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MANURIAL AMENDMENTS AND SOURCE OF WATER FOR SUPPLEMENTAL IRRIGATION OF *SAWAH*-RICE SYSTEM INFLUENCED SOIL QUALITY AND RICE YIELD

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ABSTRACT
Soil and water management research on adapting the promising sawah ecotechnology for lowland rice farming in West Africa has largely focused on the abundant inland valleys; floodplains which too represent a huge agricultural resource in the region have not been so involved. Sawah refers to a bunded, puddled and leveled basin for rice, with water inlets and outlets for irrigation and drainage, respectively. In conventional sawah, soil fertility is augmented using mineral fertilizers, with an option to harness lowland water resources for use in small-scale irrigation to create the so-called sawah typologies. In this study, we evaluated the effects of three manurial amendments (rice husk, rice-husk ash and poultry droppings, each at 10 t ha^{-1}) and NPK 20:10:10 at 400 kg ha^{-1} interacting with source of water (spring or pond) used for supplemental irrigation of three sawah typologies in a floodplain in southeastern Nigeria. Plots amended with poultry droppings and supplemented with spring water recorded the overall best performance of the sawah-rice system; the control being the unamended non-supplemented (solely rainfed) plots recorded the worst. Rice-husk ash and rice husk enhanced soil pH and soil organic carbon, respectively. The three sawah typologies showed a consistent trend thus spring-supplemented ≥ pond-supplemented ≥ non-supplemented sawah. Rice grain yield was influenced by soil total nitrogen and the sum of the three plant-nutrient basic cations (K^+, Ca^{2+} and Mg^{2+}), with the influence of K^+ alone being the greatest. To enhance rice performance including grain yields in floodplain sawah, farmers should utilise poultry droppings as soil manure and spring water for supplemental irrigation.

Key words: lowland rice, *sawah* ecotechnology; floodplain soils, organic amendments, *sawah* typology, spring water

INTRODUCTION
The African adaptive lowland *sawah*[†] system remains a highly promising platform for not just increasing rice (*Oryza sativa*) production but also attaining rice self-sufficiency in tropical Africa in a sustainable manner. *Sawah*-based rice farming is thus increasingly popular in especially West Africa where the relative abundance of such categories of lowland as inland valleys and floodplains is an advantage. Besides the fact that lowlands often are of higher soil fertility than adjacent uplands (Obalum *et al*., 2012a), they present favourable hydrological conditions for rice farming. Generally, floodplain soils show higher clay content and hence fertility status than inland-valley soils in West Africa (Abe *et al.*, 2006); the reverse is true for topo-features that make for ease of water control.

Sawah has numerous agronomic and ecological benefits. It promotes the efficiency of soil and water management; conserves the fertility of lowland soils (nutrient-rich fine particles in the saturated puddled soils, alluvial flows and geo- and topo-accumulated water settle and build-up in the topsoil) and makes for proper harnessing of water and nutrients in the lowlands (Asubonteng *et al.,* 2001; Wakatsuki and Masunaga, 2005). Considering that rice is a shallow-rooting and water-loving grain crop, this improved environment for crop growth offered by lowland *sawah* often results in increased tillering potential and grain yield of rice (Obalum *et al*., 2014). For non-*sawah* fields (with uncontrolled flooding), these sediments elude the topsoil with the attendant hampering of rice growth and yield.

[†]Among researchers and farmers, the concept of *sawah* (a word that is of Malayo-Indonesian origin) is that of a lowland rice field after being systematically designed and prepared (bunded, puddled and leveled) in a such a way as to impound water in basins for ease of water control in the field. A typical *sawah* basin has valved water inlets and outlets on the bunds for irrigation and drainage, respectively, with all inlets usually connected to site-specific sources of water in the field for irrigating the basins by channel flow as and when needed. *Sawah* is further characterized by the growing of improved varieties of rice and the application of required mineral fertilizers at recommended rates.

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Suitable amendments have been used to alleviate soil fertility-related constraints to crop growth in both inland valleys and floodplains of West Africa (Buri *et al.*, 2008; Nwite *et al.*, 2013; Tsujimoto *et al.*, 2017), the aforenoted gradient in their inherent fertility status notwithstanding. This problem is both pedogenetic and anthropogenic, such that decreases in the amounts of weatherable minerals and the rate of their release are exacerbated by inappropriate soil and agronomic management practices, leading to widespread land degradation and yield losses (Obalum *et al.*, 2012a). Without prejudice to the soil fertility conservation attribute of typical *sawah*-rice system relying solely on mineral fertilizers, there is a prospect in the use of manures in *sawah* whereby mineral fertilizers are partially or fully replaced with manurial amendments (Buri *et al.*, 2004; Nwite *et al.*, 2008, 2012).

Focusing on *sawah*-grown rice, there have also been reports of poor agronomic performance due to ineffective water control and inadequate water retention in *sawah* basins (Obalum *et al.*, 2014). Lowland soil fertility cannot be effectively restored without compatible water control and management techniques. *Sawah,* being an ecotechnological farming system, could thus be used to concurrently address the duo of declining soil fertility and poor water management in lowland rice farming. This approach which defines integrated watershed management appears promising for sustainably increasing food production in tropical Africa (Hirose and Wakatsuki, 2002).

One way to boost the performance of *sawah*-rice system is use some locally generated agro-wastes with manurial value in restoring soil fertility in the marshy lowland soils. Also, because floodplains have the peculiar problem of fairly low amenability to water control, *sawah*-rice farming in this and similar categories of lowland should explore alternative sources of water in and around the rice field for supplemental irrigation. Small-scale irrigation using lowland water resources is farmer-operated, and this is economically more viable than reliance on heavy machineries with medium to large-sized pumps for irrigating several hundreds of hectares in West Africa (Wakatsuki, 1990; Obalum *et al.*, 2011). However, lowland water resources for supplemental irrigation often differ in supplying capacity. They are bound to also differ in the amount of heat they are exposed to and the levels of organic and inorganic constituents in them, translating into differences in water quality (Haby and Pennington, 2003). These differences in quantity and quality among the waters for irrigation have prompted the use of the term '*sawah* typologies' in *sawah*-based rice farming (Nwite *et al.*, 2017).

The study by Nwite *et al.* (2017) involved three factors including manurial amendment type and *sawah* typology in a degraded soil of an inland-valley ecosystem in southeastern Nigeria. In the said study, the apparent differences in five soil amendment types (rice husk, rice-husk ash, poultry droppings, NPK fertilizer and a control) and three *sawah* typologies (spring-, pond- and non-supplemented) were reported to reflect in fertility of the inland-valley soil and rice grain yields, with the soil CEC having the dominant control over rice grain yield. Though floodplains are generally more fertile compared with inland valleys, water control is easier in the latter than the former (Abe *et al.*, 2006; Obalum *et al.*, 2011), suggesting that floodplains may respond to the treatments in Nwite *et al.* (2017) in patterns different from the ones reported from this reference study. This notion is, however, scarcely supported by empirical data at the moment. The objectives of the present study, therefore, were to (i) assess the potential of manurial amendment and source of water for supplemental irrigation for restoring the fertility *sawah*-managed floodplain soil in southeastern Nigeria, and (ii) evaluate any such effects on fertility parameters of the floodplain soil in terms of rice growth and yield.

MATERIALS AND METHODS

Site Description

The experiment was conducted in the floodplain of Ivo River in Ishiagu, Ebonyi State, Nigeria, located on 06° 25′N and 08°03′E. The mean annual rainfall in the area is 1,350 mm, spread from April to October with a mean air temperature of 29°C. The floodplain soils belonging mostly to texture class of sandy loam are classified as Aeric Tropoaquent in Soil Taxonomy corresponding to Gleyic Cambisol in the FAO system. The underlying geologic material is Shale with sand intrusions locally called the 'Asu River' group. The site is in the derived savanna vegetation zone with grasses and shrub tree combinations. The floodplain soils are mainly used for rainfed rice farming and vegetable production as the rain recedes.

Experimental Set-Up

The field was demarcated into three main plots (each 9 m × 37 m) with 0.6-m raised bunds for the treatments of small-scale irrigation using water from different sources. The three plots were maintained under rainfed conditions throughout the field study, such that the added irrigation water from different sources was merely supplemental. Thus the three main plots (treatments) representing three *sawah* typologies were designated spring-supplemented, pond-supplemented, and non-supplemented plots.

Spring-supplemented *sawah* was irrigated from a nearby spring (ca. 100 m away) connected to it by a constructed canal. Pond-supplemented *sawah* was irrigated from an artificial pond in the study site, from which water was delivered to the plots via a pumping machine with hose. Non-supplemented *sawah* was solely rainfed, and so served as the control. Overland flow into all main plots was guarded against using bunds. The small-scale irrigation treatments were investigated at three replications, achieved in this study by demarcation of each main plot into three equal blocks.

To implement the five manurial treatments, each block representing replications of the main plots was further demarcated with bunds into sub-plots each measuring 2.65 m × 7 m. The five types of soil amendment were assigned to the sub-plots; they comprised rice-mill waste otherwise called rice husk (RH) applied at 10 t ha^{-1}, partially burnt rice husk referred to as rice husk ash (RHA) applied at 10 t ha^{-1}, 10 t ha^{-1}, poultry droppings (PD) applied 10 t ha^{-1}, NPK 20:10:10 fertilizer (NPK) applied 400 kg ha^{-1}, and no amendment as the control. The organic soil amendments (RH, RHA and PD) were spread on the plots and, using a garden fork, incorporated and properly mixed with the top-(20 cm) soil two weeks before rice transplanting. The mineral fertilizer (NPK) was applied two weeks after transplanting. From the foregoing, the experimental design in this study could be described as a split-plot in a 'partially' Randomized Complete Block Design (RCBD).

In the pond-supplemented *sawah*, a pumping machine with power output of 2.8 kW, self-priming volute with 4 impeller blades and maximum discharge of 900 litres per minute, plus a total head of 26 M, was used to pump water into the field. The quantity of water applied to the spring- and pond-supplemented *sawah* was not measured; instead, water level in all the treatment basins of these two *sawah* typologies was maintained at 5-10 cm as from two weeks after transplanting until maturity, using installed sticks with bold marks at 5 and 10 cm. The 0.6 m raised bunds helped to impound water and ensure that the defined water levels in the basins were maintained. The inlets and outlets to the plots were opened whenever the water level dropped below 5 cm or rose beyond 10 cm, respectively.

Pre-Planting Activities

Before ploughing, soil samples were randomly taken from the topsoil, bulked into a composite sample and analysed for texture as well as for some key management-responsive physicochemical properties to determine their baseline values in the floodplain soil just before the study. This exercise showed that the soil, a sandy loam, had moderate soil organic carbon (SOC) concentration in the topsoil, while soil pH and cation exchange capacity (CEC) indicated low values, among other characteristics (Table 1).

A high-yielding variety of rice, Tox 3108, widely used by farmers in the study area, was first raised in the nursery. Transplanting to the field was done four weeks later at a square (20 cm × 20 cm) spacing. The plots were hoe-ploughed and manually puddled to ca. 20 cm depth before applying the treatments of this study. The RH used was collected from a rice-mill industry close to the study site. Analyses of the manurial amendments (RH, RHA and PD) for their composition showed that RH had the highest content of organic carbon (C); RHA the highest phosphorus (P), potassium (K) and magnesium (Mg); and PD the highest nitrogen (N) and calcium (Ca) (Table 2).

Table 1: Some properties of the top-(0-20 cm) soil at the study site before ploughing

Soil Properties	Value
% Clay	10
% Silt	21
% Total sand	69
pH-H_2O	3.7
pH-KCl	1.7
% Soil organic carbon	1.42
% Total nitrogen	0.09
Available phosphorus (mg kg^{-1})	4.30
Exch. bases (cmol kg^{-1}); K^+	0.08
Ca^{2+}	1.00
Mg^{2+}	1.56
Na^+	0.40
Exchangeable acidity (EA)	2.53
Cation exchange capacity (CEC)	8.22

Agronomic and Soil Data Collection

At rice booting, data were collected on plant height and tillering by counting number of tillers per stand. At rice maturity, the rice plants harvested and dried, and grain yield assessed at 90% dry matter content. Also, soil samples were collected from the replicates of the treatments. They were air-dried to constant weight and passed through a 2-mm sieve. These processed samples were analysed for soil pH, SOC, total nitrogen using standard laboratory methods as already chronicled in Nwite *et al.* (2017); soil pH by measuring in suspensions of soil in deionised H_2O and 0.1N KCl in soil-liquid mass ratio of 1:2.5, SOC by the Walkley-Black method; and total nitrogen by Kjeldahl digestion-distillation and titration method. Additionally, soil contents of the three plant-nutrient exchangeable bases (basic cations) including K^+, Ca^{2+} and Mg^{2+} were determined following the procedure described by Thomas (1982).

Data Analysis

Data were subjected to analysis of variance procedure appropriate for a split-plot experiment in an RCBD using the software GenStat Edition 3 version 7.2 (VSN International, Hemel Hempstead, UK). Significant treatment means were separated and compared by the least significant difference (LSD). In addition, rice growth and grain yield were related to the soil fertility parameters determined at rice maturity irrespective of treatment. This was done by Pearson correlations using the software SPSS for Windows (IBM SPSS Statistics 21.lnk) and by pair-wise regressions using the Microsoft Excel sheet. All inferences were made at the 5% probability level.

Table 2: Compositions (%) of the manurial amendments

Property	Rice husk	Rice-husk ash	Poultry droppings
C	33.75	3.89	16.52
N	0.700	0.056	2.100
P	0.49	11.94	2.55
K	0.11	1.77	0.48
Ca	0.36	1.40	14.40
Mg	0.38	5.00	1.20
Na	0.22	0.33	0.34
C:N	48.21	6.71	7.87

RESULTS AND DISCUSSION

Treatment Effects on Soil pH, Soil Organic Carbon and Total Nitrogen

The interaction effects of the manurial amendments and water sources for the small-scale supplemental irrigation on the soil pH as well as SOC and total nitrogen concentrations in the topsoil of the *sawah*-managed floodplain soil are shown in Table 3. Treatment affected soil pH, with highest values in RHA-amended spring- or pond-supplemented plots and lowest values in unamended non-supplemented plots. Averaged across *sawah* typologies, soil pH was higher in RHA-amended plots than the rest. This observation portrays the soil liming effect of RHA (Nwite *et al*., 2013). Ash contains oxides as hydroxides of calcium, magnesium, potassium and, to a lesser extent, sodium (Lickacz, 2002); therefore, RHA being similar to burnt or hydrated lime in its mode of action it is not surprising. Contrary to these effects of RHA on soil pH, Nnabude and Mbagwu (2001) noted that production of organic acids during the decomposition of burnt rice wastes as well as the evolution of CO_2 during the same process could decrease soil pH. During the preparation of RHA in the present study, the proportion of rice husk that was not converted into RHA but merely steamed was probably very small; so, applying the RHA to the soil resulted in its liming value dominating over the effect of decomposition of the steamed RH. *Sawah* typology influenced soil pH thus spring-supplemented > pond-supplemented > non-supplemented plots. This could be attributed to the higher pH often found of spring than pond water (Nwite *et al*., 2017), as well as to depositions of organic materials and soil minerals by the flowing water from the spring.

The concentration of SOC in the *sawah*-managed floodplain showed highest values in RH-amended spring- or pond-supplemented plots and lowest values in RHA- and NPK-amended non-supplemented plots. Averaged across *sawah* typologies, SOC tended to be highest in RH-amended plots and lowest in RHA- and NPK-amended plots. This is unsurprising as RH is highly carbonaceous with relatively small amount of nitrogen (Adubasim *et al*., 2018), implying high C-N ratio. The C-N ratio of the RH used in this study was indeed high (48.21), such that the associated high lignin content and low polyphenol content must have retarded its rate of decomposition in the soil (Schulz *et al.* 2003), especially with the submerged condition of the soil during most of the rice growth phase (Nwite *et al*., 2017). The low SOC in RHA-amended plots reflected the phenomenon whereby carbon and nitrogen in the RH were lost in form of gases to the atmosphere during burning.

Among the *sawah* typologies, SOC tended to decrease from spring-supplemented through pond-supplemented to non-supplemented plots. This trend reflected the relative frequency of wetting-drying cycles in these typologies during rice growth phase, expected to be highest in non-supplemented *sawah*. In their study of physicochemical properties of topsoils of inland-valley *sawah* fields at various locations in north-central Nigeria, Obalum *et al.* (2012b) reported higher concentrations of SOC in a bottom slope position with well-defined submergence compared to upper slope positions with negligible submergence at Nasarafu – one of their study locations. Waterlogging hampers microbial activity and decomposition of organic materials in the soil but frequent wetting–drying cycles in waterlogged soils facilitates SOC decomposition, which implies lowering of its content in the soil (Nwite *et al.*, 2017). Considering the place of SOC in soil quality (Obalum *et al*., 2017), *sawah*-rice farming in this floodplain soil should involve the use of RH as soil amendment and prolonging of submergence time in order to improve the quality of the soil.

Soil total nitrogen content showed highest values in PD-amended spring- or non-supplemented plots and lowest values in RH-amended and unamended non-supplemented plots. Averaged across *sawah* typologies, total nitrogen tended to be higher in PD- and NPK-amended plots than the rest. The RH could not improve total nitrogen, an observation attributed to the short-term nature of this field study vis-à-vis the slow rate of RH mineralization in the soil (Nwite *et al.*, 2017). As with SOC, total nitrogen tended to decrease from spring-supplemented through pond-supplemented to non-supplemented plots. Since enhanced soil water status could increase biological nitrogen fixation (Buresh *et al*., 2008), the trend observed of soil total nitrogen could be said to reflect the relative extents of water retention and submergence among the *sawah* topologies during the rice growth phase (Obalum *et al*., 2012b).

Treatment Effects on Soil Contents of Plant-Nutrient Exchangeable Bases

The interaction effects of the manurial amendments and water sources for the small-scale supplemental irrigation on the contents of the three plant-nutrient exchangeable bases in the topsoil of the *sawah*-managed floodplain soil are shown in Table 4. Treatment affected exchangeable potassium (K^+) and calcium (Ca^{2+}) in a somewhat similar manner, in that their highest values were found in RHA- and PD-amended plots of spring-and pond-supplemented *sawah* and their lowest values in the unamended (control) plots also of both spring-and pond-supplemented *sawah*. When checked for the effects of soil amendments across *sawah* typologies, these two basic cations (K^+ and Ca^{2+}) decreased in the same pattern; from RHA-amended to control plots.

For exchangeable magnesium (Mg^{2+}), the highest values were found in RHA-amended plots of all three *sawah* typologies (and these values were similar only to that found in PD-amended spring-supplemented *sawah*), and lowest values in RH-amended and control plots of spring- and/or pond-supplemented *sawah*. Across the *sawah* typologies,

Table 3: Interaction effects of manurial amendments and water sources for the small-scale supplemental irrigation on the soil pH as well as SOC and total nitrogen contents in the topsoil of *sawah*-managed floodplain soil at Ishiagu, southeastern Nigeria

Soil amendments	Soil pH				% Soil organic carbon (SOC)				% Total nitrogen			
	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*
Rice husk (RH)	5.6	5.0	4.8	*5.1*	1.09	0.92	0.72	*0.91*	0.068	0.060	0.047	*0.058*
Rice-husk ash (RHA)	6.2	6.1	5.6	*6.0*	0.82	0.61	0.43	*0.62*	0.062	0.059	0.055	*0.059*
Poultry droppings (PD)	5.1	4.9	4.6	*4.9*	0.87	0.72	0.62	*0.74*	0.080	0.073	0.082	*0.078*
NPK 20:10:10 (NPK)	5.2	4.8	4.5	*4.8*	0.64	0.68	0.48	*0.60*	0.074	0.078	0.070	*0.074*
Control	4.8	4.8	4.3	*4.6*	0.90	0.66	0.52	*0.69*	0.055	0.060	0.050	*0.055*
Mean	*5.4*	*5.1*	*4.8*		*0.86*	*0.71*	*0.55*		*0.081*	*0.066*	*0.060*	
$LSD_{(0.05)}$		0.22				0.18				0.012		

SSS - spring-supplemented *sawah*; PSS - pond-supplemented *sawah*; NSS - non-supplemented *sawah* (solely rainfed)

Table 4: Interaction effects of manurial amendments and water sources for the small-scale supplemental irrigation on topsoil contents of the three plant-nutrient exchangeable bases in the *sawah*-managed floodplain soil at Ishiagu, southeastern Nigeria

Soil amendments	Exchangeable potassium (K^+)				Exchangeable calcium (Ca^{2+})				Exchangeable magnesium (Mg^{2+})			
	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*
Rice husk (RH)	0.15	0.12	0.13	*0.13*	2.00	2.00	1.73	*1.91*	0.93	0.98	1.07	*0.99*
Rice-husk ash (RHA)	0.26	0.27	0.21	*0.25*	3.23	2.98	1.98	*2.73*	2.00	2.00	2.11	*2.04*
Poultry droppings (PD)	0.24	0.26	0.20	*0.23*	2.52	2.52	1.93	*2.32*	1.87	1.67	1.27	*1.60*
NPK 20:10:10 (NPK)	0.22	0.22	0.17	*0.20*	1.87	1.90	1.80	*1.86*	1.47	1.41	1.27	*1.38*
Control	0.09	0.10	0.10	*0.10*	1.47	1.33	1.73	*1.51*	0.93	1.10	1.11	*1.05*
Mean	*0.19*	*0.19*	*0.16*		*2.22*	*2.14*	*1.83*		*1.44*	*1.43*	*1.36*	
$LSD_{(0.05)}$		0.03				0.36				0.30		

SSS - spring-supplemented *sawah*; PSS - pond-supplemented *sawah*; NSS - non-supplemented *sawah* (solely rainfed)

the soil amendments differed in the same pattern as for K^+ and Ca^{2+} except for the lowest values in RH-amended plots instead of the control plots. Thus all three plant-nutrient exchangeable bases of this study followed the order RHA > PD > NPK > the other two treatments. The consistently highest values of these three basic cations in RHA-amended plots would be largely explained by RHA's content of potassium, calcium and magnesium hydroxides (Lickacz, 2002). In a similar study in two inland-valley soils in southeastern Nigeria with a similar set and source of soil amendments applied at the same rates as the present study, but with RHA of lower quality compared to the present study, the order was NPK > PD ≥ RHA for K^+ and PD > RHA ≥ NPK for Ca^{2+} and Mg^{2+} in the two locations (Igwe *et al*., 2013). These contrasting observations put together, we infer that the effects of RHA, relative to other organic and inorganic fertilizers, on plant-nutrient exchangeable bases in *sawah*-managed lowland soils would depend on the lowland type (inland valley or floodplain), quality of the RHA, and the basic cation of interest.

One other consistent observation is that the main effects of *sawah* typology showed higher levels of all three plant-nutrient exchangeable bases in both spring- and pond-supplemented *sawah* compared to non-supplemented *sawah* (Table 4). As opposed to the negative correlations found between soil pH and the exchangeable bases for some inland-valleys soils (Obalum *et al*., 2012b), soil pH correlated positively with soil contents of the trio of K^+, Ca^{2+} and Mg^{2+} (r = 0.574, 0.741 and 0.634, respectively) of the floodplain soil under investigation. The influence of *sawah* typology on these basic cations thus partially reflect the influence of water source for the small-scale supplemental irrigation on soil pH. Further, although the spring and pond water of this study were not analysed for their potassium, calcium and magnesium contents, the former probably had higher contents of these nutrient elements than the latter, thus partially explaining the observation made.

Notably, amending this floodplain soil with RHA was rather ineffectual for soil total nitrogen but not the three plant-nutrient exchangeable bases. This observation supports Saggar *et al.* (1990) and Nwite *et al.* (2013) that ash-amended soils could show increases in other nutrients but not nitrogen.

Treatment Effects on Plant Height, Tillering Ability and Grain Yield of the *Sawah*-Grown Rice

Table 5 shows the agronomic effects of the manurial amendments and source of water used to irrigate the *sawah* typologies, evaluated by the growth attributes (plant height and number of tillers per stand) of rice at booting as well as its grain yield at maturity. The tallest rice plants were recorded in PD-amended spring-supplemented *sawah*. This was followed by RHA- or NPK-amended spring-supplemented *sawah* which in turn was followed by PD- or NPK-amended pond-supplemented *sawah*. Number of tillers per stand was highest in PD-amended plots except in the non-supplemented *sawah*. The shortest plants and fewest tillers were found in the overall control (unamended non-supplemented *sawah*). For these growth attributes, the main effects of *sawah* typology were not evident; those of soil amendment showed PD-amended plots as surpassing NPK-amended plots, with the lowest values in the control plots.

Table 5: Interaction effects of manurial amendments and water sources for the small-scale supplemental irrigation on plant height, tillering and grain yield of rice grown in the *sawah*-managed floodplain soil at Ishiagu, southeastern Nigeria

Soil amendments	Plant height (cm)				Number of tillers per stand				Grain yield (t ha^{-1})			
	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*	SSS	PSS	NSS	*Mean*
Rice husk (RH)	42.55	39.73	38.6	*40.29*	14.40	14.34	13.28	*14.01*	6.56	6.00	6.07	*6.21*
Rice-husk ash (RHA)	43.89	40.47	39.33	*41.23*	13.80	13.75	12.66	*13.40*	6.56	6.38	6.08	*6.34*
Poultry droppings (PD)	46.71	43.34	42.24	*44.10*	15.74	15.36	13.55	*14.88*	7.82	6.56	6.10	*6.83*
NPK 20:10:10 (NPK)	43.70	43.82	40.69	*42.74*	14.20	14.17	13.84	*14.07*	7.11	6.28	6.30	*6.56*
Control	33.99	36.98	33.22	*34.73*	11.78	11.78	11.78	*11.78*	4.68	4.59	4.26	*4.51*
Mean	*42.17*	*40.87*	*38.62*		*13.98*	*13.88*	*13.02*		*6.55*	*5.69*	*5.56*	
$LSD_{(0.05)}$		0.75				0.03				0.36		

SSS - spring-supplemented *sawah*; PSS - pond-supplemented *sawah*; NSS - non-supplemented *sawah* (solely rainfed)

Rice grain yield was highest and second highest in PD- and NPK-amended spring-supplemented *sawah*, respectively, while lowest in the overall control (Table 5). Main effect of *sawah* typology was higher yield in spring- than pond- and non-supplemented *sawah* for which values were similar. *Sawah* basins when submerged often shows improvements in soil porosity, hydraulic properties and hence rice yields (Obalum *et al.,* 2012c; Nwite *et al.*, 2016). Since both spring- and pond-supplemented *sawah* were similarly submerged here, the former out-yielding the latter suggests that there is more to rice yields than any such improvements in this floodplain. Nwite *et al.* (2017) found no differences in rice yield among these three *sawah* typologies in an inland valley in southeastern Nigeria, but showed the importance of 'completely' prepared *sawah* in discriminating between spring- and pond- supplemented plots. And such intensity of *sawah* preparation was adopted here. The higher yield in the spring- than pond-supplemented *sawah* may thus be explained by the higher contents of nutrients in the spring than pond water earlier alluded to.

The soil amendments ranked thus PD ≥ NPK ≥ RHA ≥ RH > control. Ofori *et al.* (2005) showed the positive role of optimum level of inputs in the form of soil amendment in rice yield responses to good water management practices under the *sawah* system. Though the order of effects of the soil amendments in the present study in a floodplain was fairly different from that in Nwite *et al.* (2017) in an inland valley, both studies showed the preference of PD to NPK and indeed RHA and RH for *sawah* rice. By contrast, Buri *et al.* (2004) reported lower grain yields of lowland *sawah* rice in PD- than NPK-amended plots in two out of three locations within the forest ecology of Ghana. Besides the differences in ecological setting, it should be noted that Buri *et al.* (2004) applied PD at a rate (7 t ha^{-1}) lower than the rate here (10 t ha^{-1}), but N-P-K at a rate (90-60-60 kg ha^{-1}) higher than ours (the NPK 20:10:10 applied at 400 kg ha^{-1} here corresponds to N-P-K at 80-40-40 kg ha^{-1}).

Notably, the lowest grain yield due to the overall control (4.26 t ha^{-1}) is rather high when related to the values in the range of 1.50-2.60 t ha^{-1} reported for some corresponding inland-valley *sawah* systems (Buri *et al.*, 2004; Nwite *et al.*, 2017). Thus under similar *sawah* water management, floodplains may produce higher than inland valleys in West Africa.

Relationships between Rice Performance and Soil Fertility Parameters of the Study

Table 6 shows the relationships between the indices of rice performance (growth attributes and grain yield) and soil fertility parameters at rice maturity. None of these indices correlated with soil pH and SOC, but they generally correlated with total nitrogen, the three plant-nutrient exchangeable bases, and their sum. The correlation coefficients (r) show that the relationships between plant height and each of total nitrogen and K^+ were similar and stronger than those established with Ca^{2+}, Mg^{2+} and the sum of these cations. Number of tillers per stand followed suit. For grain yield, however, it was the strengths of its correlations with total nitrogen and the sum of the three basic cations that were similar, lower than that for K^+.

When the yield was regressed on total nitrogen and the sum of the three basic cations, the best form of the regressions showing greater ability of the latter than the former to predict grain yield was polynomial (Figure 1). This aligns to the dominant influence of soil CEC on yield of *sawah* rice (Nwite *et al.*, 2017). Specifically, Witt *et al.* (2005) showed the roles of the three basic cations in promoting the yields of intensively irrigated lowland rice.

The facts that yield had stronger correlation with K^+ alone than with the three basic cations summed up and that the yield could vary in a quadratic manner with these basic cations manifested when the yield was regressed separately on each of them (Figure 2). Thus of all soil fertility parameters here, K^+ is the best predictor of yield of floodplain *sawah*-grown rice, there are threshold values of these basic cations beyond which grain yield declines. For K^+, this value is, as shown by the dotted line in Figure 2, ca. 0.224 cmol kg^{-1}. This value is within the generic range of low K^+ in Nigerian soils (Chude *et al.*, 2011), and so may not represent management-target value of K^+ in lowland *sawah*-rice system. Instead, we interpret the results to be due to a linear positive relationship between soil K^+ balance and rice uptake in the various treatments. This is based on the knowledge that rice grain yield often tends to decline beyond K-fertilizer rate of 60 kg ha^{-1} (Buri *et al.*, 2008) or certain levels of K^+ uptake (Islam *et al.,* 2015; Jiang *et al.,* 2019). As with grain yield, plant height and number of tillers per stand both showed quadratic relationships with the three basic cations (figure not shown).

Table 6: Coefficients of the correlations of rice growth and yield with some fertility parameters of the *sawah*-managed floodplain soil under various manurial amendments and supplemental irrigation water sources at Ishiagu, southeastern Nigeria (n = 15)

	Soil pH	Soil organic carbon (SOC)	Total nitrogen	Plant-nutrient exchangeable bases (basic cations)			
				K^+	Ca^{2+}	Mg^{2+}	$K^+ + Ca^{2+} + Mg^{2+}$
Plant height	0.386^{ns}	0.222^{ns}	0.782***	0.787***	0.578*	0.500†	0.598*
No. of tillers per stand	0.242^{ns}	0.348^{ns}	0.674**	0.661**	0.558*	0.336^{ns}	0.505†
Grain yield	0.435^{ns}	0.208^{ns}	0.623*	0.757***	0.583*	0.524*	0.610*

ns - not significant; †marginally significant (at 10% probability level); *, ** and ***significant at 5, 1 and 0.10% probability levels, respectively

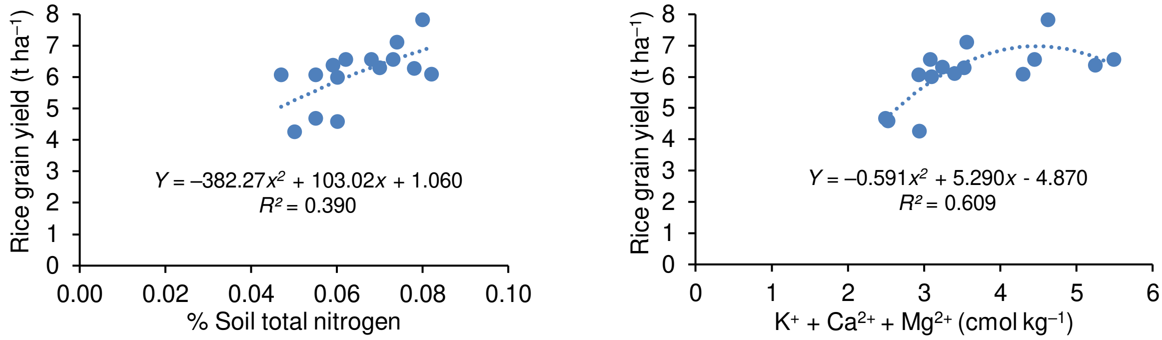

Figure 1: Relationships of rice grain yield with soil total nitrogen and sum of the three plant-nutrient exchangeable bases

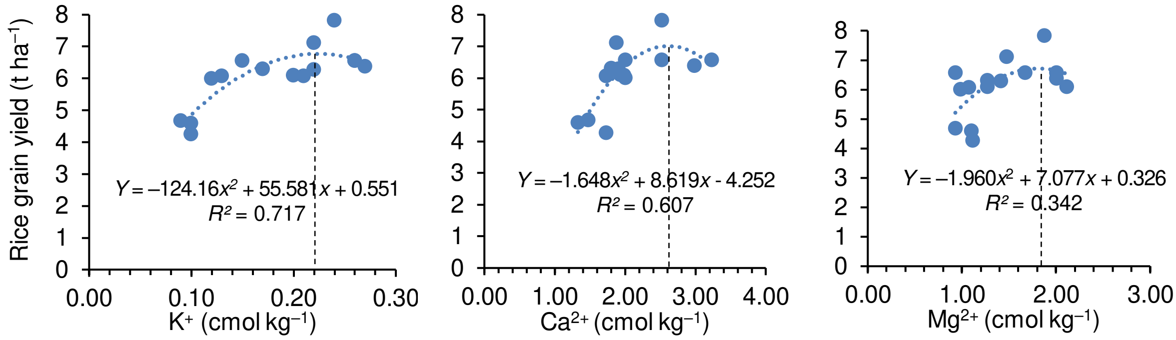

Figure 2: Relationships of rice grain yield with soil content of each of the three plant-nutrient exchangeable bases

CONCLUSIONS

The floodplain soil of this study was rather low in soil pH and poor in key plant nutrients. Within the modified rice-growing environment offered by the lowland *sawah* platform, the topsoil responded well to the manurial soil amendments and small-scale supplemental irrigation using spring and pond water. The overall best results for soil fertility parameters as well as for rice growth and grain yield were from plots with PD as manurial amendment and spring as source of water for the supplemental irrigation. The use of RHA was particularly effective in alleviating the acidity problem of the floodplain soil, while RH enhanced its SOC status and hence overall quality more than the other soil amendments. However, rice performance including grain yield was not influenced by soil pH and SOC, but by total nitrogen and the sum of the three plant-nutrient basic cations, with the influence of K^+ alone being the greatest.

By implication, 'locally adapted *sawah*' utilising PD as soil manure and receiving extra water from available spring would be preferred to 'conventional' NPK-fertilized and rainfed *sawah* in floodplain rice farming. Research should explore the exact roles of the plant-nutrient basic cations especially K^+ in the productivity of lowland *sawah*-rice systems under contrasting soil and water management practices.

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