International Journal of Plant & Soil Science
9(4): 1-19, 2016; Article no.IJPSS.20783
ISSN: 2320-7035

SCIENCEDOMAIN *international*
www.sciencedomain.org

Sawah Rice Farming Eco-technology Options for Enhancing Sustainable Nutrient Management and Rice Production in Degraded Inland Valleys of Southeastern Nigeria

J. C. Nwite[1*], A. O. Onunwa[2], C. A. Igwe[3] and T. Wakatsuki[4]

[1]Department of Crop Production Technology, Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria.
[2]Department of Soil Science and Land Resources Management, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[3]Department of Soil Science, University of Nigeria, Nsukka, Enugu State, Nigeria.
[4]Faculty of Agriculture, Shimane University, Nara, Japan.

Authors' contributions

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

Article Information

DOI: 10.9734/IJPSS/2016/20783
Editor(s):
(1) Yong In Kuk, Department of Development in Oriental Medicine Resources, Sunchon National University, South Korea.
(2) Scd Victoria Anatolyivna Tsygankova, Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds, Institute of Bio-organic Chemistry and Petrochemistry, Plant Physiology, NAS, Ukraine.
(3) Enrique Luis Cointry Peix, Department of Plant Breeding, Rosario National University, Argentina.
Reviewers:
(1) Filippo Sgroi, University of Palermo, Italy.
(2) Anonymous, Norway.
Complete Peer review History: http://sciencedomain.org/review-history/12434

Original Research Article

Received 8th August 2015
Accepted 11th November 2015
Published 26th November 2015

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 rain-fed agriculture. The water management option among the rice farmers in their lowland rice production

**Corresponding author: E-mail: johnwhite4real_2007@yahoo.com;*

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.

Sawah is generally described as a controlled water management system in the rice field which involved mainly bunding, puddling and leveling with inlets and outlets channels on the bunds for irrigation and drainage purposes. 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 study was conducted in an inland valley at Akaeze in 2010, 2011 and 2012 cropping seasons, to evaluate the effect of different water sources 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 assess 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: 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}. The results of the study showed that different water sources significantly ($p < 0.05$) improved the soil pH in the location. Soil organic carbon, total nitrogen and cation exchange capacity were significantly ($p < 0.05$) increased within the period of study by both the different water sources and amendments. It was observed that the exchangeable acidity was statistically reduced 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 gave positive improvement on the rice grain yield by the studied factors for the three years. Generally, results showed a better performance of organic amendments over mineral fertilizer in some soil chemical properties and rice grain yield improvement. The interaction of a good water source in *sawah* water management and amendment practices was observed to be a good strategy for improving some soil chemical properties in the area.

Keywords: Water sources; sawah; amendments; rice grain yield; soil properties and inland valleys.

1. 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. 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 every day, Nigerian rice farmers cry as the importations undermine domestic production [1].

Nigeria agricultural productivity fluctuates without control, mainly because the rural farmers rely on the rain for farming operations in the country. Rain-fed agriculture is a major economic activity in the developing countries and is been practiced in 80% of the total physical agricultural area with about 62 percent of the world’s stable food [1-3]. According to FAO [4], 93 percent of cultivated land in sub-Saharan Africa is merely rain-fed agriculture, 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 rain-fed lowland environment being dependent on rain-fed 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 yields from rain-fed agriculture are usually low, measuring 1 t ha^{-1} in semiarid tropical agro-ecosystems [7].

Researches have revealed that the low productivity in rain-fed agriculture is majorly due to suboptimal performance related to field management aspects rather than low physical potential [8–11]. 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 a need to sort for other water sources for supplementing the rain-fed for optimum rice production in Nigeria.

Supplementary irrigation is needed when natural precipitation is not adequate to secure grain and forage production [13].

Nigeria is blessed with enough rain and high valuable inland valleys for rice based cropping. In spite of these valuable inland valleys that abound in Nigeria especially in the Southeast for agricultural use, these areas are still facing some challenges in their exploitation.

The major limiting factors in the utilization of these inland valleys include; poor soil fertility maintenance, inadequate weed and water control [14–17]. Most soils in the West African sub-region are highly weathered and very fragile [18–22].

In order to overcome these limitations in the utilization of these inland valleys, an African adaptive *sawah* lowland farming practice with irrigation scheme for integrated watershed management have been proposed to be the most promising strategy to tackle these problems in these areas [21,23].

Sawah, an Indo-Malaysian word for padi (Malayan word for paddy) or lowland rice management system involved bunding, puddling, leveling and good water management through inlet and outlet channels for irrigation and drainage [24].

Sawah system which ensures the maintenance of water level (minimum and maximum) 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.

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 [25] 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. [26] 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 study also aims at evaluating the effects of different manure sources on soil chemical properties and grain yield improvement; and to evaluate the interactions of different water sources and soil amendments on soil properties and rice grain yield.

2. 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° 56' N and longitude 07° 41' E. The annual rainfall for the area is 1,350 mm, spread from April to October with average air temperature of 29℃. The site 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 Methods

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 (Fig. 3).

A split- plot in a randomized complete block design was used to assess 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.

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 (Fig. 2).

Fig. 1. Field preparation of rice field with power-tiller machine

Fig. 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 (Fig. 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 (Fig. 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.

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 motivation on the selection or choice of quantities of organic amendments used was based on the soil type of study area, crop type, the affordability and availability of the amendments in the area and the recommended rates for these amendments from other researches carried in the study area.

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.

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].

Fig. 3. Construction of interceptive canals and bund making for *sawah* field development

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. 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. Table 1 gave the soil of the study area as sandy loam with 100 g kg^{-1} clay and 150 g kg^{-1} silt content. The initial soil analysis 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 rice husk amendment gave the highest organic carbon (33.7%), followed by rice husk ash with 23.9%, while poultry dropping had the least value. This implies that rice husk amendment has the potentials of enriching the soil with more organic carbon pools. The analysis also indicated that poultry dropping produced the highest total nitrogen percent, 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.

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 ($p < 0.05$) higher in spring water source than other *sawah* water sources in the three years of study 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. The higher pH values obtained in spring *sawah* treated plots could be linked to the fine particles and other sediments that were eroded from the adjacent uplands and moved into the spring water which are then moved to the affected plots and get accumulated.

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

This result is not in agreement with the findings of Takase et al. [35] in a research conducted in Ghana to compared river, canal, tap and well irrigation sources and observed that none of the *sawah* water types studied gave significant increase on the pH than others, but the soils irrigated with well water had the highest pH value at the end of their three months study.

Table 3 indicated that manure application within the period of study increased the soil pH measured in water significantly ($p < 0.05$) higher than plots without manure application. The soil pH was improved significantly ($p < 0.05$) 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 RHA within the study period could be linked to the high potassium and magnesium contents in the rice husk ash material used (Table 2) which could induce a pH increase and this conforms to the submissions of Abyhammer et al. [36]; Markikainen, [37] and Nwite et al. [38]; that organic lime like ash 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 increased pH significantly higher than untreated soils. This result 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 (Table 4) indicated that water sources and amendments increased the soil organic carbon pools (SOC) significantly ($p < 0.05$) different 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 significantly ($p < 0.05$) different from other water sources within the periods of study. It was observed that apart from the first year, pond water source did not improve the SOC significantly ($p < 0.05$) higher than the rain-fed water source. The soil organic carbon mean values 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 organic carbon sequestration through improved soil management practices can have significant improvement on soil resources, because increasing soil C increases the functional capabilities of soils. 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 also gave a higher significant 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 increased the soil organic carbon (SOC) build-up significantly ($p < 0.05$) higher than their separate performance in the second and third year of the study. This agreed with the report of Bhagat and Verma [41] that incorporation of plant residues coupled with appropriate puddling and water management build up organic carbon status of soil.

3.3 Effects of Different Water Sources and Amendments on the Soil Total Nitrogen and Exchangeable Acidity

The effects of different water sources and amendments on soil total nitrogen were presented in Table 5. The artificial application of water as supplemental irrigation was significantly ($p < 0.05$) different from the rain-fed in soil total nitrogen improvement (Table 5). The improvement could be as a result of aquatic algae activities in submerged soils that commit biological nitrogen fixation through increased photosynthesis. 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 through de-nitrification process.

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

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			
Rain-fed	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			
Rain-fed	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			
Rain-fed	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			
Rain-fed	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			
Rain-fed	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

Water source for *Sawah*	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
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			
Rain-fed	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

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			
Rain-fed	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			
Rain-fed	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			
Rain-fed	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

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]. In a similar study by Buresh [43], it was reported that 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) 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 were significantly ($p < 0.05$) different from the control in soil total nitrogen improvement. It was obtained that the soil total nitrogen was improved higher 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. The better improvement made by NPK and poultry droppings on the soil total nitrogen higher the rice husk and rice husk ash is attributed to earlier mineralization that do occur in mineral fertilizers as against delayed or slow mineralization process that are obtained in organic amendments. 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.

The result conforms to the submission of Kyuma and Wakatsuki, [47] and Greenland, [48] that the level of nitrogen 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 as well as climatic conditions [46,47]. These natural soil fertility replenishment mechanisms are essential 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 differently from 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 due to downward movement of these materials.

The results also revealed that amended plots were significantly ($p < 0.05$) different from the control (non-amended plots) in decreasing the soil exchangeable acidity (EA) during the study. 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.

3.4 Effects of Different 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 higher than its initial values in the soils. It was equally observed that among the three water sources, spring water source improved the soil available phosphorous significantly ($p < 0.05$) higher 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 higher than the rain-fed field in all the years. The increased available phosphorous obtained in plots treated with supplemental irrigation over rain-fed treated plots could be attributed to increased pH and reduction in ferric iron in water controlled plots as a result of neutralization of acid soils of the area, thereby liberating available phosphorous from the fixed exchange sites.

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			
Rain-fed	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			
Rain-fed	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			
Rain-fed	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

As a general principle, as soil drying becomes more prolonged and severe under rain-fed 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, [21]; 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 increased the availability of phosphorous differently in the studied soil within the periods. It was noted generally that all the treated plots significantly ($p < 0.05$) increased the available phosphorous higher in the studied soil 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 ($p < 0.05$) increased the available phosphorous higher than inorganic nutrient source (NPK) indicating the superiority of organic manure over inorganic in soil and crop improvement. It was observed that among the organically amended plots, rice husk ash treated plots increased the available phosphorous significantly higher than others. This was followed by poultry droppings amended plots within the period of study. This could be linked to the increased soil pH recorded in those RHA amended plots during the study which have helped to liberate soil available phosphorous in its fixed exchange site due to acidic condition. The result agrees with the findings of Imolehin and Wada [25] 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.

The results (Table 8) indicated that CEC was improved differently within a short-term 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 isnatural soil fertility replenishment mechanisms that are essential for sustainable improvement in productivity of lowland rice farming systems in inherently unfertile soils in WA and SSA [49,50].

The results (Table 8) also showed that amendments significantly ($p < 0.05$) improve the soil CEC within the period of study. 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						
Rain-fed	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						
Rain-fed	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						
Rain-fed	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				
Rain-fed	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				
Rain-fed	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				
Rain-fed	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 significantly (P<0.05) improvement on the rice grain yield for the three years of study in the study area. The results (Figs 4 – 8 and Table 9) showed that among the three water sources, spring water source for supplemental irrigation, increased the rice grain yield significantly ($p < 0.05$) higher than other water sources within the period of study (Figs. 4 and 6). This was followed by the pond source of water, while the rain-fed type recorded the least yield performance of rice grain yield. The increased rice grain yields recorded in the spring and pond treated fields in the study as against the low yield obtained in the rain-fed treated fields could be attributed to increased water availability in those field throughout the growing period of the plant which are the desired growing environment for rice plant (a water-loving plant). The results implied that the low productivity obtained in rain-fed fields could be attributed to management aspects of the fields rather than low physical potentials. This is in line with a submission that crop yields from rain-fed agriculture are 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 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.

Table 9. Effects of different water source for *sawah* and amendments on rice grain yield (ton/ha)

Water source for *Sawah*	Amendments					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
			Year 1			
Rain-fed	1.80	4.40	4.20	3.10	4.00	3.50
Spring	2.03	5.37	5.73	5.37	5.23	4.75
Pond	1.77	4.63	4.83	3.13	3.17	3.51
Mean	1.87	4.8	4.92	3.87	4.13	
LSD $_{(0.05)}$ water source for sawah		0.7156				
LSD $_{(0.05)}$ Amendment		0.6250				
LSD $_{(0.05)}$ water source for *sawah* x Amendments		NS				
			Year 2			
Rain-fed	2.10	4.73	4.70	4.53	4.53	4.12
Spring	1.97	5.77	5.77	5.30	4.80	4.72
Pond	1.83	5.10	5.13	4.93	4.67	4.33
Mean	1.97	5.20	5.20	4.92	4.67	
LSD $_{(0.05)}$ water source for sawah		0.2132				
LSD $_{(0.05)}$ Amendment		0.400				
LSD $_{(0.05)}$ water source for sawah x Amendments		NS				
			Year 3			
Rain-fed	2.60	6.31	6.45	4.98	6.45	5.36
Spring	4.21	7.30	8.27	7.22	7.78	6.96
Pond	3.93	7.01	6.17	6.66	6.45	6.04
Mean	3.58	6.87	6.96	6.29	6.89	
LSD $_{(0.05)}$ water source for sawah		1.081				
LSD $_{(0.05)}$ Amendment		0.809				
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

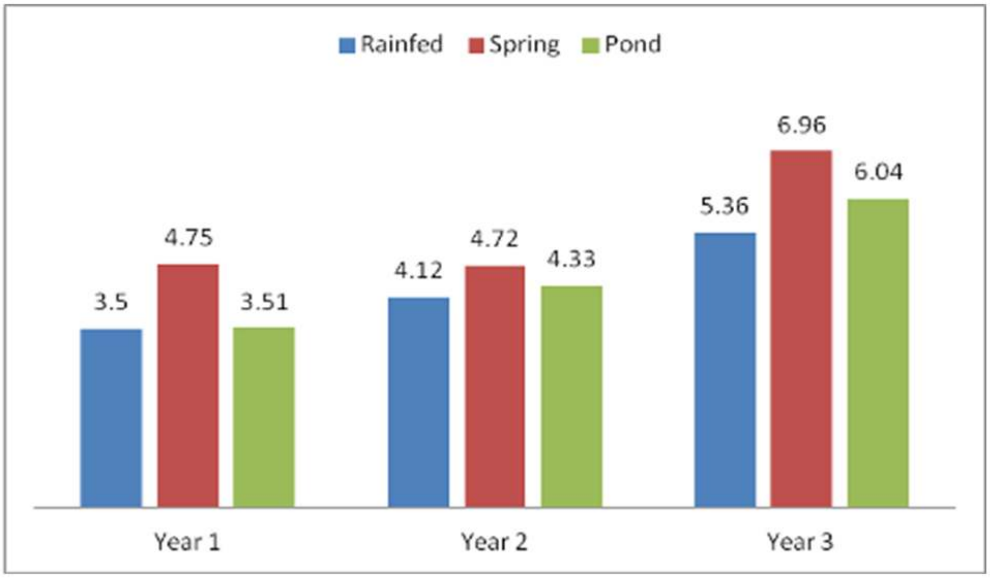

Fig. 4. Effect of different water sources on the rice grain yield (t/ha) as affected by water sources

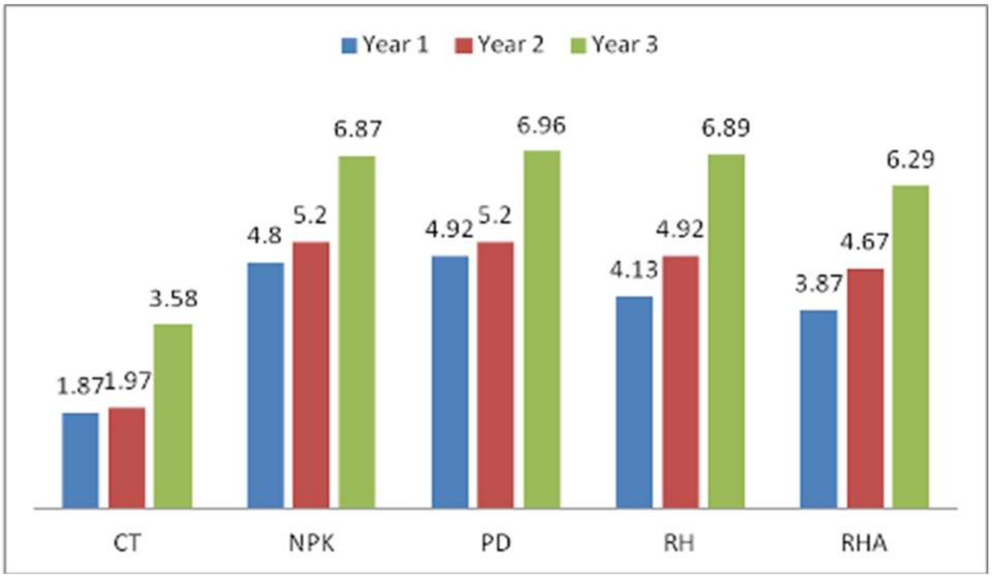

Fig. 5. Effect of soil amendments on the rice grain yield (ton/ha) as affected by amendments

Fig. 6. Yield from spring *Sawah* adopted rice field

Fig. 7. Yield from Pond *Sawah* adopted rice field

Fig. 8. Yield from Rain-fed *Sawah* adopted rice field

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.

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 (Fig. 5) also revealed the short-term superiority of organic amendments over mineral (inorganic) fertilizer in a lowland rice production. It was obtained that among the amendments; rice grain yield was increased significantly ($p < 0.05$) higher in poultry dropping (PD) treated plots than NPK fertilizer amended plots in all the years studied (Fig. 5). This result is in line with the findings of Imolehin and Wada [25] who suggested that it is better to 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 readily available. 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. The results generally indicated that all the amended plots increased the rice grain yield significantly higher than the control.

4. CONCLUSION

The study revealed the successful improvement of spring water source on both soil chemical properties and rice grain yield over other water sources 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. Organic amendments have been observed to have superior improvement on some chemical properties of the studied soil over mineral fertilizer on a short-term basis. The integration of irrigation for *sawah* management system and amendment practices could be advocated for sustainable improvement of 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 strategy for sustainable restoration of degraded inland valley soils in the Southeastern Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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 17–14.
2. FAOSTAT. Database. Food and Agriculture Organization, Rome; 2005.
   Available:http://faostat.fao.org/ (Accessed November 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; 2002.
   Available:http://www.fao.org/countryprofiles
5. Wani SP, Sreedevi TK, Rockstrom J, Ramakrishna YS. Rainfed agriculture – Past trends and future prospects. In: Wani SP, Rockstrom J, Oweis T (eds). 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. 2001; 43(4):71-78.
8. Agarwal A, 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, 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;59.
10. Rockström J, Falkenmark M. Semiarid crop production from a hydrological perspective: Gap between potential and actual yields. Critical Reviews in Plant Sciences. 2000;19(4):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.
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. 2003; 9(3):293-306.
13. Abu – Awwad M, Kharabshed A. Influence of supplemental irrigation and soil surface furrow on barley yield in arid areas affected by surface crust. J. Arid Environ. 2000;46: 227–237.
14. Moormann FR. 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.
15. Wakatsuki T, Koski T, 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.
16. Windmeijer PN, Andriesse W. Inland valleys in West Africa: An agro-ecological characteristic of rice- growing environment. ILRI. Wageningen, The Netherlands. 1993;28-37.
17. Otoo E, Asubonteng KO. 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;149-160. WARDA, Bouake, Ivory Coast.
18. Mbagwu JSC. The agricultural soils of Nigeria: Properties and agronomic significance for increased productivity. Beitrage für Tropical Landwirtschaften und Veterinari Medizin. 1989;27:395-409.
19. Nnabude PC, Mbagwu JSC. Soil water relations of a Nigerian typic haplustult amended with fresh and burnt rice mill wastes. Soil and Tillage Res. 1999;50:207-214.
20. Mbagwu JSC. Improving the productivity of a De-graded ultisol in Nigeria using organic and inorganic amendments. Part 2: Changes in physical properties. Bioresource Technology. 1992;42(3)167-175.
21. Hirose S, Wakatsuki T. Restoration of inland valley ecosystems in West Africa. 2002;56-86,222-2224. Association of agriculture and forestry statistics. Megro-Sumiya building, Tokyo, Japan.
22. Igwe CA. Erodibility of soils of the upper rainforest zone, Southeastern Nigeria. Land Degradation & Development. 2003; 14(3):323-334.
23. Hayashi K, Wakatsuki T. 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.
24. Wakatsuki T, 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. 2005;51:629-636.
25. Imolehin ED, Wada AC. Meeting the rice production and consumption needs of Nigeria with improved technologies. Int Rice Commiss Newsl FAO, Rome. 2000;49:33–41.
26. 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. 2009;104:227–232.
27. USDA. Keys to soil taxonomy. Natural Resources Conservation Services, United States Department 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 GW, Bauder JW. Particle size analysis. In: Klute A, (ed.): Methods of soil analysis, Part 1: Physical and mineralogical properties. Monograph No. 9. American Society of Agronomy, Madison. 1986;91–100.
30. McLean EO. Soil pH and Lime requirement. In: Page AL, 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 DW, Sommers LE. Total carbon, organic carbon and organic matter. In: Page AL, 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 JM, Mulvancy CS. Total nitrogen. In: Page AL, et al (eds). Methods of soil analyses. No. 9; part 2, Amer. Soc. of Agron. Inc, Madison, Wisconsin, USA. 1982;595-624.
33. Bray RH, Kurtz LT. Determination of total organic carbon and available forms of phosphorous in soils. Soil Sci. J. 1945;59: 39-43.
34. Rhoades JD. Cation exchange capacity. In: Page AL, Miller RH, Keeny DR, (eds). Methods of Soil Analysis, Part 2. Am. Soc. Agron., Madison. 1982;149-157.
35. Takase M, Sam-Amoah LK, Owusu-Sekyere JD. The effects of four sources of irrigation water on soil chemical and physical properties. Asian Journal of Plant Science. 2011;10(1):92 – 96. ISSN 1682 – 3974/ DOI: 10.3923/ajps.2011.92.96 ©

2011 Asian Network for Scientific Information.
36. Abyhammer T, Fablin A, Nelson A, Henfrindison V. Askater Foringssystem Deiproject I: Tekniker Ochmojiligheter. (Production of wood ash, techniques and possibilities). 1994;341. In Swedish with English Summary).
37. Markikainen PN. Nitrification in two coniferous forest soils after different fertilizer treatments. Soil Biol. Biochem. 2002;16:577–882.
38. Nwite JC, Obalum SE, Igwe CA, Wakatsuki T. 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. 2011;7(3):304– 310. ISSN 1817 – 3047.
39. Opara-Nadi OA, Ezua BS, Wogu A. 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. 2010;74:345–346.
41. Bhagat RM, Verma TS. Impact of rice straw management on soil physical properties and wheat yield. Soil Sci. 1991;152:108-115.
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. 1993;157:197-206.
43. Buresh RJ, Reddy KR, van Kessel C. Nitrogen transformations in submerged soils. In Nitrogen in agricultural systems. (Eds JS Schepers, WR Raun). 2008;401-436. Agronomy Monograph 49. (ASA, CSSA, and SSSA: Madison, WI, USA).
44. Becker M, Johnson DE. Improved water control and crop management effects on lowland rice productivity in West Africa. Nutrient Cycling Agroecosystems. 2001; 59:119–127.
45. Sakurai T. Intensification of rainfed wetland rice production in West Africa: Present status and potential green revolution. Developing Economies. 2006;44:232–251.
46. Touré A, Becker M, Johnson DE, Koné B, Kossou DK, Kiepe P. Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast. Field Crops Research. 2009;114:304–310.
47. Kyuma K, Wakatsuki T. Ecological economy sustainability of paddy rice systems in Asia. In: Juo ASR, Russell DF. (eds.); Agriculture and Environment. Bridging Food production in developing countries. ASA special publication No. 60, 1995;139-159. ASA, CSSA, SSA, Wisconsin.
48. Greenland DJ. Sustainability of rice farming, CABI, Wallingford, and IRRI, Los Banõs, The Philippines; 1997.
49. Eswaran H, Almaraz R, Van den Berg E, Reich P. An assessment of the soil resources of Africa in relation to productivity. Geoderma. 1997;77:1–18.
50. Abe SS, Buri MM, Issaka RN, Kiepe P, Wakatsuki T. Soil fertility potential for rice production in West African lowlands. Japan Agricultural Research Quarterly. 2010;44: 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. 1998;2:43–55.
52. Serafinelion A. Wood ash: An alternative liming material for agricultureal soils. Soil Bullettin. 2002;35:80–95.
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, Olaniyan DO. 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; 45–60.
55. Wakatsuki T, Buri MM, Oladele OI. 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. ISBN 978 4 901668 63 7. Available:http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61
56. Enwezor WO, Ohiri AC, Opuwaribo EE, Udo EJ. A review of soil fertilizer use of

crops in Southeastern zone of Nigeria. Fertilizer Procurement and Distribution Department, Lagos, Nigeria; 1988.

57. Igwe CA, Akamigbo FOR, Mbagwu JSC. Physical properties of soils of Southeastern Nigeria and the role of some aggregating agents in their stability, Soil Sci. 1995;160:431–441.
58. Abe SS, Wakatsuki T. Ecotechnology – A tiger for a rice green revolution in Sub-Saharan Africa: Basic concept and policy implications. Outlook on Agriculture. 2011;40(3):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, Gichuki F. Dry spell occurrence and maize yields for two locations in semi-arid East Africa. Agricultural Forest and Meteorology (in press). 2003;117(1–2):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 MM, Issaka RN, Wakatsuki T, 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. 2012;3(3):56–62.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12434