Journal of Soil Science and Environmental Management Vol. 3(3), pp. 56-62, March, 2012
Available online at http://www.academicjournals.org/JSSEM
DOI: 10.5897/JSSEM11.070
ISSN 2141-2391 ©2012 Academic Journals

Full Length Research Paper

Improving the productivity of lowland soils for rice cultivation in Ghana: The role of the 'Sawah' system

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Accepted 9 August, 2011

Lowlands constitute one of the largest and appropriate environments suitable for rice cultivation in Ghana. However, environmental degradation and declining soil productivity, leading to low crop yields are major concerns. Some reasons leading to such concerns may be traced to lack of proper management of our soil resources and possible unsuitable crop production systems and practices. Effective nutrient and water management in addition to suitable land preparation options are key factors for the effective and sustainable utilization of these inland valley ecosystems. Proper and meaningful management strategies therefore need to be developed in a way as to enable and encourage farmers to accept and easily adopt them. Designing and implementation of comprehensive and integrated soil management programs that will not only improve and maintain soil fertility but also make maximum use of available water are necessary. While research has shown that these environments vary considerably in soil type, water holding capacity and nutrient retention, it has been further observed that soils of most valleys are dominant in low activity clay minerals which have low nutrient and water holding capacities. Adoption of the "Sawah" system will enhance and sustain production. The "Sawah" system is characterized by nutrient replenishing mechanisms with intrinsic resistance to erosion (better water control and nutrient management). Rice responds better to fertilizer (mineral and organic) under the "Sawah" system than the traditional system of rice production in Ghana. Rice cultivation under the "Sawah" system in inland valleys in Ghana has lead to significant improvement in soil and water management. There has been a gradual and significant increase in rice grain yield in the order: farmers practice < only bunded < bunded and puddled < bunded, puddle and leveled ("sawah"), across locations and varieties. An integration of available farm manures with mineral fertilizer resulted in significant increases in paddy grain yield across locations, thus reducing the over reliance of famers on mineral fertilizers to improve soil fertility. From a significant initial increase (from less than 1.0 t ha^{-1} to over 4.5 t ha^{-1}), mean paddy grain yield under the "Sawah" system consistently and continuously increased annually and currently stands at over 6.0 t ha^{-1} among farmer groups. Mean net income generated per hector under the "sawah" system also ranged from US $1,500 to US $2,800 over the same period among farmer-groups. There was also a gradual build up of total carbon and exchangeable bases (K, Ca, Mg) leading to improved nutrient levels, even though there was a net loss of both total Nitrogen and available Phosphorus over the same period. Ghana (possibly West Africa) has the potential to increase local rice production by over 300% when the "Sawah" system is adopted.

Key words: Lowlands, improvement, rice yields, "sawah" system, soil productivity.

INTRODUCTION

In tackling the problem of poverty, food security and minimizing environmental degradation among others, rice is one crop that can be effectively used under improved technological innovations in order to create wealth. In Africa, human-induced climatic change threatens agricultural productivity. Understanding the link between

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livelihoods and managing essential services provided by natural ecosystems is critical for achieving sustainable economic growth and poverty reduction. According to UNU-IAS (2008), degradation of natural resources reduces the productivity of the poor who mostly rely on these resources. The same report continues to state that while Africa is facing diminishing agricultural stocks, high food prices and decreasing productivity, environmental stability is at the same time being lost. In a commentary, Sanchez (2010) stated clearly that too much emphasis has been placed on the development of high yielding crop varieties with little attention given to the ecology on which the plant survives. He further stated that crop yields in Africa can be tripled through proper management of the soil environment, use of fertilizer and appropriate crop varieties.

Over 60% of the annual rice requirements of most West African countries, including Ghana is imported even though the sub-region has rice growing environments (Inland valleys, flood plains, etc) that when well managed will ensure and sustain enough rice production for the West African sub-region and even for export (Andriesse et al., 1995; Wedmeijer and Andriesse, 1993; Wakatsuki, 1994; Wakatsuki et al., 2004, 2006). Lowlands, particularly flood plains and inland valleys, have been identified as the ecologies that offer considerable potential for agricultural intensification and diversification because double cropping in a year is possible using residual soil moisture. In Ghana, rice is now competing with other crops such as citrus, oil palm, cocoa, mango and vegetables in lowland crop cultivation (Buri et al., 2010). Poor water management and the inherent low fertility status (Buri and Wakatsuki, 1996; Buri et al., 1998; 1999; Issaka et al., 1996a, b, 1997) of these lowlands have been identified as the major causes for low rice yields and low crop productivity. Effective nutrient and water management, and land preparation options, are, however, lucking for the effective and sustainable utilization of these valleys. There is therefore the need for the designing and implementation of a comprehensive and integrated soil management program to provide information on improving and maintaining soil fertility while making maximum use of available water.

With the development and introduction of the “Sawah” technology to farmers in Ghana, this paper looks at the impact this improved technology has made on nutrient management, rice grain yields and economic returns towards poverty reduction, food security, rural employment and its' potential to increase national production.

MATERIALS AND METHODS

Primary data was collected through the conduction of field research, both on-station (researcher managed) and on-farm (farmer managed). Experiments were conducted at selected communities where data was gathered. Simultaneously, production activities of some farmer-groups were regularly monitored in selected communities (Adugyama, Biemso, Nsutem, and Baniekrom) located in the Ashanti region within the semi-deciduous forest zone of Ghana. Paddy grain yields and the cost of production for selected farmer-groups were monitored. For each year, farmers were assisted (on-the-job training and provision of technical services) to adopt the “Sawah” system. At harvest, information on grain yield and inputs used, including labour was obtained from farmers. For income estimation, a survey on market prices was conducted and grain yield as realized by farmers was monitored with the assistance of farmer-group executives who provided yield figures and cost of inputs used. Actual grain yield and cost of production was then calculated based on a unit area for each farmer-group. Soil fertility levels of their rice fields were monitored (samples were taken annually for laboratory analysis). Soil analysis was by the methods described by IITA (1979).

RESULTS AND DISCUSSION

Types and fertility status of lowlands in Ghana

Estimates indicate that Ghana has over one million hectors of lowlands (Wakatsuki, 2004) mainly composed of inland valleys and river floodplains. There exist a variety of soils within these lowland ecosystems in the country, the most commonly recognized ones being Gleysols, Fluvisols, Plintosols, Planosols and Lixisols. These soils types have variable characteristics depending on lowland type and location. Lowland soils in Ghana and the West Africa sub-region in general, have therefore been described as being heterogeneous that require different fertility and water management options. Buri et al. (2010) reported that most inland valleys ecologies in Ghana are very deficient in most soil nutrients (Table 1) particularly available P (mean levels < 1.5 mg kg^{-1}). This observation is collaborated by other authors (Senayah et al., 2008; Senayah and Dedzoe, 1997) who also stressed on the low levels of phosphorus. With increasing intensity in the use of lowlands for rice cultivation, Buri et al. (2010) recommended the adoption of effective nutrient and water management options. Soils of lowlands in Ghana have relatively lower levels of clay and most nutrients compared to lowlands within the West Africa sub-region and paddy field of tropical Asia (Table 1).

Technologies for management of lowlands

There are three broad systems of rice cultivation in Ghana: irrigated rice, upland rice and rice cultivated in inland valleys. Rice yield under irrigation is generally higher (4.5t ha^{-1}) followed by inland valleys (2.4 t ha^{-1}) with upland rice giving the lowest yields per unit area (≤1.0 t ha^{-1}). Lowlands are presently being considered as the appropriate environments for rice production. Within these environments, the crop is traditionally grown without any structures to control water, minimal use of fertilizers and most often than not local varieties are used. Paddy yields are therefore normally low under the traditional system and vary sharply due to yearly variation

Table 1. Soil nutrient levels of lowlands in Ghana in comparison with West Africa and paddy field of South East Asia.

Parameter	Ghana lowlands	West Africa lowlands	Paddy fields of S. E. Asia
pH (water)	5.2	5.3	6.0
Total Carbon (g kg^{-1})	9.1	12.3	14.1
Total Nitrogen(g kg^{-1})	0.88	1.08	1.30
Available Phosphorus (mg kg^{-1})	3.2	8.4	17.6
Exch. Calcium {cmol (+) kg^{-1}}	4.8	2.8	10.4
Exch. Magnesium {cmol (+) kg^{-1}}	2.5	1.3	5.5
Exch. Potassium {cmol (+) kg^{-1}}	0.3	0.3	0.4
eCEC {cmol (+) kg^{-1}}	8.6	5.8	17.8
Clay (g kg^{-1})	97	230	280

Adapted from Buri et al. (2010).

in total rainfall and its distribution. A novel system of rice production popularly referred to as 'Sawah' (bunded, puddled and leveled fields with inlet and outlet for drainage) which has been developed and is currently being practiced in some inland valleys ensures paddy yields of over 7.0 t ha^{-1}. To maintain and sustain yields, there is the need to balance biotechnology (improved varieties) with eco-technology (improved growing environment). This led to the development and introduction of the "Sawah" technology.

Increased nutrient use efficiency is basically associated with improved water management. The "Sawah" system leads to not only significant improvements in nutrient use but also in water use as well. Factors militating against soil fertility improvement include low fertilizer usage, ineffective fertilizer management under the traditional system, unfavorable land tenure systems and ineffective water management.

Under the "Sawah" system, Issaka et al. (2008) reported of significant increases in rice grain yield under improved soil and water management Rice grain yield increased significantly in the order: farmers practice < bunded only < bunded and puddled < bunded, puddled and leveled (Table 2). Effective land preparation significantly contributed to increased grain yield. Furthermore, under the "Sawah" system, rice responds positively and significantly to fertilizer additions (organic and inorganic). Buri et al. (2004) observed significant increase in paddy grain yield when both mineral fertilizer and organic amendments were either used solely or in combination (Table 4). The interaction of lower amounts of both mineral fertilizer and organic amendments gave similar and significantly higher grain yields as when higher amounts of mineral fertilizer were used solely. The use of locally available materials such as poultry droppings and cattle dung resulted in significant yield increases, which can reduce the over reliance of farmers on mineral fertilizers to improve their yields. These materials are not only locally available for use but in addition, are also environmentally friendly.

Table 3 clearly shows how the omission of any of the major nutrients (N, P, K) can significantly affect rice grain yield under improved soil and water management (the "Sawah" system). With an improved micro-growing environment under the "Sawah", system, nutrient utilization and uptake increases which intend is reflected in higher grain yields. The development of technologies that lead to both increased nutrient and water use efficiency are therefore critical for the continued use of these valleys or lowlands for crop production especially rice.

Under the "Sawah" system, both grain and total dry matter yield increased significantly over the traditional system (under farmer managed conditions). Increases were very drastic and highly significantly during the first year of introduction at most locations compared to the traditional system (Table 5). Grain yield continued to increase annually with improvement in management practices by farmers and currently stands at a mean of over 6.0 t ha^{-1} across locations (Table 6). When mean paddy grain yields under the "sawah" system are compared to mean national production figures, the new system provides over 300% yield increases per unit area. Figure 1 shows the net profit accrued from rice cultivation under the "sawah" system for some farmer groups over a five year period. Mean net revenue ranged from US $1,500 to US $2,800. While for each year mean net profit per hector was positive and continued to increase with time, mean net production cost tended to stabilize with improved management. This is an indication of how profitable lowland rice cultivation can be, particularly under improved technologies such as the "Sawah" system. This will not only create employment for the rural youth but will more importantly and significantly reduce rural poverty, guarantee food security and increase standard of living of our people.

Figure 2 shows the potential rice production under "Sawah" in Ghana. Over the period 2001 to 2009, Ghana was producing only a third (33%) of the total paddy rice it could have produced if current production systems were under "Sawah". This indicates that, national production could be increased by over 300% when the "Sawah" system is adopted on a national scale. This system was

Table 2. Effect of soil management on paddy grain yield under "Sawah" system in Southern Ghana.

Treatment/Variety	Bou. 189	Jam. 85	Sikamo	Wita 7	Mean
Year 1					
Farmers practice	3.5	3.7	2.2	3.3	3.2
Bunded non leveled	4.2	4.0	3.2	4.5	4.0
Bunded and leveled	4.8	4.5	4.3	4.9	4.6
Bunded, puddle and leveled ('Sawah')	6.2	5.5	5.6	5.4	5.7
Variety mean	4.7	4.4	3.8	4.5	
SE (soil management)	1.12				
SE (varieties)	0.98				
SE (interaction)	1.45				
Year 2					
Farmers practice	3.9	3.8	3.2	3.3	3.6
Bunded non leveled	5.1	4.9	5.1	5.3	5.1
Bunded and leveled	6.8	5.5	6.5	6.2	6.3
Bunded, puddled and leveled ('Sawah')	8.2	6.5	7.8	7.6	7.5
Variety mean	6.0	5.2	5.7	5.6	
SE (soil management)	1.12				
SE (varieties)	0.85				
SE (interaction)	1.03				

Source: Issaka et al. (2008).

Table 3. Effect of nutrient omission on paddy grain yield (t ha^{-1}) under "Sawah" system in Ghana.

Paramter	Adugyama		Biemso	
N-P_2O_5-K_2O (kg ha^{-1})	Year 1	Year 2	Year 1	Year 2
0 - 0 - 0				
0 - 90 - 90	1.29	1.48	1.39	1.47
90 - 0 - 90	2.03	2.08	1.99	2.04
90 - 90 - 0	3.09	2.31	2.75	2.53
90 – 90 - 90	6.84	6.89	7.07	7.11
SE	1.23	1.25	1.29	1.29

Source: Buri et al. (2007).

Table 4. Effect of integrated nutrient management under "Sawah" system on lowland rice yields in Ghana.

Variable	Paddy grain yield (t ha^{-1})		
Treatment	Potrikrom	Biemso No. 1	Biemso No. 2
Control (no manure, no fertilizer)	1.68	2.59	1.50
N-P_2O_5-K_2O (120-90-90) kg ha^{-1}	6.77	8.37	4.03
N-P_2O_5-K_2O (90-60-60) kg ha^{-1}	6.57	7.09	3.90
Poultry Manure (7.0 t ha^{-1})	5.96	6.36	3.82
½ Poultry Manure + ½ Mineral fertilizer	6.25	7.30	4.15
Cattle Manure (7.0 t ha^{-1})	4.54	6.25	3.05
½ Poultry Manure + ½ Mineral fertilizer	4.86	6.49	3.72
LSD (0.05)	0.99	2.14	0.84
Mean site	5.23	6.09	3.58
LSD (0.05) site		0.52	

Adopted from Buri et al. (2004).

Table 5. Comparison of yield (grain and total dry matter) under "Sawah" and traditional systems.

Area	"Sawah" system				Traditional system	
	Jasmine 85		Sikamo		Lapers/Jasmine 85	
	Grain	Stover	Grain	Stover	Grain	Stover
Nsutem	5.4	13.8	6.7	16.5	2.6	14.6
Baniekrom	6.4	18.2	6.1	15.0	2.6	18.0
Mean	5.9	16.0	6.4	15.8	2.6	16.3

National mean yield for Ghana (2009) = 2.4 t ha^{-1} as provided by Ministry of Food and Agriculture (MoFA).

Table 6. Mean grain yield of rice for farmer groups under "Sawah" system in Ghana.

Year/Group	Adugyama A	Adugyama B	Biemso A	Biemso B	Biemso C	Mean	Nat. Mean**
2001	4.0	4.4	4.8	4.7	-	4.5	1.9
2002	4.7	4.8	4.7	5.7	4.5	4.9	2.0
2003	3.8*	5.5	4.8	5.9	5.4	5.1	2.0 (6.5)
2004	5.0	5.5	5.5	6.5	5.5	5.6	2.0 (6.5)
2005	4.5	4.8*	-	5.4*	5.5	5.0	2.0 (6.5)
2006	5.6	5.7	-	-	5.8	5.7	2.0 (6.5)
2007	5.6	5.6	-	-	6.0	5.7	1.7 (6.5)
2008	5.8	6.0	-	-	6.2	6.0	2.3 (6.5)
2009	6.1	6.2	-	-	6.0	6.1	2.4 (6.5)

*Affected by floods; **source – MoFA, Ghana. Figures in parenthesis represent achievable yield.

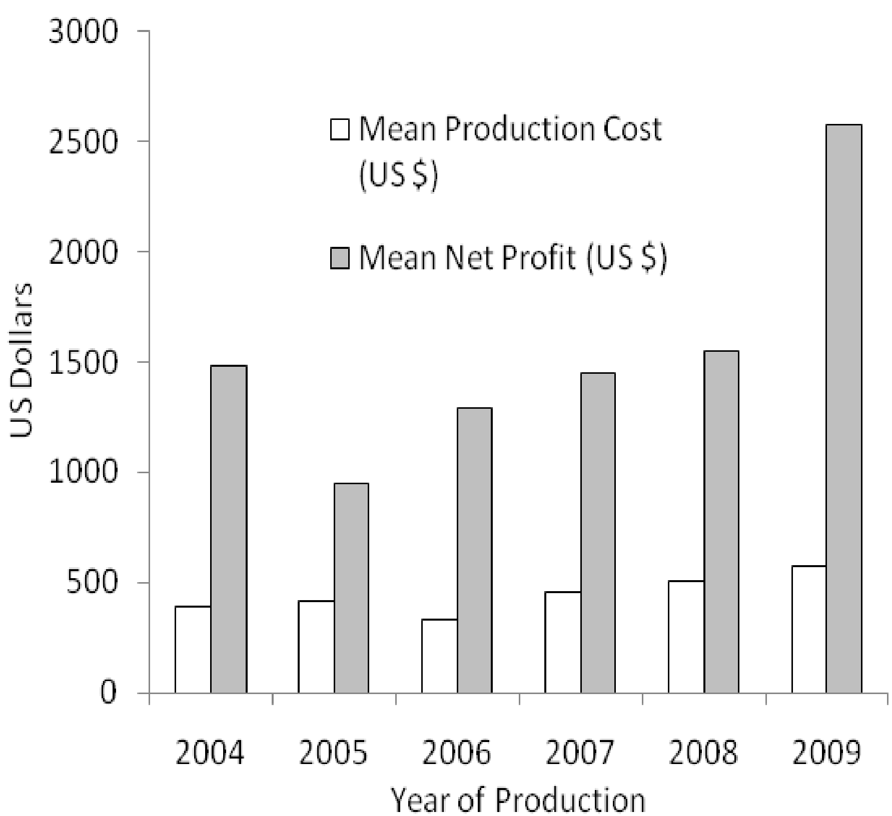

Figure 1. Mean production cost and net revenue of farmer-groups under the "Sawah" system (2004 – 2009).

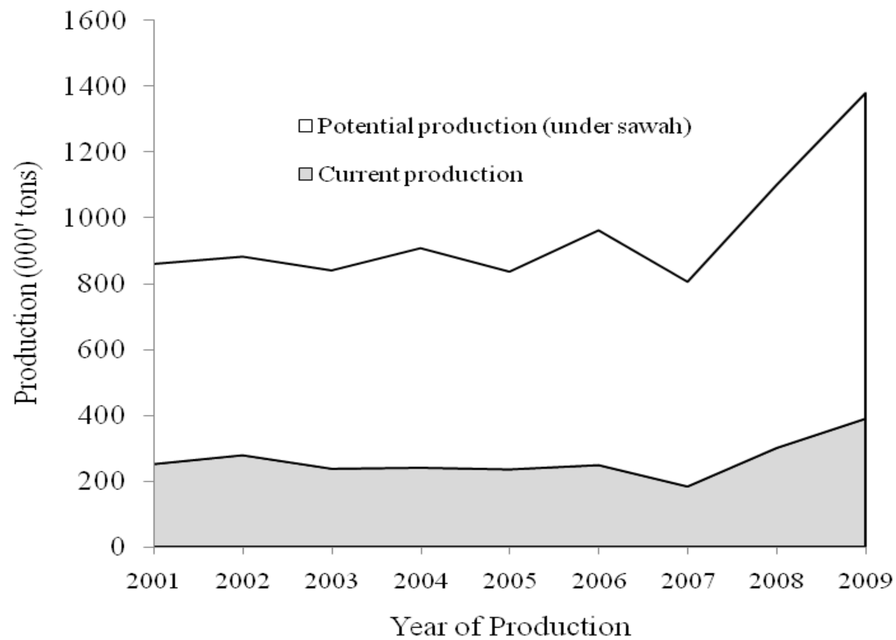

Figure 2. Potential for rice production under the "Sawah" system in Ghana.

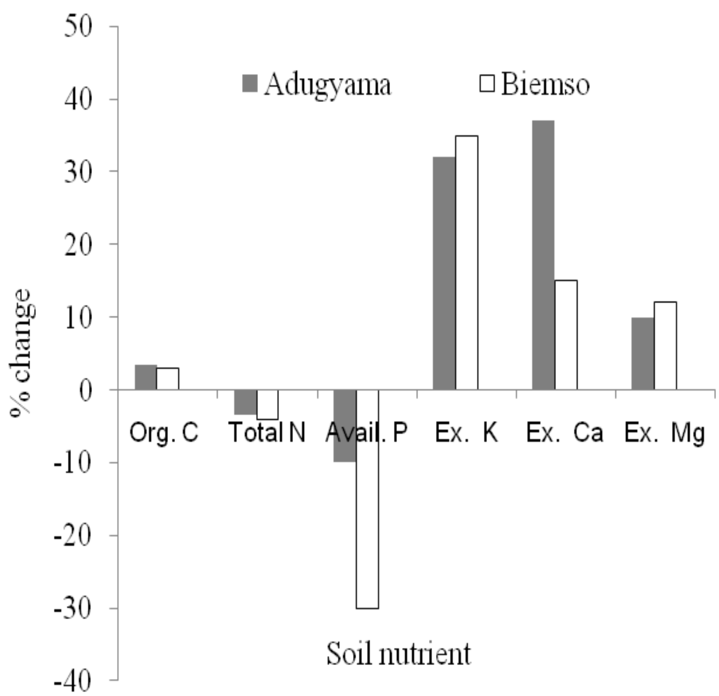

Figure 3. Influence of "sawah" system on nutrient accumulation in two valleys in Ghana (2001 – 2008).

also observed to contribute positively to nutrient accumulation and retention particularly the exchangeable bases and organic carbon. There was a net accumulation of total carbon, and the exchangeable cations (K, Ca, Mg) under "Sawah" system of rice cultivation (Figure 3). There was, however, a net reduction in the levels of total nitrogen and available phosphorus. This may be due to the higher losses of Nitrogen due to the general sandy nature of our soils and low levels of soil total phosphorus. Enhanced uptake under improved soil and water conditions partly explains the reduced levels of available Phosphorus. Particular attention should therefore be paid to Nitrogen and Phosphorus additions and their management.

Conclusion

Appropriate technology for proper development of lowlands for rice production is available in Ghana. To sustain rice cultivation in lowland ecosystems under current increased intensity, there is the need to out-scale eco-friendly technologies like the "Sawah" system across the country. This will also help reduce further land degradation associated with the traditional system. There is also the need to emphasize on integrated nutrient management focusing on local organic sources for increased grain yields. For income generation, job creation, poverty reduction and guaranteed food security in Ghana, the "Sawah" system of rice production can make a significant contribution.

ACKNOWLEDGEMENTS

The authors are very grateful to the Faulty of Agriculture, Kinki University, Japan and Japan International Research Center for Agricultural Sciences (JIRCAS) for providing financial support for data collection and conduction of field activities.

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