Trop. Agr. Develop. 60(2) : 119 − 131, 2016

Soil Fertility Management for Sustainable Lowland Rice Production in Ghana
-Farmer's Perspectives and Soil Physicochemical Properties-

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Abstract Low soil fertility, particularly in the lowlands, has been identified as a major factor limiting rice yields in Sub-Saharan Africa (SSA). A comparative study was therefore conducted in Ghana on soil fertility and farmers' perspectives of soil fertility management in the two major rice growing agro-ecological zones: the Guinea Savanna (GS) and the Equatorial Forest (EF), to examine farmers' perspectives on soil fertility, how farmers manage fertility, and to suggest proper soil fertility management for lowland rice farming. Principal component analysis was used to analyze farmers' perspectives and soil fertility characteristics of the two zones. Results show that soils characteristics vary both within and between the two agro-ecological zones. While soils in the EF zone are relatively fertile, soils of both agro-ecological zones are infertile. The soils are low in organic matter and available phosphorus. Farmer's perspectives on soil fertility management differed across the agro-ecological zones, and could be categorized into three major groups: (a) farmers having high motivation to improve soil fertility, and high awareness of soil drought; (b) farmers who have high motivation to improve soil fertility, but low awareness of the vulnerability to drought; and (c) farmers having weaker interest in soil fertility management, and preferring extensive management to proactive soil fertility management. On the basis of farmers' perspectives, the utilization of local materials would be effective in soil fertility improvement or maintenance in both agro-ecological zones, due to its high applicability for farmers.

Key words: Farmer's perspectives, Ghana, Lowlands, Rice, Soil fertility management

Introduction

Africa is a continent faced with challenges of poverty and hunger, and is therefore a region where technology development for agricultural production is urgently required. One of the factors contributing to low agricultural productivity in Sub-Saharan Africa (SSA) and particularly in Ghana is low soil fertility (Abe *et al.*, 2010; Buri *et al.*, 2010). It is therefore important to increase agricultural productivity and production stability for sustainable development in not only in Ghana but in Africa as a whole, through soil fertility improvement.

The impact of fertilizer use for crop production is considered large in regions of extremely low soil fertility, where nitrogen (N), phosphorus (P), and organic matter are deficient (Abe *et al.*, 2010). However, the application of chemical fertilizer in SSA including Ghana is only one-sixth of that in Asia, due to the high price (Mwangi, 1997; Morris *et al.*, 2007; FAO, 2011). It is difficult for small-scale farmers in SSA, who do not have sufficient financial resources, to access the market-oriented economy, and to procure fertilizers (Bumb *et al.*, 2012). Ghana is one of the countries in SSA where mineral fertilizer usage is very low (Buri *et al.*, 2010). Therefore, it is crucial issue for small-scale farmers to increase crop productivity through improving soil fertility, by using indigenous materials as a cheaper alternative to chemical fertilizer.

Specifically, authors have focused on rice, which is experiencing a rapid increase in demand, and upon which considerable amounts of foreign currency have been spent for importing into SSA in recent years (Balasubramanian *et al.*, 2007). Since 2009, CARD (Coalition for African Rice Development), a Japanese initiative, has been implemented, which aims to double rice production in SSA from 14 million to 28 million tons in 10 years (JICA/AGRA, 2008). This study intended to raise rice productivity, particularly for rain-fed lowland rice, by the dissemination of advanced soil fertility management technology.

Rice has become the second most important food crop in Ghana after maize. Although rice production in the country is spreading in almost all agricultural ecosystems from wet to dry (Buri *et al.*, 1999) from the Guinea Savanna (GS) to the Equatorial Forest (EF), and from

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Communicated by K. Inubushi
Received Jun. 25, 2015
Accepted Dec. 15, 2015
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the Sudan Savanna to the Sahel Savanna (Windmeijer and Andriesse, 1993), it is considered that GS and EF agro-ecological zones have high potential for rain-fed lowland rice production. However, there are major difference in area and production potential between these ecosystems, due to differences in soil, climate, and social and/or economic conditions. And farmer's motivation on soil fertility management also would be affected by these conditions. Thus, it is valuable to elucidate the relationship between actual soil condition and farmer's perception about soil fertility management.

This study, which involved a comparative study of soil conditions and farmer's perspectives on soil fertility management technology, aimed at suggesting appropriate soil fertility management options meeting with regional farmer's perspectives for sustainable lowland rice production systems in Ghana and may also be applicable to other regions of SSA with similar growing environments.

Material and Methods

Research Sites

In 2009, soil samples and socio-economic data were collected from October 17 to December 18 in the GS zone, and from December 1 to December 7 in the EF zone. Data and soil sample collection was conducted across six political regions covering the two major rice growing agro-ecological zones of Ghana, targeting rain-fed lowland rice farming. The Ashanti, Brong Ahafo, Central, and Western Regions were covered in the EF zone while the Northern and Upper East Regions were covered in the GS zone. Surveys were conducted by the Council for Scientific and Industrial Research-Crops Research Institute (CSIR-CRI) in the EF zone and by the University for Development Studies (UDS) in the GS zone. Areas covered are shown in the map shown in Fig. 1.

Monthly mean precipitations during 1990 to 2012 was shown in Fig. 2. Annual precipitations are 1100 mm with a unimodal pattern in Tamale located in the GS zone, and 1370 mm with a bimodal pattern in Kumasi located in the EF zone, respectively.

Survey of farmer's perspectives on soil fertility management

Sampling procedure for survey respondents

30 communities were randomly selected from both agro-ecological zones (Table 1). In the GS zone, the communities were selected through a simple random sampling (lottery method). Random sampling was again employed to select the respondents of rice farmers—ten from each community. A total of 300 lowland rice farm-

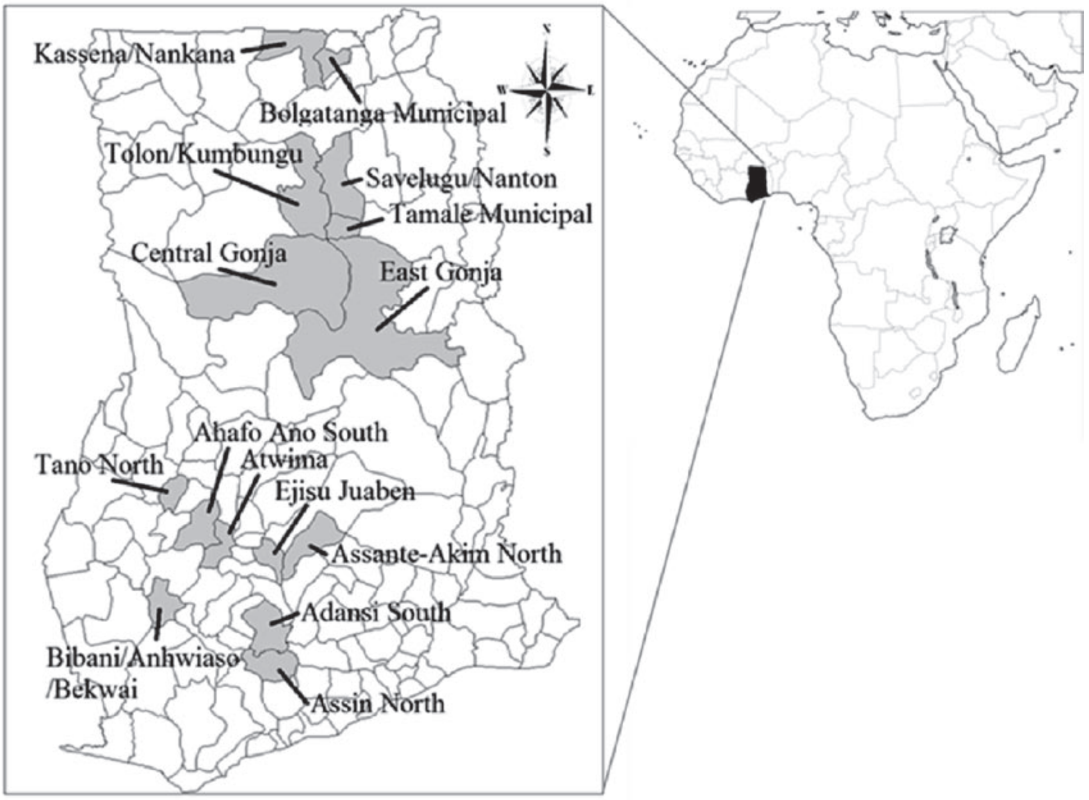

Fig.1. Site map showing areas covered under the socio-economic survey.

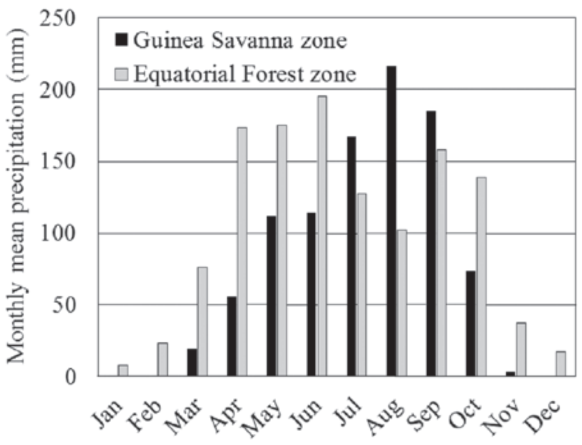

Fig. 2. Monthly mean precipitations during 1990-2012 in Guinea Savanna zone and Equatorial Forest zone. Data sourced by the Climatic Research Unit of University of East Angila (UEA). Data for Guinea Savanna zone and Equatorial Forest zone are represented by Tamale and Kumasi, respectively.

ers were therefore selected from the GS zone.

In the EF zone, a multi-stage sampling method was used. Five districts were randomly selected in the Ashanti region. Within each district, four villages where rice is cultivated were chosen at random. From each of these villages, ten farmers were randomly selected. Thus, a sample of 200 farmers was obtained from the Ashanti Region. In the other political regions (Brong-Ahafo, Central, and Western), one district was selected at random. In these selected districts, villages were again randomly selected with three villages from districts in the Brong-Ahafo and Central regions and four villages from a district in the Western region. Ten farmers were further selected at random from each village. The sample size for these regions was 100, thus also giving a total of 300 respondents from the agro-ecological zone.

Therefore, a total of 600 respondents (rice farmers) were surveyed in order to gain an understanding of farmer's perspectives on soil fertility management in the two major rice growing zones of Ghana

Questionnaire development and key parameters

The socio-economical questionnaire originally consisted of seven parts: A: identification and location specification of respondents, B: demographic and socio-economic characteristics, C: information about crop cultivation other than rice, D: rice cultivation history and farmers view on soil fertility management practices, E: rice field accessibility and proximity factors, F: access to extension service, and G: procedure of rice seed sowing in 2009.

Key parameters relating to farmers' perceptions of soil fertility were extracted from these results to elucidate the relationship between actual soil properties. Selected key parameters were "Which indicators have been used by farmers to determine soil fertility?", "How much chemical fertilizer has been used?", and "What kinds of soil fertility management practices are being presently implemented by farmers?". The interview for these parameters has generally conducted by multiple-choice test with multiple selection allowing, farmers has selected one to three answers from set options, except

Table 1. Number of interviewed communities and villagers by districts.

Agroecological zone	Region	District	Communities	Villagers
Guinea Savanna zone	Northern	Central Gonja	4	40
		East Gonja	2	20
		Savelugu-Nanton	8	80
		Tamale Metropolis	3	30
		Tolon-Kumbungu	7	70
	Upper East	Bologatanga Municipal	3	30
		Kasena-Nankana east	3	30
		Sub total of Guinea Savanna zone	30	300
Equatorial Forest zone	Ashanti	Adansi South	3	30
		Ahafo Ano South	5	50
		Asante Akyem North	4	40
		Atwima Nwabiagya	4	40
		Ejisu-Juaben	4	40
	Brong Ahafo	Tano North	4	40
	Central	Assin North	3	30
	Western	Bibiani-Anweaso-Bekwai	3	30
		Sub total of Equatorial Forest zone	30	300
		Total	60	600

for survey in fertilizer use rate which is using numerical answering.

Soil sampling and analysis procedure

Soil samples were collected from two typical rice fields in each communities covered by the socio-economic interview. Surface soils (0–20 cm) were collected from five points randomly from the field and composited as one soil sample representing the field. A total of 120 soil samples were collected from the 60 selected communities and chemically analyzed as follows:

Collected soil samples were air-dried and sieved using a 2-mm-diameter sieve. The soil pH was measured at a ratio of 1:2.5 using the glass electrode method. Organic carbon and organic matter content were determined according to Nelson and Sommers (1982). Total N was determined by the modified macro-Kjeldahl method (Bremner, 1965). Available P was extracted with the Bray-1 method (Bray and Kurtz, 1945), and P determination was conducted using the ascorbic acid-molybdenum blue method using a UV-visible spectrophotometer. Exchangeable bases were extracted with 1.0 M ammonium acetate solution (pH 7). Sodium (Na) and potassium (K) contents were determined by flame photometry, whereas calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometry (AAS). The method of Thomas (1982) was used for the determination of exchangeable acidity. Effective cation exchange capacity (eCEC) was computed as the sum equivalent of basic cations and exchangeable acidity (K + Ca + Mg + Na + Al + H). Base Saturation Ratio (BSR) was calculated by expressing the sum of basic cations as a percentage of eCEC. Particle size distribution was determined using the pipette method (Gee and Bauder, 1986).

Statistical analysis

Key indicators associated with soil fertility, i.e., indigenous indicators of soil fertility for local farmers (Table 2), chemical fertilizer utilization (Table 3), soil fertility management being practiced (Table 4), numbers of livestock and/or poultry, years of rice cultivation experience, and distance from homes to fields, were selected from the results of socio-economic interviews and converted into five principal components through the principal component analysis (PCA) method using Kyplot version 4.0 (Kyence co. ltd, Japan). A calculated standardized principal component score was used as an indicator of farmers' perspective for evaluating the relationship between soil physicochemical parameters and farmer's perspective.

Identical parameters were analyzed using the hierarchical cluster analysis method, according to Ward's method (Ward, 1963) with standardized squared Euclidean distance, to categorize lowland rice farmers in Ghana. Differences in parameters associated with soil fertility, and observed soil properties within the two agro-ecological zones were evaluated by using Student's t-test.

Results and Discussion

Farmers' perspectives on soil fertility in lowland rice fields

Indices of soil fertility on farmers rice fields?

Farmers have their own views on soil fertility and the local indicators they use to recognize fertile lands upon which they cultivate their crops, including rice.

Table 2. Farmer's indicators of soil fertility in lowland rice fields within Guinea Savanna and Equatorial Forest agro-ecological zones in Ghana.

	Guinea Savanna zone		Equatorial Forest zone		Student's t test
	Mean†	S.E.	Mean†	S.E.	
Origanic matter (Dark color of soil/Humic soil)	55.7	3.7	23.7	4.3	***
Topography (Marshy Land/Lowland)	47.4	6.9	33.9	4.3	
Soil water availability	69.1	6.2	33.1	3.8	***
Soil texture (Less sandy/Clayey soil)	29.8	3.6	22.6	3.7	
Evergreen vegetation	2.0	1.0	32.5	4.2	***
Presence of trees on field	2.7	1.3	0.8	0.5	
Types of weeds	2.0	1.0	9.6	2.1	**
Good soil drainege	3.1	1.8	1.6	0.9	
Worms and/or living things	4.6	1.6	0.4	0.4	*
Duration of fallows period	0.3	0.3	1.1	0.6	
Others	0.3	0.3	4.3	1.2	***

†Mean value of percentages of respondents who are using these indicators within 30 communities in the Guinea Savanna (GS) zone and Equatorial Forest (EF) zone, respectively. S.E.: Standard errors (n =30).

Asterisks indicate significance of difference between GS zone and EF zone, significant levels are * : $p<0.05$, **: $p<0.01$, and ***: $p<0.001$, respectively.

Table 3. Percentage of users, cost, and application rate of chemical fertilizers, such as urea, sulfate ammonium, and NPK fertilizer, in lowland rice fields within the Guinea Savanna and Equatorial Forest agro-ecological zones in Ghana.

	Guinea Savannna zone		Equatorial Forest zone		Student's t test
	Mean†	S.E.	Mean†	S.E.	
Chemical fertilizer utilizaion (%)	76.0	4.1	57.0	5.8	*
Cost (GHS†† /Acre)	29.7	4.1	24.2	3.7	
Chemical fertilizer application rate (Sac††† /acre)					
Urea	0.35	0.10	0.30	0.07	
Sulfate Ammonium	0.45	0.12	0.39	0.06	
NPK	0.54	0.10	0.68	0.14	
Other	0.02	0.01	0.00	0.00	
Total	1.36	0.30	1.37	0.22	

† Mean value of percentages of respondents within 30 communities in the Guinea Savanna (GS) zone and Equatorial Forest (EF) zone, respectively.

†† GHS: Ghana cedis, 1GHS=0.374US$ at the rate of 26th MAR 2014

††† One sac is approximately 50 kg in Ghana. S.E.: Standard errors (n =30).

Asterisk indicate significant difference between GS zone and EF zone, at level of $p<0.05$, by Student's t test.

Table 4. Farmer's actual soil fertility management practices in lowland rice fields within the Guinea Savanna and Equatorial Forest agro-ecological zones in Ghana.

	Guinea Savannna zone		Equatorial Forest zone		Student's t test
	Mean†	S.E.	Mean†	S.E.	
Animal dropping	37.8	6.4	22.3	3.7	*
Crop residue	41.7	7.2	29.1	5.2	
Compost	1.6	0.8	0.4	0.4	
Crop rotation	3.1	1.6	0.0	0.0	
Mixed cropping	3.5	1.8	0.0	0.0	
Fallow	1.8	0.7	28.5	4.1	***
Shifting cultivation	3.9	1.7	0.7	0.5	
None	41.3	7.2	44.7	5.3	

† Mean value of percentages of respondents who are conducting these managements within 30 communities in the Guinea Savanna (GS) zone and Equatorial Forest (EF) zone, respectively. S.E.: Standard errors (n =30).

Asterisks indicate significance of difference between GS zone and EF zone, significant levels are *: $p<0.05$, **: $p<0.01$, and ***: $p<0.001$, respectively.

In the GS zone, the most important soil fertility indicator for lowland rice cultivation was "soil water availability." Sixty nine percent of respondents said that soil water availability was a good indicator of soil fertility for lowland rice cultivation (Table 2). Soil water content during rice growing season seemed to be the most important factor to farmers because rice fields in this zone are generally cultivated under rain-fed conditions (Faltermeier and Abdulai, 2009) and the zone sometimes experiences severe water deficiencies (Armah *et al*., 2011). "Topography" and "organic matter" were the second and third indicators based on the views of farmers in the GS zone (Table 2). It appears that geomorphological field selection for rice cultivation, such as marshy fields (lowlands), is important because these fields can receive and retain adequate amounts of water resources for lowland rice cultivation. It is also well known that soil organic matter content is highly correlated with soil water retention capacity (Gupta and Larson, 1979; Hudson, 1994; Rawls *et al.,* 2003).

In the EF zone, "topography" was selected as the most important indicator of soil fertility management (Table 2). However, in contrast to the GS zone, differences in the percentages between the first-ranked indicator and the second- or third-ranked indicators were not salient (Table 2). The second indicator was "soil water availability," while the third was "evergreen vegetation". Toriyama *et al.* (2011) has indicated evergreen vegetation distributes in the location which has relatively higher water availability, in comparison with deciduous vegetation. Mean values of these indicators were 33.1% and 32.5%, respectively (Table 2). Lowland rice farming in the EF zone is usually practiced in inland valleys. Hence, farmers need to select the flat and marshy lowlands within the small-size watershed. In addition, farmers in this zone were recently introduced to the *Sawah* eco-technology. The *Sawah* technology is an integrated water resources management system that improves lowland rice yields (Ofori *et al.,* 2005), and mainly consists of bunding, puddling, and leveling of rice fields, with inlets and outlets for irrigation and drainage (Obalum *et al*., 2012). Seemingly, these are the reasons why topography and soil water availability are respectively ranked as the first and second most important indicators in the EF zone.

Chemical fertilizer application for lowland rice cultivation

Recently, increases in the rate of chemical fertilizer use have been reported in Ghana (Fianko *et al*., 2011) and are mainly due to subsidies from the Ghanaian government (Krausova and Banful, 2010). The percentage of farmers who applied chemical fertilizer to their lowland rice field was 76% and 57% in the GS zone and EF zone, respectively (Table 3). Earlier, Ragasa *et al.* (2013) showed that the percentages of inorganic fertilizer users in Ghana were 98% for irrigated rice fields, 68% for lowland rain-fed rice fields, and 82% for upland rain-fed rice fields, with an average of 77%. Our investigation targeted the rain-fed lowland rice farmers, and for these the mean percentage of chemical fertilizer use was 67%.

Table 3 also shows that the unit cost of chemical fertilizer application is relatively higher in the GS zone (27.5 US$ ha^{-1}) than in the EF zone (22.4 US$ ha^{-1}), although there is not significant difference. A previous report suggested the farm gate price of fertilizer was rising due to the increasing distance from farms to the nearest fertilizer seller (IFDC, 2012). According to Krausova and Banful (2010), the average of such distances in the GS zone was nearly 120 km, whereas in the EF zone, it was almost 90 km. The average chemical fertilizer application rates, as observed in this study, were 1.36 and 1.37 sacs per acre (1 sac = 50 kg), which equates to 36 kg N ha^{-1} and 35 kg N ha^{-1} for the GS and EF zones, respectively.

Present soil fertility management practices of rice farmers other than use of chemical fertilizers

Farmers' present soil fertility management practices, except chemical fertilizer application, are listed in Table 4. Use of animal dung and/or crop residues was a dominant practice by farmers' in both zones. Composting was observed to have an extremely low percentage of use (Table 4). Quansah *et al.* (2001) indicated that 43% of farmers in the GS zone were using composted refuse and/or residues. However, in the case of lowland rice farming, only 1.6% of farmers were using the composting technology. This result indicates that, for lowland farmers, direct use of indigenous organic resources is more popular than the use of pretreated material, such as composting.

In the EF zone, fallowing was another practice for soil fertility management as 29% of lowland rice farmers practiced fallowing, as opposed to only 2% of farmers in the GS zone.

The most important finding was that as much as 41% and 45% of rice farmers were not practicing any form of soil fertility management in the GS and EF zones respectively. Whether farmers do not recognize the necessity of soil fertility management or simply lack the knowledge requires further investigation. This suggests that there is still more to be done for rice farmers in Ghana to improve on soil fertility management.

Classification of farmer's perspective of soil fertility by principal component analysis and cluster analysis

To categorize farmers according to their perspectives on soil fertility, the results of interviews were subjected to PCA, using a total of 29 parameters, including 11 parameters from indicators of soil fertility (ISF) shown in Table 2, six parameters from chemical fertilizer application (CF) shown in Table 3, and eight parameters from local farmers' practices (LP) shown in Table 4, in addition, numbers of years in rice cultivation and the distance from farmers' homes to rice fields. After the PCA, five computed principal components (PCs) were selected with criteria based on changes in slope in the screen plot. A factor-loading matrix of five selected PCs is shown in Table 5.

PC1 showed higher factor loadings in CF parameters such as application rates of chemical fertilizers (NPK, urea, ammonium sulfate), and organic matter content in ISF, while fallowing and no practical management showed negative values. This PC was therefore defined as "Intensity of soil fertility management".

PC2 had higher factor loadings in the parameters of water availability, soil texture, and soil macro-fauna, such as worms, within ISF, and shifting cultivation, mix cropping and crop rotation within LP. Local practices that provided high values included cropping systems that are not usually operated in irrigated rice cultivation, but are common for upland crops. These key parameters which showed positive values seemed to be sensitive to drought or soil water retention, particularly under rain-fed cultivation. On the other hand, use of animal dung and crop residues had a negative value. Vegetation factors such as "evergreen vegetation" and "types of weeds" also showed negative factor loadings. Lowland/marshy

Table 5. Parameters used for principal component analysis (PCA) and factor loadings for each principal component.

Parameter	PC 1	PC 2	PC 3	PC 4	PC 5
CF[†] Total chemical fertilizer application rate	0.850	-0.187	-0.422	0.128	-0.137
CF NPK application rate	0.737	-0.118	-0.441	0.209	-0.113
CF Sulfate Ammonium application rate	0.729	-0.142	-0.342	0.187	-0.033
CF Urea application rate	0.727	-0.220	-0.342	0.015	-0.234
CF Other chemical fertilizer application rate	0.241	-0.084	0.008	-0.234	0.012
CF Total cost for chemical fertilizer application	0.612	-0.124	-0.458	0.130	-0.167
ISF[††] Presence of trees on the field	-0.016	-0.340	0.335	-0.117	0.159
ISF Availability of water in soil	0.415	0.650	-0.110	-0.102	0.268
ISF Evergreen vegetation	-0.530	-0.278	-0.268	0.495	0.033
ISF Length of fallow	0.083	0.032	-0.070	0.535	0.503
ISF Organic matter content	0.570	-0.169	0.173	-0.178	0.497
ISF Others	-0.339	-0.137	-0.107	0.150	-0.264
ISF Soil texture	0.080	0.542	-0.360	-0.044	0.521
ISF Topography	0.194	-0.517	0.559	-0.230	-0.276
ISF Types of weeds	-0.326	-0.256	-0.127	0.242	-0.271
ISF Well drained soil	0.029	-0.179	0.087	-0.078	0.350
ISF Worms/living things	0.225	0.663	0.159	0.007	-0.093
LP[†††] Animal dropping	0.366	-0.434	0.383	0.212	0.054
LP Compost	0.273	-0.125	0.274	0.205	-0.008
LP Crop residue	0.255	-0.615	0.324	0.298	0.291
LP Crop rotation	0.199	0.561	0.523	0.426	-0.177
LP Fallow	-0.526	-0.085	-0.223	0.444	0.111
LP Mixed cropping	0.269	0.624	0.382	0.507	-0.070
LP None	-0.183	0.625	-0.450	-0.461	-0.134
LP Shifting cultivation	0.238	0.645	0.334	0.462	-0.100
Number of livestock	0.375	0.149	0.424	-0.345	0.049
Number of poultry	0.319	-0.048	0.312	-0.099	0.039
Year rice cultivation	0.112	0.051	0.185	-0.328	0.067
Distance from home to field	0.028	0.147	0.244	-0.019	-0.488
Eigen-value	4.869	4.050	3.029	2.370	1.747
Contribution rate (%)	16.8	14.0	10.4	8.2	6.0
Accumulated proportion (%)	16.8	30.8	41.2	49.4	55.4

[†] CF is pertinent parameters for Chemical Fertilizer

[††] ISF is pertinent parameters for local Indicators of Soil Fertility

[†††] LP is parameters related to Local Practices presently conducting in the study sites

topography showed notably high negative values. Organic matter application is effective and advisable regardless of soil water regime, and topographical factors can be considered as factors relating to water collection rather than to soil water retention. Additionally, good soil water drainage showed a negative value. Negative values in PC2 are an indication that water resources were adequate, and therefore farmers need not be too much concerned about this factor. PC2 was therefore considered as "Awareness for risk of vulnerability to drought."

In PC3, although topography showed the highest positive value, there were low negative values in some of the parameters relating to chemical fertilizer application, while organic resource management showed high positive values. Therefore, PC3 was considered as "Preference for organic soil amendment to inorganic material use."

PC4 showed high factor loadings for length of fallow and evergreen vegetation in ISF, and mixed cropping, shifting cultivation, fallow, and crop rotation in LP (Table 5). Negative values were recorded under years of rice cultivation, number of livestock, and no practical management. These three negative parameters seem to be relevant to vegetation degradation in agricultural fields. Therefore, we defined PC4 as "Expectation for vegetation on soil fertility improvement".

In PC5, parameters such as soil texture, length of fallow, organic matter content, water drainage in ISF, showed high positive values. However, distance from

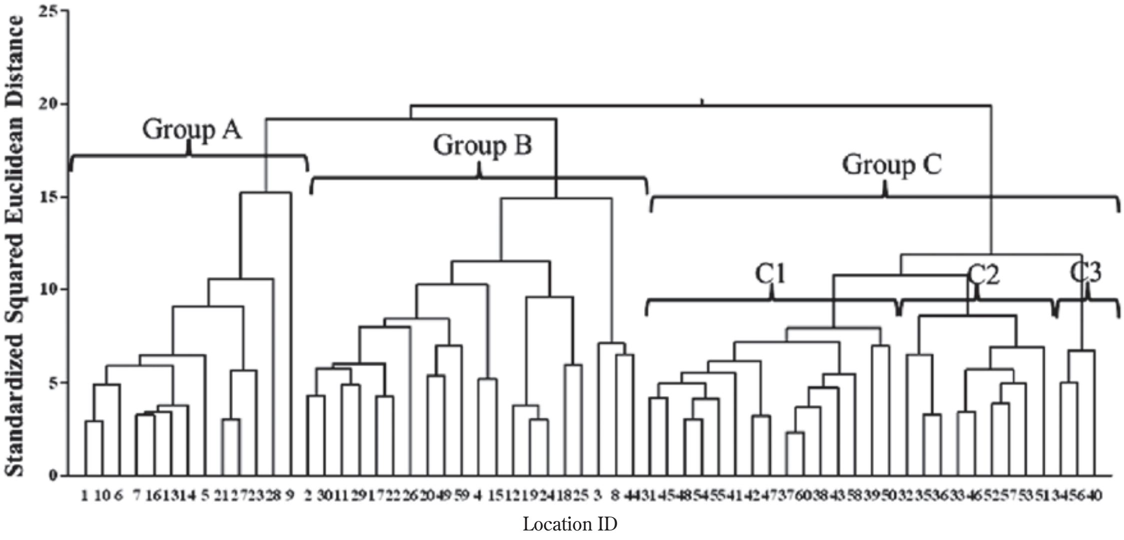

Fig. 3. Dendrogram showing clustering of study sites according to farmer's perspectives on soil fertility management.
Location IDs 1–30 are located within the Guinea Savanna and 31–60 are located within the Equatorial Forest agro-ecological zones, respectively.

farmers' homes to the field showed relatively stronger negative values. Parameters showing highly positive values were considered to relate to natural soil conditions. Thus, PC5 was designated "Recognition of natural soil physicochemical properties."

Furthermore, 60 investigated sites were categorized by cluster analysis using the 29 identical parameters of PCA analysis. The results showed that lowland rice farmers in Ghana could be mainly classified into three groups (Fig. 3). The three classified groups were characterized further using PCs as discussed earlier. Fig. 4 indicates the PC score distribution in the three classified groups. Clarified characteristics of each group, according to PCA and Cluster analysis, were as follows.

Group A had higher values in PC1, PC2, and PC5 (Fig. 4). This group had higher motivation for intensive soil fertility management, and higher awareness of vulnerability of soil water condition. They showed no preference for any type of fertilizer and used both chemical and organic fertilizers. It is important to note that all communities classified into this group were located in the GS zone.

Group B showed higher values in PC1 and PC3, but a low value in PC2 (Fig. 4). This suggests that communities in this group preferred organic matter application to chemical fertilizer. However, the low PC2 value suggests that they were less concerned about drought or soil water conditions. Most of group B (86%) were communities in the same agro-ecological zone (GS zone) as group A. However, this group showed conspicuous difference from group A in PC2 and PC3 values (Fig. 4).

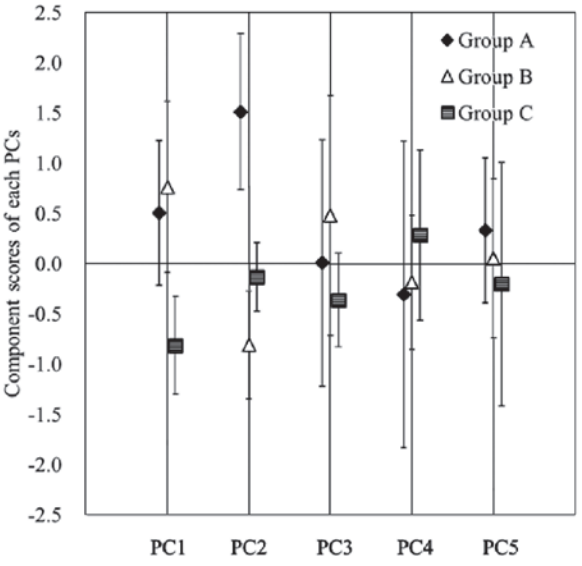

Fig. 4. Component score distribution of three farmer categories. Error bars indicate standard deviations. (Group A, n = 13; Group B, n = 20; Group C, n = 27)

These differences might be caused by differences in the topography of the GS zone. It has been stated that flooding probability is highly varied in lowland rice fields in this zone (Yamamoto *et al*., 2012), and spatial patterns in soil carbon content corresponded to the length of the waterlogging period (Tsujimoto *et al*., 2013). Although further investigation would be required, it may be considered that group B communities are located relatively close to fluvial water resources, but far from markets where they can purchase chemical fertilizer.

Group C was characterized by low scores in PC1 and PC5, but showed a high score in PC4, indicating a relatively low concern about soil fertility management. Group C can be characterized by a higher expectance of vegetation restoration (Fig. 4). All sites (100%) categorized into group C were located in the EF zone (Fig. 3). It seemed that more farmers in EF zone have a much stronger consideration that soil fertility could be maintained through vegetative restoration such as fallowing, without intensive management, in comparison with farmers in GS zone.

Physicochemical properties of lowland rice fields in Ghana

Fig. 5 shows the variation of soil physicochemical properties of the investigated lowland rice fields in the GS and EF zones of Ghana. Generally, most soils in Ghanaian lowland rice fields are acidic and are mainly silt loam in texture.

Mean soil pH in the GS zone was 5.1 within a range of 4.5 to 6.0. Mean soil organic carbon and total N contents were 0.59% and 0.06%, respectively. The mean value of eCEC for the zone was 4.5 cmolc kg^{-1}. Available P values ranged from trace levels to as high as 22 mg kg^{-1} with a mean of 11.3 mg kg^{-1}. The soil were mostly silty loam or sandy loam texture.

The mean soil pH for the EF zone was 5.5. Soil organic carbon and total N contents for this zone were significantly higher than those of the GS zone, with mean values of 1.6% and 0.16%, respectively. Over 90% of the samples showed eCEC values above 10 cmolc kg^{-1}. Available P values ranged from trace levels to 31 mg kg^{-1}, with a mean value of 11 mg kg^{-1}. Mean available P in the EF zone was comparable to that in the GS zone (11.3 mg kg^{-1}). Soil textures for both zones were generally similar: silty loam or sandy loam. Pyhsicochemical properties of lowland soils within the GS and EF zones have been previously reported by Buri *et al.* (2010). According to their findings, soil in the GS zone indicated lower values of soil pH, and total carbon, total N, available P, and exchangeable cations levels when compared to the EF zone. Under this study, observed soil properties were generally in line with earlier observations of Buri *et al.* (2010). Soil pH, organic carbon, total N, and exchangeable cations levels within the GS zone had significantly lower values ($p < 0.001$) than those with in the EF zone.

However, available P content was not significantly different between the two agro-ecological zones, even though previous studies indicated significantly higher available P levels in the EF than in the GS zones (Buri *et al.*, 2010). The critical value for soil available P using the Bray-I method is 10 mg kg^{-1} in West Africa (FAO, 2000). According to Mallarino *et al.* (2013), Bray-I P values are classified into interpretative categories designated as very low (0–8 mg kg^{-1}), low (9–15 mg kg^{-1}), optimum (16–20 mg kg^{-1}), high (21–30 mg kg^{-1}), and very high (>31 mg kg^{-1}). Although the mean available P values in each zone were slightly higher than the critical value (10 mg kg^{-1}), soil available P content in this study were generally low. Over 73% of lowland rice fields within the

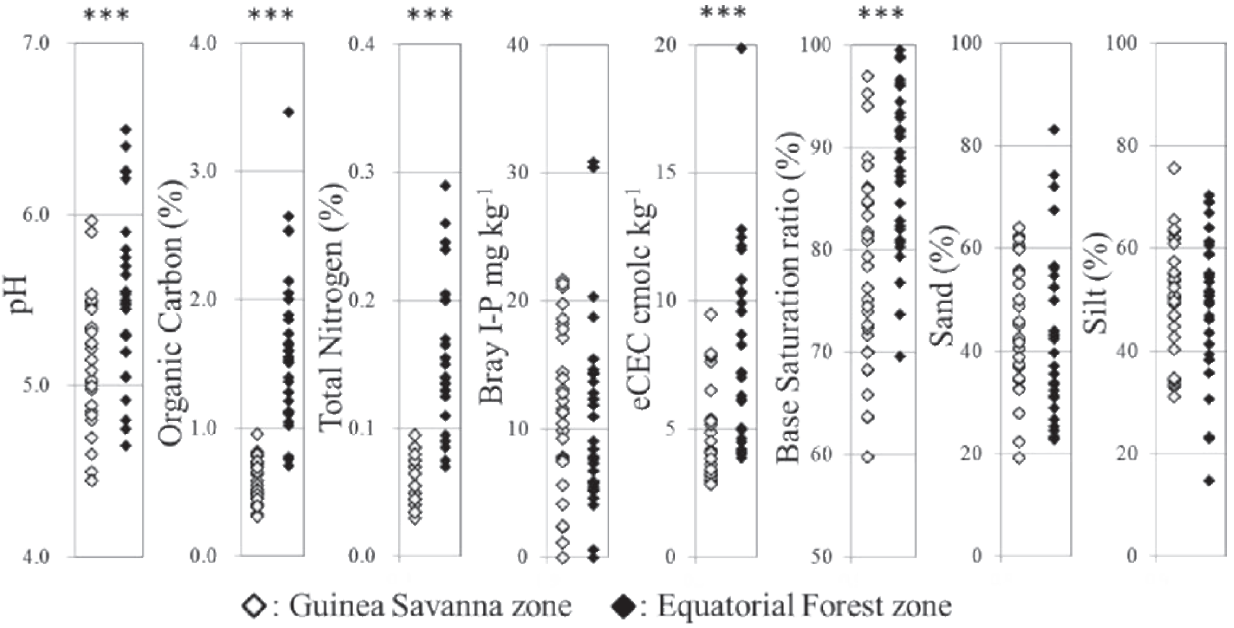

Fig. 5. Soil physicochemical properties of lowland rice fields in Guinea Savanna and Equatorial forest zones, Ghana.
Asterisks indicated above the each plot area denote significant difference calculated by Student's t test, between Guinea Savanna zone and Equatorial Forest zone, ***: $p<0.001$.

GS and over 83% within the EF zones were categorized into either low or very low P levels.

As mentioned above, most of the lowland rice fields sampled within the EF zone were located in inland valleys, while most sites within the GS zone were located in flood plains. It is probable that such different toposequential conditions affected the soil pH and organic matter content, as these parameters are affected by water conditions, and have different organic matter decomposition rates. On the other hand, available P seemed to be mainly affected by fertilization and/or soil amendment application. There were no significant differences in the total quantities of chemical fertilizers applied as shown in Table 3.

Relatively lower levels of soil fertility parameters within the GS zone, suggest a higher necessity for effective soil fertility management if rice production is to be sustained.

The relationship between farmers' perspectives and soil properties

To elucidate the proper soil fertility management in the two agro-ecological zones, the relationship between PC scores as farmers' perspective and observed soil properties was investigated. A correlation matrix between five PCs and soil properties is shown in Table 6. PC1 showed a significant negative correlation with soil organic matter content (SOM; $p < 0.001$), total N content (T-N; $p < 0.001$), and base saturation ratio (BSR; $p < 0.05$). The relationship between PC1 and SOM is plotted in Fig. 5. As discussed earlier, lowland rice farmers in Ghana recognize SOM to be one of the most important indicators of soil fertility. The negative correlation revealed that farmers who own SOM-deficient fields are conducting more intensive management to improve soil fertility. Comparison between the two zones indicates that lowland farmers in the GS zone are more aware of soil fertility management than those in the EF zone (Fig. 6).

PC2 did not show any significant correlation with any soil parameters, whereas soil pH, SOM, and total N showed relatively higher correlation coefficients than others (Table 6). As mentioned earlier, PC2 was the PC of awareness for risk of vulnerability to drought. Soil water conditions were mainly affected by physical conditions such as particle size distribution. Therefore, it should have been positively correlated with these parameters. However, these correlations were not significant (Table 6). Since PC2 consisted of factors associated with water management systems, such as water collection, existence of water reservoirs, or influence of flooding, these parameters would be independent of soil texture. In other words, water environments and corresponding water managements, rather than physical soil conditions, are more related to farmers' subjective judgment on drought risk.

Antwi-Agyei *et al.* (2012) noted that vulnerability to drought in Ghana has geographical and socioeconomic patterns, with regions in the GS zone being the most vulnerable, and that it is because these regions have the lowest adaptive capacity due to lower socio-economic development and rain-fed agriculture.

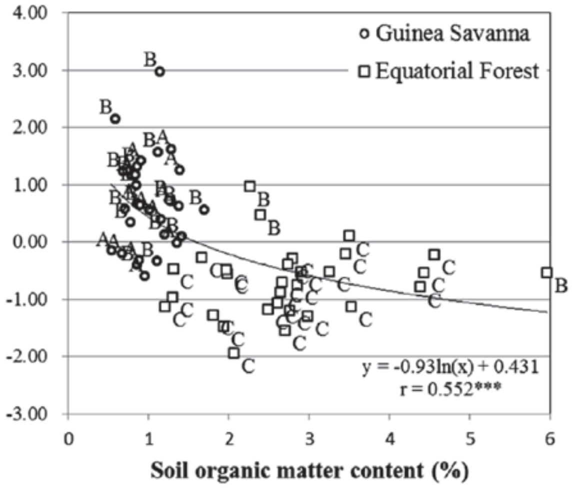

Fig. 6. Relationship between PC1 score and soil organic matter content of lowland rice field in Ghana. The letters next to each symbol indicates the classified farmers group through cluster analysis.

Table 6. Correlation matrix between principal component scores and soil physicochemical properties.

	pH	SOC	SOM	T-N	Bray P	Ex.Ca	Ex.Mg	Ex.K	T.E.B.	Ex.Acid	eCEC	BSR	Sand	Silt	Clay
PC1	-0.212	-0.488 ***	-0.488 ***	-0.492 ***	-0.173	-0.216	-0.218	-0.239	-0.228	0.148	-0.222	-0.270 *	-0.010	0.063	-0.152
PC2	-0.179	-0.182	-0.184	-0.196	0.069	-0.137	-0.078	-0.089	-0.114	0.129	-0.106	-0.102	-0.028	0.033	0.003
PC3	0.014	-0.217	-0.218	-0.230	0.327 *	-0.213	-0.221	-0.212	-0.225	-0.077	-0.241	-0.134	0.092	-0.012	-0.303 *
PC4	0.285 *	0.213	0.222	0.205	-0.020	0.249	0.208	0.338 *	0.246	-0.267 *	0.229	0.352 **	0.015	-0.062	0.149
PC5	-0.141	-0.374 **	-0.369 **	-0.426 ***	0.184	-0.289 *	-0.203	-0.302 *	-0.271 *	-0.020	-0.283 *	-0.198	0.239	-0.199	-0.233

*, **, *** indicates significant correlation with $p < 0.05$, < 0.01, and < 0.001, by Student's t test, respectively.
SOC: Soil organic carbon, SOM: Soil organic matter, T.E.B.: Total exchangeable bases, eCEC: Effective Cation exchange capacity, BSR: Base saturation ratio.

PC3 showed a positive correlation with available P content ($p < 0.05$) and negative correlation with clay content ($p < 0.05$), as shown in Table 6. It is an indication that available P content was higher in the fields of people who prefer to use organic resources. Farmers in Ghana generally purchase chemical fertilizer mainly N based and not P based. Although the most popular chemical fertilizer in Ghana is NPK compound fertilizer, others are mainly simple N fertilizers such as urea and ammonium sulfate. Most rice farmers are poorly resourced and therefore tend to purchasing simple N fertilizer for economic reasons. On the other hand, most of organic resources in Ghana contain P as organic P source. Thus, higher preference for organic resource has resulted in higher available P content in the soil. The negative correlation with clay contents clearly showed that sandy soils needed organic resource additions to improve both their physical and chemical properties, such as eCEC. Hence, communities with sandy soils had a higher preference for organic resources.

PC4 indicated a significant positive correlation with BSR ($p < 0.01$) and exchangeable K ($p < 0.05$), but a negative correlation with exchangeable acidity ($p < 0.05$). PC4 is the component of expectation for soil fertility improvement by vegetation restoration. From the analysis, lowland rice fields with high BSR and low acidity were not extensive and their fertility could be adequately improved without any artificial management. Group C in particular showed a higher value in PC4 (Fig. 4), an indication that farmers thought favorably of extensive management such as fallowing.

PC5 is the principal component of natural conditions of soil physicochemical property. Many parameters of observed soil properties therefore showed significant correlations with PC5: SOC ($p < 0.01$), SOM ($p < 0.01$), total N ($p < 0.001$), exchangeable Ca ($p < 0.05$), exchangeable K ($p < 0.05$), total exchangeable bases ($p < 0.05$), and effective CEC ($p < 0.05$). These significant correlations indicated that farmers recognized and monitored soil fertility and/or soil properties on their own rice fields by using some traditional indicators. It is well known that soil fertility is affected by various factors. Soil physicochemical property is only one part of these factors. However, the fact that Ghanaian lowland rice farmers correctly recognized and monitored their soil properties was an indication of their high potential to improve soil fertility supported by appropriate integrated management protocols. Training on scientific knowledge about soil and ecology will further empower farmers to improve crop production.

Patterns in soil fertility management in the two agro-ecological zones

As discussed above, results showed that lowland rice farmers in Ghana could be mainly categorized into three groups; all of Group C's communities were located in the EF zone, whereas Groups A and B's farmers were mainly in the GS zone.

Farmers in the GS zone, (Groups A and B), displayed considerable motivation and conducted intensive management to improve soil fertility under relatively lower soil fertility conditions. One of these groups showed the willingness to use both chemical and organic fertilizer. However, another group had a greater preference for organic resources. This may be due to differences in the affordability and accessibility of chemical fertilizer. Although soil conditions have been observed to have large variances, it is necessary to note that the use of indigenous organic resources is a key factor to improving fertility in soils that have inherently infertile characteristics, as demonstrated by the organic resource utilization by all farmers in the region. Issaka *et al.* (2012) reported that rice residues and cow dung were useful especially in the GS zone, because of their availability and easier accessibility.

When the economic conditions of farmers improves, chemical fertilizer application can be promoted, but the high cost of chemical fertilizer currently is a major hindrance. As indicated earlier, the ratio of chemical fertilizer users to the average cost of chemical fertilizer was higher in the GS than in the EF zone, while application rates in both zones remained the same. As discussed above, it is obvious that the relatively higher cost of chemical fertilizers is a reflection of the longer distance to the market (IFDC, 2012). Although the Ghana government has been addressing this subject through offering subsidies, accessibility to and affordability of chemical fertilizer needs to be improved in the region.

Within the EF zone, lowland rice farmers categorized into group C had relatively weaker motivation regarding proactive soil fertility management practices. This was probably due to favorable natural soil properties, and to the superiority of water resource management in farmer's perspectives against other management practices. Study sites in this zone were generally located in inland valleys, which are considered suitable for optimum water control (Wakatsuki and Masunaga, 2005).

Although improved water resource management is effective in rice cultivation (Becker and Johnson, 2001), soil fertility management is equally important, so as to maintain and/or restore soil conditions against nutrient depletion (Issaka *et al*., 1996). Due to weaker motivation for soil fertility management in this zone, technical options need to be facilitated with more affordable and accessible resources. Thus, the soil fertility management in this zone should be based on effective and efficient use of organic resources, and with due consideration for resources accessibility. This should not be limited to rice residues, which are the most accessible resource; the main organic industrial wastes such as poultry dung and saw dust have advantages in terms of availability and accessibility in the EF zone (Issaka *et al*., 2011). P fertilization with affordable P resource would also be required to offset the observed and anticipated limitation of soil P availability.

As discussed above, observed lowland rice farmers group in Ghana has generally categorized by motivation on soil fertility management and vulnerability for drought. It can be considered that these categorization would be changed due to climate changes, although Maddison (2007) pointed it is difficult to immediately change farmer's practice and perception, and adapt to climate change. Further investigation would be required to elucidate changes in farmer's perspectives on soil fertility management due to climate change.

Conclusion

Lowland rice fields in the two major rice growing agro-ecological zones in Ghana were observed to be infertile. Lowland soils within the GS and EF had low organic matter and available P contents even though soils in the EF zone showed relatively higher levels.

Farmer's perspectives for soil fertility management differed across the agro-ecological zones and could be categorized mainly into three groups: (a) farmers having higher motivation to improve soil fertility through the use of chemical and organic fertilizers, and having higher awareness of soil drought; (b) farmers who want to improve soil fertility through the use of organic resources rather than chemical fertilizers, but whose awareness of vulnerability to drought is low; and (c) farmers having a weaker interest in soil fertility management, and preferring extensive management to intensive soil fertility management. Differences among these groups could be attributed to both socio-economic and geographical conditions. Hence soil fertility management practices need to be proposed with due consideration to local context.

Judging from farmers' perspectives, soil organic matter and water conditions were the two most important indicators of the soil fertility status of lowland rice fields. This suggests that indigenous organic resource utilization would be more applicable in both agro-ecological zones, while improving accessibility to inorganic fertilizer in both zones is also necessary. Application of organic material would contribute not only to maintaining water and/or nutrient-holding capacity of the soil but also to improving soil chemical properties through the addition of plant nutrient elements.

The relationship between scientifically evaluated soil properties and farmers' judgments and actual practices showed that farmers who cultivate relatively infertile soil had a stronger motivation to improve soil fertility and practiced good management, using whatever means possible than farmers with more favorable soil conditions. Especially for the farmers who have the lower motivation on soil fertility management, affordable and applicable management would be suggested such as organic resource application which requires less additional work and cost.

This study revealed that lowland rice farmer's perspectives on soil fertility management in Ghana, regionally changes due to geographical diversity i.e. soil characteristics, water availability, and socio-economical context. However, it has not been conducted about quantitative evaluation for effect of farmer's soil fertility management which is presently practicing in both agro-ecological zone on crop production improvement. Further investigation would be required.

Acknowledgement

This study is a component "The study on improvement of soil fertility with use of indigenous resources in rice systems of sub-Sahara Africa Project," which was funded by Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan. The authors are grateful to all staff at the University for Development Studies (UDS), CSIR-Soil Research Institute (SRI), and CSIR-Crop Research Institute (CRI) in Ghana for their dedicated support.

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