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Complementary Effects of Rice Mill Waste and NPK Fertilizer on Some Physico-Chemical Properties and Productivity of a Degraded Ultisol in Southeastern Nigeria

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Abstract: Inputs of organic and inorganic compounds in agriculture have a strong influence on soil properties and productivity. This study investigated the influence of Rice mill Waste (RW) in combination with or without NPK 15:15:15 on some physico-chemical properties and productivity of an Ultisol cropped with cocoyam (Colocasia esculenta (L) schott) in Umudike, Southeastern, Nigeria. The study was laid out in a Randomized Complete Block Design (RCBD) comprising 11 treatments (2.5, 5, 10 and 20 t ha^{-1} RW combined with 200 or 400 kg ha^{-1} NPK, 30 t ha^{-1} RW alone, 400 kg ha^{-1} NPK alone and a control) in 3 replicates. Data generated were subjected to Analysis of Variance. Relative to the control, significant increases with application of 30 t ha^{-1} RW were 127.1% for available P, 87.5 for percent total N, 213.2 for percent Organic Matter (OM), 113.6 for exchangeable Ca and 138.5 for exchangeable Mg. Enhancements in other treatments in the chemical parameters, when compared to the control, were not significant except the applications of 20 t ha^{-1} RW + 200 kg ha^{-1} NPK on percent OM and 5 t ha^{-1} RW +400 kg ha^{-1} NPK on exchangeable Na. Similarly, applications of 30 t ha^{-1} RW and a combination of 20 t ha^{-1} RW +400 kg ha^{-1} NPK significantly enhanced Mean Weight Diameter (MWD). Improvements in saturated hydraulic conductivity (Ksat) and reduction in percent Dispersion Ratio (DR) were not significant. Also, amendments improved soil productivity indicated by non-significant increases in sucker numbers and plant height of cocoyam. These results indicate the potentials of RW in improving the physico-chemical properties and productivity of degraded tropical Ultisols.

Key words: Organic ultisols, RCBD, sucker

INTRODUCTION

The reducing fertility of tropical soils had been replenished in traditional farming by long fallow periods as a stable and biologically efficient method. Due to increasing man to land ratio and adverse socio-economic changes, fallow periods are shortening to meet the increasing demand for food and other agricultural produce[1-3]. To meet this growing need, inclusion of organic soil amendments in the cropping systems within the tropics is mandatory as an efficient way to recycle nutrients and Soil Organic Matter (SOM).

For their quick-acting ability, inorganic fertilizers are used in the region[4]. However, the amounts applied are normally insufficient to meet crop demands due mainly to their high cost and uncertain availability. Their use can also exacerbate the problem of soil acidity[5].

Application of organic residues increases SOM, buffers the soil and improves aggregate stability[6]. The total amounts of nutrients released from organic amendments for crop uptake depend on the quality, the rate of application, the nutrient release pattern and the environmental conditions[7].

One of the salient aspects of simultaneous application of organic and inorganic fertilizers is the potential for positive interactions between both inputs leading to added benefits in the form of extra crop yield and enhanced soil fertility and productivity[8].

The objectives of this study were to evaluate the effects of applying RW with and without NPK fertilizer on some physico-chemical properties of a coarse-textured Ultisol in southeast agro-ecological zone of Nigeria and to determine the effect of application of the amendments, both singly and in combination with each other, on the growth of cocoyam.

MATERIALS AND METHODS

We conducted the study at Umudike (05°29'N and 07°33'E) with r ainforest type of vegetation. The mean

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annual rainfall is 2238 mm. Maximum and minimum temperatures are 32 and 23°C, respectively, while relative humidity is in the range of 63-80%.

Experimental design and soil sampling: The experiment comprised 11 treatments laid in a randomized complete block design with 3 replications. Plot size was 5x4 m. The RW was incorporated in ridges before the planting of cocoyam while the NPK fertilizer (15:15:15) was applied in bands six Weeks After Planting (6WAP).

Undisturbed core samples were collected from each plot at 0-15 cm depth whereas auger samples were taken at 0-30 cm depth. The auger samples were air-dried at room temperature before a portion was passed through a 5.6 mm sieve for wet sieving in order to determine the Mean Weight Diameter (MWD) of water stable aggregates. The other portion, for routine analysis, was crushed and passed through a 2 mm sieve while a portion of the 2 mm-sieved soil was ground in a mortar and passed through a 0.15 mm sieve for determination of total N and OM.

Field observations: Sucker count and plant height were taken at 13th and 16th Week after Planting (WAP), respectively.

Laboratory analyses: Particle size distribution was determined by the hydrometer method of Bouyoucos[9] using calgon and also water as dispersants. Dispersion Ratio (DR) was computed as

$$DR = \frac{\%\ \text{silt} + \text{clay in water}}{\%\ \text{silt} + \text{clay in calgon}} \times 100 \qquad (1)$$

Saturated hydraulic conductivity (Ksat) was determined by the constant head method[10]. Mean Weight Diameter (MWD) of water-stable aggregates was determined by the procedure of Kemper and Chepil[11] as modified by Mbagwu *et al.*[12]. Soil pH was measured electrometrically with a pH meter both in water and in KCl using a soil: liquid suspension ratio of 1:2.5. Organic carbon was determined by the Walkley-Black procedure of Nelson and Summers[13] while total N was determined by the micro-Kjeldahl digestion method[14]. Available phosphorus was by Bray II method of Bray and Kurtz[15].

After extraction with IN ammonium acetate solution, exchangeable Na and K were determined by flame photometry while Ca and Mg were determined by an EDTA titration method. Exchangeable Acidity (EA) was determined by the KCl displacement method of McLean[16]

Table 1: Some properties of the soil and the rice mill waste (RW) used in the study

	Value	
Property	Soil	RW
Sand (%)	94.84	-
Silt (%)	1.40	-
Clay (%)	3.76	-
Textural class	sand	-
MWD (mm)	0.20	-
DR (%)	118.50	-
K_{sat} (cmmm^{-1})	0.53	-
pH (Kcl)	3.90	-
pH (H_2O)	4.58	5.79
OC (%)	0.53	23.50
Total N (%)	0.08	0.43
ON	6.63	54.65
Avail. P (mg kg^{-1})	14.00	-
Ca (cmol (+) kg^{-1})	1.40	-
Mg (cmol (+) kg^{-1})	0.52	-
K(cmol (+) kg^{-1})	0.06	-
Na(cmol (+) kg^{-1})	0.10	-
ECEC (cmol (1) kg^{-1})	5.68	-

whereas Effective Cation Exchange Capacity (ECEC) and percent Base Saturation (BS) were computed from the values of exchangeable cations as:

$$ECEC = Ca + Mg + K + Na + EA \qquad (2)$$

$$\%BS = \frac{Ca + Mg + K + Na}{ECEC} \times 100 \qquad (3)$$

Some properties of the soil studied and the RW used are shown in Table 1.

Data analysis: Data collected were subjected to Analysis of Variance (ANOVA). Significant means were detected using the Fisher's Least Significant Difference (F-LSD) at 5% probability level. Correlation analysis of organic matter and the physical parameters was performed.

RESULTS AND DISCUSSION

Changes in pH, OM, total N and available P: There were improvements in soil pH, OM, total N and avail P in the RW amended plots compared to the control Table 2. Oguike and Mbagwu[17] and Oguike *et al.*[5] made similar observations in respect of modification of soil pH due to organic amendment. Range of pH (H_2O) values in RW-amended plots were from 4.80 to 5.50 reflecting reduction in soil acidity by 4.8 to 20.1%. The changes in soil acidity were not significant. However, application of 400 kg ha^{-1} NPK alone increased soil acidity slightly above the control indicating the exacerbation of problem of acidity associated with the use of inorganic fertilizer[5].

Table 2: pH, OM, Total N and avail P of soil-amended wit RW and NPK fertilizer

	pH				
Treatment	H_2O	KCI	Avail P Mg kg^{-1}	Total N (%)	OM (%)
Control	4.58	3.90	14.00	0.08	0.91
400 kg ha^{-1} Total NPK	4.50	3.40	22.00	0.09	1.72
30 t ha^{-1} Total RW	5.50	4.42	31.80	0.15	2.85
20 t ha^{-1} Total RW+ 400 kg ha^{-1} NPK	5.20	4.40	26.00	0.10	2.50
10 t ha^{-1} RW +400 kg ha^{-1} NPK	5.20	4.00	25.00	0.10	2.04
5 t ha^{-1} RW +400 kg ha^{-1} NPK	5.00	4.00	21.90	0.09	2.00
2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK	4.80	3.90	20.00	0.09	1.98
20 t ha^{-1} RW +200 kg ha^{-1} NPK	5.10	4.00	26.00	0.13	2.63
10 t ha^{-1} RW +200 kg ha^{-1} NPK	5.20	4.00	22.00	0.11	2.28
5 t ha^{-1} RW + 200 kg ha^{-1} NPK	5.00	3.92	21.00	0.10	2.10
2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK	5.00	4.00	21.00	0.09	2.00
F-LSD (0.05)	3.83	2.16	17.63	0.06	1.69

Table 3: Exchange properties of soil amended with RW and NPK fertilizer

	Cmol (+) kg^{-1}						
Treatment	(AL +H)	Ca	Mg	K	Na	ECEC	BS (%)
Control	3.52	1.40	0.52	0.06	0.10	5.60	37.10
400 kg ha^{-1} NPK	3.53	1.46	0.84	0.08	0.15	5.97	43.10
30 t ha^{-1} RW	3.00	2.99	1.24	0.12	0.15	7.50	60.00
20 t ha^{-1} RW + 400 kg ha^{-1} NPK	3.04	1.60	1.00	0.15	0.17	5.96	48.99
10 t ha^{-1} RW +400 kg ha^{-1} NPK	3.04	1.58	0.82	0.14	0.16	5.74	47.04
5 t ha^{-1} RW + 400 kg ha^{-1} NPK	3.20	1.50	0.75	0.12	0.24	5.81	44.92
2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK	3.28	1.48	0.60	0.11	0.14	5.61	41.50
20 t ha^{-1} RW +200 kg ha^{-1} NPK	3.24	1.56	0.88	0.15	0.16	5.99	45.91
10 t ha^{-1} RW + 200 kg ha^{-1} NPK	3.19	1.47	0.67	0.15	0.13	5.61	43.10
5 t ha^{-1} RW +200 kg ha^{-1} NPK	3.26	1.66	0.64	0.13	0.10	5.79	43.70
2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK	3.40	1.61	0.65	0.11	0.10	5.87	42.08
F-SD (0.05)	2.49	1.14	0.64	0.14	0.10	4.56	35.81

Relative improvement in available P was observed in all treated plots while the application of 30 t ha^{-1} RW showed a significant improvement by 127.1% above the control. The least improvement of 42.9% was recorded in plot treated with 2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK. Improvements in available P, followed increasing rates of RW amendment irrespective of NPK combination and appear to be directly related to its content in the RW used. This observation substantiates reports by Bernal *et al*.[18]; Mbagwu and Piccolo[19]; Mbagwu *et al*[20].

There was significant improvement in total N relative to the control when 30 t ha^{-1} RW was applied. Although, there was a non-significant improvement in all the other treatments compared to the control, the N status of all the treatments was generally low. This could be due to the high C/N ratio of the RW used Table 1. Perhaps, a loss of soil N occurred due to leaching which may have resulted in the low total N recorded in all the RW-amended plots.

In all treated plots, soil OM increased with increasing application rates of RW despite the NPK combination. Similar results were reported by Oguike and Mbagwu[17, 21], and Oguike *et al*[5]. Applications of 30 t ha^{-1} RW and 20 t ha^{-1} RW + 200 kg ha^{-1} NPK showed significant improvements above the control by 213.2 and 109.9%, respectively. Values observed when RW was combined with 400 kg ha^{-1} NPK were lower than with 200 suggesting that lower rates of NPK in combination with RW amendments could provide long-lasting significant improvements on degraded tropical soils.

Changes in exchange properties: Exchange properties of soil amended with RW and NPK fertilizer are shown in Table 3. Exchangeable Acidity (EA) decreased in all treatments but increased slightly in the NPK alone treatment relative to the control. This reflects the result of the pH measured in water. 30 t ha^{-1} RW-amended plot recorded the highest decrease relative to the control, verifying the result obtained for pH in water. This result corroborates the findings of Oguike and Mbagwu[17]. Reduction in acidity with RW application could be attributed to the removal of Al from the soil exchange sites by OM from decomposing RW. Similar inference was made by Hargrove and Thomas[22]. The reduction could also be as a result of neutralization of Al by Ca and Mg released from the decomposition of RW[12].

ECEC, BS and exchangeable Ca, Mg, K and Na increased in all treated plots. The relative improvement in ECEC compared to the control was the contribution of the bases due to the RW amendment. Although significant improvements were observed only with the application of 30 t ha^{-1} RW and 5 t ha^{-1} RM + 400 kg ha^{-1} NPK in Ca and Mg on one hand and Na on the other, respectively, non-significant improvement was observed in all other treatments relative to the control. The increased exchange properties could be due to mineralization of applied RW with consequent release of nutrients. The improvements reflected the increasing rate of RW application. Lower values of Ca, Mg, K and Na were recorded in the NPK alone treatment than the proceeding RW alone treatment. Also, the exchangeable acidity was higher in the NPK alone than in the RW alone treatments. Probably, the inorganic NPK fertilizer might have induced slight increase in acidity[5] which possibly affected microbial activities during mineralization thereby keeping the exchangeable bases lower than in the other treatments aside of the control. Contrary to this, the inorganic fertilizer might have induced more rapid mineralization and the nutrients utilized by the cocoyam plant as confirmed by observed increases in plant height and sucker number Table 4. Mbagwu[20] made similar suggestions while reporting improvements in exchange properties of soil due to organic and inorganic amendments.

Changes in physical properties: Modifications in physical properties of soil due to amendment with RW and NPK fertilizer are shown in Table 5. Relative to the control, the physical parameters measured increased with increasing rates of amendments. Compared to the control, MWD significantly increased by 220% in the 30 t ha^{-1} RW and by 200% in the 20 t ha^{-1} RW + 400 kg ha^{-1} NPK whereas improvements in the other plots were not significant. The MWD of water-stable aggregates ranged from 0.32 to 0.64 mm in the amended plots representing 60 to 229% improvements in aggregation above the control. This observation corroborates the finding of Whitbread *et al.*[23] who reported a correlation between macro aggregates and total carbon.

Dispersion Ratio (DR) decreased by 49.6% when 30t/haRW was applied. Reduction in the values of DR due to amendment indicated a decrease in the % dispersible clay. Results of MWD and DR imply that both micro-and macro- aggregates were stable. This stability could be due to the role of OM as an aggregating agent since it can penetrate clay domain to form complex chelates with polyvalent cations[24]. The correlation of OM with the physical parameters measured supports this assertion. Table 4.

In comparison with the control, saturated hydraulic conductivity (K_{sat}) increased by 132.1%. This supports the findings of Mbagwu[19] who reported that incorporation of organic waste increased soil hydraulic conductivity, though the magnitude depended on the rate of application. The higher K_{sat} due to amendment implied reduced run-off and less erosion. The fairly rapid K_{sat} observed even in the control may be attributed to the coarse-texture of the soil[24]. The correlation of OM with the physical parameter measured supports this assertion Table 4.

Table 4: Correlation matrix of OM with physical properties with soil amended with RW and NPK fertilizer

	OM	MWD	DR	Ksat
OM	-	0.810**	-0.712*	0.936**
MWD	-	-	-0.847**	0.920**
DR			-	-0.823**
Ksat				-

** Significant at 0.01 probability level (2-tailed), * Significant at 0.05 probability level (2-tailed)

Table 5: Some physical properties of soil amended with RW and NPK fertilizer

Treatment	MWD (mm)	DR (%)	Ksat (cm min^{-1})
Control	0.20	118.50	0.53
400 kg ha^{-1} NPK	0.32	104.10	0.60
30 t ha^{-1} RW	0.64	59.71	1.23
20 t ha^{-1} RW + 400 kg ha^{-1} NPK	0.60	62.44	1.23
10 t ha^{-1} RW + 400 kg ha^{-1} NPK	0.58	66.01	0.97
5 t ha^{-1} RW + 400 kg ha^{-1} NPK	0.48	69.14	0.89
2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK	0.41	72.41	0.77
20 t ha^{-1} RW + 200 kg ha^{-1} NPK	0.52	63.14	1.14
10 t ha^{-1} RW + 200 kg ha^{-1} NPK	0.49	67.09	0.91
5 t ha^{-1} RW + 200 kg ha^{-1} NPK	0.41	70.20	0.83
2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK	0.39	74.20	0.73
F-LSD$_{(0.05)}$	0.38	60.31	0.72

Table 6: Suckers number and plant height at 13th and 16th week, respectively, after planting

Treatment	Sucker No.	Plant height (cm)
Control	10.30	46.40
400 kg ha^{-1} NPK	19.30	49.50
30 t ha^{-1} RW	11.30	52.10
20 t ha^{-1} RW + 400 kg ha^{-1} NPK	9.00	51.30
10 t ha^{-1} RW + 400 kg ha^{-1} NPK	15.00	50.40
5 t ha^{-1} RW + 400 kg ha^{-1} NPK	19.30	46.90
2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK	20.00	46.70
20 t ha^{-1} RW + 200 kg ha^{-1} NPK	17.70	47.40
10 t ha^{-1} RW + 200 kg ha^{-1} NPK	12.30	60.00
5 t ha^{-1} RW + 200 kg ha^{-1} NPK	15.70	47.80
2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK	18.70	44.20
F-LSD (0.05)	12.20	38.50

Data represent mean values

Growth of cocoyam: Combination of RW and NPK fertilizer stimulated the growth of cocoyam as observed during plant height and sucker number measurements shown in Table 6. Similar results have been recorded by other researchers[25, 26] who used organic residues as soil amendments.

In comparison with the control, sucker number increased with decreasing rates of RW with both NPK combinations except for the 20 t ha^{-1} RW treatments. This may be suggesting that high rates of RW does not support increase in sucker number. However, the

400 kg ha^{-1} NPK in combination with RW performed better than the combination with 200 kg ha^{-1} NPK. 13WAP, the largest number of suckers was observed in the 2.5 t ha^{-1} RW + 400 kg ha^{-1} NPK while the least was recorded in the 20 t ha^{-1} RW + 400 kg ha^{-1} NPK representing 94.2% increase and 12.6% decrease, respectively, compared to the control. This reduction however, negates the effect of organic wastes on plant growth and development. Contrary to this observation, plant height increased with increasing rate of application of RW in combination with 400 or 200 kg ha^{-1} NPK with a deviation in the 20 t ha^{-1} RW + 200 kg ha^{-1} NPK treatment. Except for 2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK, all other treatments performed better than the control. Comparing the two fertilizer rates in combination with RW, the 400 kg ha^{-1} out-performed the 200 kg ha^{-1}. Although, the tallest plant was observed in the 10 t ha^{-1} RW + 200 kg ha^{-1} NPK, the shortest was observed in the 2.5 t ha^{-1} RW + 200 kg ha^{-1} NPK treatments indicating that high rates of RW and NPK may be required for growth of cocoyam in Ultisol within the agro-ecological area under study.

CONCLUSION

The results from this study have shown that soil amendment with RW has the potential to improve the physico-chemical properties of the Ultisol. The use of RW alone at 30t/ha performed better than the other treatments in all parameters measured. Therefore, rice mill waste applied to degraded tropical soils as manure or mulch material will enhance the properties as well as the productivity of such soils.

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