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

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

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

INTRODUCTION

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

Poor soil fertility and inefficient weed and water control are the major constraints to proper utilization of these inland valleys for sustainable rice-based cropping. In order to overcome such difficulties and for effective and sustainable crop production in inland valleys of Nigeria, new farming system(s) that can restore and enrich poor soils must be developed [4-7]. For sustainable
increase to cope with present population expansion, the African adaptive Sawah- lowland farming, with small scale irrigation scheme for integrated watershed management, will be the most promising strategy to tackle these problems and restore the degraded inland valleys in these areas for increased and sustainable food production [1, 8, 9].

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

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

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

**MATERIALS AND METHODS**

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

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

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

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

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

- Sub-plot I; Complete sawah- bunded,puddled and leveled rice field (CS)
- Sub-plot II; Farmers environment- no bunding and leveling rice field (FE)
Sub-plot II; Incomplete sawah- bundling with minimum leveling and puddling rice field (ICS) 
Sub-plot IV; Partial sawah- after bunding, no puddling and leveling rice field (PS)

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

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

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

**Laboratory Methods:** Soil samples were air-dried and sieved with 2 mm sieve. Soil fractions less than 2 mm from individual samples were then analyzed using the following methods; Particle size distribution of less than 2 mm fine earth fractions was measured by the hydrometer method as described by Gee and Bauder [13]. Soil pH was measured in a 1:2.5 soil:0.1 M KCl suspensions [14]. The soil OC was determined by the Walkley and Black method described by Nelson and Sommers [15]. Total nitrogen was determined by semi-micro kjeldahl digestion method using sulphuric acid and CuSO4 and Na2SO4 catalyst mixture [16]. CEC was determined by the method described by Rhoades [17].

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

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

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

**RESULTS AND DISCUSSION**

**Effects of Sawah Water Management Systems and Amendments on the Soil Ph and Organic Carbon (OC):** The influence of the sawah water management systems and amendments on the soil pH and organic carbon are presented (Table 3). The results showed that the soil pH
Temperature of the soil, the amount of reducible substances, or the amount of ferric iron is too low to produce sufficient ferrous iron for the buffering to become operatives, the pH may tend to decrease. Nwite et al., [6] remarked that pH increased significantly in sawah water – managed system in a study conducted in a similar location for two years to evaluate sawah and non-sawah water management systems.

The results also showed that the pH measured in water differed significantly among the treatments. It was obtained that the soil pH was significantly improved higher in soils treated with rice husk ash. The pH ranged from 3.6 to 4.9 in the first year and 3.9 to 5.0 in the second year (control to rice husk ash treated plots), respectively. The significant improvement made by RHA on pH agrees with the findings of Nwite et al., [9] and Markikainen, [20] who stated that ash amendment could induce a pH increase by as much as 0.6 – 1.0 units in humus soils. It was also obtained from the results that the interactions of sawah types and growing environments significantly improved pH in the second year of study, while the interactions of sawah types, growing environment and soil amendments significantly increased the soil pH for the two years of study.
The results indicated that soil organic carbon was positively influenced by sawah type with spring sawah type showing higher accumulation. It was shown that SOC ranged from 0.84% - 1.02% and 0.91 – 1.10% (rain-fed to spring), in the 1\textsuperscript{st} and 2\textsuperscript{nd} year, respectively. Sawah growing environments significantly affected soil organic carbon (SOC) of the studied soils with complete sawah growing environment giving higher SOC pool than others including farmers’ fields (0.79 – 1.27%). This means that sawah eco-technology is significant in harnessing the health conditions of the soil and reduction in global warming. Hirose and Wakatsuki, [1]; Wakatsuki et al., [21] submitted that sawah fields will contribute to the alleviation of global warming problems through the fixation of carbon in forest and sawah soils in ecologically sustainable ways.

This result also affirms the findings of Igwe et al. [22] that higher soil organic carbon was recorded in soils with finer fraction (WSA<1.00) brought about by well puddle activity associated with a complete sawah technology.

Treated soils significantly improved the soil organic carbon relatively higher than the control in all the growing environments. A significantly higher SOC concentration was obtained from plots amended with rice husk dust than plots amended with other treatments (0.62 – 1.18%), CT to RH treated plots, respectively. The result confirms the findings of Lee et al., [23] who reported from a long-term paddy study in southeast Korea that continuous application of compost improved SOC concentration and soil physical properties in the plough layer, relative to inorganic fertilizer application. The results also showed that there was significant improvement on the buildup of SOC with the interactions of sawah types, growing environments and amendments at a long-term management. This agreed with the submission that incorporation of plant residues coupled with appropriate puddling and water management build up organic carbon status of soil [24].

### Effects of Sawah Water Management Systems and Amendments on the Soil Total Nitrogen and Cation Exchange Capacity (CEC):

The soil total nitrogen was statistically (P< 0.05) improved by the different sawah types in the study (Table 4). The results also indicated that there was significant difference among the sawah growing environments. Among the sawah growing environments, complete sawah statistically improved soil total nitrogen higher than other growing environments.
Table 5: Effects of sawah water management systems and amendments on rice grain yield (t/ha)

<table>
<thead>
<tr>
<th>Sawah types</th>
<th>Pumping</th>
<th>Rainfed</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>FE</td>
<td>ICS</td>
</tr>
<tr>
<td>Amendts</td>
<td>Grain yield (ton/ha)</td>
<td>Grain yield (ton/ha)</td>
<td>Grain yield (ton/ha)</td>
</tr>
<tr>
<td>Year 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>1.90</td>
<td>1.77</td>
<td>1.57</td>
</tr>
<tr>
<td>NPK</td>
<td>4.70</td>
<td>3.40</td>
<td>3.67</td>
</tr>
<tr>
<td>PD</td>
<td>3.43</td>
<td>3.40</td>
<td>5.20</td>
</tr>
<tr>
<td>RH</td>
<td>4.47</td>
<td>4.50</td>
<td>3.87</td>
</tr>
<tr>
<td>RHA</td>
<td>4.17</td>
<td>3.87</td>
<td>3.70</td>
</tr>
<tr>
<td>Mean</td>
<td>3.69</td>
<td>3.39</td>
<td>3.60</td>
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<tr>
<td>LSD (0.05) Sawah type</td>
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<td></td>
</tr>
<tr>
<td>LSD (0.05) Environment</td>
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<tr>
<td>LSD (0.05) Amendment (Amendt)</td>
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<tr>
<td>LSD (0.05) Sawah type X Environment X Amendt</td>
<td>NS</td>
<td></td>
<td></td>
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<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>1.93</td>
<td>2.10</td>
<td>2.20</td>
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<tr>
<td>NPK</td>
<td>6.03</td>
<td>5.30</td>
<td>4.97</td>
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<tr>
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<td>4.75</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LSD (0.05) Sawah type X Environment X Amendt</td>
<td>NS</td>
<td></td>
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</tbody>
</table>

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

with the highest value recorded in the spring sawah type (0.08 and 0.11%), in the 1st and 2nd year, respectively. This affirms the submissions made by some researchers that, soil submergence also promotes biological nitrogen fixation (BNF) [25] and submerged soils can sustain an indigenous N supply for rice as evidenced by long-term stable yields in minus-N plots in long term experiments. The results equally pointed highly significant differences on the soil total nitrogen with the treatments application. Plots treated with organic amendments; PD and RH improved TN better than others including control plots. The values varied from 0.05 to 0.07% (CT – PD) in the 1st year and 0.06 to 0.09% (CT – PD/RH) in the 2nd year. This result confirms the submissions of Imolehin and Wada [26] who advocated a reversion to the use of organic materials in wetland rice cultivation as a more realistic option for farmers than continued reliance on inorganic fertilizers, which in addition to their deleterious effects on the soil are not readily available. The result showed a significant improvement on the TN with the interactions of sawah types and environments on a long-term basis. The results showed that CEC was improved upon by sawah types within the period of study. It was generally observed that all sawah growing environment significantly highly influenced the CEC relative to the farmers’ environment. It was also obtained that among the sawah growing environments, complete sawah growing environment in spring sawah type improved the CEC of the soil higher in the study (11.3 and 13.8 cmolkg⁻¹), 1st and 2nd year respectively. This result implies that soil erosion which tries to erode most topsoil nutrient of most inland valleys are eliminated or reduced when all the components of sawah technology is employed during lowland rice field operations. These assertion agrees with those obtained by Hirose and Wakatsuki [1], Ofori et al. [27] and Wakatsuki and Masunaga [28] that the soils formed and nutrients released during
rock-weathering and soil formation processes in upland areas arrive and accumulate in lowland areas through geological fertilization processes, such as soil erosion and sedimentation, as well as surface and ground water movements or colluvium formation processes. Ideal land use patterns and landscape management practices will optimize the geological fertilization processes through the optimum control of hydrology in a given watershed. Irrigation, surface and sub-surface water also increase the supply of nutrients, such as Si, Ca, Mg, K and sulfate. This contribution provides an ecological engineering basis for long-term intensive sustainability of lowland sawah-based rice farming. These natural soil fertility replenishment mechanisms are essential for enhancing the sustainability and productivity of lowland rice farming systems in inherently unfertile soils in West Africa and Sub Saharan Africa [29].

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

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

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

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

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

**CONCLUSIONS**

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

**REFERENCES**


