Original Research Article

SAWAH RICE FARMING ECO-TECHNOLOGY OPTIONS FOR EHANCING SUSTAINABLE NUTRIENT MANAGEMENT AND RICE PRODUCTION IN DEGRADED INLAND VALLEYS OF SOUTHEASTERN NIGERIA

ABSTRACT

Nigeria Agricultural productivity 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. Consequently, traditional water management systems in the lowlands rice production in Ebonyi State that is regarded as a major rice producing State in Nigeria who also rely on the rain, 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. 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 West Africa in the last two decades. *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. This study was conducted in an inland valley at Akaeze in 2010, 2011 and 2012 cropping seasons, to evaluate the effect of different sources of water for *sawah* water management system and amendments on soil properties and rice grain yield. A split- plot in a randomized complete block design was used to asses two factors at different levels. Three sources of water; rain-fed, spring type and pond type constituted the main plot, while the amendments, that constituted the sub- plots were applied as: 10 tha^{-1} rice husk (RH); 10 tha^{-1} of rice husk ash; 10 tha^{-1} of poultry droppings; 400 $kgha^{-1}$ of N.P.K. 20:10:10 and 0 tha^{-1} (control). The treatments were replicated three times in each of the subplots. The results of the study showed that the soil pH was significantly ($p < 0.05$) improved by different water types in the location. The results also indicated that soil organic carbon and total nitrogen were positively ($p < 0.05$) influenced in the two locations by both the different water sources and amendments. The result shows a significant improvement on the CEC by both factors, while the exchangeable acidity was reduced differently by different water sources and amendments within the periods. It was also recorded that available phosphorous were positively improved by different water sources and amendments in different forms in the area. The result equally indicated that rice grain yield was positively increased by the studied factors for the three years. Generally, results showed the superiority of organic amendments over mineral fertilizer in some soil chemical properties and rice grain yield improvement. The results equally showed that the combination of a good water source in *sawah* water management and amendment practices will improve some soil chemical properties.

Key words: water sources, *sawah,* amendments, rice grain yield, soil properties and inland valleys

1.0 INTRODUCTION

Increasing rice production both to meet the country's food requirements and to help the world overcome food crisis is one major issue facing Nigeria today. Nigeria is now one of the largest food importers in the world. In 2010 alone, Nigeria spent 356 billion naira on importation of rice. Nigeria is eating beyond its means. While we all smile as we eat rice everyday, Nigerian rice farmers cry as the importations undermine domestic production [1].

Nigeria agricultural productivity fluctuates, mainly because the country's agriculture is rain-fed and subsistence farmers rely on the rain for farming activities in the country. Rain-fed agriculture is an important economic activity in the developing world. Globally, rain-fed agriculture is practiced in 80% of the total physical agricultural area and generated 62 percent of the world's staple food [2, 3]. In sub-Saharan Africa, 93 percent of cultivated land is rain fed [4], thus playing a crucial role in food security and water availability [5]. Kadigi *et al.* [6] argues that land for rain-fed agriculture varies depending on the amount and distribution of rainfall in the area.

Rain-fed lowland farmers are typically challenged by poor soil quality, drought/flood conditions, and erratic yields. Yields from rain-fed agriculture are often low, generally around 1 t ha^{-1} in semiarid tropical agro-ecosystems [7]. There is ample evidence to suggest that the low productivity in rain-fed agriculture is due more to suboptimal performance related to management aspects rather than to low physical potential [8 – 11]. This means that in the developing countries with the most rapid population growth, dependence on rain-fed agriculture operating at suboptimal level is high. Gowing *et al;* [12] maintained that inadequate soil moisture and low soil fertility have been top challenges facing rain-fed agriculture.

To narrow the yield gap in rain-fed lowlands environments, improvement of farm infrastructures such as land leveling, irrigation and drainage facilities modifications should be done. Supplementary irrigation is needed when natural precipitation is not adequate to secure grain and forage production [13].
In their assessment of rice production technologies in Nigeria, Imolehin and Wada [14] 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. Lee *et al.* [15] 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. However, the superiority of locally available organic materials over inorganic fertilizers in terms of soil properties reformation and stability after puddling of natural wetlands in our tropical environment is not yet confirmed.

Nigeria is relatively blessed with enough rain and high potential inland valleys for rice based cropping. In spite of the potentials of these Nigeria inland valleys especially the Southeast for agricultural use, these areas are yet to be exploited fully.
The major constraints in the utilization of these inland valleys have been outlined as; poor soil fertility maintenance, inadequate weed and water control [16 – 19]. Most soils in the West African sub-region are highly weathered and very fragile [20 – 24].

In order to overcome these limitations in the utilization of these inland valleys, an African adaptive *sawah* lowland farming with small scale irrigation scheme for integrated watershed management will be the most promising strategy to tackle these problems [23, 25].

Sawah has been described as an Indo-Malaysian word for padi (Malayan word for paddy) or lowland rice management system comprising bunding, puddling, levelling and good water management through irrigation and drainage [26].
Sawah system ensures that certain water level (minimum and maximium) is maintained in field plots during the growing period of the plant. It restores/replenishes the lowland with nutrients as it resists erosion. 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.
The study aimed at evaluating three different water sources; spring, pond and rain-fed for *sawah* development at farmers level for sustainable nutrient management and rice production in inland valleys of Southeastern Nigeria. The objective of study also include, to evaluate the contributions of different manure types to changes in soil properties and grain yield and determine the interactions of different water sources and soil amendments on soil properties and rice grain yield.

2.0 MATERIALS AND METHODS

2.1 Location of the Study

This study was conducted in an inland valley at Akaeze in 2010, 2011 and 2012 cropping seasons to evaluate the effects of different sources of water for *sawah* water management system and amendments on soil properties and rice grain yield. 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. The sites is within the derived savanna vegetation zone with grassland and tree combinations. The soils are described as Aeric Tropoaquent [27] or Gleyic Cambisol [28]. The soils 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.

2.2 Field method

The field was divided into three different main plots where the three sources of water for irrigation were located. Bulk (composite) sample was collected at 0- 20 cm soil depth in the study area for initial soil characteristics. The three main plots were demarcated into five subplots with a 0.6 m raised bunds where the soil amendments were applied (Figure 3).
A split- plot in a randomized complete block design was used to asses the two factors at different levels. The three sources of water that constituted main plot include;

- rain-fed *sawah* which involved plots where water supply was only from rain water and no irrigation water was allowed to flow into the plots.
- spring type, on its own was where water source was from a spring that flows into the field and perhaps rainfall with some control, and
- pond type involved water application to plots as supplemental irrigation with pumping machine from an artificial pond in the field.

Figure 1: Field preparation with power-tiller machine

Generally, Water was circulated in the field by manipulation of the bunds. The water flows from the spring to the plots through a constructed canal from the spring source to the field and the spring is close-by to the field, less than 100 m away (Figure 2).

Figure 2: Constructed canal from the spring source and the artificial pond for supplemental irrigation.

The quantity of water issued to the plots was not measured rather the depth of water was maintained at 5 cm- 10 cm throughout the growing period of the rice except in the rain-fed plots where only the water harvested by each plot during rainfall that settle in the plots. Ruled sticks with bold marks on 10 cm and 5 cm points were mounted permanently on each plot to check the water level or depth in the field. In the pumping type a pumping machine with rated power output of 2.8 kilowatts, self priming volute with 4 impeller blades and maximum discharge of 900 litres/minute, plus a total Head of 26 M, was used to pump water from an artificial pond into the field receiving pumping water as a supplemental irrigation, whenever water depth in the plots is below 5 cm (Figure 2).

The water introduction in each case was made 2 weeks after transplanting and this was maintained till the stage of ripening of the rice grains. The water from these different sources in the field is presumed to have different qualities and as such would have different effect on the soil properties and rice yield.

Figures 3: Construction of interceptive canals and bund making for *sawah* field development

The amendments that constituted the sub- plots were applied as follows:

- PD Poultry droppings @ 10 ton/ha
- F NPK fertilizer (20:10:10) @ 400 kg/ha recommended rate for rice in the zone
- RH Rice husk @ 10 t ha^{-1};
- RHA Rice husk ash @ 10 t ha^{-1}
- CT Control @ 0 t ha^{-1}

The treatments were replicated three times in each of the main-plots. The PD, RHA and RH were spread on the plots that received them and incorporated manually into the top 20 cm soil depth 2 weeks before transplanting. The nutrient contents of these organic amendments were determined (Table 2).
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.

Figure 4: New transplanted *sawah* field

2.3 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 [29]. Soil pH was measured in a 1:2.5 soil:0.1 M KCl suspensions [30]. The soil organic carbon was determined by the wet oxidation method of Walkley and Black (1934) as modified by Nelson and Somners [31]. Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and $CuSO_4$ and Na_2SO_4 catalyst mixture [32]. Available phosphorus was measured by the Bray II method [33]. CEC was determined by the method described by Rhoades [34]. While exchangeable acidity (EA) was measured using the method of McLean [30].

2.4 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 1% and 5% Levels of probability.

3.0 RESULTS AND DISCUSSION

3.1 Soil Properties and Organic Amendments

3.1.1 Soil properties

The soil physical and chemical properties are reported in Table 1. Generally, the soils of the study area are sandy loam with 100 g kg^{-1} clay and 150 g kg^{-1} silt content. The analysis indicated that the soil has low pH, exchangeable bases and cation exchange capacity (Table 1).
Soil organic carbon concentration was moderate, whereas the soil total nitrogen value was 0.091%.

3.1.2 Organic amendments properties

Rice husk amendment had the highest percentage of 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 had the highest values for percentage potassium and magnesium, while the highest percentage calcium was obtained from poultry dropping.

Table 1: **Some properties of the topsoil of the experimental plots (0-20 cm) before tilling and amendment**

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

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	P	C:N
			(%)				
PD	16.50	2.10	0.48	14.40	1.20	2.55	7.86
RH	33.70	0.70	0.11	0.36	0.38	0.49	48.14
RHA	23.90	0.06	0.65	1.00	1.40	11.94	398.33

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

3.2 Effects of Water Sources and Amendments on the Soil pH and Organic Carbon

The results (Table 3) showed that the soil pH measured in water was significantly ($p < 0.05$) improved by *sawah* water source in the three years of study with spring water source giving the best improvement with pH values of 4.12, 4.64 and 4.94 in the 1st, 2nd and 3rd year of study, while the rain-fed recorded the least values (3.89, 4.31 and 4.65), 1st, 2nd and 3rd year, respectively. The result also showed that the pH-increasing trend directly followed the year of study progression.
Generally, the result disagrees with the findings of Takase *et al.* [35] 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.
The soil pH was significantly ($p < 0.05$) improved higher in soils treated with rice husk ash in all the three water sources for *sawah* development in the three years of study. The significant improvement made by RHA on pH agrees with the findings of Abyhammer *et al.* [36]; Markikainen, [37] and Nwite *et al.* [38]; 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 soils. These results is in conformity with the findings of Opara-Nnadi *et al.* [39] who reported pH increase following the application of organic wastes.
The interactions of water sources and amendments improved pH only in the first year of study.

The results on soil organic carbon (Table 4) indicated that water sources and amendments significantly ($p < 0.05$) increased the soil organic carbon pools (SOC) differently in the soil for the three years of study. The result shows that among the water sources, spring water source did improve the SOC statistically ($p < 0.05$) higher than other water sources within the periods of study. It was observed that apart from the first year, pond water source did not significantly ($p < 0.05$) improved the SOC better that the rain-fed water source. The soil organic carbon mean values ranged from 1.02 – 1.36%, 1.21 – 1.47% and 1.20 – 1.49%, in the 1st, 2nd and 3rd year of study, respectively. However, the significant improvement made by spring water source over other water sources could be attributed to finer fractions that were moved into the plots by the water during flow from the spring through the canal. Follet [40] 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.
It was also obtained from the results (Table 4) that soil amendments significantly ($p < 0.05$) improved the soil organic carbon relatively higher than the control within the periods of study. The result equally indicated a significantly higher SOC pool on plots amended with rice husk dust than plots amended with other treatments. It was also noted that all the amended plots significantly ($p < 0.05$) increased the soil organic carbon pool higher than the control. The mean values varied from 0.65 – 1.66% in the first year, 0.88 – 1.63% in the second year and 0.93 – 1.55% in the third year.
The results also showed that there was significant improvement on the buildup of SOC with the interactions of water sources and amendments in the second and third year of the study. This agreed with the submission that incorporation of plant residues coupled with appropriate puddling and water management build up organic carbon status of soil [41].

Table 3: Effects of water source for *sawah* and amendments on soil pH

Water source for *Sawah*	Amendments					
	CT	NPK	PD	RH	RHA	Mean
Year 1						
Rained	3.37	3.93	4.07	3.83	4.23	**3.89**
Spring	3.57	3.70	4.23	4.33	4.77	**4.12**
Pond	3.40	3.90	4.03	3.93	4.47	**3.95**
Mean	**3.44**	**3.84**	**4.11**	**4.03**	**4.49**	
LSD $_{(0.05)}$ water source for *sawah*				0.1025		
LSD $_{(0.05)}$ Amendment				0.1313		
LSD $_{(0.05)}$ water source for *sawah* x Amendments				0.2157		
Year 2						
Rained	3.47	4.50	4.50	4.50	4.60	**4.31**
Spring	3.73	4.80	4.80	4.73	5.13	**4.64**
Pond	3.53	4.40	4.70	4.43	4.80	**4.37**
Mean	**3.58**	**4.57**	**4.67**	**4.56**	**4.84**	
LSD $_{(0.05)}$ water source for *sawah*				0.1105		
LSD $_{(0.05)}$ Amendment				0.1412		
LSD $_{(0.05)}$ water source for *sawah* x Amendments				NS		
Year 3						
Rained	3.60	4.77	4.90	4.97	5.03	**4.65**
Spring	3.97	5.03	5.13	5.03	5.53	**4.94**
Pond	3.90	5.00	5.03	5.00	5.37	**4.86**
Mean	**3.82**	**4.93**	**5.02**	**5.00**	**5.31**	
LSD $_{(0.05)}$ water source for *sawah*				0.0956		
LSD $_{(0.05)}$ Amendment				0.1167		
LSD $_{(0.05)}$ water source for *sawah* x Amendments				NS		

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

Table 4: Effects of water source for *sawah* and amendments on soil organic carbon (%)

Water source for *Sawah*	Amendments					
	CT	NPK	PD	RH	RHA	Mean
Year 1						
Rained	0.59	1.15	1.14	1.28	0.94	**1.02**
Spring	0.67	1.62	1.58	1.92	0.99	**1.36**
Pond	0.70	1.30	1.28	1.79	1.03	**1.22**
Mean	**0.65**	**1.35**	**1.33**	**1.66**	**0.99**	
LSD $_{(0.05)}$ water source for sawah				0.2108		
LSD $_{(0.05)}$ Amendment				0.2079		
LSD $_{(0.05)}$ water source for sawah x Amendments				NS		
Year 2						
Rained	0.85	1.35	1.24	1.36	1.26	**1.21**
Spring	0.99	1.81	1.46	1.89	1.20	**1.47**
Pond	0.80	1.47	1.31	1.64	1.03	**1.25**
Mean	**0.88**	**1.54**	**1.34**	**1.63**	**1.16**	
LSD $_{(0.05)}$ water source for sawah				0.1864		
LSD $_{(0.05)}$ Amendment				0.1372		
LSD $_{(0.05)}$ water source for sawah x Amendments				0.2540		
Year 3						
Rainfed	0.92	1.18	1.23	1.38	1.27	**1.20**
Spring	0.95	1.80	1.52	1.91	1.27	**1.49**
Pond	0.90	1.41	1.42	1.36	1.10	**1.24**
Mean	**0.93**	**1.46**	**1.39**	**1.55**	**1.21**	
LSD $_{(0.05)}$ water source for sawah				0.1716		

LSD $_{(0.05)}$ Amendment	0.1416
LSD $_{(0.05)}$ water source for sawah x Amendments	0.2530

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

3.3 Effects of water sources and amendments on the soil total nitrogen and exchangeable acidity

The result (Table 5) indicated that the supplemental irrigated plots significantly ($p < 0.05$) improved the soil total nitrogen higher than the rain-fed treated plots in the second and third year. The values varied from 0.082 – 0.095% in the second year and 0.89 – 0.104% in the third year. However, spring water source increased the soil total nitrogen higher than the pond and rain-fed significantly. These results implied that rain-fed agriculture does not permit proper water management systems in the field with other factors causing alternate wetting and drying of the field which do lead to loss of the element.
It has been reported that alternate wetting and drying could consequently lead to a slightly greater loss of broadcast fertilizer N and soil N by nitrification-denitrification, but this loss is expected to decrease with increasing age of the rice crop due to increased competition of rice with microorganisms for ammonium before it can be nitrified and for nitrate before it can be denitrified in uncontrolled flooded condition [42].
This affirms the submissions made by some researchers that, soil submergence also promotes biological nitrogen fixation (BNF) [43], 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.* [43] 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 equally pointed highly significant differences on the soil total nitrogen with application of amendments in all the three years of the study. Generally, all the treated plots significantly ($p < 0.05$) improved soil total nitrogen more than the control. It was obtained that the soil total nitrogen was improved better by the application of NPK fertilizer, followed by the poultry droppings in all the years of study. This result confirms the submissions of Becker and Johnson, [44]; Sakurai, [45]; and Toure *et al.* [46] 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 only (one of the *sawah* system components).
The result agrees with the findings of Kyuma and Wakatsuki, [47] and Greenland, [48] that the amount of nitrogen fixed by microbes varies from 20 to 100 $kgha^{-1}year^{-1}$, and sometimes reaches up to 200 $kgha^{-1}year^{-1}$, depending on soil and water management and climatic conditions [46, 47]. 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-Sahara Africa [49, 50].

It is important to note from the result (Table 6) that exchangeable acidity reduced significantly ($p < 0.05$) by different water sources for *sawah* development within the study period. The result (Table 6) shows that both spring and pond water sources drastically reduced the exchangeable acidity better than the rain-fed for the three years of study. It was recorded that even though exchangeable acidity (EA) was positively reduced within the periods, there were increasing trends in the EA as year progresses. The values ranged from 1.76 – 2.14 cmol/kg in the 1st year, 2.24 – 3.07 cmol/kg in the 2nd year and 2.57 – 3.53 cmol/kg in the 3rd year. This could be attributed to low clay and silt built in the top 0 – 20 cm as the year progresses.
The results also revealed that there was significant ($p < 0.05$) decrease on the EA due to soil amendments. It was recorded that among the soil amendments, Rice husk ash (RHA) significantly ($p < 0.05$) lowered the EA more than other amendments including the control. This agrees with the findings of Errikson, [51] and Serafinelion, [52] who submitted that ashes generally have good acid-neutralizing capacity and ability to supply the soil with basic elements (Ca, K, Mg, Na) and available P; and this depends on the contents of oxides, hydroxides and carbonates of these elements. It was also obtained that there was no significant improvement due to the interactions of water sources and amendments in all the years of study.

Table 5: Effects of water source for *sawah* and amendments on soil total nitrogen (%)

Water source	Amendments

for *Sawah*	CT	NPK	PD	RH	RHA	Mean
Year 1						
Rainfed	0.047	0.089	0.093	0.105	0.085	**0.084**
Spring	0.059	0.117	0.098	0.079	0.084	**0.088**
Pond	0.056	0.105	0.093	0.080	0.085	**0.084**
Mean	**0.054**	**0.104**	**0.095**	**0.088**	**0.084**	
LSD $_{(0.05)}$ water source for sawah			NS			
LSD $_{(0.05)}$ Amendment			0.02056			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 2						
Rainfed	0.048	0.095	0.094	0.090	0.082	**0.082**
Spring	0.060	0.117	0.103	0.103	0.095	**0.095**
Pond	0.063	0.103	0.095	0.084	0.087	**0.087**
Mean	**0.057**	**0.105**	**0.097**	**0.092**	**0.088**	
LSD $_{(0.05)}$ water source for sawah			0.006124			
LSD $_{(0.05)}$ Amendment			0.006221			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 3						
Rainfed	0.061	0.103	0.105	0.086	0.088	**0.089**
Spring	0.065	0.124	0.126	0.110	0.095	**0.104**
Pond	0.061	0.114	0.105	0.098	0.087	**0.093**
Mean	**0.062**	**0.114**	**0.112**	**0.098**	**0.090**	
LSD $_{(0.05)}$ water source for sawah			0.0117			
LSD $_{(0.05)}$ Amendment			0.0077			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			

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

Table 6: Effects of water source for *sawah* and amendments on soil exchangeable acidity (EA) $cmolkg^{-1}$

Water source for *Sawah*	Amendments CT	NPK	PD	RH	RHA	Mean
Year 1						
Rainfed	3.00	2.40	2.07	1.87	1.37	**2.14**
Spring	2.40	1.93	1.47	2.00	1.00	**1.76**
Pond	2.60	2.13	1.87	2.00	0.93	**1.91**
Mean	**2.67**	**2.16**	**1.80**	**1.96**	**1.10**	
LSD $_{(0.05)}$ water source for sawah			0.2317			
LSD $_{(0.05)}$ Amendment			0.2056			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 2						
Rainfed	4.33	3.80	3.03	2.90	1.30	**3.07**
Spring	2.87	2.80	1.87	2.40	1.27	**2.24**
Pond	3.20	3.33	2.47	2.47	1.37	**2.57**
Mean	**3.47**	**3.31**	**2.46**	**2.59**	**1.31**	
LSD $_{(0.05)}$ water source for sawah			0.166			
LSD $_{(0.05)}$ Amendment			0.686			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 3						
Rainfed	5.27	4.33	3.40	3.33	1.33	**3.53**
Spring	3.13	3.33	2.20	2.87	1.33	**2.57**
Pond	3.43	4.73	2.80	2.87	1.67	**3.10**
Mean	**3.94**	**4.13**	**2.80**	**3.02**	**1.44**	
LSD $_{(0.05)}$ water source for sawah			0.318			

LSD $_{(0.05)}$ Amendment	1.020
LSD $_{(0.05)}$ water source for sawah x Amendments	NS

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

3.4 Effects of water sources and amendments on the soil available phosphorous and cation exchanage capacity (CEC)

The results (Table 7) showed that different water sources creditably increased positively ($p < 0.05$) the available phosphorous for the three years of study more than its initial values soils. It was equally obtained that among the three water sources, spring water source improved statistically higher the soil available phosphorous than other water source in the first and third year of study, while pond water source improved the available phosphorous significantly ($p < 0.05$) higher in the second year. These results (Table 7) showed that those plots treated with supplemental irrigation significantly increased the available phosphorous better than the rain-fed field in all the years. As a general principle, as soil drying becomes more prolonged and severe under rainfed condition, the availability of soil available phosphorous to rice tends to decrease and the availability of zinc in acid soils tends to increase [53]. Wakatsuki *et al.* [54]; Hirose and Wakatsuki, [23]; Wakatsuki *et al.* [55]; affirmed that under flood conditions, phosphorous availability is increased through the reduction of ferric iron. Both acid and alkaline soils are neutralized or mitigated by appropriate control of flooding. Hence, micronutrient availability is also increased. These mechanisms encourage not only the growth of rice plants, but also the growth of various aquatic algae and other aerobic and anaerobic microbes, which increase nitrogen fixation through increased photosynthesis, and control oxidation and reduction potential in *sawah* systems as multifunctional wetlands.
It was also obtained (Table 7) that the applications of amendments significantly ($p < 0.05$) highly affected the availability of phosphorous in the studied soil within the periods. It was noted generally that all the treated plots significantly ($p < 0.05$) increased the available phosphorous in the studied soil more than the control plots. This result is in line with the submission that 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 [56, 57]. The results (Table 7) also revealed that in all the years, organic nutrient sources did significantly ($p < 0.05$) improved the available phosphorous better than inorganic nutrient source (NPK) indicating the superiority of organic manure over inorganic in soil and crop improvement. In their assessment of rice production technologies in Nigeria, Imolehin and Wada [14] 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. Lee *et al.* [15] 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 (Table 8) indicated that there was a short-term improvement on the CEC by use of different water sources for *sawah* development. This means that CEC of the soil gradually responds to different water sources for *sawah* development. The significant improvement on the CEC by spring *sawah* system attributed to edge-advantage it has for collecting eroded sediments from adjacent uplands through enhanced capacity of water harvesting. The essence of the *sawah* system is water control, not only on a field scale but also on a watershed scale [58].
These natural soil fertility replenishment mechanisms are essential for enhancing the sustainability and productivity of lowland rice farming systems in inherently unfertile soils in WA and SSA [49, 50]. Moreover, there are generally few concerns about soil erosion in the lowlands.
The results also indicated a significant improvement on the soil CEC due to amendments within the period of study. It was observed that all the treated plots significantly improved the CEC higher relative to the control. Poultry dropping amendment generally improved the soil CEC higher than other amendments in the 1st year, rice husk ash and rice husk improved the CEC higher in the 2nd and 3rd year of study, respectively. The values varied from 4.47 – 7.69 $cmolkg^{-1}$, 4.40 – 11.38 $cmolkg^{-1}$ and 5.96 – 14.91 $cmolkg^{-1}$, in the first, second and third year, respectively.

Table 7: Effects of water source for *sawah* and amendments on soil available phosphorous ($mgkg^{-1}$)

Water source for *Sawah*	Amendments					
	CT	NPK	PD	RH	RHA	Mean
Year 1						
Rained	3.95	4.68	4.04	4.93	7.83	5.09
Spring	3.39	5.88	6.06	7.91	9.48	6.54
Pond	2.88	6.19	6.65	6.17	7.24	5.83
Mean	**3.40**	**5.58**	**6.33**	**6.33**	**8.19**	
LSD $_{(0.05)}$ water source for sawah			1.076			
LSD $_{(0.05)}$ Amendment			1.552			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 2						
Rained	3.78	4.97	7.57	6.23	7.97	**6.10**
Spring	4.42	10.56	8.48	10.58	15.26	**8.02**
Pond	3.56	8.51	8.30	9.54	10.01	**9.83**
Mean	**3.92**	**8.01**	**8.12**	**8.79**	**11.08**	
LSD $_{(0.05)}$ water source for sawah			2.090			
LSD $_{(0.05)}$ Amendment			2.155			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 3						
Rained	3.78	6.03	8.49	6.53	8.73	6.71
Spring	5.14	11.26	10.10	10.89	18.86	11.25
Pond	3.88	9.58	10.30	10.83	10.47	9.02
Mean	**4.27**	**8.96**	**9.63**	**9.42**	**12.69**	
LSD $_{(0.05)}$ water source for sawah			1.472			
LSD $_{(0.05)}$ Amendment			2.278			
LSD $_{(0.05)}$ water source for sawah x Amendments			3.671			

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

Table 8: Effects of water source for *sawah* and amendments on soil cation exchange capacity CEC (cmolkg^{-1})

Water source for *Sawah*	Amendments					
	CT	NPK	PD	RH	RHA	Mean
Year 1						
Rained	4.13	5.60	6.93	6.67	6.93	**6.05**
Spring	5.20	8.60	9.87	8.67	8.40	**8.15**
Pond	4.07	6.67	6.27	6.93	6.67	**6.12**
Mean	**4.47**	**6.96**	**7.69**	**7.42**	**7.33**	
LSD $_{(0.05)}$ water source for sawah			1.453			
LSD $_{(0.05)}$ Amendment			1.080			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 2						
Rained	4.13	8.20	8.87	9.00	8.40	**7.72**
Spring	5.20	10.60	13.20	13.80	14.07	**11.37**
Pond	3.87	9.27	10.00	9.87	11.67	**8.93**
Mean	**4.40**	**9.36**	**10.69**	**10.89**	**11.38**	
LSD $_{(0.05)}$ water source for sawah			2.474			
LSD $_{(0.05)}$ Amendment			1.941			
LSD $_{(0.05)}$ water source for sawah x Amendments			NS			
Year 3						
Rainfed	3.93	10.07	9.93	10.40	8.80	**8.63**
Spring	6.93	13.30	18.13	17.40	13.07	**13.77**
Pond	7.00	13.27	16.13	16.93	11.40	**12.95**

Mean	**5.96**	**12.21**	**14.73**	**14.91**	**11.09**
LSD $(_{0.05})$ water source for sawah				1.186	
LSD $(_{0.05})$ Amendment				0.995	
LSD $(_{0.05})$ water source for sawah x Amendments				1.769	

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

3.5 Effects of water sources and amendments on the rice grain yield (t/ha)

The effects of water sources for *sawah* development was observed to have significantly (P<0.05) improved the rice grain yield for the three years of study in the study area. The results (Figures 5 – 9) showed that among the three water sources, spring water source for supplemental irrigation, highly significantly increased the rice grain yield. This was followed by the pond source of water, while the rain-fed type recorded the least yield performance of rice grain yield. This result is in line with a submission that yields from rain-fed agriculture are often low, generally around 1 t ha^{-1} in semiarid tropical agro-ecosystems [7], and this fact explains why rain-fed agriculture is estimated to contribute only some 60% of the world crop production [4]. IRRI [59] reported that rice production in the rain-fed lowland environment being dependent on rain-fed conditions, is very susceptible to climatic variability which results in low yields.

Kadigi *et al*. [6] argues that land for rain-fed agriculture varies depending on the amount and distribution of rainfall in the area. Gowing *et al.* [12]; Barron *et al.* [60]; Mupangwa *et al.* [61]; Makurira *et al.* [62] maintained that inadequate soil moisture and low soil fertility have been top challenges facing rain-fed agriculture.

However, the higher yield recorded in rain-fed plots above the standard 2 t/ha yield for traditional rice production in the studied area could be attributed to high management practices such as improved water control and soil amendments adopted in this study. Agarwal and Narain, [8]; Benites *et al.* [9]; Rockström and Falkenmark, [10]; SIWI, [11] argued that there is ample evidence to suggest that the low productivity in rain-fed agriculture is due more to suboptimal performance related to management aspects rather than to low physical potential.

The above result also agrees with the findings of Buri *et al.* [63] 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.

They further reported that rice yield in the *sawah* system is usually about 2–3 t ha^{-1} without any fertilizer application, and this yield is continuously attainable at least for several decades without any fallow period.

The results (Figure 7) also revealed the long-term superiority of organic amendments over mineral (inorganic) fertilizer in a lowland rice production. It was obtained that among the amendments; poultry dropping (PD) gave the highest significant increase in the rice grain yield in all the years studied. It was also recorded that rice husk (RH) followed the PD in improving the grain yield of rice on the third year of the study. This is in line with the submissions of Imolehin and Wada [14] 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. Lee *et al.* [15] 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.

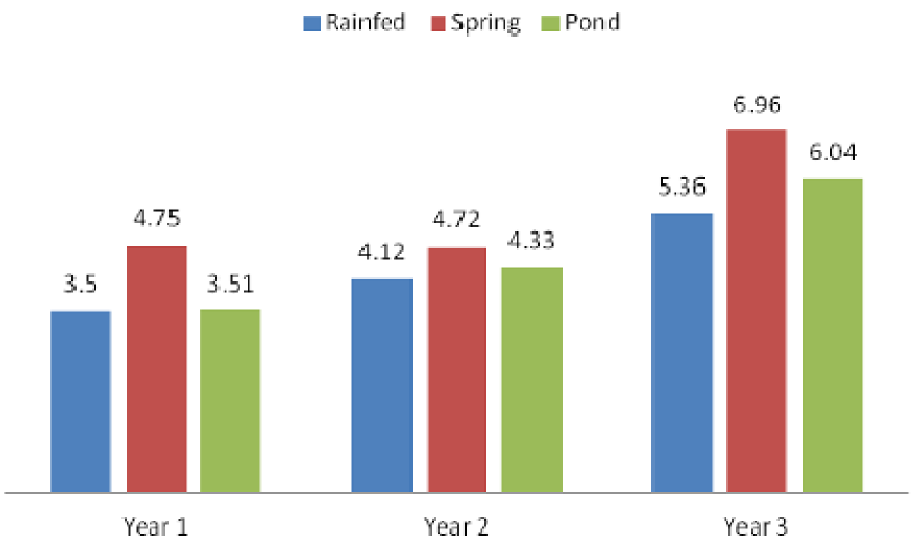

Figure 5: Effect of different water sources on the rice grain yield (t/ha)

Figure 6: Effect of soil amendments on the rice grain yield (ton/ha)

Figure7: Yield from spring *sawah* adopted rice field

Figure 8: Yield from Pond *sawah* adopted rice field

Figure 9: Yield from Rain-fed *sawah* adopted rice field

4.0 CONCLUSION

The study revealed the superiority of spring water source over other water sources in improving both the soil chemical properties and rice grain yield, as it aids in full realization of the geological fertilization process that do occur in inland valley *sawah* system. The study showed that supplemental irrigation gave higher significant improvement than the rain-fed water source on the soil chemical properties studied and rice grain yield on a short-term basis. It was also noted the superiority of organic amendments over mineral fertilizer in the selected soil chemical properties and rice grain yield improvement. It was equally obtained that the combination of supplemental irrigation for *sawah* management system and amendment practices improved the soil properties and rice grain yield. Therefore, s*awah* eco-technology is possibly the most promising rice production method and restoration of degraded inland valley soils in the Southeastern Nigeria. The 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.

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