WFL Publisher
Science and Technology
Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.7 (1) : 214-218. 2009 *www.world-food.net*

Effect of soil and water management practices on the growth and yield of rice in the forest agro-ecology of Ghana

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Received 8 October 2008, accepted 12 December 2008.

Abstract

Rice production in Ghana faces several problems: notably water shortage, low soil fertility, poor soil and water management and appropriate varieties for the various production systems. A study was started in 2006 and repeated in 2007 with the main objective of comparing the effect of four soil and water management practices on the growth and yield of four rice varieties [Bouake 189, Sikamo and Wita 7 (medium maturing varieties) and Jasmine 85 (early maturing variety)]. The four soil and water management practices included: 1) farmers' practice (Control) (plots ploughed and puddled); 2) bunded non-leveled field (plots bunded, ploughed and puddled); 3) bunded and leveled field (plots bunded, ploughed, puddled and leveled) and 4) sawah (plots bunded, ploughed, puddled and leveled). Supplementary irrigation was provided only to the sawah plots. Grain yield was similar for all the varieties. Soil and water management practices affected some soil properties. Soil pH and exchangeable cations increased in 2007 for all bunded treatments, the increase being more pronounced under sawah treatment. Soil and water management practices significantly influenced number of panicles per plant, harvest index and grain yield. In 2007 grain yield increased in the following order, farmers' practice<bunded non-leveled <bunded leveled < sawah. 'Bouake 189' under sawah treatment gave the highest grain yield which was similar to 'Sikamo' and 'Wita 7' also under sawah treatment. In addition to making water available, structures for water control (bunding, puddling and leveling) were essential and significantly improved rice yield.

Key words: Bunding, leveling, puddling, soil properties, water management.

Introduction

In West Africa demand for rice has been growing steadily since 1973 partly due to population growth and substitution away from the region's coarse grains (maize, sorghum and millet) [1]. Other major factors are rapid urbanization and associated changes in family occupational structures and income [2]. All these factors influence the preference away from the traditional staples towards rice. Presently over 50% of rice consumed in Ghana is imported [2] putting more strain on the country's foreign reserves.

In Ghana rice yield vary markedly between the various production systems [3]. Under upland condition grain yield average of 1.0 t/ha is increasing to 2.2 t/ha in the inland valleys and to 4.5 t/ha under irrigation. National rice yield average is 1.2 t/ha. Increasing rice yield per unit area is critical if total production is to increase.

Introduction of the 'sawah' technology (bunded, puddled and leveled rice field with irrigation and drainage facilities) to farmers in part of Ashanti region showed significant increase in their rice yield [4]. Rice yield of farmer groups introduced to sawah increased from an average of 1.0 t/ha to 4.0 t/ha in the first year. Significant variation in rice yield under different rice environments using 'Sikamo' as a test crop have been reported [5]. Puddling does not only control weeds and ease transplanting but retains water by reducing the rate of percolation [6]. This action ensures that water is available for rice growth and development. Several authors have reported yield losses due to decreasing water supply to the rice plant [7-11]. Yield losses of 0.0-70% when rice was grown under dry conditions have been observed [8]. Generally there is a trade-off between land productivity (grain yield) and water productivity (water savings). Water savings up to 78% were obtained when rice was grown under dry condition compared to flooded condition but yield decreased from 7.9 to 3.4 t/ha [10]. The effect of three water regimes (flooded, intermittent irrigation and dry cultivation) on rice varieties were studied [12]. The varieties behaved differently under the various water regimes. While two varieties performed better under dry cultivation the third variety gave the best yield under flooded condition. This study evaluated the performance of four rice varieties under four soil management practices.

Methodology

Experimental site and design: The experiment was established in 2006 at Biemso No. 1 and repeated in 2007. Biemso No. 1 lies on latitude 6°52'N and longitude 1°51'W in the Ahafo Ano South district of the Ashanti region of Ghana. A split-split plot design with three replications was employed. All treatments were fertilized (90-60-60 kg/ha N-P_2O_5-K_2O) using urea, triple supper phosphate and muriate of potash.

Main plot treatments were four soil and water management options: 1) farmer's practices (Control), plots were ploughed and puddled; 2) bunded non-leveling field, plots were bunded, ploughed and puddled; 3) bunded and leveled field; plots were bunded, ploughed, puddled and leveled; 4) sawah, plots were bunded, ploughed, puddled and leveled with supplementary irrigation when necessary.

Sub-plot treatments consisted of four rice varieties Bouake 189, Sikamo and Wita 7 (medium maturing varieties) and Jasmine 85 (early maturing variety). All the rice varieties were initially nursed and later transplanted at 20 cm x 20 cm spacing with two seedlings per hill. Half of the nitrogen and all phosphorus and potassium were applied a week after transplanting. The remaining nitrogen was applied at booting. Weeding was done when necessary. Each plot measured 3.0 m x 4.0 m.

At maturity, 2.0 m^2 area per treatment was demarcated and harvested. Yield components (grain, stover, number of panicles/ plant, plant height) were measured and yield per hectare estimated. The statistical software, Statistics 8, was used for data analysis. Standard error was used as the mean separator.

Soil sampling and analysis: Initial soil samples were taken (0-20 cm) before the field layout was done. Soil sampling was done per plot at harvest for the 2 years. Soil samples were brought to Soil Research Institute laboratory and air-dried at room temperature. The air-dried soil samples were ground and passed through 2 mm sieve. Soil pH was measured using a glass electrode (pH meter) in a soil to water ratio of 1:2.5 [13]. Organic carbon was determined by the wet combustion method [14], total nitrogen by micro Kjeldahl method [15] and available phosphorus according to Bray and Kurtz [16]. Exchangeable cations (Ca, Mg, K) were extracted with 1.0 M ammonium acetate solution and determined by atomic absorption spectrometry [16].

Results

Soil properties: Initial soil properties and changes in these properties under the various soil management practices are presented in Table 1. Under farmers' practice soil properties were almost similar to the initial properties with a slight decline in exchangeable cations and soil pH in 2007. Soil pH and exchangeable cations under bunded non-leveled and bunded and leveled treatments increased over the initial values. These increases were more pronounced under sawah treatment.

Plant height: Plant heights for the two years are presented in Figs 1a-b. For both years plant height for the medium maturing varieties were similar and taller than the early maturing variety. Soil management did not influence plant height.

Number of panicles per plant: In 2006 interaction between soil management and rice variety did not show clear differences in number of panicles per plant (Fig. 2a). Number of panicles per plant for 'Bouake 189' was highest under bunded and leveled and sawah soil management practices while bunded non-leveled and farmers' practices gave similar and lower number of panicles per plant. For 'Jasmine 85', 'Sikamo' and 'Wita 7 number of panicles per plant was similar for bunded non-leveled, bunded and leveled and sawah soil management practices but higher than in the farmers' practice.

The effect of soil management and rice variety on number of panicles per plant was clearer in 2007 (Fig. 2b). Sawah treatment gave the highest number of panicles/plant for all the medium maturing varieties (Bouake 189, Sikamo and Wita 7). For 'Bouake 189' and 'Sikamo', the order of number of panicles per plant is sawah> bunded leveled field> bunded non-leveled field> farmers' practice. Consistently farmer's practices gave the lowest number of panicles per plant.

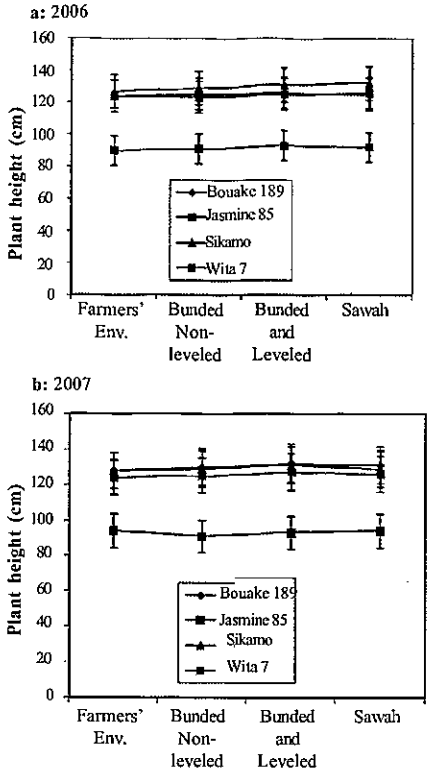

Figure 1. Effect of interaction between soil management and rice on plant height in 2006 and 2007.

Table 1. Evolution of soil properties under the various soil management practices.

Parameter	Initial soil properties	Farmers' practice		Bunded non-leveled		Bunded & leveled		Sawah	
		2006	2007	2006	2007	2006	2007	2006	2007
Soil pH	5.3	5.2	5.0	5.4	5.5	5.5	5.6	5.5	6.1
Organic carbon (g kg^{-1})	15.4	15.6	16.5	15.8	16.8	15.5	17.2	15.6	16.5
Total nitrogen (g kg^{-1})	1.40	1.32	1.38	1.42	1.46	1.44	1.48	1.52	1.55
Bray No. 2 P (mg kg^{-1})	3.50	2.40	3.20	3.60	3.50	3.85	4.30	4.20	4.90
Exch. K [cmol(+) kg^{-1}]	0.04	0.03	0.03	0.05	0.08	0.06	0.12	0.09	0.14
Exch. Ca [cmol(+) kg^{-1}]	4.20	3.86	3.55	4.35	4.67	4.45	5.20	4.65	5.50
Exch. Mg [cmol(+) kg^{-1}]	2.10	2.00	1.85	2.30	2.25	2.34	2.40	2.35	2.45
ECEC [cmol(+) kg^{-1}]	6.24	5.89	5.43	6.70	7.00	6.85	7.72	7.09	8.09
Soil type	Eutric gleysol								

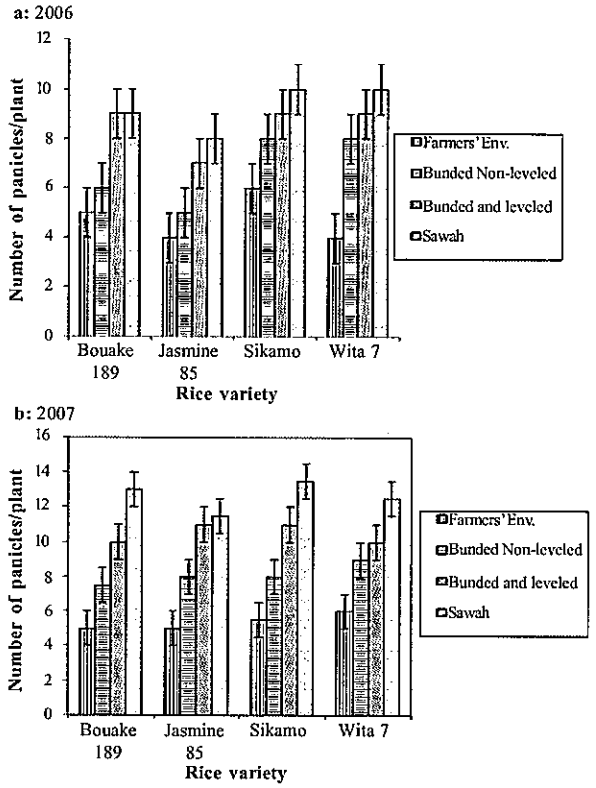

Figure 2. Effect of interaction between soil management and rice on number of panicles/plant in 2006 and 2007.

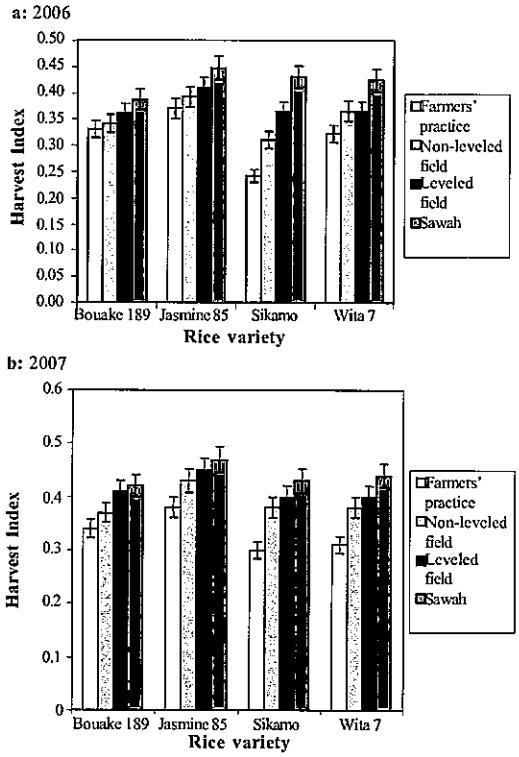

Figure 3. Effect of interaction between soil management and rice on harvest index.

Harvest index: Under the various rice environments, sawah and bunded and leveled rice fields gave the highest harvest index (HI) followed by bunded non-leveled rice field (Figs 3a-b). 'Jasmine 85' gave the highest HI while the other varieties gave similar values. 'Jasmine 85' under sawah condition showed the highest HI which was significantly higher than most of the interactions.

Stover yield: For 2006 stover yield was similar for all the soil management practices (Table 2). 'Bouake 189' gave significantly higher stover yield over 'Jasmine 85' but similar to 'Sikamo' and 'Wita 7'. 'Bouake 189' under sawah treatment gave significantly higher stover yield over farmers' practice.

In 2007 soil management affected stover yield significantly (Table 2). Stover yield under sawah was significantly higher than that for farmers' practice and bunded non-leveled field. The medium varieties gave similar stover yield which were higher than that of 'Jasmine 85'. 'Bouake 189' and 'Sikamo' under sawah and bunded and leveled environments, and 'Wita 7' under sawah environment gave significantly higher stover yield over farmers' practice.

Grain yield: In 2006 soil management significantly affected grain yield (Table 3). Sawah environment gave higher grain yield over farmers' practice and bunded non-leveled treatment but similar to bunded and leveled treatment. Mean grain yield was similar for all the rice varieties. Interaction between soil management and rice variety showed that all the rice varieties under sawah environment gave significantly higher grain yield than under farmers' practice and bunded non-leveled treatment (Table 3).

Results in 2007 were almost similar to that of 2006 (Table 3). Under soil management, grain yield increased in the following order, farmers' practice< bunded non-leveled field< bunded and leveled field < sawah. Mean varietal grain yields were similar. Interaction between soil management and rice variety was again significant. Sawah environment interacted with all the rice varieties to give higher grain yield than under farmers' practice and bunded non-leveled fields. Under sawah environment, 'Bouake 189' and 'Sikamo' gave higher grain yield than 'Jasmine 85'. Grain yield was generally higher in 2007 than in 2006 (Table 3).

Discussion

Changes in soil properties: Exchangeable cations (Ca, Mg and K) and soil pH increased for bunded non-leveled, bunded and leveled and sawah treatments. These findings confirm earlier observations [4]. These scientists observed increasing levels of exchangeable cations when monitoring fertility levels of fields of farmers who had adopted the sawah technology. The site is usually flooded at least twice a year. Fine materials which are transported during flooding settle and remain within the bunds when flooding recedes. Materials carried by flooded water are probably richer in these cations and hence the improvement of their levels. Lack of structures to trap sediments may explain why farmers' practice showed relatively low levels of these nutrients.

Growth and yield components: Soil management practice did not influence plant height (Fig. 1). Under all the soil management practices the crop probably had enough moisture to grow. The medium maturing varieties were, however, taller than the early

Table 2. Effect of soil management on stover yield (t/ha) of rice.

Soil management	'Bouake 189'	'Jasmine 85'	'Sikamo'	'Wita 7'	Mean
			2006		
Farmers' practice	7.1	6.3	6.9	6.9	6.8
Bunded non-leveled field	8.1	6.2	7.1	7.8	7.3
Bunded & leveled field	8.5	6.5	7.5	8.5	7.8
Sawah	9.8	6.8	7.4	7.3	7.8
Variety mean	8.4	6.5	7.2	7.6	
SE for Soil Management	0.95				
SE for Varieties	1.54				
SE for Interaction	2.56				
			2007		
Farmers' practice	7.5	6.2	7.6	7.4	7.2
Bunded non-leveled field	8.7	6.4	8.5	8.6	8.1
Bunded & leveled field	9.8	6.6	9.8	9.2	8.9
Sawah	11.2	7.2	10.4	9.8	9.7
Variety mean	9.3	6.6	9.1	8.8	
SE for Soil Management	1.24				
SE for Varieties	1.72				
SE for Interaction	2.25				

Table 3. Effect of soil management on grain yield (t/ha) of rice.

Soil management	'Bouake 189'	'Jasmine 85'	'Sikamo'	'Wita 7'	Mean
			2006		
Farmers' practice	3.5	3.7	2.2	3.3	3.2
Bunded non-leveled field	4.2	4.0	3.2	4.5	4.0
Bunded & leveled field	4.8	4.5	4.3	4.9	4.6
Sawah	6.2	5.5	5.6	5.4	5.7
Variety mean	4.7	4.4	3.8	4.5	
SE for Soil Management	1.12				
SE for Varieties	0.98				
SE for Interaction	1.45				
			2007		
Farmers' practice	3.9	3.8	3.2	3.3	3.6
Bunded non-leveled field	5.1	4.9	5.1	5.3	5.1
Bunded & leveled field	6.8	5.5	6.5	6.2	6.3
Sawah	8.2	6.5	7.8	7.6	7.5
Variety mean	6.0	5.2	5.7	5.6	
SE for Soil Management	1.12				
SE for Varieties	0.85				
SE for Interaction	1.03				

maturing variety, this is due to physiological differences.

Under sawah condition the crop produced significantly higher numbers of panicles per plant than in the other treatments, gave the highest HI which was similar to bunded and leveled treatment and ultimately higher grain yield than the other treatments (Table 3). In addition to puddling and leveling to reduce loss of water through percolation, water was made available to the crop through irrigation, hence the crop performed better resulting in higher grain yield under the sawah environment. These observations support the findings of many authors [7-11] who stressed on the importance of water on rice grain yield. In particular yield losses over 50% when rice was grown under dry condition have been reported. Bunded and leveled and bunded non-leveled treatments which had structures to control water showed higher HI than farmers' practice resulting in higher grain yield. Leveling under sawah or bunded and leveled treatments resulted in uniform plant growth and may partly explain why bunded leveled treatment gave higher grain yield than bunded non-leveled treatment.

All varieties performed better under the sawah treatment. In 2007, 'Bouake 189' under sawah treatment gave the highest grain yield which was similar to 'Sikamo' and 'Wita 7' also under sawah treatment.

Conclusions

Under bunded non-leveled, bunded and leveled and sawah soil pH and exchangeable cations increased with time. These parameters decreased under farmers' practice. Grain yield increased in the following order: farmers' practice< bunded non-leveled < bunded and leveled<sawah. 'Bouake 89', 'Sikamo' and 'Wita 7' interacted with sawah to give higher grain yield than 'Jasmine 85',

Acknowledgements

This project was funded by the Government of Japan under the "New Sawah Project" with Prof. T. Wakatsuki as team leader to which the authors are very grateful. The authors further thank Edward Kissi, Ebenizer Aidoo and Tony Abutiate for their technical assistances.

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