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Effect of Different Land Preparation Methods for *Sawah* System Development on Soil Productivity Improvement and Rice Grain Yield in Inland Valleys of Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author JCN designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors BAE and CAI managed the literature searches, analyses of the study performed the spectroscopy analysis and author CIK managed the experimental process. Author TW identified the species of plant. All authors read and approved the final manuscript.

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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.

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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.

Keywords: Sawah; tillage environment; water management; amendments; rice grain yield; soil properties.

1. 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. 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.

Fig. 1. Arial photograph of study area

Akaeze lies at approximately latitude 05° 56' N and longitude 07° 41' E. The annual rainfall for the area is 1,350 mm, spread from April to October with average air temperature of 29℃ [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

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. 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.

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.

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

	Amendment		
(RHA)	**Poultry dropping (PD)**	**Rice husk (RH)**	**Rice husk ash**
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

Table 3. Effects of tillage environments and amendments soil pH

Sawah tillage environments	Amendments					
	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

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.

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

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.

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 2nd and 3rd 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 1st, 2nd and 3rd 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.

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

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

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 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 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

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. 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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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