Original Research Article

EFFECT OF DIFFERENT LAND PREPARATION METHODS FOR *SAWAH* SYSTEM DEVELOPMENT ON SOIL PRODUCTIVITY IMPROVEMENT AND RICE GRAIN YIELD IN INLAND VALLEYS OF SOUTHEASTERN NIGERIA

ABSTRACT

The development of agriculture in inland valleys of Southeastern Nigeria could not be realized merely due to inability of the farmers to develop these potential and abundant inland valleys for such water loving crops like rice using appropriate water management systems.

In an attempt to replicate the successful Japanese *Satoyama* watershed management model in the African agro-ecosystems, *sawah* rice cultivation technology has been introduced to farmers' fields. A study was conducted in an inland valley at Akaeze, Ivo Local Government Area of Ebonyi State, Southeastern Nigeria, in 2012, 2013 and 2014 cropping seasons using the same watershed and treatments, to assess the effects of different tillage environments and different amendments in *sawah* water management system on soil chemical properties and rice grain yield. *Sawah* described as an Indo-Malaysian word for padi, refers to leveled rice field surrounded by bunds with inlets and outlets for irrigation and drainage. A split- plot in a randomized complete block design was used to evaluate these two factors. The four tillage environments (complete *sawah* tillage- bunded, puddled and leveled rice field (CST); farmers tillage environment- no bunding and leveling rice field (FTE); incomplete *sawah* tillage- bundding with little leveling and puddling rice field (ICST) and partial *sawah* tillage- bunding with no puddling and leveling rice field (PST)) for rice growing served as main plots. The amendments, which constituted the sub-plots, were applied in the following forms: 10 t ha^{-1} rice husk ash, 10 t ha^{-1} of rice husk, 400 $kgha^{-1}$ of N.P.K. 20:10:10, 10 t ha^{-1} of poultry droppings, and 0 t ha^{-1} (control). The additive residual effects of the amendments were not studied in the course of this research. A bulk soil sample was collected at 0-20 cm depth in the location before tillage and amendments for initial soil characteristics. At each harvest, another set of soil sample was collected on different treated plots to ascertain the changes that occurred in the soil due to treatments application. Selected soil chemical properties analyzed include; soil pH, OC, total nitrogen, exchangeable bases (Na^+, Ca^{2+}, Mg^{2+} and K^+) and CEC, while the rice grain yields was also measured at each harvest. The soil amendments were analyzed for N, P, K, Ca, Mg, Na, and organic carbon. Data collected were subjected to statistical analysis using Genstat 3 7.2 Edition. Results showed that the soil pH, organic carbon (OC) and total nitrogen (TN) including the exchangeable bases were significantly ($p < 0.05$) improved by different tillage parameters for the three years of study. CEC was significantly ($p < 0.05$) improved by the tillage environments on the 2nd and 3rd year of studies. Soil amendments significantly ($p < 0.05$) improved the soil pH, OC, TN and all the exchangeable bases within the periods of study. The interaction significantly ($p < 0.05$) improved the soil exchangeable Ca^{2+} and Mg^{2+} on the third year of study. The result showed a significant improvement on the rice grain yield by the tillage environments and amendments within the periods of study. It was also obtained that all the *sawah* adopted tillage environments positively improved both the soil parameters and rice grain yield relatively higher than the farmers' tillage environment.

Key words: *sawah,* tillage environment, water management, amendments, rice grain yield, soil properties

INTRODUCTION

Increasing food production to overcome food insecurity is one major challenge facing Nigeria today. Nigeria is a country that is well blessed with adequate rainfall and abundant inland valleys for cropping. Despite these abundant inland valleys in Nigeria, especially in the Southeast for Agricultural use, these areas have not been fully exploited.

Soil fertility degradation and inefficient weed and water control have been the limiting factors to the proper utilization of these inland valleys for sustainable rice-based cropping [1 – 4].

The soils of Southeastern Nigeria especially that– of Ebonyi State is low in fertility. The soils have been observed to be acidic, low in organic matter status, cation exchange capacity and other essential nutrients [5 – 9]. Researches on the interaction of organic and inorganic manure with water control systems to improve soil chemical properties in rice *sawah* management system have not received much attention in Nigeria.

Determining appropriate fertility, weed and water management practices could lead to improved and sustainable crop yields in these areas. An African adaptive *sawah* lowland farming with irrigation scheme for integrated watershed management will be the most encouraging strategy to resolve these problems and restore the degraded inland valleys of these areas for increased and sustainable food production [10 – 12]. With the introduction of the *sawah* rice production technology to Nigeria in the late 1990s and its high compatibility with our inland valleys, the position of these land resources in our agricultural development in Southeastern Nigeria and realization of –food security is increasingly becoming clearer Obalum *et al*. [13].

The problem with the full adoption of the technology in this part of the country is that farmers still rely more on their traditional method of water control. They do not know much about the field preparation as to incorporate the components of the technology into their rice farming land operation. Farmers need to know that rice field environment determines how soil fertility, weed and water control can best be managed for optimum rice production.

Andriesse, [14] noted that in order to realize and sustain the potential benefits accruable from cultivating the inland valleys of West Africa, much of the research effort in these land resources is geared towards alleviating productivity constraints.

Sawah has been described severally as an *Indo-Malaysian* word for *padi* (Malay word for paddy) or lowland rice management system comprising bunding, puddling, levelling and good water management through irrigation and drainage [15].

Sawah system through its control/ maintenance of field surface water level during plant growth period, contribute to the alleviation of global warming problems through the fixation of carbon in forest and *sawah* soils in ecologically sustainable ways.

It restores/replenishes the lowland with nutrients through geological fertilization as it resists erosion. The mechanisms in *sawah* system of nutrient replenishments in lowlands through geological fertilization encourage not only rice growth, but also the breeding of various microbes, which improves biological nitrogen fixation [16].

In southeastern Nigeria, especially Ebonyi State, activities aimed at ensuring food security include the cultivation of rice in the numerous inland valleys in the area under the traditional and partial *sawah* tillage systems. The impacts of full adoptions of the complete *sawah* tillage system (in which puddling is a key soil management practice) in terms of soil fertility improvement and crop yield have not been studied.

This study aims at bridging the gaps in knowledge of appropriate *sawah* tillage methods for the development of suitable *sawah* environment in inland valley rice production and soil fertility maintenance among the rice farmers in Nigeria. It also aimed at assessing different soil amendments using different ploughing (tillage environments) to *sawah* technology for appropriate fertility, rice and water management in inland valleys of Southeastern Nigeria.

2.0 MATERIALS AND METHODS

2.1 Location of Study

The study was conducted in 2012, 2013 and 2014 on the floodplain of Ivo River in Akaeze, Ebonyi South agro-ecological zone of Ebonyi State.

Figure 1: Arial photograph of study area

Akaeze lies at approximately latitude $05^{0} 56^{'}$ N and longitude $07^{0} 41^{'}$ E. The annual rainfall for the area is 1,350 mm, spread from April to October with average air temperature of 29^{o} C [17]. The area falls within the derived savanna of Southeastern Nigeria with a low-lying and undulating relief. The geology of the area comprises sequences of sandy shales, with fine grained micaceous sandstones and mudstones that is Albian in age and belongs to the Asu River Group [18].
The soils are described as Aeric Tropoaquent [19] or Gleyic Cambisol [20]. Soils are mainly used by the farmers for rain-fed rice production during the rainy seasons and vegetable production as the rain subsides.

2.2 Field method

The experimental field was demarcated into four main plots where the four different tillage practices were adopted. A composite sample was collected at 0- 20 cm soil depth using soil auger for initial soil characteristics (Table 1). Out of the four main plots, three were later divided into sub-plots with a 0.6 m raised bunds. In these plots, the water level was controlled at an approximate level of between 5 cm to 10 cm from 2 weeks after transplanting to the time of ripening of the rice grains, while in unbunded plots that represent the farmers' traditional field; water was allowed to flow in and out as it comes, as described below:
The four tillage practices which represented the 4 main plots include;

- Main plot I; Complete *sawah* tillage: bunded, puddle and leveled rice field (CST)
- Main plot II; Incomplete *sawah* tillage: bunded and puddle with minimum leveling rice field (ICST)
- Main plot III; Partial *sawah* tillage: bunded, no puddling and leveling rice field (PST)
- Main plot IV; Farmers tillage practice: no bunding, puddling and leveling rice field (FTE)

The complete and incomplete *sawah* tillage practices were tilled with power-tiller according to the specification of the tillage practice; the rest of other tillage practices were manually tilled using the specifications stated above.
The sub-plots demarcated from the main-plots with 0.6 m raised bunds were treated with soil amendments. A split-plot in a randomized complete block design (RCBD) was used to arrange the treatments in the sub-plots. The amendments were as follows:

- Poultry droppings (PD) @ 10 ton/ha
- NPK fertilizer (20:10:10) (NPK) @ 400 kg/ha recommended rate for rice in the zones
- Rice husk ash (RHA) @ 10 ton/ha obtain within the vicinity

- Rice husk (RH) @ 10ton/ha, also obtained within the vicinity
- Control (CT - no soil amendment)

Table 1: **Initial properties of the topsoil of the studied site (0-20 cm) before tilling and treatments application**

Soil Property	Value
Clay (%)	10
Silt (%)	21
Total sand (%)	69
Textural class	SL
Organic matter %	2.64
Organic carbon % (OC)	1.61
Total nitrogen % (N)	0.091
pH (H_2O)	3.6~~(?)~~
pH (KCl)	3.0
Exchangeable bases ($cmolkg^{-1}$)	
Sodium (Na)	0.15
Potassium (K)	0.04
Calcium (Ca)	1.0
Magnesium (Mg)	0.6
Cation exchange capacity (CEC)	5.6
Exchangeable acidity (EA)	3.2
Available phosphorous (mg/kg)	4.20
Base saturation (BS)	24.70

L = Loamy soil; SL = Sandy-loam soil

Table 2: **Nutrient compositions (%) in the amendments**

	Amendment		
	Poultry dropping (PD)	**Rice husk (RH)**	**Rice husk ash (RHA)**
OC	16.52	33.75	3.89
N	2.10	0.70	0.056
Na	0.34	0.22	0.33
K	0.48	0.11	1.77
Ca	14.4	0.36	1.4
Mg	1.2	0.38	5.0
P	2.55	0.49	11.94
C:N	7.87	48.21	6.71

OC = Organic carbon; N = Nitrogen; Na = Sodium; K = Potassium; Ca = Calcium; Mg = Magnesium; P = Phosphorous; C:N = Carbon: Nitrogen ratio

The treatments were replicated three times in each of the four main-plots to give a total of twenty sub-plots in each of the main-plot, with each sub-plot measuring 6 m x 6 m. The PD, RHA and RH were incorporated manually into the top 20 cm soil depth using hand fork in each of the plots that received them 2 weeks before the transplanting was done. The nutrient contents of these organic amendments were determined as presented in Table 2.

A high-tillering and yielding rice variety *Oryza sativa var. FARO 52 (WITA 4)* was used as a test crop for the study. The rice seeds were first raised in the nursery and later transplanted to the main field after 3 weeks in nursery. At maturity, the rice were harvested, threshed, dried and the yield weight was computed at 90% dry matter content (10% moisture content). At the end of each harvest, another set of soil samples were collected from each replicate of every plot for chemical analyses to determine the changes that occurred in the soil due to the amendments.

2.3 Laboratory Analysis

Auger samples were collected from all the identified sampling points from the top (0–20 cm) soil in triplicates at each harvest.

The auger topsoil samples were air-dried and sieved with 2 mm sieve. Soil fractions less than 2 mm from individual samples were then analyzed using the following methods; Particle size distribution of less than 2 mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder [21]. Soil pH was measured in a 1:2.5 soil:0.1 M KCl suspensions (22). The soil OC was determined by the Walkley and Black method described by Nelson and Sommers [23]. Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and $CuSO_4$ and Na_2SO_4 catalyst mixture [24]. Exchangeable cations were determined by the method of Thomas [25]. CEC was determined by the method described by Rhoades [26].

2.4 Data analysis

Data analysis was performed using GENSTAT 3 7.2 Edition. Treatment means were separated and compared using Least Significant Difference (LSD) and all inferences were made at 5% Level of probability.

3.0 RESULTS AND DISCUSSION

3.1 Effects of *sawah* tillage environments and amendments on the soil pH

The results of soil pH (Table 3) revealed that there was significant difference ($P<0.05$) among the *sawah* tillage environment. The results (Table 3) indicated that among the tillage environments, complete *sawah* tillage environment significantly increased the soil pH in all the 2nd and 3rd year of study. The pH values varied from 3.79 – 4.02, 4.30 – 4.64, 4.47 – 4.83 (farmers' – complete sawah tillage environment) in the 1st, 2nd and 3rd year of study, respectively. It was noted from the results that farmers tillage environment generally performed statistically ($p < 0.05$) lower relatively to other *sawah* tillage environment for the three years of study. The increased pH values in complete *sawah* tillage environment could be attributed to the geological fertilization with materials from the upland region that are later moved into the rice field, thereby increasing the base saturation of the soil, hence improvement in the pH of the soil. This agreed with Wakatsuki *et al.* [27] and Fashola *et al.* [28] who affirmed that fertile topsoil formed in forest ecosystem and sedimentation of the eroded topsoil in lowland *sawah* is the geological fertilization process. Generally, the significant improvement made in pH of the studied soil by the complete *sawah* tillage environments where water is ponded could also be linked to the findings of Russel [29], that the pH of a submerged soil usually rises, but where the temperature of the soil, the amount of reducible substances, or the amount of ferric iron is too low to produce sufficient ferrous iron for the buffering to become operatives, the pH may tend to decrease.

Nwite *et al.* [9] remarked that pH increased significantly in *sawah* water – managed system in a two year of study to evaluate *sawah* and non-*sawah* water management systems in a similar location.

The soil pH was improved significantly ($p < 0.05$) higher in soils treated with rice husk ash in all the *sawah* tillage including the farmers' tillage environment for the three years of study. The values ranged from 3.57 – 4.30, 3.50 – 4.84 and 3.73 – 5.03, in the 1st, 2nd and 3rd year of study, respectively. The significant improvement made by RHA on pH is in conformity with the findings of Abyhammer *et al.* [30]; Markikainen, [31] and Nwite *et al.* [12]; who stated that ash amendment could induce a pH increase by as much as 0.6 – 1.0 units in humus soils. Generally, the result showed that soils treated with amendments increased pH significantly higher than untreated for period of study. This result is in conformity with the finding of Opara-Nnadi *et al.* [32] who reported pH increase following the application of organic wastes.

Table 3: Effects of Tillage environments and amendments soil pH

***Sawah* Tillage**	**Amendments**

environments

	CT	NPK	PD	RH	RHA	Mean
Year 1						
Complete	3.6	3.7	4.1	4.2	4.5	**4.02**
Incomplete	3.6	3.9	4.3	3.8	4.4	**4.01**
Partial	3.6	3.8	3.8	3.9	4.3	**3.88**
Farmer	3.5	4.0	3.7	3.8	3.9	**3.79**
Mean	**3.57**	**3.84**	**3.97**	**3.93**	**4.30**	
LSD $_{(0.05)}$ Tillage environments			NS			
LSD $_{(0.05)}$ Amendment			0.1789			
LSD $_{(0.05)}$ Tillage environments x Amendments			0.3553			
Year 2						
Complete	3.7	4.8	4.8	4.7	5.1	**4.64**
Incomplete	3.4	4.8	4.8	4.7	4.9	**4.51**
Partial	3.4	4.7	4.6	4.6	4.7	**4.42**
Farmer	3.4	4.5	4.6	4.4	4.6	**4.30**
Mean	**3.50**	**4.68**	**4.68**	**4.63**	**4.84**	
LSD $_{(0.05)}$ Tillage environments			0.1182			
LSD $_{(0.05)}$ Amendment			0.0897			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 3						
Complete	4.0	5.0	4.9	4.9	5.3	**4.83**
Incomplete	3.7	4.8	4.9	4.8	5.0	**4.65**
Partial	3.7	4.8	4.8	4.8	5.0	**4.61**
Farmer	3.5	4.6	4.8	4.7	4.8	**4.47**
Mean	**3.73**	**4.83**	**4.83**	**4.97**	**5.03**	
LSD $_{(0.05)}$ Tillage environments			0.1952			
LSD $_{(0.05)}$ Amendment			0.1230			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

3.2 Effects of *sawah* tillage environments and amendments on the soil organic carbon (SOC)

It was also observed that *sawah* tillage environments significantly ($p < 0.05$) affected soil organic carbon (SOC) pool higher compared to farmers' tillage method (Table 4). The results (Table 4) showed that complete *sawah* tillage environment significantly ($p < 0.05$) improved the soil organic carbon pool over other *sawah* tillage environments. 0.92 – 1.34, 1.03 – 1.47, 1.06 – 1.51 range values were obtained in the first, second and third year, farmers' to complete tillage field, respectively. This could be attributed to finer fractions that were formed after the destruction of the soil structure due to puddling in the complete *sawah* tillage environment [13]. This shows the superiority of *sawah* eco-technology if the whole components are fully employed on *sawah* farming operations. It is also significant in harnessing the health conditions of the soil and reduction in global warming. Hirose and Wakatsuki, [10]; Wakatsuki *et al.* [33] submitted that *sawah* fields will contribute to the alleviation of global warming problems through the fixation of carbon in forest and *sawah* soils in ecologically sustainable ways.

This result equally agrees with the findings of Igwe *et al.* [17] that higher soil organic carbon was recorded in soils with finer fraction of water stable aggregate (WSA<1.00) brought by well puddle activity associated with a complete *sawah* technology. This arrangement confirms the submission of Igwe and Nwokocha [34] and Lee *et al.* [35] that more SOC was found in finer aggregates than in the macro-aggregates. Follet [36] showed that sequestering CO_2 from the atmosphere through improved soil management practices can have a positive impact on soil resources, because increasing soil C increases the functional capabilities of soils.
The results (Table 4) indicated that amended plots significantly ($p < 0.05$) improved the soil organic carbon relatively higher than the control plots within the period of study. The result equally indicated a significantly higher SOC pool on plots amended with rice husk dust than plots treated with other

amendments. The result confirms the findings of Lee *et al.* [35] who reported from a long-term paddy study in southeast Korea that continuous application of compost improved SOC concentration and soil physical properties in the plough layer, relative to inorganic fertilizer application. The results also showed that there was significant improvement on the buildup of SOC with the interactions of *sawah* tillage environments and amendments at a long-term management. This agreed with the submission that incorporation of plant residues coupled with appropriate puddling and water management build up organic carbon status of soil [37].

Table 4: Effects of Tillage environments and amendments on soil organic carbon (%)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	0.83	1.72	1.21	1.85	1.09	**1.34**
Incomplete	0.76	1.22	1.21	1.28	1.15	**1.13**
Partial	0.90	1.02	1.03	1.47	1.21	**1.13**
Farmer	0.63	1.09	1.09	1.21	0.57	**0.92**
Mean	**0.78**	**1.26**	**1.14**	**1.45**	**1.01**	
LSD $_{(0.05)}$ Tillage environments			0.2650			
LSD $_{(0.05)}$ Amendment			0.2579			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 2						
Complete	0.99	1.81	1.46	1.89	1.20	**1.47**
Incomplete	0.92	1.28	1.49	1.53	1.22	**1.29**
Partial	0.87	1.19	1.42	1.57	1.14	**1.24**
Farmer	0.74	1.11	1.14	1.22	0.96	**1.03**
Mean	**0.88**	**1.35**	**1.38**	**1.55**	**1.13**	
LSD $_{(0.05)}$ Tillage environments			0.2134			
LSD $_{(0.05)}$ Amendment			0.1558			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 3						
Complete	1.07	1.80	1.52	1.91	1.27	**1.51**
Incomplete	0.92	1.21	1.55	1.38	1.24	**1.26**
Partial	0.67	1.27	1.53	1.69	1.13	**1.26**
Farmer	0.83	1.17	1.13	1.20	0.99	**1.06**
Mean	**0.87**	**1.36**	**1.43**	**1.54**	**1.16**	
LSD $_{(0.05)}$ Tillage environments			0.1897			
LSD $_{(0.05)}$ Amendment			0.2131			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

3.3 Effects of *sawah* tillage environments and amendments on the soil total nitrogen

The results (Table 5) also indicated that there was significant difference among the *sawah* tillage environments in the second and third year of study in the site. It was equally obtained that among the four tillage environments, complete *sawah* tillage environment significantly ($p < 0.05$) improved soil total nitrogen higher than other tillage adopted environments. This affirms the submissions made by some researchers that, soil submergence also promotes biological nitrogen fixation (BNF) [38], and submerged soils can sustain an indigenous N supply for rice as evidenced by long-term stable yields in minus-N plots in long term experiments. Buresh *et al.* [38] stated that uncontrolled water in lowland rice field results in alternate wetting and drying which leads to greater sequential nitrogen-denitrification than with continuous submergence.

The results (Table 5) equally pointed highly significant (Table 5) differences on the soil total nitrogen with application of amendments in all the three years of the study. It was observed that NPK amended plots did improve the element higher within the period of study, especially on the 2nd and 3rd year. Consequently, there was an increased trend in the soil total nitrogen as the year progresses.

The interaction of the two factors only improved the soil total nitrogen significantly in the second year of study.

Table 5: Effects of Tillage environments and amendments on soil total nitrogen (%)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	0.059	0.117	0.098	0.079	0.084	**0.088**
Incomplete	0.049	0.098	0.084	0.065	0.075	**0.074**
Partial	0.051	0.089	0.093	0.088	0.112	**0.087**
Farmer	0.050	0.089	0.079	0.084	0.061	**0.073**
Mean	**0.053**	**0.098**	**0.089**	**0.079**	**0.087**	
LSD $_{(0.05)}$ Tillage environments			NS			
LSD $_{(0.05)}$ Amendment			0.02060			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 2						
Complete	0.060	0.117	0.103	0.103	0.095	**0.095**
Incomplete	0.045	0.110	0.095	0.089	0.081	**0.084**
Partial	0.041	0.095	0.099	0.092	0.099	**0.085**
Farmer	0.043	0.079	0.075	0.072	0.069	**0.068**
Mean	**0.047**	**0.100**	**0.093**	**0.089**	**0.086**	
LSD $_{(0.05)}$ Tillage environments			0.00679			
LSD $_{(0.05)}$ Amendment			0.00684			
LSD $_{(0.05)}$ Tillage environments x Amendments			0.01340			
Year 3						
Complete	0.065	0.117	0.116	0.107	0.089	**0.099**
Incomplete	0.047	0.114	0.098	0.095	0.085	**0.088**
Partial	0.041	0.102	0.107	0.098	0.094	**0.089**
Farmer	0.047	0.083	0.079	0.080	0.075	**0.073**
Mean	**0.050**	**0.104**	**0.100**	**0.095**	**0.086**	
LSD $_{(0.05)}$ Tillage environments			0.01268			
LSD $_{(0.05)}$ Amendment			0.00876			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

3.4 Effects of *sawah* tillage environments and amendments on the exchangeable bases

The results (Tables 6, 7, 8 and 9) indicated that different *sawah* tillage environments significantly improved the exchangeable bases with complete *sawah* tillage environment giving a higher significant ($p < 0.05$) increase in the exchangeable bases in the three years of study than others. Generally, all the *sawah* tillage environments with *sawah* technology component(s) statistically ($p < 0.05$) improved the exchangeable bases relatively higher than the farmers'/traditional adopted tillage environment. Eswaran *et al.*, [39]; Abe *et al.*, [40] reported that these natural soil fertility replenishment mechanisms observed in *sawah* adopted plots are essential for enhancing the sustainability and productivity of lowland rice farming systems in inherently unfertile soils in West Africa and Sub-Saharan Africa. Nwite *et al.,* [9] affirms that essential plant nutrients such as K^+, Ca^{2+} and Mg^{2+} including fertility index like the CEC were improved upon in *sawah* managed plots than non-*sawah* managed plots within the studied period in an experiment conducted in one of the same location. The results (Tables 6, 7, 8 and 9) also showed that the soil amendments equally improved ($P<0.05$) the exchangeable bases in the studied location. Generally, the result confirmed that rice husk ash performed significantly higher in the improvement of the exchangeable bases than other treatments. This result confirms the submission of Nwite *et al.* [12] that amending the lowland soils of Southeastern Nigeria with plant residue ash under *sawah* management system of rice production improved the organic carbon and total nitrogen, exchangeable K^{+}, Ca^{2+} and Mg^{2+} of the soil.

It was also recorded that the interactions of the four tillage environments and amendments significantly improved the exchangeable magnesium and calcium in the second and third year of study.
This result agrees with Buri *et al.* [41] who report that 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.

Table 6: Effects of Tillage environments and amendments on soil exchangeable sodium (cmolkg^{-1})

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	0.107	0.153	0.177	0.197	0.150	**0.157**
Incomplete	0.107	0.173	0.183	0.197	0.120	**0.156**
Partial	0.143	0.247	0.197	0.187	0.140	**0.183**
Farmer	0.100	0.157	0.153	0.127	0.137	**0.135**
Mean	**0.114**	**0.183**	**0.178**	**0.177**	**0.137**	
LSD ($_{0.05}$) Tillage environments			NS			
LSD ($_{0.05}$) Amendment			0.02772			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			
Year 2						
Complete	0.163	0.250	0.243	0.240	0.267	**0.233**
Incomplete	0.140	0.223	0.227	0.217	0.240	**0.209**
Partial	0.153	0.220	0.223	0.220	0.233	**0.210**
Farmer	0.130	0.203	0.193	0.187	0.203	**0.183**
Mean	**0.147**	**0.224**	**0.222**	**0.216**	**0.236**	
LSD ($_{0.05}$) Tillage environments			0.01844			
LSD ($_{0.05}$) Amendment			0.01748			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			
Year 3						
Complete	0.183	0.260	0.263	0.250	0.290	**0.249**
Incomplete	0.173	0.233	0.237	0.230	0.250	**0.225**
Partial	0.173	0.240	0.233	0.230	0.260	**0.227**
Farmer	0.153	0.223	0.203	0.193	0.213	**0.197**
Mean	**0.171**	**0.239**	**0.234**	**0.226**	**0.227**	
LSD ($_{0.05}$) Tillage environments			0.02638			
LSD ($_{0.05}$) Amendment			0.02475			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

Table 7: Effects of Tillage environments and amendments on soil exchangeable potassium (cmolkg^{-1})

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	0.017	0.057	0.097	0.053	0.070	**0.059**
Incomplete	0.013	0.050	0.060	0.040	0.057	**0.044**
Partial	0.013	0.036	0.050	0.030	0.047	**0.035**

Farmer	0.013	0.023	0.023	0.016	0.040	**0.023**
Mean	**0.014**	**0.042**	**0.058**	**0.035**	**0.053**	
LSD ($_{0.05}$) Tillage environments				0.01713		
LSD ($_{0.05}$) Amendment				0.01484		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
Year 2						
Complete	0.027	0.070	0.090	0.073	0.093	**0.071**
Incomplete	0.013	0.067	0.110	0.063	0.087	**0.068**
Partial	0.023	0.067	0.080	0.067	0.063	**0.060**
Farmer	0.013	0.053	0.070	0.053	0.060	**0.050**
Mean	**0.019**	**0.064**	**0.088**	**0.064**	**0.076**	
LSD ($_{0.05}$) Tillage environments				0.01032		
LSD ($_{0.05}$) Amendment				0.01031		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
Year 3						
Complete	0.040	0.073	0.097	0.077	0.103	**0.078**
Incomplete	0.040	0.077	0.123	0.073	0.090	**0.081**
Partial	0.033	0.073	0.087	0.077	0.087	**0.071**
Farmer	0.023	0.067	0.087	0.070	0.067	**0.063**
Mean	**0.034**	**0.073**	**0.098**	**0.074**	**0.087**	
LSD ($_{0.05}$) Tillage environments				NS		
LSD ($_{0.05}$) Amendment				0.01873		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

Table 8: Effects of Tillage environments and amendments on soil exchangeable calcium (cmolkg^{-1})

***Sawah* Tillage environments**	**Amendments** CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	1.13	1.67	1.80	1.47	1.87	**1.59**
Incomplete	1.07	1.57	1.53	1.50	1.83	**1.50**
Partial	1.00	1.53	1.47	1.47	1.47	**1.39**
Farmer	1.00	1.43	1.33	1.53	1.40	**1.34**
Mean	**1.05**	**1.55**	**1.53**	**1.49**	**1.64**	
LSD ($_{0.05}$) Tillage environments				0.0751		
LSD ($_{0.05}$) Amendment				0.1625		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
Year 2						
Complete	1.13	2.07	1.97	1.93	2.67	**1.95**
Incomplete	1.00	1.77	2.00	1.77	2.20	**1.75**
Partial	1.00	1.80	1.80	1.77	2.00	**1.67**
Farmer	1.00	1.60	1.60	1.60	1.70	**1.50**
Mean	**1.03**	**1.81**	**1.84**	**1.77**	**2.14**	
LSD ($_{0.05}$) Tillage environments				0.1017		
LSD ($_{0.05}$) Amendment				0.1266		
LSD ($_{0.05}$) Tillage environments x Amendments				0.2403		
Year 3						
Complete	1.27	2.13	2.13	2.00	2.93	**2.09**
Incomplete	1.07	1.87	2.13	1.80	2.43	**1.86**
Partial	1.03	1.97	1.93	1.93	2.20	**1.81**
Farmer	1.00	1.70	1.77	1.70	1.77	**1.59**
Mean	**1.09**	**1.92**	**1.99**	**1.86**	**2.33**	

LSD $_{(0.05)}$ Tillage environments			0.1485			
LSD $_{(0.05)}$ Amendment			0.1606			
LSD $_{(0.05)}$ Tillage environments x Amendments			0.3108			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash.

Table 9: Effects of Tillage environments and amendments on soil exchangeable magnesium ($cmolkg^{-1}$)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	0.37	1.27	1.20	1.07	1.93	**1.17**
Incomplete	0.47	1.00	1.20	1.13	1.27	**1.01**
Partial	0.53	1.13	0.93	1.00	1.53	**1.03**
Farmer	0.40	0.93	1.07	.080	1.27	**0.89**
Mean	**0.44**	**1.08**	**1.10**	**1.00**	**1.50**	
LSD $_{(0.05)}$ Tillage environments			NS			
LSD $_{(0.05)}$ Amendment			0.2636			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 2						
Complete	0.60	1.73	1.97	1.73	2.73	**1.75**
Incomplete	0.60	1.60	1.73	1.43	2.00	**1.47**
Partial	0.63	1.30	1.40	1.13	1.80	**1.25**
Farmer	0.43	1.00	1.07	1.00	1.27	**0.95**
Mean	**0.57**	**1.41**	**1.54**	**1.33**	**1.95**	
LSD $_{(0.05)}$ Tillage environments			0.1182			
LSD $_{(0.05)}$ Amendment			0.1413			
LSD $_{(0.05)}$ Tillage environments x Amendments			0.2696			
Year 3						
Complete	0.93	1.93	2.07	1.93	2.93	**1.96**
Incomplete	0.70	1.80	1.87	1.60	2.27	**1.65**
Partial	0.70	1.40	1.40	1.23	2.00	**1.35**
Farmer	0.50	1.10	1.17	1.07	1.37	**1.04**
Mean	**0.71**	**1.56**	**1.63**	**1.46**	**2.14**	
LSD $_{(0.05)}$ Tillage environments			0.1479			
LSD $_{(0.05)}$ Amendment			0.1409			
LSD $_{(0.05)}$ Tillage environments x Amendments			0.2789			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash.

3.5 Effects of *sawah* tillage environments and amendments on the soil cation exchange capacity (CEC)

The values of CEC (Table 10) in the whole soils in the first year was not positively influenced by different tillage environments, but the use of different *sawah* tillage environments significantly ($p < 0.05$) improved the CEC in the 2^{nd} and 3^{rd} year of study. It was generally observed that all *sawah* tillage environments significantly ($p < 0.05$) highly influenced the CEC relative to the farmers' environment, with complete tillage environment improving it best. The CEC values varied from 5.87 – 6.75 cmol (+) kg^{-1}, 5.59 – 10.31 cmol (+) kg^{-1} and 5.83 – 11.31 cmol (+) kg^{-1}, in the 1^{st}, 2^{nd} and 3^{rd} year, respectively. This result implies that there was a realization of geological fertilization mechanism and cycling of nutrients in the inland valley soils of the area studied. This means that soil erosion effect which do erode most topsoil nutrients in most inland valleys of Southeastern Nigeria can be eliminated or reduced when all the components of *sawah* technology is employed during lowland rice field operations. These submission agrees with [42, 43, 10, 44, 45] that the soils formed and nutrients released during rock-weathering and soil formation processes in upland areas arrive and accumulate in lowland areas through geological fertilization processes, such as soil erosion and sedimentation, as well as surface and ground water movements or colluviums formation processes. Ideal land use patterns and landscape management practices will optimize the geological fertilization processes through the optimum control of hydrology in a given watershed [39, 40].

The results (Table 10) also indicated a significant improvement on the soil CEC due to amendments within the period of study. Generally, there was a -short-term improvement on the CEC of the locations with the application of different amendments. Poultry dropping amended plots generally improved the soil CEC higher than other amendments within the periods of study. The values ranged from 4.55 – 7.35 cmol (+) kg^{-1}, 4.33 – 9.47 and 4.35 – 10.60 cmol (+) kg^{-1}, in the first, second and third year of study.

Table 10: Effects of Tillage environments and amendments on soil cation exchange capacity (cmolkg^{-1})

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	4.53	6.27	8.67	6.53	7.73	**6.75**
Incomplete	4.67	5.20	7.47	6.40	7.33	**6.21**
Partial	5.33	5.20	6.73	6.07	7.40	**6.15**
Farmer	3.67	5.80	5.67	7.27	6.93	**5.87**
Mean	**4.55**	**5.62**	**7.13**	**6.57**	**7.35**	
LSD $_{(0.05)}$ Tillage environments			NS			
LSD $_{(0.05)}$ Amendment			1.035			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 2						
Complete	4.60	10.33	12.07	13.07	11.47	**10.31**
Incomplete	4.47	8.20	10.67	7.07	8.20	**7.72**
Partial	4.60	9.47	8.40	7.20	8.27	**7.59**
Farmer	3.63	5.77	6.73	5.07	6.73	**5.59**
Mean	**4.33**	**8.44**	**9.47**	**8.10**	**8.67**	
LSD $_{(0.05)}$ Tillage environments			2.021			
LSD $_{(0.05)}$ Amendment			1.348			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			
Year 3						
Complete	5.20	10.60	14.07	13.80	13.20	**11.37**
Incomplete	3.87	8.80	12.73	11.47	8.73	**9.12**
Partial	4.67	10.47	8.73	7.67	9.07	**8.12**
Farmer	3.67	5.87	6.87	5.93	6.80	**5.83**
Mean	**4.35**	**8.93**	**10.60**	**9.72**	**9.45**	
LSD $_{(0.05)}$ Tillage environments			1.381			
LSD $_{(0.05)}$ Amendment			1.703			
LSD $_{(0.05)}$ Tillage environments x Amendments			NS			

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash, NS = non-significant.

3.6 Effects of *sawah* tillage environments and amendments on the rice grain yield

The results (Table 11) indicated a significant difference in the grain yield with the different *sawah* tillage environments in all the planting years. It did record that the highest significant values in the grain yield were obtained in complete *sawah* adopted tillage environment relative to other tillage environments including the farmers' tillage environment. The mean values varied from 2.84 – 4.75 t ha^{-1}, 3.28 – 4.72 t ha^{-1} and 6.06 – 6.96 t ha^{-1} in the 1st, 2nd and 3rd year of planting, respectively (Table 11). The result agrees with the submissions of Becker and Johnson, [46]; Ofori *et al*, [44]; Touré *et al*, [47] that improved performance of field water management can sustainably increase rice yields. On the other hand, the higher grain yield of 6.06 t/ha recorded in the farmers' field could be attributed to higher level of nutrients management involved and improved variety used in the study. This agrees with the findings of Buri *et al.*, [41] who maintained that lowlands constitute one of the largest and appropriate environments suitable for rice cultivation. They further stated that, within these environments, 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 in total rainfall and its distribution.

Generally, all the *sawah* tillage environments significantly increased the grain yield higher than the farmers' growing environment within the three years of study, except in 1st and 3rd year where the partial and farmers' field statistically performed same.
The results indicated ~~higher~~much significant ($p < 0.05$) improvements in the yield of rice in the amended plots over the non-amended (control) plots for the three years of planting. The results showed the range mean values of the rice as; 1.91 to 4.23 t ha^{-1} in the first year, 1.62 to 4.77 t ha^{-1} in the second year and 3.76 to 7.47 t ha^{-1} in the third year of planting. It was observed that poultry dropping amended plots significantly ($p < 0.05$) gave higher grain yield value among the amendments including the control. This increase in the yield in PD treated plots could be attributed to higher nitrogen percent in the material which might have been translated to the improved tillering, hence, improved yield.
Achieving high yield in most West African ecology is difficult without soil amendment, as the soils are highly leached, porous and low in essential plant nutrient [6, 48].

The results equally indicated a significant increase in the grain yield of rice due to the interaction of sawah tillage environment and the amendments within the periods of study.
This result confirms the submissions of Becker and Johnson, [46]; Sakurai, [49]; and Toure *et al.* [47], that *sawah* system development can improve rice productivity in the lowlands to a great extent when applied in combination with improved varieties and fertilizers, and a certain amount of improvement can even be expected by bund construction which is one of the *sawah* system components.

Table 11: Effects of *Sawah* Tillage environments and amendments on the Rice Grain Yield (ton/ha)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	2.03	5.37	5.73	5.37	5.23	**4.75**
Incomplete	1.97	3.70	4.17	3.10	3.83	**3.35**
Partial	1.87	3.37	3.77	3.07	4.10	**3.23**
Farmer	1.77	3.47	3.27	3.37	2.33	**2.84**
Mean	**1.91**	**3.98**	**4.23**	**3.73**	**3.88**	
LSD $_{(0.05)}$ Tillage environments				0.7956		
LSD $_{(0.05)}$ Amendment				0.5520		
LSD $_{(0.05)}$ Tillage environments x Amendments				1.1885		
Year 2						
Complete	1.97	5.77	5.77	5.30	4.80	**4.72**
Incomplete	2.00	4.90	4.90	4.73	4.60	**4.23**
Partial	1.43	4.27	4.37	4.80	4.67	**3.91**
Farmer	1.07	3.40	4.03	4.17	3.73	**3.28**
Mean	**1.62**	**4.58**	**4.77**	**4.75**	**4.45**	
LSD $_{(0.05)}$ Tillage environments				0.5494		
LSD $_{(0.05)}$ Amendment				0.5894		
LSD $_{(0.05)}$ Tillage environments x Amendments				1.1422		
Year 3						
Complete	4.21	7.30	8.27	7.22	7.78	**6.96**
Incomplete	3.86	7.15	6.80	6.94	6.52	**6.25**
Partial	3.51	6.38	7.64	7.50	7.29	**6.46**
Farmer	3.44	5.82	7.15	7.43	6.45	**6.06**
Mean	**3.76**	**6.66**	**7.47**	**7.27**	**7.01**	
LSD $_{(0.05)}$ Tillage environments				0.550		
LSD $_{(0.05)}$ Amendment				0.685		

LSD $(_{0.05})$ Tillage environments x Amendments	1.30

CT = control, NPK = nitrogen. phosphorous. potassium, PD = poultry dropping, RH = rice husk, RHA = rice husk ash.

4.0 CONCLUSION

The study revealed the significant performance of complete *sawah* tillage environment in ensuring the optimum restoration of degraded inland valley soils with optimum grain yield. It was noted the superiority of organic amendments (poultry droppings and rice husk dust) over mineral fertilizer on a short-term bases in soil properties and grain yield improvement. The combination of complete components of *sawah* management and soil amendment practices would improve the soil properties and rice grain yield. Therefore, s*awah* ecotechnology is possibly the most promising strategy for increased rice production and realization of food security in Nigeria. These natural soil fertility replenishment mechanisms are essential for enhancing the sustainability and productivity of lowland rice farming systems in inherently unfertile soils in Southeastern Nigeria. The mechanisms in *sawah* system of nutrient replenishments encourage not only rice growth, but also the breeding of various microbes, which improves biological nitrogen fixation. It restores/replenishes the lowland with nutrients as it resists erosion.

References

1. Moormann, F.R. Problem in characterizing and classifying wetland soils. In wetland soils. Characterization, classification, utilization. Proceeding of a workshop 26 mar. to 5 April 1984, 1985. 53-68, IRRI, Los Banos, Philippines.
2. Wakatsuki, T; Koski, T. and Palada, M. Ecological engineering for sustainable rice farming in inland valley (Ivs) in West Africa. Paper presented at the second WAFSRN symposium. Accra, Ghana; 1989.
3. Windmeijer, P. N. and Andriesse, W. Inland valleys in West Africa: An Agro-ecological characteristics of rice- growing environment, 1993. Pp28-37, ILRI. Wageningen, The Netherlands.
4. Otoo, E. and Asubonteng, K.O. Reconnaissance characterization of inland valleys in Southern Ghana. In characterization of inland valley Agron-ecosystems. A tool for their sustainable use. Proceeding of a workshop, 6 to 10 Nov. 1995, p 149-160. WARDA, Bouake, Ivory Coast. 10 Nov. 1995, p 149-160. WARDA, Bouake, Ivory Coast, 1995.
5. Asadu, C.L.A. and F.O.R. Akamigbo. Relative 13. FAO, 1988. Soil Map of the World: 1:5 million Contributions of Organic matter and clay fractions to cation exchange capacity of soils in southeastern Nigeria. Samaru Journal of Agricultural Research, 7: 1990; 17-23.
6. Enwezor, W.O., A.C. Ohiri, E.E. Opuwaribo and E.J. Udoh,. A review of fertilizer use of crops in Southeastern Zone of Nigeria. Fertilizer Procurement and Distribution Department, Lagos; 1988.
7. Nnabude, P.C. and J.S.C. Mbagwu. Soil water relations of a Nigerian Typic Haplustult Amended with fresh and burnt rice-mill wastes. Soil and tillage Research, 50(3-4): 1999. 207-214.
8. Ogbodo, E.N. and P.A. Nnabude. Evaluation of the Performance of three varieties of upland rice in degraded acid soil in Abakaliki, EbonyI State. Journal of technology and Education in Nigeria, 9(2): 2004; 1-7.
9. Nwite, J.C; C. A. Igwe and T. Wakatsuki. Evaluation of Rice Management System in an Inland Valley in Southeastern Nigeria. I: Soil Chemical Properties and Rice Yield, Paddy and Water Environment, Vol. 6, No. 3, 2008, pp. 299 – 30.
10. Hirose, S and Wakatsuki, T. Restoration of inland valley ecosystems in West Africa. 2002, Pp56-86, 222-2224. Association of agriculture and forestry statistics. Megro-Sumiya building, Tokyo, Japan.
11. Hayashi, K and T. Wakatsuki. Sustainable soil fertility management by indigenous and scientific knowledge in Sahel zone of Niger, in the CD- ROM Transactions of the 17th World congress of soil science, symposium No. 15. ~~perceptions~~ Perceptions of soil management: Matching indigenous and scientific knowledge systems, paper No. 1251; 2002.
12. Nwite, J.C., S.E. Obalum, C.A. Igwe and T. Wakatsuki. Properties and Potential of Selected Ash Sources for Improving Soil Condition and Sawah Rice Yields in a Degraded Inland Valley in Southeastern Nigeria. World Journal Agricultural Sciences, 7(3): 304-310. 2011. ISSN 1817-3047.

13. Obalum, S.E., J.C. Nwite, J. Oppong, C.A. Igwe and T. Wakatsuki. Comparative topsoil characteristics of sawah rice fields in selected inland valleys around Bida, North-Central Nigeria: Textural, structural and Hydro-physical properties. J. Paddy Water Environ. 2011; 9: 291-299. DOI 10.1007/s10333- 010-0233-3. Springer.
14. Andriesse, W. Mapping and characterizing inland valley agro-ecosystems: the case of West Africa. In: Wetland characterization and classification for sustainable agricultural development. FAO Corporate Document Repository. 1998. Available online: http://www.fao.org/docrep/003/x6611e/x6611e03a.htm#1_MAP
15. Wakatsuki, T. and Masunaga, T. Ecological engineering for sustainable food production and the restoration of degraded watersheds in Tropics of low pH soils: Focus on West Africa. Soil Sci. Plant Nutri; 51: 2005; 629-636.
16. Nwite, J.C, B.A. Essien, C.I. Keke, C A. Igwe, T. Wakatsuki. Evaluation of Water Sources for Sawah Management in the Restoration of Degraded Lowlands and Sustainable Rice Production in Southeastern Nigeria. Asian Journal of Agriculture and Food Sciences (ISSN: 2321 – 1571) Volume 01– Issue 03, August 2013
17. Igwe, C.A; J. C. Nwite; K. U. Agharanya; Y. Watanabe; S. E. Obalum; C. B. Okebalama & T. Wakatsuki. Aggregate-associated soil organic carbon and total nitrogen following amendment of puddled and sawahmanaged rice soils in Southeastern Nigeria, Archives of Agronomy and Soil Science, 2012; DOI:10.1080/03650340.2012.684877.
18. Ezeh, H. N. and E. Chukwu. Small scale mining and heavy metals pollution of agricultural soils: The case of Ishiagu Mining District, South Eastern Nigeria. Journal of Geology and Mining Research Vol. 3(4) 2011; pp. 87-104, April 2011.
19. USDA. Keys to Soil Taxonomy. Natural Resources Conservation Services, United States Department of Agriculture, Washington, D.C; 1998.
20. FAO. Soil Map of the World: 1:5 million (Revised Legend). World Soil Resources Report, 60. Food and Agricultural Organization (FAO), Rome; 1988.
21. Gee, G.W. and J.W. Bauder, Particle Size Analysis. In: Klute A (ed) Methods of Soil Analysis, part 1: Physical and Mineralogical Properties. Agronomy Monograph No 9. American Society of Agronomy, Madison, 1986. pp: 91-100.
22. McLean, E.O. Soil pH and lime requirement. In: A.L. Page, R.H. Miller and D.R. Keeny, (eds.). Methods of Soil Analysis, Part 2. Am. Soc. Agron., Madison, 1982, pp: 199-224.
23. Nelson, D.W. and L.E. Sommers. Total carbon, total organic carbon and organic matter. In: Sparks DL (ed) Methods of soil analysis, part 3: chemical methods. Agronomy Monograph No 9. American Society of Agronomy, Madison, 1996; pp: 961-1010.
24. Bremner, J.M. and C.S. Mulvancy. Total Nitrogen. In: A.L. Page et al., (eds.). Methods of Soil Analysis. No.9; part 2, Amer. Soc. Of Agron. Inc, Madison, Wisconsin, USA., 1982, pp: 595-624.
25. Thomas, G.W. Exchangeable cations. In: A.L. Page, R.H. Miller and D.R. Keeny, (eds.), Methods of Soil Analysis, Part 2. Am. Soc. Agron. Monogr., Madison, 1982; pp: 159-165.
26. Rhoades, J.D. Cation exchange capacity. In: A.L. Page, R.H. Miller and D.R. Keeny, (eds.). Methods of Soil Analysis, Part 2. Am. Soc. Agron., Madison, 1982. pp: 149-157.
27. Wakatsuki T, Buri MM, and Fashola 0.0. Restoration of degraded inland valley watersheds in West Africa by sustainable “Sawah” development. Paper presented at the International Conference on “Managing Soils for Food Security, Human Health and the Environment: Emerging Strategies for Poverty Alleviation,” 2003; GIMPA-Accra, Ghana, July 28- August 2, 2003.
28. Fashola, O.O; K. Hayashi and T. Wakatsuki. Effect of water management and polyolefin – coated urea on growth and nitrogen uptake of indica rice. J. Plant Nutr. 25: 2002; 2173 – 2190.
29. Russels, E.J. Soil conditions and plant growth (11th eds.) Alan Wild (eds.) 1988. Longman Group U.K. Ltd. Pp 898 – 908.
30. Abyhammer, T; A. Fablin; A. Nelson and V. Henfrindison. Askater Forings system Deiproject I: Tekniker Ochmojiligheter. (Production of wood ash, techniques and possibilities), 1994; pp: 341. In Swedish with English Summary).
31. Markikainen, P.N. Nitrification in two coniferous forest soils after different fertilizer treatments. Soil Biol. Biochem., 16: 2002, 577 – 882.
32. Opara-Nadi, O.A; B.S. Ezua; A. Wogu. Organic manures and inorganic fertilizers added to an acid ultisol in Southeastern Nigeria: II. Effects on soil chemical properties and nutrient loss, In: proceedings of the 15th Annual Conf. SSSN, Kaduna, Nigeria; 1987.

33. Wakatsuki T, Buri MM and Oladele O.I. West African green revolution by eco-technology and the creation of African SATOYAMA systems. Kyoto Working Papers on Area Studies No. 63; 2009, (G-COE Series 61). Center for Southeast Asian Studies, Kyoto, Japan. 30 p. ISBN 978 4 901668 63 7. http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61
34. Igwe CA, Nwokocha D. Soil organic matter fractions and microaggregation in a ultisol under cultivation and secondary forest in southeastern Nigeria. Aust J Soil Res. 44: 2006, 627–635.
35. Lee SB, Lee CB, Jung KY, Park KD, Lee D, Kim PJ. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. Soil Till. Res. 104: 2009, 227–232.
36. Follet RF. Soil carbon sequestration and greenhouse gas mitigation. Soil Sci Soc Am J. 74: 2010, 345–346.
37. Bhagat, R.M. and Verma, T.S. Impact of rice straw management on soil physical properties and wheat yield. Soil Sci. 152: 1991, 108-115.
38. Buresh RJ, Reddy KR, van Kessel C. Nitrogen transformations in submerged soils. In ‘Nitrogen in agricultural systems’. (Eds JS Schepers, WR Raun), 2008; pp. 401- 436. Agronomy Monograph 49. (ASA, CSSA, and SSSA: Madison, WI, USA).
39. Eswaran, H., Almaraz, R., Van den Berg, E., and Reich, P. ‘An assessment of the soil resources of Africa in relation to productivity’, Geoderma, Vol 77, 1997, pp 1–18.
40. Abe, S. S., Buri, M. M., Issaka, R. N., Kiepe, P., and Wakatsuki, T. ‘Soil fertility potential for rice production in West African lowlands’, *Japan Agricultural Research Quarterly*, Vol 44, 2010, pp 343–355.
41. Buri M.M; Issaka, R.N, Wakatsuki, T, and Kawano N. Improving the productivity of lowland soils for rice cultivation in Ghana: the role of the ‘sawah’ system. Journal of Soil Science & Environment management Vol. 3(3), 2012, pp. 56 – 62.
42. Greenland, D. J. Sustainability of Rice Farming, CABI, Wallingford, and IRRI, Los Banõs, The Philippines, 1997.
43. Wakatsuki, T., Shinmura, Y., Otoo, E., and Olaniyan, D. O. ‘System for integrated watershed management of small inland valleys in West Africa’, in: Institutional and Technical Options in the Development and Management of Small Scale Irrigation, Water Report No 17, FAO, Rome, 1998, pp 45–60.
44. Ofori, J., Hisatomi, Y., Kamidouzono, A., Masunaga, T., and Wakatsuki, T. ‘Performance of rice cultivars in various ecosystems developed in inland valleys, Ashanti region, Ghana’, Soil Science and Plant Nutrition, Vol 51, 2005, pp 469–476.
45. Wakatsuki, T. and Masunaga, T. Ecological engineering for sustainable food production and the restoration of degraded watersheds in Tropics of low pH soils: Focus on West Africa. Soil Sci. Plant Nutri; 51: 2005, 629-636.
46. Becker, M., and Johnson, D. E. ‘Improved water control and crop management effects on lowland rice productivity in West Africa’, Nutrient Cycling Agroecosystems, Vol 59, 2001, pp 119–127.
47. Touré, A., Becker, M., Johnson, D. E., Koné, B., Kossou, D. K., and Kiepe, P. ‘Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast’, Field Crops Research, Vol 114, 2009, pp 304– 310.
48. Igwe, C.A; Akamigbo F.O.R and Mbagwu J.S.C. Physical properties of soils of Southeastern Nigeria and the role of some aggregating agents in their stability, Soil Sci. 160: 1995. 431 – 441.
49. Sakurai, T. ‘Intensification of rainfed wetland rice production in West Africa: present status and potential green revolution’, Developing Economies, Vol 44, 2006, pp 232–251.