight (g)
IS	5.5	292.0	91.0	27.0	73.0	28.0
RS	3.0	234.0	73.0	17.0	62.0	26.0
UBLL	1.3	173.0	53.0	10.0	49.0	25.0
LSD (0.05)	0.2	9.0	6.0	1.1	1.2	0.4

Table 6. Combined analysis of variance for grain yield, growth and yield components.

Sources of variation	*df*	Grain yield	No. of spikelets (m^{-2})	No. of spikelets ($panicle^{-1}$)	No. of panicles (m^{-2})	% Filled grain	1,000 grain weight	Plant height	Days to 50% flowering
Growing seasons (Y)	1	***	***	***	***	NS	***	NS	NS
Cultivars (C)	22	***	***	***	***	***	***	***	***
Ecosystems (E)	2	***	***	***	***	***	***	***	NS
Input level (IP)	1	***	***	***	***	***	***	***	***
Y×C	22	***	***	***	**	NS	***	***	*
Y×E	2	***	***	***	***	***	NS	NS	*
Y×IP	1	***	***	**	*	NS	*	***	NS
C×E	44	***	***	***	***	***	***	***	***
C×IP	22	***	***	***	***	**	***	***	NS
E×IP	2	***	***	***	***	***	***	***	NS
Y×C×E	44	***	***	***	***	**	***	***	*
Y×C×IP	22	***	***	***	***	NS	NS	***	NS
Y×E×IP	2	***	***	**	**	**	*	NS	NS
C×E×IP	44	***	***	**	***	**	***	***	**
Y×C×E×IP	44	***	***	**	***	NS	***	***	NS

*Significant at 0.05 level. **Significant at 0.01 level. ***Significant at 0.001 level. NS, not significant at 0.05 level.

The grain yield in the irrigated sawah (IS) and the rainfed sawah (RS) systems was 323% and 130% higher than that in the UBLL system (Table 5). The large differences in the IS system compared with the UBLL system can be explained by the multifunctionality of the sawah type characterized by the high performance of constructed wetlands, which can control weeds, neutralize soil pH, increase the P content, enhance the availability of other plant nutrients, fix nitrogen as well as conserve soil and water (Ponnamperuma 1972; Wakatsuki 1994; Wakatsuki and Masunaga 2004).

The growing season significantly affected the yield and yield parameters except for the percentage of filled grains (Table 6), but did not affect the plant height and number of days to 50% flowering. There was an adequate amount of rain water during the 2001 and 2002 period (Fig. 1) for good plant performance but the variability in the distribution of rainfall may explain the differences in yield between the two seasons, particularly in the two-rainfed systems (RS and UBLL). Since no severe drought temporarily stopped plant growth completely in either of the 2-year experimental period, the seasons did not affect the number of days to 50% flowering. According to Obermueller and Mikkelson (1974) and Lillay and Fukai (1994), the number of days to flowering or maturity can only be delayed if drought temporarily interrupts the growth of the plants during the vegetative growth stage. Terminal drought experienced during this experiment did not affect significantly the percentage of filled grains, presumably because a sufficient amount of assimilates had been stored during the plant growth stages (Singh et al. 1995).

Differences in the amount and distribution of rainfall in the two growing seasons may explain the significant interaction between growing seasons and input levels (Table 6). Uptake and utilization of plant nutrients for plant growth and development are markedly influenced by the availability of water (in this case rainfall for both RS and UBLL systems). Again in the absence of com-

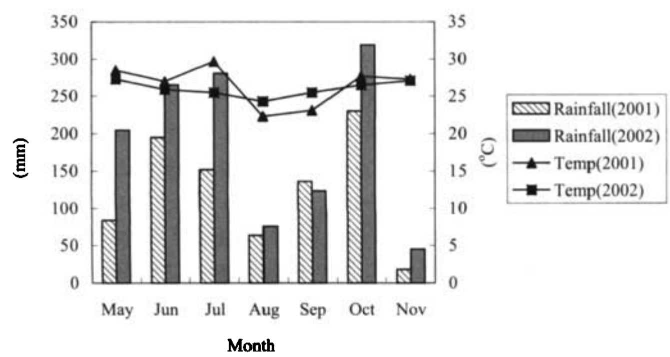

Fig. 1. Monthly rainfall (mm) and mean temperature during the experiment at the study site, Biemso, Ashanti Region in 2001 and 2002.

Table 7. Mean grain yield, and yield components of 23 rice cultivars grown in three ecosystems at two input levels across growing seasons in Ashanti region, 2001 and 2002.

Growing season	Production environment	Grain yield ($Mg\ ha^{-1}$)		No. of panicles (m^{-2})		No. of spikelets ($panicle^{-1}$)		No. of spikelets ($m^{-2} \times 1,000$)		% Filled grain		1,000-grain weight (g)	
		HIL	LIL	HIL	LIL	HIL	LIL	HIL	LIL	HIL	LIL	HIL	LIL
2001	IS	7.01	3.6	325	268	105	70	33.6	19.5	79.4	74.4	26.9	26.3
	RS	3.3	1.8	273	199	65	66	17.7	13.1	70.6	56.0	26.3	26.7
	UBLL	1.6	0.4	207	137	65	38	13.3	5.1	47.0	36.8	26.0	23.3
2002	IS	7.3	4.0	323	265	104	80	34.3	21.1	79.8	71.7	27.0	26.5
	RS	4.2	2.1	270	201	93	71	22.0	14.1	73.0	59.0	26.7	25.3
	UBLL	2.0	0.5	217	140	73	39	15.7	5..3	46.5	36.5	26.0	23.4
	LSD (0.05)[a]	0.1		5.3		2		0.5		0.7		0.3	
	LSD (0.05)[b]	0.1		6.5		2		0.6		0.8		0.3	

[a]LSD values for comparing means within and across growing seasons and input levels. [b]LSD values for comparing means within and across ecosystems.

Table 8. Mean grain yield and yield components of 23 rice cultivars grown in lowland ecosystems at low and high input levels.

Entry No.	Cultivar	IS		RS		UBLL	
		HIL	LIL	HIL	LIL	HIL	LIL
		(Mg ha^{-1})					
1	WAB	4.6	2.9	2.8	1.6	2.1	0.6
2	Emok	4.0	2.8	2.9	1.3	1.4	0.5
3	PSBRC34	7.7	3.5	3.0	2.1	2.0	0.4
4	PSBRC54	8.0	3.7	3.8	2.1	1.7	0.4
5	PSBRC66	5.7	3.3	3.8	2.0	1.8	0.4
6	BOAK189	7.0	3.8	3.7	2.0	1.4	0.3
7	WITA 8	7.8	4.2	4.4	2.1	1.8	0.5
8	Tox3108	7.1	4.1	4.0	2.3	2.3	0.6
9	IR5558	7.9	4.0	3.8	2.0	1.8	0.5
10	IR58088	7.7	4.0	3.7	1.8	1.4	0.3
11	IR54742	7.7	4.3	4.0	2.2	1.9	0.4
12	C123CU	6.9	4.1	4.2	1.9	2.0	0.4
13	CT9737	6.5	4.0	4.0	1.7	1.9	0.6
14	CT8003	7.3	3.8	3.8	1.7	2.0	0.5
15	CT9737-P	8.2	4.0	4.3	1.8	1.2	0.5
16	WITA 1	7.6	3.6	3.3	1.8	0.9	0.3
17	WITA 3	7.6	3.5	4.1	2.0	1.3	0.5
18	WITA 4	8.0	4.1	3.7	2.1	1.5	0.3
19	WITA 6	8.0	3.5	4.0	2.3	1.4	0.3
20	WITA 7	7.3	3.7	3.8	2.2	2.0	0.4
21	WITA 9	7.6	4.4	4.5	2.8	2.0	0.6
22	WITA 12	7.6	4.0	3.8	1.9	1.8	0.4
23	GK88	7.5	3.8	3.5	2.0	1.8	0.5
	Mean (n=23)	7.2	3.8	3.8	2.0	1.7	0.4
	Range	(4.0–8.2)	(2.8–4.4)	(2.8–4.5)	(1.3–2.8)	(0.9–2.3)	(0.3–0.6)
	SD	1.51	0.81	0.81	0.45	0.44	0.12

Entry 1–7: Early-maturing cultivars. Entry 8–23: Medium-maturing cultivars.

plete submergence, weed infestation may drastically reduce the grain yield.

A significant growing season × ecosystem × input interaction was observed for all the parameters studied (Table 6). Across the growing seasons, the yield of rice was relatively stable under the high input level (HIL) regime of IS compared with that of both RS and UBLL, which depended only on rainfall as a source of water (Table 7). The high yield of rice for both seasons in IS under the HIL regime was due to the increase in the panicle number and number of spikelets per panicle. The relatively low yield under the rainfed conditions may be due to the low availability of plant nutrients. According to De Datta and Buresh (1989), the utilization of nutrients, particularly nitrogen, under rainfed conditions is low due to losses by run-off, volatilization and denitrification as a result of flooding that alternates with droughty conditions. However, the grain yield in the rainfed sawah exceeded that in UBLL by 164%, probably due to the presence of more effective water-conserving structures (i.e. bunding and leveled field), which enhanced water availability to the crop.

Yield response of rice cultivars to inputs as influenced by the extent of water availability varied significantly (Table 8). Rice yield ranged between 4.0 and 8.3 Mg ha^{-1} when high inputs were applied in the irrigated sawah system. For instance WITA 6, PSBRC54, CT9737P, WITA 4 and WITA 6 yielded 8.0 Mg ha^{-1} or more, whereas WAB and Emok of *Oryza glaberrima* origin produced 4.6 and 4.0 Mg ha^{-1}, respectively under the same growing conditions. The low response of WAB and Emok to optimum growing conditions could be due to the low tillering ability and low response to nutrients, particularly nitrogen—which characterize *O. glaberrima* rice.

Average yield of rice (3.8 Mg ha^{-1}) in the irrigated sawah under the low input regime was similar to that in the rainfed sawah under the high input regime. Performance of individual cultivars in these two systems did not differ significantly (Table 8). The yield level of rice in the irrigated sawah with low inputs may be due to the submerged conditions which resulted in effective suppression of weeds and release of some fixed plant nutrients for uptake by the rice plants. In economic terms, it is reasonable to select irrigated sawah with low inputs over rainfed sawah, which requires costlier inputs to produce an equal amount of rice. However, considering the soil mining effect due to the lack of inputs in the irrigated sawah system, sustainable rice production over a longer period of time could be adversely affected.

In the unbunded-unleveled lowland system, interspecific WAB (*Oryza glaberrima*×*Oryza sativa*) performed better in terms of yield than most of the improved *Oryza sativa* cultivars used in this experiment (Table 8). These results could be due to the high competitive ability with weeds and relatively higher drought tolerance trait (Jones et al. 1997; Dingkuhn and Sow 1997). However, the overall average yield of 1.7 Mg ha^{-1} recorded in UBLL under the high input regime was too low for any meaningful rice production system. This, therefore indicates that the performance of improved varieties even with optimum inputs would be low in the absence of good water management.

CONCLUSION

There was a high yield response to good water management conditions in the sawah system with optimum input level. About 70% of the cultivars tested in the irrigated sawah system achieved a grain yield of 7.0 Mg ha^{-1} or higher. Cultivars responded differently to the changes in water availability and input levels. Cultivars of *glaberrima* origin Emok and inter-specific WAB (*sativa*×*glaberrima*) appeared to be better adapted to stressed conditions. Cultivars with short growing duration could be more suitable for cultivation under the rainfed systems. In the absence of irrigation facilities, the rainfed sawah system may enable cultivars to produce an economic yield under rainfed conditions. This was evident in the current study, as in the RS system, the average yield increased by 163% over that of unbunded and unleveled lowland ecosystem across growing seasons and input levels.

Agronomic evaluation for the selection of rice cultivars must be performed in various ecosystems based on the local farming systems, to ensure their sustainability.

The higher yield response (7.0 Mg ha^{-1}) observed in the irrigated sawah system for most of the improved cultivars used in the present study underscored the need for widely adopting the system in the West African subregion, if the Green Revolution experienced by the South-East Asian countries is to be achieved.

REFERENCES

Asubonteng KO, Andah WEI, Kubota D, Hayashi K, Masunaga T, and Wakatsuki T 2001a: Characterization and evaluation of Inland valley watershed for sustainable agricultural production: Case study for semi-deciduous forest zone in the Ashanti region of Ghana. *Tropics*, **10**, 539–553

Asubonteng KO, Otoo E, Kubota D, Hayashi K, Masunaga T, and Wakatsuki T 2001b: Effect of Sawah-Based Farming System on Rice Cultivation in the Inland Valley Bottom of the Ashanti Region, Ghana. *Tropics*, **10**, 555-564

Crosson P 1995: Natural resources and environmental consequences of rice production. *In* Fragile Lives in Fragile Ecosystems. Proceedings of International Rice Research Conference 13–17 Feb., IRRI, Los Banos, Laguna, Philippines, p. 83–100

Dawe D and Dobermann A 1999: Defining productivity and yield. IRRI Discussion paper series No. 33, IRRI, Los Banos, Laguna, Philippines

De Datta SK and Buresh RJ 1989: Integrated nitrogen management in irrigated rice. *Advance Agron.*, **10**, 143–149

Dingkuhn M and Sow A 1997: Potential yield of irrigated rice in Sahel. *In* Irrigated Rice in Sahel: Prospect for Sustainable Development, Ed. KM Meizan, MCS Wopereis, M Dingkuhn, J Deckers, and TF Randolph, p. 361–380, West Africa Rice Development Association, Bouake, Cote d'Ivoire

FAOSTAT 2004: FAOSTAT Database, http://apps.fao.org/

Fashola OO, Hayashi K, Masunaga T, and Wakatsuki T 2001: Use of Polyolefin-coated urea to improve Indica rice cultivation in sandy soil of West Africa. *Jpn. J. Trop.*, **45**(2), 108–118

Hirose S and Wakatsuki T 2002: Restoration of inland valley Ecosystems in West Africa, 600 p., Norin Tokei Kyuokai, Tokyo

International Institute of Tropical Agriculture (IITA) 1992: Food Production in Sub-Saharan Africa. 1. IITA's contributions, 208 p., IITA, Ibadan, Nigeria

Johnson DE 1996: Weed management in smallholder rice production in the tropics. *In* Radcliffe's IPM World Textbook, Ed. EB Radcliffe and WD Hutchison, URL: http://ipm world.umn.edu, University of Minnesota, St. Paul, MN

Jones MP, Dingkuhn M, Aluko GK, and Semon M 1997: Interspecific *Oryza sativa* L.×*Oryza glaberrima* steud. Progenies of upland rice improvement. *Euphytica*, **92**, 237–246

Kendig A, William B, and Wayne-Smith C 2003: Rice weed control. *In* Rice: Origin, History, Technology and Production, Ed. C Wayne-Smith and RH Dilday, p. 457–472, Wiley Series in Crop Science, John Wiley and Sons, Inc., Hoboken NJ

Lillay JM and Fukai S 1994: Effect of timing and severity of water stress on four diverse rice cultivars. III. Phenological development, crop growth and grain yield. *Field Crops Res.*, **37**, 225–234

Maclean JL, Dawe DC, Hardy B, and Hettel GP (eds.) 2002: Rice Almanac: Source Book for the Most Important Economic Activity on Earth. 3rd ed., 270 p, Oxford University Press US, CABI Publishing

Norman RJ, Wilson CE Jr, and Slaton NA 2002: Soil fertilization and mineral nutrition in U.S mechanized rice culture. *In* Rice: Origin, History, Technology and Production, Ed. C Wayne-Smith and RH Dilday, p. 331–412, Wiley Series in Crop Science, John Wiley and Sons, Inc., Hoboken, NJ

Obermueller AJ and Mikkelson DS 1974: Effect of water management and soil aggregation on the growth and nutrient uptake of rice. *Agron. J.*, **66**, 627–632

Pathnaik RN, Pande K, Ratho SN, and Jachuk PJ 1991: Consistent performance of rice hybrids. *Crop Res.*, **4**, 272–279

Ponnamperuma FN 1972: The chemistry of submerged soils. *Adv. Agron.*, **24**, 29–96

PPMED/MOFA 1999: Report. Policy, Planning, Monitoring and Evaluation Division. Ministry of Food and Agriculture, p. 12–14, Accra, Ghana

Sakurai T 2002: Adoption of modern rice variety and water control technology in West Africa's rainfed lowland. Paper presented at the workshop on the Green Revolution in Asia and its Transferability to Africa, Dec. 8–10, 2002, Tokyo, Japan

SAS/STATVIEW. Using Stat View 1999: Statistical Analytical System Institute (SAS), Inc., Cary, NC, 3rd Ed., p. 1–288

Singh U, Cassman KG, Ladha JK, and Bronson KF 1995: Innovative nitrogen management strategies for lowland rice system. *In* Fragile Lives in Fragile Ecosystems, p. 229–254, IRRI, Los Banos, Laguna, Philippines

Singh U, Patil SK, Das RO, Padilla JL, Singh VP, and Pal AR 1999: Nitrogen dynamics and crop growth on and alfisol and a vertisol under rainfed lowland rice-based cropping systems. *Field Crops Res.*, **61**, 237–252

Wada G and Matsushima S 1962: Analysis of yield determining processes and its application to yield production and culture improvement of lowland rice. *Proc. Crop Sci. Soc. Jpn.*, **31**, 15–18

Wakatsuki T 1994: Soil, people and sustainable agriculture in tropics: Potential of sawah-based agriculture in tropical Africa. *Tropics*, **3**, 3–17

Wakatsuki T and Masunaga T 2004: Ecological engineering for sustainable food production and the restoration of degraded watersheds in tropics of low pH soils. *In* Proceedings of the 6th International Symposium on Plant-Soil Interactions at Low pH, Aug. 1–5, 2004, Sendai, p. 92–93, International Steering Committee on Plant-Soil Interactions at Low pH and Japanese Society of Soil Science and Plant Nutrition

Wakatsuki T, Shinmura Y, Otoo E, and Olaniyan GO 1998: Africa-based Sawah System for the Integrated Watershed Management of the Small inland valley of West Africa. FAO Water Report No. 17, 56–79

WARDA 1997a: Annual Report 1997, West African Rice Development Association, Bouake, Cote d'Ivoire

WARDA 1997b: WARDA Medium Term Plan 1998–2000, West African Rice Development Association, Bouake, Cote d'Ivoire

WARDA 1998: Annual Report 1998, West African Rice Development Association, Bouake, Cote d'Ivoire

Windmeijer PN and Andriesse W 1993: Inland Valley in West Africa. An Agro Ecological Characterization of Rice Growing Environment, p. 28–37, ILRI, Wageningen

Yoshida S 1981: Fundamentals of Rice Crop Science, IRRI, Los Banos, Laguna, Philippines