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Soil Fertility Improvement and Sustainable Rice Production in Degraded Inland Valleys of Southeastern Nigeria Through *Sawah* Rice Farming Technology

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Abstract: Agricultural productivity in Nigeria fluctuates, mainly because the country's agriculture is rain-fed and subsistence farmers rely on the rain as the main backbone of farming in the country. Traditional water management systems in the lowlands rice production in Ebonyi State that is regarded as a major rice producing State in Nigeria are characterized by the fact that farmers focus on storage of water in the rice field, without any possibility to divert water from one place to another. An inland valleys at Ikwo in Ebonyi State, South-eastern Nigeria was used in 2010 and 2011 cropping seasons to determine the level of utilization of degraded lowlands in Ebonyi State for sustainable *sawah* rice production and soil fertility maintenance. A split-split-plot in a randomized complete block design was used to asses three factors at different levels. Three sources of water (*sawah* types); rain-fed *sawah,* spring type and pump type constituted main plot, four rice growing environments; complete *sawah* (CS); farmers' environment (FE); incomplete *sawah* (ICS) and partial *sawah* (PS) constituted sub-plots. The amendments, that constituted the sub-sub-plots were applied as follows: 10 tha^{-1} rice husk (RH); 10 tha^{-1} of rice husk ash; 10 tha^{-1} of poultry droppings; 400 kg^{-1} of N.P.K. 20:10:10 and 0 tha^{-1} (control). These treatments were applied in soils for the two seasons of study. The treatments were replicated three times in each of the subplots. The results of the study showed that the soil pH, OC and TN were significantly improved by *sawah* types in the studied soil. These elements were also improved statistically upon by the different growing environments in different ways. It was also obtained that the amendments equally significantly influenced these elements. The results indicated that the CEC was positively improved by *sawah* types, growing environments and amendments in different forms in both first and second year of study. It was noted the superiority of organic amendments over mineral fertilizer on a long-term bases in soil properties and grain yield improvement. The results equally showed that the combination of good *sawah* management and amendment practices will improve the soil properties and rice grain yield.

Key words: *Sawah* · Environments · Amendments · Rice grain yield · Soil properties and inland valleys

INTRODUCTION

Nigeria has a fairly high potential for irrigation development as her irrigated area was estimated at 233,000 ha in 1998; the largest in West Africa, but the percentage of irrigated area is as low as 0.8% [1]. Fortunately, these inland valleys or floodplains, which have specific hydrological conditions and have been cited as having high potential for the development of rice-based smallholder farming systems at village levels, occur abundantly in Nigeria [2-3]. In spite of the potentials of these Nigeria inland valleys for Agricultural use, these areas are yet to be exploited fully.

Poor soil fertility and inefficient weed and water control are the major constraints to proper utilization of these inland valleys for sustainable rice-based cropping. In order to overcome such difficulties and for effective and sustainable crop production in inland valleys of Nigeria, new farming system(s) that can restore and enrich poor soils must be developed [4-7]. For sustainable

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increase to cope with present population expansion, the African adaptive *Sawah*- lowland farming, with small scale irrigation scheme for integrated watershed management, will be the most promising strategy to tackle these problems and restore the degraded inland valleys in these areas for increased and sustainable food production [1, 8, 9].

In Nigeria, there have been studies on the use of organic and inorganic amendments in the improvement of the soil chemical properties and crop yields, but none has dwelt on the interaction of these soil amendments with water management systems to improve soil properties under rice *sawah* management system.

The term "*Sawah"* refers to leveled rice field surrounded by bunds with inlets and outlets for irrigation and drainage. *Sawah* is generally described as a controlled water management in the field where the soil is expected to be bunded, puddle and leveled in order to impound water provided by rain water or underground water discharge through seepage or springs, or by rise in the level of a stream and river in an inland valley, or using modern source from well pumps, taps, canal and storage of large quantities of water in reservoirs or ponds [1, 10]. Traditional water management systems in the lowlands rice production in Ebonyi State that is regarded as a major rice producing State in Nigeria are characterized by the fact that farmers focus on storage of water in the rice field, without any possibility to divert water from one place to another. Famers make straight bunds with grass materials across the valley bottom to store water in the fields. These traditional practices usually lead to differences in rice performance and yield from the same field and large disparity in soil characteristics of the same field. The above observed problems led to this study.

This is aimed at bridging the gaps in knowledge of appropriate inland valleys and *sawah* technology development in Nigerian lowlands among the farmers.

MATERIALS AND METHODS

Site Description: The study was conducted in 2010 and 2011 on a floodplain lying adjacent to spring source of water in Igweledoha Amagu, Ikwo Local Government Area of Ebonyi State, Southeastern Nigeria. The area lies within latitude 06°08'40"N and longitude 08°06' 35" E. The site is within the derived savanna vegetation zone with grassland and tree combinations. The annual rainfall for the area is 1,350 mm, spread from April to October with average air temperature of 29°C. The soils are described as Aeric Tropoaquent [11] or Gleyic Cambisol [12]. The soil have moderate soil organic carbon (OC) content on the topsoil, low in pH and low cation exchange capacity (CEC). Soils are mainly used for rain-fed rice cultivation during the rains and vegetable production as the rain recedes.

Field Method: The experimental design used was a split- split-plot in a randomized complete block design (RCBD). The study site was divided into three main-plots in such a way that the spring plots stands on its own, plus the other two plots. Each of the main-plot was divided into four sub- plots where the four rice growing environments were located. Each of the four rice growing environments was later divided into five sub-sub-plots that receive the amendments. Bulk (composite) sample was collected at 0- 20 cm soil depth for initial soil characteristics. Out of the four sub-plots, three were demarcated with a 0.6 m raised bunds. In these sub-plots, water was controlled and maintained to an approximate level of between 5 cm to 10 cm from 2 weeks after transplanting to the stage of ripening of the grains, while in other sub-plot without bunds which represent the traditional field; water was allowed to flow in and out as it comes, as described below:

Three *sawah* types were used which constituted the main-plots and these include;

- Rain-fed *sawah,* spring type and pump *sawah* type. The rain-fed *sawah* involved plots where its water supply was only from rain water and artificial water was not allowed to flow into the plots.
- Spring *sawah* on its own was where its water source was from a spring that flows into the field. The plots that received this spring water were usually opened when water is needed in those plots and the spring water is allowed to flow into them.
- Pump type involve the one where water pumping machine was used to pump water from an artificial pond in the field into the plots that receive the water and water flow from outside into the plots was not allowed.

However, four rice growing environments constituting sub-plots were used in each *sawah* system. These include;

- Sub-plot I; Complete *sawah*- bunded,puddled and leveled rice field (CS)
- Sub-plot II; Farmers environment- no bunding and leveling rice field (FE)

- Sub-plot II; Incomplete *sawah*- bundding with minimum leveling and puddling rice field (ICS)
- Sub-plot IV; Partial *sawah*- after bunding, no puddling and leveling rice field (PS)

There were five levels of manure application, including the control that made up the sub-sub-plots, which were replicated three times in each of the sub-plots:

- Sub-sub-plot I; Rice husk----------------(10 ton/ha)---RH
- Sub-sub-plot II; Rice husk ash------------(10 ton/ha)---RHA
- Sub-sub-plot III; Poultry droppings-------(10 ton/ha)----PD
- Sub-sub-plot IV; N. P. K. 20: 10: 10------(400kg/ha)----NPK
- Sub-sub-plot V; Control (Zero application)--------------CT

The study was undertaken in 3 cropping seasons using the same watershed and treatments.

The test crop was high-tillering rice variety *Oryza sativa var. FARO 52 (WITA 4)*. The rice seeds were first raised in the nursery and later transplanted to the main field after 3 weeks in nursery. At maturity, rice grains were harvested, dried and yield computed at 90% dry matter content. At the end of harvest, soil samples were collected from each replicate of every plot from each of the location for chemical analyses.

Laboratory Methods: Soil 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 [13]. Soil pH was measured in a 1:2.5 soil:0.1 M Kcl suspensions [14]. The soil OC was determined by the Walkley and Black method described by Nelson and Sommers [15]. Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and $CuSO_4$ and Na_2SO_4 catalyst mixture [16]. CEC was determined by the method described by Rhoades [17].

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

Table 1: General description of soil characteristics of the studied area before puddling and amendments

Soil Properties	Ikwo
Clay (g kg^{-1})	160
Silt (g kg^{-1})	130
Sand (g kg^{-1})	710
Textural class	Sandy loam
OC (g kg^{-1})	13.00
TN (g kg^{-1})	0.90
pH (H_2O)	4.30
Na^+ ($cmol_c$ kg^{-1})	0.03
K^+ ($cmol_c$ kg^{-1})	0.04
Ca^{2+} ($cmol_c$ kg^{-1})	0.90
Mg^{2+} ($cmol_c$ kg^{-1})	0.76
CEC ($cmol_c$ kg^{-1})	9.86

OC= organic carbon; TN= total nitrogen; K^+= exchangeable potassium; Ca^{2+}= exchangeable calcium; Mg^{2+} = exchangeable magnesium; CEC= cation exchange capacity

Table 2: Properties of the organic amendments

Amendment	OC	Total N (%)	K	Ca	Mg
PD	16.50	2.10	0.48	14.40	1.20
RH	33.70	0.70	0.11	0.36	0.38
RHA	23.90	0.06	0.65	1.00	1.40

PD= poultry droppings; RH= rice husk powder; RHA= rice husk burnt ash; OC= organic carbon

Soil Properties; Organic Amendments and Water Properties Studied: The prominent soil chemical properties are reported in Table 1. Generally, the soil from the study site is sandy loam with 160 g kg^{-1} clay and 130g kg^{-1} silt content. The analysis showed that soil organic carbon concentration was high in the site. pH measured in water was moderately high in the soils. The analysis indicated that the soil is low in exchangeable bases and the CEC was moderate.

The analysis of the amendments (Table 2) showed that rice husk had the highest percentage organic carbon, followed by rice husk ash, while poultry dropping recorded the least value. This means that rice husk has the potentials of enriching the soil more with organic carbon pools. The analysis also indicated that total nitrogen was higher in poultry dropping, while the least TN was recorded in rice husk ash. The analysis (Table 2) showed that rice husk ash gave the highest values for percentage potassium and magnesium, while the highest percentage calcium was obtained from poultry dropping.

RESULTS AND DISCUSSION

Effects of *Sawah* Water Management Systems and Amendments on the Soil Ph and Organic Carbon (OC): The influence of the *sawah* water management systems and amendments on the soil pH and organic carbon are presented (Table 3). The results showed that the soil pH

Table 3: Effects of sawah types, growing environments and soil amendments on soil pH and organic carbon (OC) at 0 – 20 cm soil depth

	Sawah types																							
	Pumping sawah type								Rain-fed sawah type								Spring sawah type							
	CS		FE		ICS		PS		CS		FE		ICS		PS		CS		FE		ICS		PS	
Amendts	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC	pH	OC
Year 1																								
CT	3.9	0.63	3.4	0.51	3.6	0.63	3.5	0.61	3.6	0.57	3.3	0.48	3.5	0.60	3.4	0.51	4.3	0.89	3.5	0.64	3.9	0.77	3.7	0.64
NPK	4.6	1.08	4.3	0.94	4.6	1.02	4.5	0.89	4.6	0.93	4.5	0.81	4.5	0.90	4.5	0.80	4.8	1.30	4.7	1.00	4.7	1.03	4.8	0.89
PD	4.8	1.14	4.4	0.94	4.7	0.99	4.5	1.03	4.7	0.88	4.5	0.87	4.6	1.00	4.5	0.87	5.0	1.25	4.7	0.95	4.9	1.13	4.7	1.01
RH	4.7	1.21	4.3	0.97	4.7	1.27	4.6	1.14	4.6	1.15	4.5	0.91	4.6	1.03	4.5	1.10	4.8	1.34	4.3	1.02	4.7	1.24	4.6	1.13
RHA	5.1	1.03	4.6	0.87	5.0	1.05	4.8	0.86	4.9	0.88	4.6	0.86	4.9	0.95	4.7	0.74	5.4	1.16	4.7	1.12	5.0	0.84	4.9	1.03
Mean	4.6	1.02	4.2	0.85	4.5	0.99	4.4	0.91	4.5	0.88	4.3	0.79	4.4	0.90	4.3	0.81	4.9	1.19	4.3	0.94	4.7	1.00	4.5	0.94
LSD (0.05) *sawah* type for pH									0.066									OC	0.115					
LSD (0.05) Environment for pH									0.068									OC	0.063					
LSD (0.05) Amendments for pH									0.054									OC	0.088					
LSD (0.05) *Sawah* type X Environment for pH									0.112									OC	NS					
LSD (0.05) *Sawah* type X Environment X Amendments for pH									0.199									OC	NS					
Year 2																								
CT	4.2	0.66	3.6	0.54	4.0	0.63	3.8	0.58	3.9	0.70	3.5	0.52	3.8	0.62	3.6	0.53	4.5	0.94	3.8	0.67	4.1	0.84	4.1	0.69
NPK	5.0	1.10	4.6	0.97	4.8	1.25	4.7	0.95	4.7	0.98	4.7	0.87	4.7	0.95	4.7	0.87	5.0	1.33	4.8	1.02	4.9	1.06	5.0	1.07
PD	5.1	1.20	4.7	0.96	5.0	1.06	4.7	1.11	4.8	1.04	4.6	0.93	4.8	1.03	4.7	0.93	5.1	1.36	4.8	1.02	5.0	1.25	4.9	1.16
RH	4.9	1.31	4.7	0.99	4.8	1.28	4.8	1.21	4.7	1.21	4.7	0.96	4.8	1.11	4.7	1.11	5.0	1.43	4.7	1.12	4.8	1.30	4.8	1.12
RHA	5.3	1.07	4.8	0.93	5.1	1.07	4.9	0.95	5.0	1.02	4.8	0.92	5.0	1.01	4.9	0.90	5.6	1.28	4.8	1.15	5.2	1.06	5.0	1.04
Mean	4.9	1.07	4.5	0.88	4.7	1.09	4.6	0.97	4.7	0.99	4.5	0.84	4.6	0.94	4.5	0.87	5.0	1.27	4.6	1.00	4.8	1.10	4.8	1.02
LSD (0.05) *Sawah* type for pH									0.054									OC	0.063					
LSD (0.05) Environment for pH									0.058									OC	0.046					
LSD (0.05) Amendment (Amendt) for pH									0.055									OC	0.057					
LSD (0.05*) Sawah* type X Environment for pH									NS									OC	NS					
LSD (0.05) *Sawah* type X Environment X Amendt for pH									0.194									OC	NS					

CS = Complete *sawah;* FE = Farmer's environment; ICS = Incomplete *sawah*; PS = Partial *sawah*; CT = Control; NPK = Nitrogen: Phosphorous: Potassium; PD = Poultry dropping; RH = Rice husk; RHA = Rice husk ash; LSD (0.05) = Fishers' Least Significant Difference @ 5% probability level; NS = Not significant

measured in water was significantly improved by *sawah* types in the two years of study with spring water *sawah* type giving the best improvement on the soil pH. The mean values of 4.4 to 4.6 and 4.6 to 4.8 in the 1st and 2nd year of planting, ranging from rain-fed to spring sawah type, respectively were recorded. The results (Table 3) also indicated that the pH changes from 4.3 to 4.6 and 4.5 to 5.0 within the two years of study; from farmers' to complete sawah growing environment indicating that complete *sawah* growing environment significantly increased the soil pH higher than other growing environments. Generally, the result disagrees with the findings of Takase *et al*., [18] who compared river, canal, tap and well irrigation sources in Ghana and found that though none of these *sawah* water types gave significantly higher pH than others, soils irrigated with well water recorded the highest pH value at the end of three months of their study.

Generally, the significant improvement in pH of soils in all the *sawah* growing environments where water is ponded could also be linked to the findings of Russel [19], 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*., [6] remarked that pH increased significantly in *sawah* water – managed system in a study conducted in a similar location for two years to evaluate *sawah* and non-*sawah* water management systems.

The results also showed that the pH measured in water differed significantly among the treatments. It was obtained that the soil pH was significantly improved higher in soils treated with rice husk ash. The pH ranged from 3.6 to 4.9 in the first year and 3.9 to 5.0 in the second year (control to rice husk ash treated plots), respectively. The significant improvement made by RHA on pH agrees with the findings of Nwite *et al*., [9] and Markikainen, [20] who stated that ash amendment could induce a pH increase by as much as 0.6 – 1.0 units in humus soils. It was also obtained from the results that the interactions of *sawah* types and growing environments significantly improved pH in the second year of study, while the interactions of *sawah* types, growing environment and soil amendments significantly increased the soil pH for the two years of study.

Table 4: Effects of sawah types, growing environments and soil amendments on soil total nitrogen (TN) and cation exchange capacity (CEC) at 0 – 20 cm soil depth

	Sawah types																							
	Pumping sawah type								Rain-fed sawah type								Spring sawah type							
	CS		FE		ICS		PS		CS		FE		ICS		PS		CS		FE		ICS		PS	
Amendts	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC	TN	CEC
Year 1																								
CT	0.05	8.2	0.04	6.5	0.05	7.9	0.04	7.4	0.06	7.9	0.04	5.7	0.05	7.4	0.05	7.3	0.06	8.3	0.05	6.7	0.05	7.5	0.05	7.4
NPK	0.08	11.5	0.06	10.7	0.08	11.1	0.08	11.1	0.08	10.9	0.06	9.9	0.07	10.5	0.08	10.6	0.09	12.3	0.07	9.9	0.08	10.8	0.08	11.5
PD	0.08	12.2	0.07	10.6	0.08	10.9	0.07	11.1	0.09	12.0	0.06	10.2	0.07	11.4	0.08	10.7	0.09	12.6	0.07	10.9	0.08	11.5	0.08	11.1
RH	0.07	10.9	0.05	9.4	0.07	12.1	0.09	11.4	0.08	10.5	0.06	10.9	0.07	10.6	0.10	11.2	0.08	10.7	0.07	9.9	0.07	10.6	0.07	10.5
RHA	0.06	11.8	0.04	11.5	0.06	12.2	0.07	10.7	0.07	11.1	0.06	10.1	0.07	11.2	0.07	11.4	0.07	12.3	0.05	10.3	0.06	11.5	0.07	10.7
Mean	0.07	10.9	0.05	9.8	0.06	10.8	0.07	10.4	0.07	10.5	0.06	9.4	0.07	10.2	0.07	10.2	0.08	11.3	0.06	9.5	0.07	10.4	0.07	10.2
LSD (0.05) *Sawah* type for TN									0.0041									CEC	NS					
LSD (0.05) Environment for TN									0.0059									CEC	0.530					
LSD (0.05) Amendment (Amendt) for TN									0.0056									CEC	0.477					
LSD (0.05) *Sawah* type X Environment for TN									NS									CEC	NS					
LSD (0.05) *Sawah* type X Environment X Amendt for TN									NS									CEC	NS					
Year 2																								
CT	0.06	8.3	0.04	6.9	0.05	8.2	0.05	7.5	0.06	8.1	0.04	6.2	0.05	7.5	0.06	7.5	0.07	9.0	0.06	6.9	0.06	7.8	0.06	7.7
NPK	0.09	13.1	0.07	11.0	0.09	12.5	0.09	12.1	0.09	12.0	0.07	10.7	0.08	11.6	0.08	11.1	0.11	13.8	0.07	10.5	0.10	12.5	0.10	11.9
PD	0.09	14.2	0.08	10.9	0.10	13.3	0.09	12.3	0.09	13.7	0.07	10.7	0.09	12.4	0.09	12.1	0.12	15.8	0.07	11.1	0.12	14.2	0.09	12.5
RH	0.09	12.9	0.06	11.0	0.10	13.3	0.09	12.1	0.10	12.3	0.07	11.1	0.09	10.8	0.12	11.9	0.12	14.3	0.07	10.5	0.11	12.3	0.09	11.6
RHA	0.08	13.5	0.06	11.9	0.08	13.6	0.08	12.5	0.07	14.1	0.07	11.1	0.09	13.7	0.08	12.7	0.11	15.8	0.06	12.1	0.08	13.5	0.09	12.7
Mean	0.08	12.4	0.06	10.4	0.08	12.2	0.08	11.3	0.08	12.0	0.07	9.95	0.08	11.2	0.09	11.1	0.11	13.8	0.07	10.2	0.09	12.1	0.09	11.3
LSD (0.05) *Sawah* type for TN									0.0053							CEC =	0.499							
LSD (0.05) Environment for TN									0.0056							CEC =	0.524							
LSD (0.05) Amendment (Amendt) for TN									0.0057							CEC =	0.464							
LSD (0.05*)* *Sawah* type X Environment for TN									0.0091							CEC	NS							
LSD (0.05) *Sawah* type X Environment X Amendt for TN									NS							CEC	NS							

CS = Complete *sawah;* FE = Farmer's environment; ICS = Incomplete *sawah*; PS = Partial *sawah*; CT = Control; NPK = Nitrogen: Phosphorous: Potassium; PD = Poultry dropping; RH = Rice husk; RHA = Rice husk ash; LSD (0.05) = Fishers' Least Significant Difference @ 5% probability level; NS = Not significant

The results indicated that soil organic carbon was positively influenced by *sawah* type with spring *sawah* type showing higher accumulation. It was shown that SOC ranged from 0.84% - 1.02% and 0.91 – 1.10% (rain-fed to spring), in the 1st and 2nd year, respectively. *Sawah* growing environments significantly affected soil organic carbon (SOC) of the studied soils with complete *sawah* growing environment giving higher SOC pool than others including farmers' fields (0.79 – 1.27%). This means that *sawah* eco-technology is significant in harnessing the health conditions of the soil and reduction in global warming. Hirose and Wakatsuki, [1]; Wakatsuki *et al*., [21] 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 also affirms the findings of Igwe *et al*. [22] that higher soil organic carbon was recorded in soils with finer fraction (WSA<1.00) brought about by well puddle activity associated with a complete *sawah* technology.

Treated soils significantly improved the soil organic carbon relatively higher than the control in all the growing environments. A significantly higher SOC concentration was obtained from plots amended with rice husk dust than plots amended with other treatments (0.62 – 1.18%), CT to RH treated plots, respectively. The result confirms the findings of Lee *et al*., [23] 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* types, growing 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 [24].

Effects of *Sawah* Water Management Systems and Amendments on the Soil Total Nitrogen and Cation Exchange Capacity (CEC): The soil total nitrogen was statistically (P< 0.05) improved by the different *sawah* types in the study (Table 4). The results also indicated that there was significant difference among the *sawah* growing environments. Among the *sawah* growing environments, complete *sawah* statistically improved soil total nitrogen higher than other growing environments

Table 5: Effects of *sawah* water management systems and amendments on rice grain yield (t/ha)

	Sawah types											
	Pumping				Rainfed				Spring			
	CS	FE	ICS	PS	CS	FE	ICS	PS	CS	FE	ICS	PS
Amendts	Grain yield (ton/ha)				Grain yield (ton/ha)				Grain yield (ton/ha)			
Year 1												
CT	1.90	1.77	1.57	1.90	1.97	1.53	1.87	1.90	1.83	1.93	2.10	1.87
NPK	4.70	3.40	3.67	5.37	6.30	4.90	6.07	5.30	4.60	2.57	4.10	4.57
PD	3.43	3.40	5.20	4.47	7.80	4.97	4.73	5.50	4.53	2.97	4.83	4.87
RH	4.47	4.50	3.87	4.63	8.00	4.53	6.80	7.90	4.70	2.80	4.13	4.00
RHA	4.17	3.87	3.70	4.83	6.57	5.47	6.00	6.53	4.07	3.07	4.27	3.23
Mean	3.69	3.39	3.60	3.43	6.13	4.28	5.09	5.43	3.95	2.67	3.89	3.71
LSD (0.05) *Sawah* type					NS							
LSD (0.05) Environment					0.248							
LSD (0.05) Amendment (Amendt)					0.296							
LSD (0.05*) Sawah* type X Environment					0.659							
LSD (0.05) *Sawah* type X Environment X Amendt					NS							
Year 2												
CT	1.93	2.10	2.20	1.57	1.97	1.53	1.87	1.90	2.53	1.97	2.10	2.10
NPK	6.03	5.30	4.97	5.53	6.30	4.90	6.07	5.30	6.90	5.67	6.03	5.83
PD	6.97	5.73	6.23	7.90	7.80	4.97	4.73	5.50	9.43	6.43	8.13	7.50
RH	6.37	5.43	5.93	5.23	8.00	4.53	6.80	7.90	7.83	6.00	7.43	7.77
RHA	6.33	5.20	6.30	5.10	6.57	5.47	6.00	6.53	6.83	5.80	6.53	6.27
Mean	5.53	4.75	5.13	5.07	6.13	4.28	5.09	5.43	6.70	5.17	6.04	5.89
LSD (0.05) *Sawah* type					NS							
LSD (0.05) Environment					0.440							
LSD (0.05) Amendment (Amendt)					0.518							
LSD (0.05*) Sawah* type X Environment					0.876							
LSD (0.05) *Sawah* type X Environment X Amendt					NS							

CS = Complete *sawah;* FE = Farmer's environment; ICS = Incomplete *sawah*; PS = Partial *sawah*; CT = Control; NPK = Nitrogen: Phosphorous: Potassium; PD = Poultry dropping; RH = Rice husk; RHA = Rice husk ash; LSD (0.05) = Fishers' Least Significant Difference @ 5% probability level; NS = Not significant

with the highest value recorded in the spring *sawah* type (0.08 and 0.11%), in the 1st and 2nd year, respectively. This affirms the submissions made by some researchers that, soil submergence also promotes biological nitrogen fixation (BNF) [25] 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.

The results equally pointed highly significant differences on the soil total nitrogen with the treatments application. Plots treated with organic amendments; PD and RH improved TN better than others including control plots. The values varied from 0.05 to 0.07% (CT – PD) in the 1st year and 0.06 to 0.09% (CT – PD/RH) in the 2nd year. This result confirms the submissions of Imolehin and Wada [26] who advocated a reversion to the use of organic materials in wetland rice cultivation as a more realistic option for farmers than continued reliance on inorganic fertilizers, which in addition to their deleterious effects on the soil are not readily available. The result showed a significant improvement on the TN with the interactions of *sawah* types and environments on a long-term basis.

The results showed that CEC was improved upon by *sawah* types within the period of study. It was generally observed that all *sawah* growing environment significantly highly influenced the CEC relative to the farmers' environment. It was also obtained that among the *sawah* growing environments, complete *sawah* growing environment in spring *sawah* type improved the CEC of the soil higher in the study (11.3 and 13.8 $cmolkg^{-1}$), 1st and 2nd year respectively. This result implies that soil erosion which tries to erode most topsoil nutrient of most inland valleys are eliminated or reduced when all the components of *sawah* technology is employed during lowland rice field operations. These assertion agrees with those obtained by Hirose and Wakatsuki [1], Ofori *et al*. [27] and Wakatsuki and Masunaga [28] 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. Irrigation, surface and sub-surface water also increase the supply of nutrients, such as Si, Ca, Mg, K and sulfate. This contribution provides an ecological engineering basis for long-term intensive sustainability of lowland *sawah*-based rice farming. These natural soil fertility replenishment mechanisms are essential for enhancing the sustainability and productivity of lowland rice farming systems in inherently unfertile soils in West Africa and Sub Saharan Africa [29].

The results also indicated a significant improvement on the soil CEC due to amendments within the period of study. Poultry dropping (PD) amendment (11.8 and 13.1 cmol kg^{-1}) in the 1st and 2nd year, generally improved the soil CEC higher than other amendments.

Effects of *Sawah* Water Management Systems and Amendments on the Rice Grain Yield (t/ha): The effects of *sawah* water types was observed not to have significantly ($P<0.05$) improved the rice grain yield. Though not significant, spring water source of supplemental irrigation increased the rice grain yield higher than others.The result also showed that growing environments significantly improved the grain yield of rice in the two years of study. Complete *sawah* growing environment statistically increased the grain yield higher than other environments; 3.08 – 3.95 t/ha and 4.28 – 6.70 t/ha in the first and second year of planting, respectively. In agreement with this result, it has been empirically revealed that sustainable rice productivity in the *sawah* system is much higher than in the upland system. The *sawah* system is the only practical option that allows rice farmers to enjoy optimal water management in their fields. Improved performance of field water management can sustainably increase rice yields [27, 30, 31].

The result also revealed the long-term superiority of organic amendments over mineral (inorganic) fertilizer in a lowland rice production. Among the amendments; poultry dropping (PD) followed by RH gave the highest significant increase in the grain yield in two the years. The values varied from 1.87 – 4.12 t/ha and 1.98 – 6.78 t/ha in the 1st and 2nd year of planting, respectively.

In their assessment of rice production technologies in Nigeria, Imolehin and Wada [26] advocated a reversion to the use of organic materials in wetland rice cultivation as a more realistic option for farmers than continued reliance on inorganic fertilizers, which in addition to their deleterious effects on the soil are not readily available.

The results obtained showed that the interactions of *sawah* types and growing environments significantly improved the grain yield of rice. Therefore, *sawah* system development can improve rice productivity in the lowlands to a great extent when applied in combination with improved varieties, manures (fertilizers) and environment; and certain amount of improvements in the *sawah* development can even be expected by bund construction, puddling and leveling; which are *sawah* system components [32, 30].

CONCLUSIONS

It was important to note that the results revealed the superiority of spring *sawah* water source over other *sawah* types as it aids in full realization of the geological fertilization process that do occur in inland valley *sawah* system. The results also showed better performance of complete *sawah* environment in ensuring the optimum restoration of degraded inland valley soils with optimum grain yield. Superiority of organic amendments over mineral fertilizer on a long-term bases in soil properties and grain yield improvement was observed. It was equally obtained that the combination of good *sawah* management and amendment practices will improve the soil properties and rice grain yield. *Sawah* ecotechnology is possibly therefore, the most promising rice production method because the *sawah* system is a highly productive and sustainable rice production system.

REFERENCES

1. Hirose, S. and T. Wakatsuki, 2002. Restoration of inland valley ecosystems in West Africa, pp: 56-86, 222-2224. Association of agriculture and forestry statistics. Megro-Sumiya building, Tokyo, Japan.
2. Wakatsuki, T., T. Koski and M. Palada, 1989. For sustainable rice farming in inland valley (Ivs) in West Africa. Paper presented at the second WAFSRN symposium. Accra, Ghana.

3. Otoo, E. and K.O. Asubonteng, 1995. 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, pp: 149-160. WARDA, Bouake, Ivory Coast.
4. Kamidohzono, A., F. Ishida, Darmawan, T. Masunaga and T. Wakatsuki, 2002a. Indigenous soil fertility evaluations in Sipisag village of Minangkabau people, West Sumatra, Jpn. J. Soil Sci. Plant Nutr., 73: 741-753.
5. Kamidohzono, A., F. Ishida, Darmawan, T. Masunaga and T. Wakatsuki, 2002b. Indigenous knowledge and Techniques for soil and landscape formation in watersheds of Sipisag village, West Sumatra, Jpn. J. Soil Sci. Plant Nutri., 73: 755-763.
6. Nwite, J.C., C.A. Igwe and T. Wakatsuki, 2008a. Evaluation of Rice Management System in an Inland Valley in Southeastern Nigeria. I: Soil Chemical Properties and Rice Yield, *Paddy and Water Environment*, 6(3): 299-307.
7. Nwite, J.C., C.A. Igwe and T. Wakatsuki, 2008b. Rice yield and changes in some soil properties improvement and rice yield in a *sawah* rice farming following *sawah* in an inland valley in southeastern Nigeria. Proceedings of Int. Conf. on Sustainable Agriculture for Food, Energy and Industry (ICSA), pp: 988-992, 2-6 July, 2008 at Hokkaido University Conference Hall, Sapporo, Japan.
8. Hayashi, K. and T. Wakatsuki, 2002. 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 of soil management: Matching indigenous and scientific knowledge systems, paper, pp: 1251.
9. Nwite, J.C., S.E. Obalum, C.A. Igwe and T. Wakatsuki, 2011. Properties and potential of selected ash sources for improving soil condition and rice yields in a degraded Inland Valley in Southeastern Nigeria. World Journal of Agricultural Sciences, 7(3): 304-310.
10. Nwite, J.C., S.E. Obalum, C.A. Igwe, E.N. Ogbodo, C.I. Keke, B.A. Essien and T. Wakatsuki, 2012. Sawah Rice System, a Technology for Sustainable Rice Production and Soil Chemical Properties Improvement in Ebonyi State of Southeastern Nigeria. World Journal of Agricultural Sciences, 8(4): 351-358.
11. USDA, 1998. Keys to Soil Taxonomy. Natural Resources Conservation Services, United States Department of Agriculture, Washington, D.C.
12. FAO, 1988. Soil Map of the World: 1:5 million (Revised Legend). World Soil Resources Report, 60. Food and Agricultural Organization (FAO), Rome.
13. Gee, G.W. and J.W. Bauder, 1986. Particle size analysis. In: Klute A. (ed.): Methods of Soil Analysis, Part 1: Physical and Mineralogical Properties. Monograph No. 9. American Society of Agronomy, Madison, pp: 91-100.
14. McLean, E.O., 1982. Soil pH and Lime requirement. In: A.L. Page *et al*. (eds.), Methods of soil analyses (No. 9, part 2), 199-224. Amer. Soc. of Agron, Soil Sci. Soc. Am; Inc. Madison, Wisconsin, U.S.A.
15. Nelson, D.W. and L.E. Sommers, 1982. Total Carbon, Organic Carbon and Organic Matter. In: A.L. Page *et al*. (eds.). Methods of Soil Analyses (No.9, part 2), 552- 553). Amer. Soc. of Agron. In: Soil Sci. Soc. Amer., Inc, Madison, Wisconsin, U.S.A.
16. Bremner, J.M. and C.S. Mulvancy, 1982. Total Nitrogen. In: A.L. Page *et al* (eds.). Methods of Soil Analyses. No. 9; part 2, Amer. Soc. of Agron. Inc, Madison, Wisconsin, USA, pp: 595-624.
17. Rhoades, J.D., 1982. 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, pp: 149-157.
18. Takase, M., L.K. Sam-Amoah and J.D. Owusu-Sekyere, 2011. The effects of four sources of irrigation water on soil chemical and physical properties. Asian Journal of Plant Science, 10(1): 92-96.
19. Russels, E.J., 1988. Soil Conditions and Plant Growth (11th eds.) Alan Wild (eds.) 1988. Longman Group U.K. Ltd., pp: 898-908.
20. Markikainen, P.N., 2002. Nitrification in two coniferous forest soils after different fertilizer treatments. Soil Biol. Biochem., 16: 577-882.
21. Wakatsuki, T., M.M. Buri and O.I. Oladele, 2009. West African green revolution by eco-technology and the creation of African SATOYAMA systems. Kyoto Working Papers on Area Studies No. 63 (G-COE Series 61). Center for Southeast Asian Studies, Kyoto, Japan. pp: 30. ISBN 978 4 901668 63 7. http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61

22. Igwe, C.A., J.C. Nwite, K.U. Agharanya, Y. Watanabe, S.E. Obalum, C.B. Okebalama and T. Wakatsuki, 2012. Aggregate-associated soil organic carbon and total nitrogen following amendment of puddled and sawah managed rice soils in Southeastern Nigeria, Archives of Agronomy and Soil Science, DOI:10.1080/03650340.2012.684877.
23. Lee, S.B., C.B. Lee, K.Y. Jung, K.D. Park, D. Lee and P.J. Kim, 2009. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. Soil Till Res., 104: 227-232.
24. Bhagat, R.M. and T.S. Verma, 1991. Impact of rice straw management on soil physical properties and wheat yield. Soil Sci., 152: 108-115.
25. Buresh, R.J., KR. Reddy and C. Van Kessel, 2008. Nitrogen Transformations in Submerged soils. In 'Nitrogen in Agricultural Systems'. (Eds JS Schepers, WR Raun) pp. 401-436. Agronomy Monograph 49. (ASA, CSSA and SSSA: Madison, WI, USA).
26. Imolehin, E.D. and A.C. Wada, 2000. Meeting the rice production and consumption needs of Nigeria with improved technologies. Int Rice Commiss Newsl FAO, Rome, 49: 33-41..
27. Ofori, J., Y. Hisatomi, A. Kamidouzono, T. Masunaga and T. Wakatsuki, 2005. Performance of rice cultivars in various ecosystems developed in inland valleys, Ashanti region, Ghana, Soil Science and Plant Nutrition, 51: 469-476.
28. Wakatsuki, T. and T. Masunaga, 2005. 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 Nutr., 51: 629-636.
29. Abe, S.S., M.M. Buri, R.N. Issaka, P. Kiepe and T. Wakatsuki, 2010. Soil fertility potential for rice production in West African lowlands'. Japan Agricultural Research Quarterly, 44: 343-355.
30. Touré, A., M. Becker, D.E. Johnson, B. Koné, D.K. Kossou and P. Kiepe, 2009. Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast', Field Crops Research, pp: 114.
31. Abe, S.S. and T. Wakatsuki, 2011. Ecotechnology – a tiger for a rice green revolution in Sub-Saharan Africa: Basic concept and policy implications. Outlook on AGRICULTURE, 40(3): 221-227. Doi: 10.5367/oa.2011.0049.
32. Sakurai, T., 2006. Intensification of rainfed wetland rice production in West Africa: present status and potential green revolution, Developing Economies, 44: 232-251.