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Sustainable Management and Improvement of Soil Physical Properties and Rice Grain Yield in Degraded Inland Valleys of Southeastern Nigeria

J. C. Nwite[1*], B. A. Essien[1], C. I. Keke[1], C. A. Igwe[2] and T. Wakatsuki[3]

[1]Department of Crop Production Technology, Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria.
[2]Department of Soil Science, University of Nigeria, Nsukka, Nigeria.
[3]Faculty of Agriculture, Shimane University, Nara, Japan.

Authors' contributions

This work was carried out in collaboration between all authors. Author JCN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. They also managed the literature searches. Authors BAE and CIK Proof-read and managed the analyses of the study. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Nigeria is relatively blessed with rain and high potential of inland valleys. The major constraints in the utilization of these inland valleys for sustainable rice based cropping include, poor soil properties maintenance, inadequate weed and water control. In an attempt to replicate the successful Japanese *Satoyama* watershed management model in the African agro-ecosystems, *sawah* rice cultivation technology has been introduced to West Africa in the last two decades. This study was conducted in an inland valley at Akaeze, Ivo Local Government Area of Ebonyi State, Southeastern Nigeria, in 2010, 2011 and 2012 cropping seasons, to evaluate the effects of four different tillage specifications and different amendments under *sawah* water management system on soil properties and rice grain yield. *Sawah* has been described as an Indo-Malaysian word for padi (Malayan word for paddy) or lowland rice management system comprising bunding, puddling, levelling and good water management through irrigation and drainage. A split- plot in a randomized complete block design was used to evaluate these two factors. The four

**Corresponding author: E-mail: johnsmallpot@gmail.com;*

tillage specifications for rice growing are; complete *sawah* tillage- bunded, puddled and leveled rice field (CST); farmers tillage environment- no bunding and leveling rice field (FTE); incomplete *sawah* tillage- bundding with minimum leveling and puddling rice field (ICST) and partial *sawah* tillage- after bunding, no puddling and leveling rice field (PST). The five levels of manure application including the control, which were replicated three times included; rice husk at 10 ton/ha; rice husk ash at 10 ton/ha; poultry droppings at 10 ton/ha; N. P. K. 20: 10: 10 at 400kg/ha and the control (Zero application). The study was undertaken in 3 cropping seasons (2010, 2011 and 2012) using the same watershed and treatments. The effects of additive residual effects of the amendments were not studied in the course of this research. A bulk soil sample at 0-20 cm depth and core samples were collected in the location before tillage and amendments for initial soil characteristics. At the end of each harvest of the three cropping seasons, another soil sampling was carried out on the different treated plots to ascertain the changes that occurred in the soil due to the treatments application. Selected physical analyses were carried on those soils collected, while the soil amendments were analyzed for N, P, K, Ca, Mg, Na, and organic carbon. The soil physical properties analyzed for included; soil BD, total porosity, mean weight diameter, water retention and saturated hydraulic conductivity. The soil bulk density (BD) was significantly reduced differently by the tillage environments and soil amendments in the three years of study. It was observed that the interaction of the environments and amendments did positively ($P<0.05$) reduced the soil BD in the first and second year of study. The total porosity was also improved in the same periods of study in the location by the studied factors and their interactions. The mean weight diameter water retention (*WR*) and saturated hydraulic conductivity (*Ksat*) were also significantly improved upon in different forms by the factors and the interaction. The effects of tillage types and amendments were observed to have significantly ($P<0.05$) improved the rice grain yield.

Keywords: Water stable aggregate; mean weight diameter; hydraulic conductivity; water retention; rice grain yield; Sawah; inland valleys.

1. INTRODUCTION

Rice response to tillage varies with soil texture and climatic water balance [1]. Depending on the soil texture, tillage may induce a gain or loss in soil permeability which may affect rice yield through better retention of surface water. Wet tillage (puddling) and compaction in rice field soils decreases water permeability by decreasing the volume of transmission pores [1]. Sharma and Bhagat [2] have found out that in soils with less than 70 percent sand, puddling as well as compaction are equally effective in decreasing water percolation to satisfactory levels for growing a good crop of rice. The choice of method(s) depends upon factors like susceptibility of rice to compaction levels, residual effects of puddling and regeneration of soil structure after puddled crop. However, in soils having greater than 70 percent sand, compaction rather than puddling is effective in decreasing water permeability [3].

Puddling is one of the normal land preparation processes employed in the development of *sawah* fields, which are usually located in lowlands. *Sawah* has been described as an Indo-Malaysian word for padi (Malayan word for paddy) or lowland rice management system comprising bunding, puddling, levelling and good water management through irrigation and drainage. Nwite et al. [4] reported that, in spite of the destruction of soil structure during the rice cultivation the dispersion ratio was improved on the long run by sawah water management. They also obtained that *sawah* managed soils reduced significantly soil bulk density in the first and second year of planting thus increasing the soil total porosity during the same period. Moisture content was also improved in sawah management while wilting point (WP) increased significantly in the second year of planting.

More importantly, the *sawah* system is even advantageous 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 [5]. 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 [6-9].

Establishment of effective *sawah* management system for increased rice production in southeastern Nigeria involves the manipulation of certain soil physical properties in form of ecological engineering works. This manipulation of soil physical properties may involve deep earth movement and tillage to achieve a better topographic setting and optimal soil physical condition. Wakatsuki and Masunaga [10] remarked that ecological engineering of the inland watershed by the local people are required to increase agricultural productivity. These techniques according to them include leveling, bonding, and construction of canals and head dykes. Most soils in the West African sub-region are highly weathered and very fragile [11-15]. Mbagwu [16] reported that physical degradation of soils in the tropics resulted from soil erosion by water and mechanical land clearing using bulldozers. Lal [17] and Mbagwu et al. [18] showed that this degradation was manifested in high bulk density, low total and macro porosity, reduced water infiltration and transmission rate and low water retention and available water capacity within the root zone.

Rengasamy et al. [19] had earlier indicated that many soils used for irrigated or dry land agriculture are difficult to manage owing to their tendency to develop unsatisfactory structure particularly in their surface layers. Breakdown of aggregates leads to surface crusting, reduced water infiltration, restricted plant establishment and growth. The reason for the breakdown is normally as a result of slaking and dispersion of aggregates. These negative physical conditions of the soils added to poor nutrient status of such soils according to Mbagwu [16] resulted in poor crop productivity and often abandonment of such lands leading to reduction in resource base of rural farmers.

The use of organic wastes in the management of degraded soils or soils used for *sawah* rice management production is sustainable [20,21]

The objectives of study include, to determine changes in soil physical characteristics and crop yield due to different tillage operations, to evaluate the contributions of different manure types to changes in the soil physical properties and grain yield, and to determine the interactions of different tillage types and soil amendments on soil physical properties and rice grain yield.

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted in an inland valley at Akaeze in 2010, 2011 and 2012 cropping seasons to evaluate the effects of different *sawah* adopted tillage environments and amendments on soil physical properties and rice grain yield. Akaeze lies at approximately latitude 05º55' N and longitude 07º40' E. The annual rainfall for the area is 1,350 mm, spread from April to October with average air temperature of 29ºC. The major geological material for the area is shale from the Asu River formation.

The location of the study is within the derived savanna vegetation zone with grassland and tree combinations. The soils are described as Aeric Tropoaquent [22] or Gleyic Cambisol [23]. The soils have moderate soil organic carbon (OC) content (11.80 g/kg) on the topsoil, low in pH (3.8) and low cation exchange capacity (CEC), 6.8 $cmolkg^{-1}$. Soils are mainly used for rain-fed rice cultivation during the rains and vegetable production as the rain recedes.

2.2 Field Method

The field was divided into four different main plots where the four tillage environments were located. Bulk (composite) Auger and core samples were collected within 0- 20 cm soil depth for initial soil characteristics. The four main plots were demarcated into five subplots with a 0.6 m raised bunds where the soil amendments were applied, except the farmers' environment.

A split- plot in a randomized complete block design was used to asses the two factors at different levels. The four tillage types that constituted main plot include;

- Complete *sawah* tillage method- bunded,puddled and leveled rice field (CST)
- Farmers tillage environment- no bunding and leveling rice field (FTE)
- Incomplete *sawah* tillage method/environment- bundding with minimum leveling and puddling rice field (ICST)
- Partial *sawah* tillage method/environment - after bunding, no puddling and leveling rice field (PST)

Generally, Water was circulated in the field by manipulation of the bunds, except in the farmers' tillage environment. The water flows from a 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. 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 farmers' tillage environment where there was no bund to control the water level. 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. The water introduction was made 2 weeks after transplanting and this was maintained till the stage of ripening of the rice grains.

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

- PD Poultry droppings @ 10 ton/ha
- NPK 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}

2.2.1 Organic amendments properties

Rice husk amendment 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.

The treatments were replicated three times in each of the sub-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 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 Collection of Soil Samples and Laboratory Methods

Auger and core samples were collected from all the identified sampling points from the top (0–20 cm) soil. The auger topsoil 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 [24].

2.3.1 Particle size analyses

Particle size distribution of the samples was determined by the hydrometer method [24].

2.3.2 Bulk Density (BD)

Core samples were allowed to drain freely for 24 hrs before being oven dried for determination of bulk density. This was determined by calculation as:

BD = Mass of dry soil (g) / vol. of same (cm^3) as described by the Blake and Hartge's [25] method.

2.3.3 Total porosity

Total porosity was calculated as:

1 – (The determined bulk density/an assumed particle density of 2.65 Mg/m^3) × 100 (%).

2.3.4 Saturated hydraulic conductivity (Ksat)

The saturated hydraulic conductivity (Ksat) was determined using the method of Klute and Dirksen [26] and was calculated as:

$Ksat = (Q/At)\ (L/\Delta H);$

where Ksat is the saturated hydraulic conductivity (cm hr^{-1}), Q is the steady state volume of outflow from the entire soil column (cm^3), A is the the cross-sectional area (cm^2), t is the time interval (h), L is the length of the core sample (cm) and ΔH is the change in the hydraulic head (cm).

2.3.5 Mean Weight Diameter (MWD)

Mean weight diameter (MWD) of WSA [27], calculated as:

$$MWD = \sum_{i=1}^{n} X_i W_i,$$

where MWD is the mean weight diameter, Xi is the mean diameter of a given size fraction (mm), Wi is the proportion by weight of total aggregates in a given size fraction (g g^{-1}) and n = the number of sieves used.

2.4 Data Analysis

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

3. RESULTS AND DISCUSSION

3.1 Initial Soil Physical Properties

The prominent soil physical properties are reported in Table 1. Generally, the soils are sandy loam with 100 g kg^{-1} clay and 150 g kg^{-1} silt content. Bulk density value of the soil is1.50 Mg cm^{-3} while mean-weight diameters of the soil aggregates was 1.30 mm.

Table 1. 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

The bulk density (BD) of the studied soil was significantly ($p \leq 0.05$) affected by the tillage environments in the first year of study (Table 3). The amendments significantly ($p \leq 0.05$) reduced the soil BD within the three years of study with poultry dropping and rice husk giving better performance for the periods. It was obtained that the *sawah* adopted tillage methods reduced the bulk density of the studied soils within the studied periods lower than the farmers' adopted tillage method. In agreement to these results, Abe et al. [28] found in two non-puddled inland valleys with fairly equal clay contents in Abakaliki and Bende in southeastern Nigeria an appreciable increase in topsoil BD with silt content. However, Tripathi et al., [29] found an increase in bulk density with conventional tillage in a silty loam soil. It has been shown that one of the beneficial agronomic effects of puddling is a reduction in BD [30–32].

Table 2. Soil properties of the topsoil of the experimental Field (0 – 20 cm) before tillage operations and amendments

Soil Property	Value
Clay (g kg^{-1})	100
Silt (g kg^{-1})	150
Sand (g kg^{-1})	750
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.50
Mean-weight diameter (MWD) (mm)	1.30
OC (g kg^{-1})	11.80

Table 3. Effects of tillage environments and amendments on soil bulk density (mg/m^2)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
	Year 1					
Complete	1.37	1.27	1.26	1.27	1.26	1.29
Incomplete	1.39	1.32	1.27	1.28	1.27	1.31
Partial	1.40	1.30	1.29	1.30	1.27	1.31
Farmer	1.44	1.35	1.34	1.36	1.36	1.37
Mean	**1.40**	**1.31**	**1.29**	**1.30**	**1.29**	
LSD ($_{0.05}$) Tillage environments				0.01605		
LSD ($_{0.05}$) Amendment				0.01987		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
	Year 2					
Complete	1.37	1.27	1.25	1.21	1.31	1.28
Incomplete	1.41	1.26	1.25	1.25	1.27	1.29
Partial	1.41	1.32	1.27	1.26	1.32	1.32
Farmer	1.45	1.29	1.31	1.34	1.30	1.34
Mean	**1.41**	**1.28**	**1.27**	**1.27**	**1.30**	
LSD ($_{0.05}$) Tillage environments				NS		
LSD ($_{0.05}$) Amendment				0.04031		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
	Year 3					
Complete	1.35	1.25	1.21	1.11	1.29	1.24
Incomplete	1.39	1.23	1.16	1.23	1.22	1.25
Partial	1.38	1.31	1.23	1.23	1.29	1.29
Farmer	1.45	1.26	1.29	1.31	1.27	1.32
Mean	**1.39**	**1.26**	**1.23**	**1.22**	**1.27**	
LSD ($_{0.05}$) Tillage environments				NS		
LSD ($_{0.05}$) Amendment				0.0664		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		

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

3.2 Effects of *Sawah* Tillage Environments and Amendments on the Soil Bulk Density (BD) and Total Porosity (TP)

Nnabude and Mbagwu [12] showed that rice waste, either burnt or fresh condition could be effective in the improvement of soil properties. The importance of lower bulk density in the soil as portrayed by the *sawah* managed plots is the improvement of soil aeration, tilt and better water infiltration in addition to unreserved root penetration [4].

The total porosity also followed the trend in the soil bulk density. In all the years, total porosity (Table 4) were always significantly higher in complete *sawah* managed growing environment. The results (Table 4) here also showed the beneficial contribution of the organic amendments in improving the soil total porosity.

Table 4. Effects of tillage environments and amendments on soil total porosity (%)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
	Year 1					
Complete	48.0	52.9	52.5	52.5	53.9	**52.0**
Incomplete	46.7	50.4	52.7	52.5	52.4	**50.9**
Partial	46.3	51.0	51.1	51.0	53.0	**50.5**
Farmer	45.3	48.9	49.5	48.5	48.4	**48.1**
Mean	**46.6**	**50.8**	**51.5**	**51.1**	**51.9**	
LSD ($_{0.05}$) Tillage environments				1.033		
LSD ($_{0.05}$) Amendment				1.361		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
	Year 2					
Complete	48.2	52.7	53.6	55.3	50.1	51.97
Incomplete	46.6	52.8	52.9	53.2	53.1	51.72
Partial	46.3	49.5	52.4	52.6	49.5	50.07
Farmer	44.5	50.8	50.4	49.0	50.7	49.07
Mean	**46.40**	**51.47**	**52.32**	**52.50**	**50.85**	
LSD ($_{0.05}$) Tillage environments				NS		
LSD ($_{0.05}$) Amendment				2.050		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		
	Year 3					
Complete	48.9	52.7	54.2	58.0	51.3	53.03
Incomplete	47.9	53.6	56.1	53.7	53.9	53.02
Partial	47.8	50.6	53.7	53.7	51.2	51.38
Farmer	45.2	52.3	51.3	50.0	50.6	49.88
Mean	**47.44**	**52.29**	**53.81**	**53.84**	**51.76**	
LSD ($_{0.05}$) Tillage environments				NS		
LSD ($_{0.05}$) Amendment				2.581		
LSD ($_{0.05}$) Tillage environments x Amendments				NS		

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

3.3 Effects of *Sawah* Tillage Methods/ Environments and Amendments on soil Mean- Weight Diameter

Mean-weight diameter (MWD) was significantly influenced by different tillage methods/ environments with partial *sawah* adopted tillage environment giving the highest significant increase for the last two years of study, as against a back-drop of MWD recorded in complete *sawah* tillage type (Table 5). Generally, all the plots with *sawah* tillage components increased MWD statistically higher relative to the farmers' growing environment in the last two years (Table 5). In contrast to this result, Nwite et al. [4] submitted that in the non *sawah* management an average value of 0.75 mm was obtained as against an average of 0.56 mm in *sawah* managed plots. These lower values of MWD in *sawah* managed plots may be advantageous when considered in the entire dynamics of low land or flooded rice production. This condition may be more favourable to rice requirements in terms of the physical soil condition to enable puddling.

Table 5. Effects of *Sawah* tillage environments and amendments on soil Mean Weight Diameter (MWD)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	1.03	1.30	1.20	1.36	1.32	**1.24**
Incomplete	0.89	1.11	1.21	1.13	0.95	**1.06**
Partial	0.92	1.22	1.26	1.26	1.23	**1.18**
Farmer	0.96	1.38	1.32	1.13	1.07	**1.17**
Mean	**0.95**	**1.25**	**1.25**	**1.22**	**1.14**	
LSD $_{(0.05)}$ Tillage environments				0.1205		
LSD $_{(0.05)}$ Amendment				0.0925		
LSD $_{(0.05)}$ Tillage environments x Amendments				NS		
Year 2						
Complete	1.03	1.68	1.72	1.62	1.67	1.54
Incomplete	0.99	1.76	1.72	1.74	1.66	1.57
Partial	1.03	1.72	1.77	1.77	1.85	1.63
Farmer	0.78	1.34	1.52	1.20	1.28	1.23
Mean	**0.96**	**1.62**	**1.68**	**1.58**	**1.61**	
LSD $_{(0.05)}$ Tillage environments				0.1033		
LSD $_{(0.05)}$ Amendment				0.0906		
LSD $_{(0.05)}$ Tillage environments x Amendments				NS		
Year 3						
Complete	1.12	1.99	1.98	1.81	1.88	1.75
Incomplete	1.09	1.89	1.87	1.98	1.85	1.74
Partial	1.19	2.16	2.15	1.88	1.91	1.86
Farmer	1.03	1.89	1.84	1.86	1.67	1.66
Mean	**1.11**	**1.98**	**1.96**	**1.88**	**1.83**	
LSD $_{(0.05)}$ Tillage environments				NS		
LSD $_{(0.05)}$ Amendment				0.1427		
LSD $_{(0.05)}$ Tillage environments x Amendments				NS		

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

Soil amendments significantly improved the MWD. All the amended plots statistically ($p \leq 0.05$) increased the MWD relatively higher than the control.

3.4 Effects of *sawah* tillage Methods/Environments and Amendments on the Soil Water Retention (WR) and Saturated Hydraulic Conductivity (*Ksat*)

Water retention (WR) was significantly improved by different *sawah* tillage types for the whole three years of study (Table 6). In this regard, complete *sawah* adopted tillage environment made the best capacity of water retention and was followed by the incomplete *sawah* adopted tillage environment. Generally, all the plots with one or whole *sawah* tillage component(s) significantly increased the water retention higher than the farmers' adopted tillage environment (Table 6). Conservation tillage (reduced tillage) can lead to important improvements in the water storage in the soil profile [33–35]. Soil loosening by means of deep-tillage systems improves water infiltration, internal drainage, and aeration in the soil; increases root depth, intensity, and development; and allows for deeper fertilizer placement [36,37].

Table 6. Effects of *Sawah* tillage environments and amendments on soil water retention

Sawah Tillage environments	Amendments					
	CT	NPK	PD	RH	RHA	Mean
Year 1						
Complete	20.87	39.22	39.95	29.09	36.56	33.14
Incomplete	21.20	29.26	32.57	26.59	27.05	27.33
Partial	20.27	26.37	30.41	21.88	27.29	25.24
Farmer	19.95	20.87	21.92	21.99	21.90	21.33
Mean	**20.57**	**28.93**	**31.21**	**24.89**	**28.20**	
LSD ($_{0.05}$) Tillage environments			2.490			
LSD ($_{0.05}$) Amendment			1.946			
LSD ($_{0.05}$) Tillage environments x Amendments			4.038			
Year 2						
Complete	20.54	32.56	36.96	34.30	26.55	30.18
Incomplete	22.54	32.22	29.00	26.97	29.66	28.08
Partial	21.90	27.20	28.93	29.19	30.33	27.51
Farmer	20.22	21.18	21.35	19.97	22.09	20.96
Mean	**21.30**	**28.29**	**29.06**	**27.61**	**27.16**	
LSD ($_{0.05}$) Tillage environments			2.089			
LSD ($_{0.05}$) Amendment			2.373			
LSD ($_{0.05}$) Tillage environments x Amendments			4.560			
Year 3						
Complete	23.58	35.86	40.86	40.16	30.55	34.20
Incomplete	23.77	34.51	33.57	29.32	31.64	30.56
Partial	21.95	29.95	30.21	31.18	32.57	29.17
Farmer	21.44	22.44	23.78	21.34	23.32	22.46
Mean	**22.69**	**30.69**	**32.10**	**30.50**	**29.52**	
LSD ($_{0.05}$) Tillage environments			2.488			
LSD ($_{0.05}$) Amendment			2.585			
LSD ($_{0.05}$) Tillage environments x Amendments			5.036			

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

The results (Table 6) also showed that amendments relatively improved the water retention of the studied soil differently. Poultry dropping relatively improved the WR higher than other amendments. It was obtained that all the treated plots increased the water retention capacity of the soils higher than the control. The results (Table 6) also showed that the interactions of *sawah* tillage environments and amendments significantly ($p \le 0.05$) influenced the water retention capacities of the studied soils for the periods of study. Further studies conducted on long term addition of residue and tillage combinations to typical rice soils in north-western India have shown favorable modifications in soil physical properties [30,38].

The saturated hydraulic conductivity (*Ksat*) varied significantly among the four tillage adopted environments (complete, incomplete, partial and farmers' environment) in a reverse order as the level of *sawah* technology components adopted, thus highlighting yet the complementary role of ponding to puddling in minimizing deep percolation losses in *sawah* fields (Table 7). In other studies, water infiltration was greater in tilled soil than in untilled soil [39,40].

Table 7. Effects of *Sawah* tillage environments and amendments on soil saturated hydraulic conductivity (cm/hr)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	4.32	24.26	23.36	26.00	19.82	**19.55**
Incomplete	3.73	23.26	23.00	26.59	22.90	**19.90**
Partial	3.79	19.96	24.43	17.25	17.28	**16.54**
Farmer	2.97	9.26	12.56	9.32	9.77	**8.78**
Mean	**3.70**	**19.18**	**20.84**	**19.79**	**17.44**	
LSD ($_{0.05}$) Tillage environments			1.645			
LSD ($_{0.05}$) Amendment			3.760			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			
Year 2						
Complete	3.44	21.79	23.42	20.45	19.22	**17.66**
Incomplete	2.49	16.21	14.67	21.78	18.66	**14.76**
Partial	2.89	16.89	15.94	17.19	15.29	**15.81**
Farmer	3.16	7.42	6.55	8.27	6.19	**6.32**
Mean	**2.89**	**16.89**	**15.94**	**17.19**	**15.29**	
LSD ($_{0.05}$) Tillage environments			5.949			
LSD ($_{0.05}$) Amendment			5.361			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			
Year 3						
Complete	3.98	23.30	25.91	22.57	21.95	**19.54**
Incomplete	2.66	19.57	15.77	24.11	20.39	**16.50**
Partial	2.51	24.99	19.67	21.71	16.53	**17.08**
Farmer	3.49	8.47	6.80	8.98	6.78	**6.90**
Mean	**3.16**	**19.08**	**17.04**	**19.34**	**16.41**	
LSD ($_{0.05}$) Tillage environments			5.972			
LSD ($_{0.05}$) Amendment			6.362			
LSD ($_{0.05}$) Tillage environments x Amendments			NS			

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

The effectiveness of puddling followed up with compaction in the formation of plough sole layer at the plough depth and hence reduction of conductivity [41] would be expected to be most evident in this study area.

The result (Table 7) also indicated that *Ksat* was significantly increased by amendments. It was obtained that all the treated plots relatively ($P \leq 0.05$) increased *Ksat* higher than the control for the three years of study. It was recorded that among the amendments, rice husk gave higher improvement at a long-term basis, followed by poultry dropping. This result is in line with the submission of Nwite et al. [4] in a research conducted at Ishiagu of same zone, that although the saturated hydraulic conductivity (*Ksat*) was not significant with water management in first and second years of their study, yet the amendments were able to change the saturated hydraulic conductivity significantly.

It was also observed that the interactions of the different *sawah* tillage types/environments and amendments did not significantly ($p \leq 0.05$) improved the *Ksat* in the soil within the three years of study.

3.5 Effects of *Sawah* Tillage Methods/Environments and Amendments on Rice Grain Yield

The result (Table 8) also showed that *sawah* tillage environments significantly improved the grain yield of rice in the three years of study. The result (Table 8) indicated that complete *sawah* tillage environment statistically increased the grain yield higher than other growing environments. 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. Centuries of successful rice cultivation in monsoon Asia demonstrate the invaluable productivity and sustainability of the *sawah* rice production system [42,43]. Abe and Wakatsuki, [5], reported that the essence of the *sawah* system is water control, not only on a field scale but also on a watershed scale. 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 [6-8].

The result also revealed the short-term superiority of organic amendments over mineral (inorganic) fertilizer in a lowland rice production. From the result (Table 8), it was obtained that among the amendments; poultry dropping (PD) gave the highest significant increase in the grain yield in all the years studied in both sites. 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 in both locations. In their assessment of rice production technologies in Nigeria, Imolehin and Wada [44] 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 (Table 8) showed that the interactions of tillage environments and amendments significantly ($p \leq 0.05$) improved the grain yield of rice in the years of study. Therefore, *sawah* system development can improve rice productivity in the lowlands to a great extent when applied in combination with improved varieties and manures (fertilizers), and a certain amount of improvement in the *sawah* development can even be expected by bund construction only; one of the *sawah* system components [6-8].

Table 8. Effects of *Sawah* tillage environments and amendments on the rice grain yield (ton/ha)

***Sawah* Tillage environments**	**Amendments**					
	CT	**NPK**	**PD**	**RH**	**RHA**	**Mean**
Year 1						
Complete	2.03	5.37	5.73	5.37	5.23	**4.75**
Incomplete	1.97	3.70	4.17	3.10	3.83	**3.35**
Partial	1.87	3.37	3.77	3.07	4.10	**3.23**
Farmer	1.77	3.47	3.27	3.37	2.33	**2.84**
Mean	**1.91**	**3.98**	**4.23**	**3.73**	**3.88**	
LSD ($_{0.05}$) Tillage environments				0.7956		
LSD ($_{0.05}$) Amendment				0.5520		
LSD ($_{0.05}$) Tillage environments x Amendments				1.1885		
Year 2						
Complete	1.97	5.77	5.77	5.30	4.80	**4.72**
Incomplete	2.00	4.90	4.90	4.73	4.60	**4.23**
Partial	1.43	4.27	4.37	4.80	4.67	**3.91**
Farmer	1.07	3.40	4.03	4.17	3.73	**3.28**
Mean	**1.62**	**4.58**	**4.77**	**4.75**	**4.45**	
LSD ($_{0.05}$) Tillage environments				0.5494		
LSD ($_{0.05}$) Amendment				0.5894		
LSD ($_{0.05}$) Tillage environments x Amendments				1.1422		
Year 3						
Complete	4.21	7.30	8.27	7.22	7.78	**6.96**
Incomplete	3.86	7.15	6.80	6.94	6.52	**6.25**
Partial	3.51	6.38	7.64	7.50	7.29	**6.46**
Farmer	3.44	5.82	7.15	7.43	6.45	**6.06**
Mean	**3.76**	**6.66**	**7.47**	**7.27**	**7.01**	
LSD ($_{0.05}$) Tillage environments				0.550		
LSD ($_{0.05}$) Amendment				0.685		
LSD ($_{0.05}$) Tillage environments x Amendments				1.30		

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

4. CONCLUSION

The study indicated that the soil bulk density (BD) was significantly reduced by the tillage environments and soil amendments in the three years of study. It was also observed that the interaction of the tillage environments and amendments did positively reduced the soil BD in the first and second year of study. The total porosity followed the same trend as bulk density within the periods of study due to the studied factors and their interactions. The mean weight diameter (MWD), water retention (*WR*) and saturated hydraulic conductivity (*Ksat*) were also significantly improved upon in different forms by the factors and their interaction. The effects of tillage types and amendments were observed to have significantly improved the rice grain yield.

The study revealed the better performance of complete *sawah* tillage method in ensuring the optimum restoration of degraded inland valley soils with optimum grain yield. It was noted the superiority of organic amendments over mineral fertilizer on a short-term bases in soil physical properties and grain yield improvement.

Generally, the study confirms that relevant tillage operations and amendments can significantly improve soil physical characteristics and rice yields.

Sawah ecotechnology is therefore, possibly the most promising rice production method because the *sawah* system is already a highly productive and sustainable rice production system.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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