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

The decline in agricultural productivity in Nigeria is merely because the rural farmers which constitute the bulk of Nigerian crop farmers rely on the rainfall for their agricultural activities. Rice farmers in Ebonyi State, regarded as a major rice producing State in Nigeria rely on rainfed agriculture. The water management option among the rice farmers in their lowland rice production in the area is the use of grass materials in the demarcation of the fields into basins for water storage without any form of water diversion from one place to another as a way of controlling the field water. In an attempt to replicate the successful way of controlling water in the African agro-ecosystems, otherwise known as “Japanese Satoyama watershed management model”, *sawah* rice cultivation technology has been introduced to West Africa in the last decades.

~~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 sytem in the rice field which involved mainly bunding, puddling and leveling with inlets and outlets channels on the bunds for irrigation and drainage purposes. ~~where the soil is expected to be bunded, puddle, and leveled in order to impound~~ The irrigation water may be 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. The~~is~~ study was conducted in an inland valley at Akaeze in 2010, 2011 and 2012 cropping seasons, to evaluate the effect of different water sources ~~of water~~ for *sawah* water management system and amendments on soil chemical 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 replicated three times and were applied in the following manner ~~as~~: rice husk (RH) @ 10 t ha^{-1}, rice husk ash (RHA) @ 10 t ha^{-1}, poultry droppings (PD) @ 10 t ha^{-1}, N.P.K. @ 400 kg ha^{-1} and no amendment @ 0 t ha^{-1}. ~~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 different water sources significantly ($p < 0.05$) improved the soil pH ~~was significantly ($p < 0.05$) improved by different water types~~ in the location. ~~The results also indicated that soil~~ Soil organic carbon, ~~and~~ total nitrogen and cation exchange capacity were ~~positively~~ significantly ($p < 0.05$) ~~influenced~~ increased ~~in the two locations~~within the period of study by both the different water sources and amendments. ~~The result shows a significant improvement on the CEC by both factors, while~~ It was observed that the exchangeable acidity was statistically 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~~ gave positive improvement on the rice grain yield ~~was positively increased~~ by the studied factors for the three years. Generally, results showed ~~the superiority~~ a better performance of organic amendments over mineral fertilizer in some soil chemical properties and rice grain yield improvement. The ~~results equally showed that the combination~~ interaction of a good water source in *sawah* water management and amendment practices ~~will~~ was observed to be a good strategy for improving ~~e~~ some soil chemical properties in the area.

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

1.0 INTRODUCTION

The well-established and growing demand for rice in Nigeria presently has necessitated the need for increasing rice production both to meet the country's food requirements and for the realization of rice green revolution in Nigeria. ~~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 without control, mainly because the ~~country's agriculture is rain-fed and subsistence~~ rural farmers rely on the rain for farming ~~activities~~ operations in the country. Rain-fed agriculture is ~~an important~~ a major economic activity in the developing ~~world~~ countries and is been practiced in 80% of the total physical agricultural area with about 62 percent of the world's stable food [1, 2, 3]. ~~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~~ According to FAO [4], 93 percent of cultivated land in sub-Saharan Africa is merely rainf-fed agriculture, ~~sub-Saharan Africa, 93 percent of cultivated land is rain fed [4],~~ thus playing a crucial role in food security and water availability [5]. Rice farmers in the study area who are dependent on the rain for their rice production make straight bunds across the valley bottom to store water in the fields. The lowlands are often slightly concave; these straight bunds result in deep water in the lowest parts of the lowland, and hardly any flooding near the fringes. 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. Kadigi *et al.* [6] argues that land for rain-fed agriculture varies depending on the amount and distribution of rainfall in the area. Rice production in the rainfed lowland environment being dependent on rainfed conditions is very susceptible to climatic variability which results in low yields.

Rain-fed lowland farmers are typically challenged by poor soil quality, drought/flood conditions, and erratic yields. Study has shown that ~~Y~~ yields from rain-fed agriculture are ~~often~~ usually low, ~~generally around~~ measuring 1 t ha^{-1} in semiarid tropical agro-ecosystems [7]. ~~There is ample evidence to suggest~~Researches have revealed that the low productivity in rain-fed agriculture is majorly due ~~more~~ to suboptimal performance related to field 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 poor field management practices resulting to inadequate soil moisture and low soil fertility have been top challenges facing rain-fed agriculture.

The improvement of farm infrastructures like bunding, leveling of the field surface, irrigation and drainage modifications will go a long way in reducing the yield gap in rain-fed inland valley environments. The surface water could be maintained more evenly over the field's entire surface with leveling operation helping to improve soil conditions for rice production. Considering the gap yield in rain-fed agriculture and the current demand for rice in Nigeria, there is need to sort for other water sources for supplementing the rainfed for optimum rice production in Nigeria.
~~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~~ valuable inland valleys for rice based cropping. In spite of ~~the potentials of~~ these ~~Nigeria~~ valuable inland valleys that abound in Nigeria especially in the Southeast for agricultural use, these areas are ~~yet to be~~ still facing some challenges in their ~~exploited fully~~exploitation.
The major ~~constraints~~ limiting factors in the utilization of these inland valleys ~~have been outlined as~~include; 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 practice with ~~small scale~~ irrigation scheme for integrated watershed management ~~will have been proposed to~~ be the most promising strategy to tackle these problems in these areas[23, 25].

Sawah, ~~has been described as~~ an Indo-Malaysian word for padi (Malayan word for paddy) or lowland rice management system ~~comprising~~ involved bunding, puddling, level~~l~~ing and good water management through inlet and outlet channels for irrigation and drainage [26].
Sawah system which ensures the maintenance of water level (minimum and maximium) in the field plots during the growing period of the plant contribute to the alleviation of global warming problems through the fixation of carbon in forest and *sawah* soils in ecologically sustainable ways.
~~*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 through geological fertilization 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.
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. 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 an improved SOC concentration and soil physical properties with continuous application of compost in a plough layer of a long-term rice paddy, 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.
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~~ aims at evaluating ~~e~~ the ~~contributions~~ effects of different manure ~~types~~ sources ~~to changes in~~ on soil chemical properties and grain yield improvement; and to ~~determine~~ evaluate 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 site~~s~~ 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 with the help of the bunds inlets and outlets channels (Figure 3). 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,~~ Table 1 gave the soil~~s~~ of the study area ~~are~~ as sandy loam with 100 g kg^{-1} clay and 150 g kg^{-1} silt content. The initial soil analysis ~~indicated~~ showed 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

Table 2 shows that ~~R~~ rice husk amendment ~~had~~ gave the highest ~~percentage of~~ organic carbon (33.7%), followed by rice husk ash with 23.9%, while poultry dropping ~~recorded~~ had the least value. This ~~means~~ implies that rice husk amendment has the potentials of enriching the soil ~~more~~ with more organic carbon pools. The analysis also indicated that poultry dropping produced the highest total nitrogen percent ~~was higher in poultry dropping~~, while the least TN was recorded in rice husk ash which could be attributed to the burning of the material. 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

Tables 3 and 4 presented the effects of different sources of water and amendments on the soil pH and organic carbon for three years of study. 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~~This result ~~disagrees~~ is not in agreement with the findings of Takase *et al.* [35] in a research conducted in Ghana ~~who~~ to compared river, canal, tap and well irrigation sources ~~in Ghana~~ and ~~found~~ observed that ~~though~~ none of the ~~se~~ *sawah* water types studied gave significant~~ly~~ ~~higher~~ increase on the pH than others, but the soils irrigated with well water ~~recorded~~ had the highest pH value at the end of their three months ~~of their~~ study.
Table 3 indicated that manure application within the period of study significantly ($p < 0.05$) increased the soil pH measured in water. The soil pH was improved 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. This was followed by plots amended with poultry dropping, while the least pH value was obtained from plots with no amendments. The values ranged from 3.44 – 4.49 in the 1st year, 3.58 – 4.84 in the 2nd year and 3.82 – 5.31 in the 3rd year of study. The results of the three years showed the pH increases as the year progresses. The significant improvement on the soil pH recorded in plots treated with ~~made by~~ RHA within the study period ~~on pH agrees with~~ conforms to the ~~findings~~ submissions of Abyhammer *et al.* [36]; Markikainen, [37] and Nwite *et al.* [38]; ~~who stated~~ that organic lime like ash ~~amendment~~ material could induce a pH increase by as much as 0.6 – 1.0 units in humus soils. Generally, the results showed that treated soils ~~treated with amendments~~ increased pH significantly higher than untreated soils. This~~ese~~ results ~~is in conformity~~ agrees 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 the soil pH significantly only in the first year of study.

Table 4 presents the effect of water source for *sawah* development and amendments on soil organic carbon. 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 pool 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~~ varied 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 or sediments 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~~ organic carbon sequestration through improved soil management practices can have ~~a positive impact~~ significant improvement on soil resources, because increasing soil C increases the functional capabilities of soils.
~~It was also obtained from the~~ The results (Table 4) showed that soil amendments significantly ($p < 0.05$) improved the soil organic carbon pool relatively higher than the control within the periods of study. The result ~~equally indicated~~ also gave a higher significant~~ly~~ ~~higher~~ improvement on the SOC pool on plots amended with rice husk dust than plots amended with other treatments. This higher improvement made by rice husk dust on the soil organic carbon could be attributed to high content/percent of carbon in the

rice husk dust used as amendment (Table 2). 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 the interactions of water sources and amendments ~~there was~~ significantly ($p < 0.05$) improved ~~ment 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 Bhagat and Verma [41] ~~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 different 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 different 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 different water sources and amendments on the soil total nitrogen and exchangeable acidity

The soil total nitrogen was significantly ($p < 0.05$) improved within the period of study (Table 5). The soil total nitrogen was found to increase significantly with the artificial application of water as supplemental irrigation compared to the rainfed (Table 5). 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. This implies that soil total nitrogen increase progressively as the year of the study increases. 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~~ In a similar study by Buresh [43], it was reported that ~~soil submergence also promotes biological nitrogen fixation (BNF) [43], and~~ submerged soils can promotes biological nitrogen fixation (BNF) and 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 (Table 5) ~~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. The soil total nitrogen values varied from 0.054 – 0.104, 0.057 – 0.105 and 0.062 – 0.114; in the 1st, 2nd and 3rd year of study, respectively. This result confirms the submissions of Becker and Johnson, [44]; Sakurai, [45]; and Toure *et al.* [46] that *sawah* system development when used in combination with improved varieties and fertilizers 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~~ conforms to the submission of Kyuma and Wakatsuki, [47] and Greenland, [48] that the ~~amount~~ level of nitrogen ~~fixed~~ fixation in submerged soils 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~~ as well as climatic conditions [46, 47]. These natural soil fertility replenishment mechanisms are essential ~~for enhancing the sustainability and~~ sustainable approach for improved 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. These results can be linked to higher accumulation of topsoil nutrients in the spring water source. 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 different water sources for *sawah* and amendments on soil total nitrogen (%)

Water source for *Sawah*	**Amendments**					
	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 different water sources 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 different water sources and amendments on the soil available phosphorous and cation exchange 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 in the soils. It was equally ~~obtained~~ observed that among the three water sources, spring water source improved the soil available phosphorous ~~statistically~~ significantly ($p < 0.05$) higher ~~the soil available phosphorous~~ than other water sources 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 ($p < 0.05$) 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,~~ The result agrees with the findings 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 rice 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~~ a significant improvement~~d~~ in SOC concentration and soil physical properties with continuous application of compost 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 result (Table 8) revealed that the spring water irrigated soils in the study significantly ($p < 0.05$) increased the cation exchange capacity higher than the pond irrigated plots, while the rainfed fields gave the least CEC values throughout the period of study. The results showed the range values as; 6.05 – 8.15 cmol(+) Kg^{-1}, 7.72 – 11.37 cmol(+) Kg^{-1}, and 8.63 – 13.77 cmol(+) Kg^{-1}, in the 1st, 2nd and 3rd year of the study. The results implied that there was a progressive increase in the cation exchange capacity as the year of study progresses. 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].
Studies have shown that sawah system is~~These~~ natural soil fertility replenishment mechanisms that are essential for sustainable improvement in ~~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 (Table 8) also ~~indicated~~ showed that amendments ~~a~~ significantly ($p < 0.05$) improve~~ment on~~ the soil CEC ~~due to amendments~~ within the period of study. ~~It was observed that~~Generally, 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 dust 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 different 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 different 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 different water sources and amendments on the rice grain yield (t/ha)

The effects of water sources for *sawah* development and different amendments on the rice grain yield were presented on table 9. The results (Table 9) revealed that there was ~~observed to have~~ significantly (P<0.05) improvement ~~d~~ on the rice grain yield for the three years of study in the study area. The results (Figures 4 ~~5~~ – 8 ~~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 crop yields from rain-fed agriculture are ~~often~~ usually low, generally around 1 t ha^{-1} compared to irrigated agriculture 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~~ suggested that the low productivity obtained in rain-fed agriculture ~~is due more~~ could be attributed 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~~ findings of Imolehin and Wada [14] who ~~advocated~~ suggested that it is better to ~~a reversion~~ revert to the use of organic materials in wetland rice cultivation as a more realistic option for farmers than continued reliance on inorganic fertilizers, which not only affect the soil negatively, but cannot be ~~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.

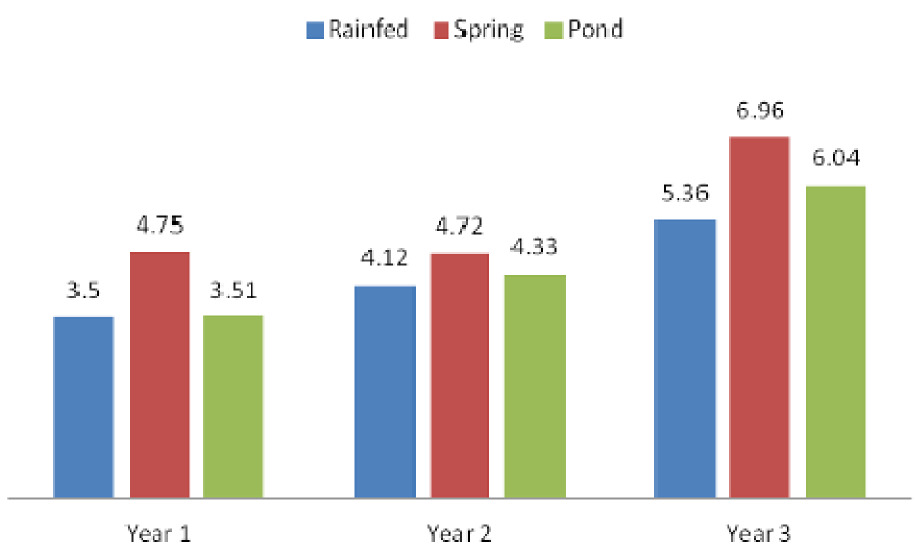

Figure 4 ~~5~~: Effect of different water sources on the rice grain yield (t/ha)

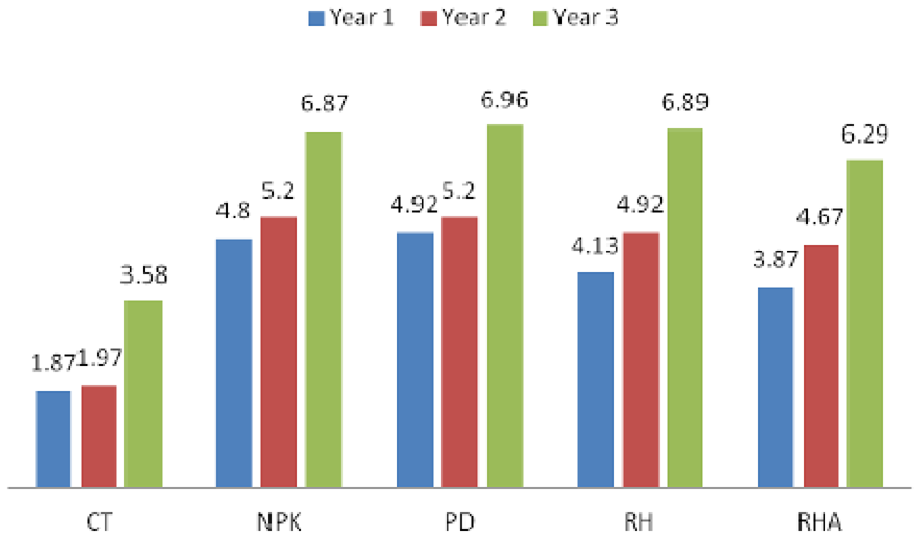

Figure 5 ~~6~~: Effect of soil amendments on the rice grain yield (ton/ha)

Figure 6 ~~7~~: Yield from spring *sawah* adopted rice field

Figure 7 ~~8~~: Yield from Pond *sawah* adopted rice field

Figure 8 ~~9~~: Yield from Rain-fed *sawah* adopted rice field

4.0 CONCLUSION

The study revealed the ~~superiority~~ successful improvement of spring water source on both soil chemical properties and rice grain yield over other water sources ~~in improving both the soil chemical properties and rice grain yield, as it aids in full realization of the~~ within the study period, through its mechanisms of regular 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 o~~ Organic amendments have been observed to have superior improvement on some chemical properties of the studied soil over mineral fertilizer ~~in the selected soil chemical properties and rice grain yield improvement~~on a short-term basis. ~~It was equally obtained that t~~ The ~~combination~~ integration of ~~supplemental~~ irrigation for *sawah* management system and amendment practices could be advocated for sustainable improvement ~~d~~ of ~~the~~ soil properties and rice grain yield in degraded inland valleys of Southeastern Nigeria. Therefore, s*awah* eco-technology is possibly the most promising rice production ~~method~~ strategy ~~and~~ for sustainable 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.~~

REFERENCES

1. Adesina, A. Keynote address on: Achieving a doubly green agricultural transformation in Nigeria, delivered by Dr. Akinwunmi Adesina, Hon. Minister of Agric. and Rural Dev., on the occasion of 36th annual conference of the Soil Science Society of Nigeria, University of Nigeria, Nsukka,

Enugu State, 12th March 2012. Proceedings of the 36th Annual Conference of the Soil Science Society of Nigeria (SSSN) 12th – 16th March 2012. University of Nigeria, Nsukka. Pp xvii – xiv.

2. FAOSTAT. Database. Food and Agriculture Organization, Rome. Accessed November 2005. [http://faostat.fao.org/] 2005.
3. Bhattacharya A. Sustainable Livelihood Based Watershed Management – Watershed Plus Approach, 2nd Working Group meeting of ERIA, Japan IGES; 2008.
4. FAO. Nepal country profile. http://www.fao.org/countryprofiles. 2002.
5. Wani SP, Sreedevi TK, Rockstrom J, Ramakrishna YS. "Rainfed Agriculture – Past Trends and Future Prospects", In: Wani SP, Rockstrom J and Oweis T (eds) (2009). Rainfed Agriculture: unlocking the potential, Oxfordshire: CABI International, 2009.
6. Kadigi RMJ, Kashaigili JJ, Mdoe NS. The economics of irrigated paddy in Usangu Basin in Tanzania: Water utilization, productivity, income and livelihood implications. Phys. Chem. Earth, 29/15-18: 2004; 1091-1100.
7. Rockstrom, J. Green water security for the food makers of tomorrow: Windows of opportunity in drought-prone savannahs. *Water Science and Technology* 43 (4): 2001. 71-78.
8. Agarwal, A. and Narain, S. Dying Wisdom. Rise, Fall and Potential of India's Traditional Water Harvesting System. Centre for Science and Environment, Faridabad. India: Thomson Press Ltd, 1997.
9. Benites, J., Chuma, E., Fowle, R., Kienzle, J., Molapong, K., Manu, J., Nyagumbo, I., Steiner, K. and van Veenhuizen, R. (eds). Conservation Tillage for Sustainable Agriculture. Proceedings from an International Workshop, Harare, 22–27 June. Part 1. Workshop Report. Deutsche Gesellschaft, GTZ, Eschborn, Germany, 1998. 59pp.
10. Rockström, J. and Falkenmark, M. Semiarid Crop Production from a Hydrological Perspective: Gap Between Potential and Actual Yields. Critical Reviews in Plant Sciences, Vol. 19(4), 2000. pp. 319-346.
11. SIWI. Water Harvesting for Upgrading of Rain-fed Agriculture. Problem Analysis and Research Needs. SIWI Report 11, Stockholm International Water Institute (SIWI), Stockholm, Sweden, 2001. 97 pp.
12. Gowing JW, Young MDB, Hatibu N, Mahoo HF, Rwehumbiza F, Mzirai, OB. Developing Improved Dryland Cropping Systems For Maize In Semi-Arid Tanzania. Part II. Use of a Model to Extrapolate and Add Value to Experimental Results, Exp. Agric., 9(3): 2003. 293-306.
13. Abu – Awwad, M and A. Kharabshed. Influence of supplemental irrigation and soil surface furrow on barley yield in arid areas affected by surface crust. J. Arid Environ. 46: 2000. 227 – 237.
14. Imolehin ED, Wada AC. Meeting the rice production and consumption needs of Nigeria with improved technologies. Int Rice Commiss Newsl FAO, Rome 49: 2000. 33–41.
15. Lee SB, Lee CB, Jung KY, Park KD, Lee D, Kim PJ. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. Soil Till Res. 104: 2009. 227–232.
16. Moormann, F.R. Problem in characterizing and classifying wetland soils. In wetland soils. Characterization, classification, utilization. Proceeding of a workshop 26 mar. to 5 April 1984, 1985. 53-68, IRRI, Los Banos, Philippines.
17. Wakatsuki, T; Koski, T. and Palada, M. Ecological engineering for sustainable rice farming in inland valley (Ivs) in West Africa. Paper presented at the second WAFSRN symposium. Accra, Ghana, 1989.
18. Windmeijer, P. N. and Andriesse, W. Inland valleys in West Africa: An Agro-ecological characteristics of rice- growing environment, 1993. pp28-37, ILRI. Wageningen, The Netherlands.
19. Otoo, E. and Asubonteng, K.O. Reconnaissance characterization of inland valleys in Southern Ghana. In characterization of inland valley Agron-ecosystems. A tool for their sustainable use. Proceeding of a workshop, 6 to 10 Nov. 1995, p 149-160. 1995. WARDA, Bouake, Ivory Coast.
20. Mbagwu, J. S. C. "The Agricultural Soils of Nigeria: Properties and Agronomic Significance for Increased Productivity," Beitrage für Tropical Landwirtschaften und Veterinari Medizin, Vol. 27, 1989. pp. 395-409.
21. Nnabude, P.C. and J.S.C. Mbagwu, Soil water relations of a Nigerian typic haplustult amended with fresh and burnt rice mill wastes. Soil and Tillage Res.,50: 1999. 207-214.

22. Mbagwu, J. S .C. “Improving the Productivity of a De-graded Ultisol in Nigeria Using Organic and Inorganic Amendments. Part 2: Changes in Physical Properties,” Bioresource Technology, Vol. 42, No. 3, 1992. pp. 167- 175.
23. Hirose, S and Wakatsuki, T. Restoration of inland valley ecosystems in West Africa.Pp56-86, 222-2224. 2002. Association of agriculture and forestry statistics. Megro-Sumiya building, Tokyo, Japan.
24. Igwe, C.A. “Erodibility of Soils of the Upper Rainforest Zone, Southeastern Nigeria,” Land degradation & De-velopment, Vol. 14, No. 3, 2003, pp. 323-334.
25. Hayashi, K and T. Wakatsuki. Sustainable soil fertility management by indigenous and scientific knowledge in Sahel zone of Niger, in the CD- ROM Transactions of the 17th World congress of soil science, symposium No. 15. perceptions of soil management: Matching indigenous and scientific knowledge systems, paper No. 1251, 2002.
26. Wakatsuki, T. and Masunaga, T. Ecological engineering for sustainable food production and the restoration of degraded watersheds in Tropics of low pH soils: Focus on West Africa. Soil Sci. Plant Nutri; 51: 2005, 629-636.
27. USDA. Keys to Soil Taxonomy. Natural Resources Conservation Services, United StatesDepartment of Agriculture, Washington, D.C, 1998.
28. FAO. Soil Map of the World: 1:5 million (Revised Legend). World Soil Resources Report, 60. Food and Agricultural Organization (FAO), Rome, 1988 .
29. Gee G.W., Bauder J.W. Particle size analysis. In: Klute A. (ed.): Methods of Soil Analysis, Part 1: Physi¬cal and Mineralogical Properties. Monograph No. 9. American Society of Agronomy, Madison, 1986. 91–100.
30. McLean, E.O. Soil pH and Lime requirement. In: A.L. Page et.al. (eds.), Methods of soil analyses (No. 9, part 2), 1982.199-224. Amer. Soc. of Agron.; Soil Sci. Soc. Am; Inc. Madison, Wisconsin, U.S.A.
31. Nelson, D.W. and L.E. Sommers. Total carbon, organic carbon and organic matter. In: A.L. Page et.al. (eds.). Methods of soil analyses (No.9, part 2), 552-553). 1982. Amer. Soc. of Agron. In: Soil Sci. Soc. Amer., Inc, Madison, Wisconsin, U.S.A.
32. Bremner, J.M and Mulvancy, C.S. 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. 1982. Pp 595-624.
33. Bray, R.H and L.T. Kurtz. Determination of total organic carbon and available forms of phosphorous in soils. Soil Sci. J. 59: 1945. 39-43.
34. Rhoades, J.D. Cation exchange capacity. In: A.L. Page, R.H. Miller and D.R. Keeny, (eds.). Methods of Soil Analysis, Part 2. Am. Soc. Agron., Madison, 1982. pp: 149-157.
35. Takase, M; L.K. Sam-Amoah and J.D. Owusu-Sekyere. The effects of four sources of irrigation water on soil chemical and physical properties. Asian Journal of Plant Science 10(1): 92 – 96, 2011. ISSN 1682 – 3974/ DOI:10.3923/ajps.2011.92.96. © 2011 Asian Network for Scientific Information.
36. Abyhammer, T; A. Fablin; A. Nelson and V. Henfrindison. Askater Foringssystem Deiproject I: Tekniker Ochmojiligheter. (Production of wood ash, techniques and possibilities), 1994. pp: 341. In Swedish with English Summary).
37. Markikainen, P.N. Nitrification in two coniferous forest soils after different fertilizer treatments. Soil Biol. Biochem., 16: 2002, 577 – 882.
38. Nwite, J.C; S.E. Obalum; C.A. Igwe and T. Wakatsuki. 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, 2011. ISSN 1817 – 3047.
39. Opara-Nadi, O.A; B.S. Ezua; A. Wogu. Organic manures and inorganic fertilizers addeded to an acid ultisol in Southeastern Nigeria: II. Effects on soil chemical properties and nutrient loss, In: proceedings of the 15th Annual Conf. SSSN, Kaduna, Nigeria. 1987.
40. Follet RF. Soil carbon sequestration and greenhouse gas mitigation. Soil Sci Soc Am J. 74: 2010. 345–346.
41. Bhagat, R.M. and Verma, T.S. Impact of rice straw management on soil physical properties and wheat yield. Soil Sci. 152: 1991.108-115.
42. Buresh RJ, Castillo EG, De Datta SK. Nitrogen losses in puddled soils as affected by timing of water deficit and nitrogen fertilization. Plant and Soil: 157, 1993, 197-206.

43. Buresh RJ, Reddy KR, van Kessel C. Nitrogen transformations in submerged soils. In 'Nitrogen in agricultural systems'. (Eds JS Schepers, WR Raun), 2008. pp. 401- 436. Agronomy Monograph 49. (ASA, CSSA, and SSSA: Madison, WI, USA).
44. Becker, M., and Johnson, D. E. 'Improved water control and crop management effects on lowland rice productivity in West Africa', Nutrient Cycling Agroecosystems, Vol 59, 2001. pp 119–127.
45. Sakurai, T. 'Intensification of rainfed wetland rice production in West Africa: present status and potential green revolution', Developing Economies, Vol 44, 2006. pp 232–251.
46. Touré, A., Becker, M., Johnson, D. E., Koné, B., Kossou, D. K., and Kiepe, P. 'Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast', Field Crops Research, Vol 114, 2009. pp 304– 310.
47. Kyuma, K and Wakatsuki, T. Ecological economy sustainability of paddy rice systems in Asia. In: Juo, A.S.R. and Russell, D.F. (eds.); Agriculture and Environment. Bridging Food production in developing countries. ASA special publication No. 60, 1995. p 139-159, ASA, CSSA, SSA, Wisconsin.
48. Greenland, D. J. Sustainability of Rice Farming, CABI, Wallingford, and IRRI, Los Banõs, The Philippines, 1997.
49. Eswaran, H., Almaraz, R., Van den Berg, E., and Reich, P. 'An assessment of the soil resources of Africa in relation to productivity', Geoderma, Vol 77, 1997. pp 1–18.
50. Abe, S. S., Buri, M. M., Issaka, R. N., Kiepe, P., and Wakatsuki, T. 'Soil fertility potential for rice production in West African lowlands', Japan Agricultural Research Quarterly, Vol 44, 2010 pp 343–355.
51. Errikson, H. Short term effects of granulated wood ash on forest soil chemistry in Southwest and Northwest Sweden. Scandinvian J. Forest. Res. Supplement, 2: 1998. 43 – 55.
52. Serafinelion, A. Wood ash: An alternative liming material for agricultureal soils, Soil Bullettin, 35: 2002. 80 – 95.
53. Dobermann A, Fairhurst T. 'Rice: Nutrient Disorders and Nutrient Management'. (Potash and Phosphate Institute and Potash and Phosphate Institute of Canada: Singapore and International Rice Research Institute: Los Baños, Philippines), 2000.
54. Wakatsuki, T., Shinmura, Y., Otoo, E., and Olaniyan, D. O. 'System for integrated watershed management of small inland valleys in West Africa', in: Institutional and Technical Options in the Development and Management of Small Scale Irrigation, Water Report No 17, FAO, Rome, 1998. pp 45–60.
55. Wakatsuki T, Buri MM and Oladele O.I. West African green revolution by eco-technology and the creation of African SATOYAMA systems. Kyoto Working Papers on Area Studies No. 63 (G-COE Series 61). Center for Southeast Asian Studies, Kyoto, Japan. 2009. 30 p. ISBN 978 4 901668 63 7.http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61.
56. Enwezor, W.O., A.C. Ohiri, E.E. Opuwaribo and E.J. Udo. A review of soil fertilizer use of crops in Southeastern zone of Nigeria. Fertilizer Procurement and Distribution Department, Lagos, Nigeria, 1988..
57. Igwe, C.A; Akamigbo F.O.R and Mbagwu J.S.C. Physical properties of soils of Southeastern Nigeria and the role of some aggregating agents in their stability, Soil Sci. 160: 1995. 431 – 441.
58. Abe, S.S and Wakatsuki T. Ecotechnology – a tiger for a rice green revolution in Sub-Saharan Africa: Basic concept and policy implications. Outlook on agriculture Vol. 40, No. 3, 2011, pp 221 – 227. Doi: 10.5367/oa.2011.0049.
59. IRRI (International Rice Research Institute). Physical measurements in rice soils: the Japanese methodologies. Los Baños (Philippines): IRRI, 1987.
60. Barron, J., Rockstrom, J., Hatibu, N. and Gichuki, F. Dry spell occurrence and maize yields for two locations in semi-arid East Africa. Agricultural Forest and Meteorology (in press);117 (1–2): 2003. 23–37.
61. Mupangwa W, Love D, Twomlow S. Soil–water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe, Phys. Chem. Earth, 31 15-16): 2006. 893-900.
62. Makurira H, Mul ML, Vyagusa NF, Uhlenbrook S, Savenije HHG. Evaluation of community-driven smallholder irrigation in dryland South Pare Mountains, Tanzania: A case study of Manoo micro dam, Phys. Chem. Earth, 32(15-18): 2007.1090-1097.

63. Buri M.M; Issaka, R.N, Wakatsuki, T, and Kawano N. Improving the productivity of lowland soils for rice cultivation in Ghana: the role of the 'sawah' system. Journal of Soil Science & Environment management Vol. 3(3), 2012. pp. 56 – 62.