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Integrated fertilizer management impact on soil chemical properties, growth and yield of orange-fleshed sweet potato (*ipomoea batatas* (l) lam) at Ikwo, Ebonyi State, Nigeria

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ABSTRACT

A field experiment was conducted at Alex Ekwueme Federal University Teaching and Research Farm, Ndufu-Alike, Ebonyi State, Nigeria, in the 2022 planting season to evaluate the impact of integrated fertilizer on soil chemical characteristics, growth, and yield of orange-fleshed sweet potato (OFSP). The treatments comprised Rice Mill Waste (RMW) applied at 0, 2, 4, and 6 tons/ha and Nitrogen 27: Phosphorus 13: Potassium 13 (NPK 27:13:13) fertilizer applied at 0, 200, 400, and 600 kg/ha, which were combined to produce 16 treatment combinations with three replicates in a Randomized Complete Block Design (RCBD). All the data collected were subjected to the analysis of variance (ANOVA) using the GENSTAT software package, and the treatment means were separated using Fisher's Least Significant Difference (LSD) at a 5% level of probability. The findings of the study demonstrated that the amended plots showed improvements in soil chemical characteristics as well as the growth and yield parameters of Orange Fleshed Sweet Potato (OFSP) over the control. The application of amendment at the rate of 6t/ha RMW + 600kg/ha NPK produced the best results. The combination of RMW and NPK fertilizer significantly ($P<0.05$) improved soil chemical properties like pH, available phosphorus, soil organic carbon, total nitrogen, soil exchangeable properties, and increased OFSP growth and yield components like the number of branches, vine length, number of leaves, and yield of OFSP. The integration of both organic and inorganic fertilizer materials could enhance the growth and yield of OFSP as well as the nutrient level of the soil.

Contribution/Originality: Rice mill waste is a high-carbon organic amendment that will be of great benefit to soils with low organic matter content when integrated with inorganic fertilizer (a nitrogen source) to help prevent nitrogen immobilization, resulting in greater improvement in soil chemical characteristics and orange-fleshed sweet potato yield components.

1. INTRODUCTION

Food is one of the basic necessities of man, and its production is heavily reliant on soil fertility. In Africa, declining soil fertility and decreased productivity are key concerns (Sanchez & Jama, 2002) as they pose a serious threat to food security (Goda, 2019). Therefore, maintaining soil fertility is essential to both the sustainability of soil resources and continuous food production. To address the issues of soil fertility, productivity, and, by extension, food security that are affecting the world, the incorporation of various soil amendments from both organic and inorganic sources has proven to be a sustainable solution (Chukwu, Mbanaso, Obasi, Nwoko, & Ogbuagu, 2004).

Certain nutrients are known to be abundant in organic waste. Although crops benefit greatly from these nutrients, their application can alter plant nutrient availability through microbial-mediated transformations and their byproducts (Agyenim, Ayeni, Oso, & Ojeniyi, 2008). Rice mill wastes (RMW), though they impact good structural attributes to the soil, have little or relatively low effects on soil chemical properties due to their low surface area as well as low degradability due to high carbon and low nitrogen content (Chukwu et al., 2004). It might immobilize nitrogen, which would inhibit microbial respiration and plant growth (Anikwe, 2000). Crop yield, soil tilth enhancement, soil fertility restoration, and overall soil sustainability are all enhanced by the nitrogen, phosphorus, calcium, and organic carbon found in rice mill waste (Nwite & Azuka, 2019). The easily accessible nutrients found in inorganic fertilizers are good for the soil and crops. Ali, Usman, and Ojeniyi (2020) and Ogbodo (2013) noted that the application of NPK fertilizer at different rates increased the soil's total nitrogen, organic matter, cation exchange capacity, and exchangeable acidity.

Sweet potatoes are a vital crop for the survival of resource-poor Nigerian farmers because of their high yield per unit area and time, which increases their ability to reduce poverty and ensure food security (National Root Crops Research Institute (NRCRI), 2009). Orange-fleshed sweet potato (OFSP) varieties are a nutritious type of sweet potato that is additionally rich in beta-carotene (precursor to vitamin A), which is now being used in Africa to combat a widespread vitamin A deficiency in 250,000 – 500,000 children. These varieties are gaining great attention as a means of mitigating common health-related problems associated with vitamin A deficiency in low-income households. These varieties are believed to be the most affordable dietary source of vitamin A available for low-income households (Laurie, Calitz, Adebola, & Lezar, 2013). OFSP also has powerful antioxidants that help prevent cancers, as well as natural sugars, which are slowly released into the bloodstream, helping to ensure a balanced source of energy without the spikes in blood sugar that are sometimes associated with fatigue and weight gain (Ukpabi, Ekeledo, & Ezigbo, 2012).

Orange-fleshed sweet potato production in Nigeria still faces several challenges, such as low yield. The average yield of the crop remains in a very low range of 4.0 t/ha compared to the average yield values of 15 to 30 t/ha obtained in other sweet potato-producing countries of the world, such as China (Odebode, 2004). High-yielding orange-fleshed sweet potato varieties are sensitive to fertilizers (Nedunchezhiyan, Byju, Naskar, & Mukherjee, 2010). Fertilizer application is an important option available to farmers for yield improvement in most soils (Okpara, Okon, & Ekeleme, 2009).

The integration of organic wastes with inorganic fertilizer as a soil amendment has been widely recommended, due to the organic wastes promoting a healthy growing environment while inorganic fertilizer provides quick nutrition. While assessing the effect of nitrogen N-fortified rice mill waste at Obubra, Cross River State, Ojikpong, and Kekong (2019) observed an increase in soil potassium (K), calcium (Ca), pH, and organic matter. Uwah, Udoh, and Iwo (2011) reported that the combination of 15 t ha-1 of poultry manure and 120 kg ha-1 produced the highest yield of cocoyam in 2006. Rice mill waste as an organic amendment is not frequently used because of its high carbon-to-nitrogen ratio. The supply of nitrogen with inorganic fertilizer can help prevent nitrogen immobilization due to the high carbon content of rice mill waste. This will be of great benefit to soils with low organic matter content, resulting in greater improvement in soil chemical characteristics and orange-fleshed sweet potato yield components.

The objective of this study was to assess the impacts of rice mill waste and NPK 27:13:13 on soil chemical properties, growth, and yield of orange-fleshed sweet potato in Ikwo, Ebonyi State.

2. MATERIAL AND METHODS

2.1. Experimental Site

The field experiment was conducted during the 2022 planting seasons at the Faculty of Agriculture Teaching and Research Farm, Alex Ekwueme Federal University, Ndufu-Alike (AEFUNAI), Ebonyi State. It is located at approximately latitudes 06° 07' 34" N and 06° 07' 40" N and longitudes 08° 08' 09" E and 08° 08' 14" E, with an altitude of 142 m. The climate is mainly humid tropical, with a total precipitation of 2168 mm per year, an average annual temperature of about 27 °C, and an annual relative humidity between 60% and 80%. The rainfall regime is bimodal: a long wet season from April to July is interrupted by a brief "August break," followed by another short rainy season from September to October or early November. The dry season lasts from early November to March (Alex Ekwueme Federal University Ndufu Alike (AE-FUNAI), 2020). The soil of the experimental area is well-drained sandy soil, classified as Ultisol (Federal Department of Agriculture and Land Resources, 1985).

2.2. Experimental Layout

A total area of land of 398.75 m^2 (27.5 m by 14.5 m) was used for the experiment in 2022. The field was mechanically cleared, plowed, harrowed, and ridged with a tractor. The ridges were spaced at 1 m intervals in a 3 m by 2 m plot with a furrow of 0.5 m. The experiment was a factorial experiment laid out in a Randomized Complete Block Design (RCBD) with three (3) replications.

2.3. Experimental Treatments

The treatments comprised rice Mill Waste (RMW) and NPK 27-13-13 fertilizer. The RMW was applied at the rates of 0, 2, 4, and 6 t ha-1, and the NPK at the rates of 0, 200, 400, and 600 kg/ha, which combined to give 16 treatment combinations, with three replicates. The RMW was sourced from the rice mill section of Nwakpu market, Ndufu-Alike, while the NPK 27-13-13 fertilizer was sourced from Ebonyi State Fertilizer and Chemical Company, Abakaliki, Ebonyi State.

2.4. Planting Material and Treatment Application

The experimental test crop is Orange Flesh Sweet Potato (UMUSPO 3), commonly called Mother Delight, which was obtained from the National Root Crop Research Institute, Umudike, Abia State. The treatments were applied 4 weeks after planting the Orange Flesh Sweet Potato vines. The vine cuttings, measuring 20 cm in length, were planted at a spacing of 1 m by 0.3 m along the crest of the ridge, resulting in a total plant population of 40 plants per plot and 33,333 plants per hectare. Supplying was done two weeks after planting (WAP). Weeding was performed manually with a hoe at 6 and 10 weeks after planting (WAP). The ridges were earthed up to avoid exposure to the Orange Flesh Sweet Potato roots.

2.5. OFSP Data Collection

Orange-fleshed sweet potato growth and data were collected as follows: (a) Vine length was measured at 4, 8, and 12 weeks after treatment application with a measuring tape from the base of the plant vine to the tip of the vine. (b) The number of leaves was counted at 4, 8, and 12 weeks after treatment application. (c) The number of branches was counted at 4, 8, and 12 weeks after treatment application. (d) The weight of storage roots per plot (kg/plot) at harvest was taken with a scale, and (f) total storage root yield (t/ha) at harvest was measured with a scale.

2.6. Soil Sample Collection and Preparation

A composite soil sample was collected prior to treatment application for the characterization of the experimental site. Soil samples were collected using a soil auger at a depth of 0 to 20 cm at the end of the experiment for chemical analysis. The soil samples were air-dried at room temperature and sieved through a 2 mm sieve.

2.7. Soil Chemical Analysis

The following soil chemical properties were determined using the standard procedure: The soil pH (in a 1:2.5 soil-to-water ratio) was measured using a glass electrode pH meter (Thomas, 1996). The organic carbon was determined using the dichromate wet oxidation method of Walkley and Black (1934), as explained by Nelson and Sommers (1982). Available phosphorus was determined by the Bray 2 method as described by Bray and Kurtz (1945). Total nitrogen was measured using the Kjeldahl method according to Bremner (1996). Exchangeable cations such as K+, Ca2+, Mg2+, and Na+ were analyzed according to the method of Summer and Miller (1996). Exchangeable acidity was determined following the method of Mclean (1965). Effective Cation Exchange Capacity (ECEC) was calculated as follows: ECEC = K + Ca + Na + Mg + EA, and Percent Base Saturation (%BS) was computed using this formula: %BS = TEB × 100 ECEC.

2.7. Data Analysis

All collected data were subjected to analysis of variance (ANOVA) for factorial experiments in a randomized complete block design (RCBD) using the GenStat statistical package 17th Edition (GenStat, 2014), and Fisher's Least Significant Difference (FLSD) was used to separate the treatment means at a 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Properties of the Soil Used for the Study

The experimental soil is characterized as sandy loam that is slightly acidic, with low levels of organic carbon, nitrogen, available phosphorus, and exchangeable bases, as shown in Table 1. This implies that the fertility of the soil is low.

Table 1. Some physicochemical properties of the soil before treatment application.

Soil properties	2022
Sand (%)	59.60
Silt (%)	20.10
Clay (%)	20.30
Textural class	Sandy-loam
Soil pH (Water)	5.92
Soil pH ($CaCl_2$)	5.08
Organic carbon (%)	0.69
Organic matter (%)	1.18
Total nitrogen (%)	0.16
C:N ratio	4.31
Available phosphorus (mg kg^{-1})	28.20
Ca^{2+} ($cmol^{-1}$ kg^{-1})	1.65
Mg^{2+} ($cmol^{-1}$ kg^{-1})	0.88
K^+ ($cmol^{-1}$ kg^{-1})	0.112
Na^+ ($cmol^{-1}$ kg^{-1})	0.225
Total exchangeable bases (TEB) ($cmol^{-1}$ kg^{-1})	2.867
Exchangeable acidity ($cmol^{-1}$ kg^{-1})	2.64
Effective cation exchange capacity (ECEC) ($cmol^{-1}$ kg^{-1})	5.507
Percentage base saturation (%)	52.06

3.2. The Chemical Composition of Amendments Used for the Study

The chemical composition of the rice mill waste used in the experiment is shown in Table 2. In this table, the rice mill waste has higher values in organic carbon and organic matter, with low nitrogen and available phosphorus content, while inorganic fertilizer has high values of nitrogen, available phosphorus, and potassium.

Table 2. Chemical composition of the amendments used for the experiment.

Properties	Rice mill waste	Inorganic fertilizer
Organic carbon (%)	28.28	-
Organic matter (%)	48.75	-
Total nitrogen (%)	0.655	27
Available phosphorous (mg/kg)	0.528	13
C:N ratio	43.17	-
Potassium (cmol$^+$/kg)	-	13

3.3. Impact of Rice Mill Waste and NPK Fertilizer on Soil Chemical Properties

3.3.1. Impact of Rice Mill Waste and NPK Fertilizer on Soil pH (Water), Soil Organic Carbon and Total Nitrogen

Table 3 displays the impact of rice mill waste and NPK 27:13:13 fertilizer on soil pH, soil organic carbon, and total nitrogen. The findings indicate that the soil pH, total nitrogen, and organic carbon of the amended plots improved significantly ($P < 0.05$) compared to the control. The soil pH, soil organic carbon, and total nitrogen increased with the increasing rate of amendment applied. The highest values were obtained with the application of 6 t ha^{-1} RMW + 600 kg ha^{-1} NPK.

The increase in soil pH could be attributed to the removal or precipitation of Al $(OH)_3$ from the soil exchangeable sites by organic matter from the decomposition of the amendments. The increase in soil pH from the treated plots confirmed the liming effects of agro-wastes. This aligned with the findings from Oguike, Chukwu, and Njoku (2006) and Ohaekweiro (2016) who observed increased soil pH in rice mill waste and NPK fertilizer amended plots over control.

The increased soil organic carbon may be due to the high carbon content of RMW and the mineralization of the organic wastes during decomposition, which provides a good environment for the decomposing microorganisms (Badalucco, Grego, Dell'Orco, & Nannipieri, 1992). This probably resulted in the release of organic-bound nutrients, as reflected in the increased soil organic carbon. A similar result was obtained by Oguike et al. (2006); Ohaekweiro (2016) and Chukwu et al. (2004) with the application of rice mill waste and NPK fertilizer.

The increased soil total nitrogen may be due to the chemical fertilizer applied and the mineralization of the organic wastes during decomposition, which probably resulted in the release of organic-bound nutrients, as reflected in the increased soil total nitrogen. This agrees with the findings of Oguike et al. (2006); Ohaekweiro (2016) and Chukwu et al. (2004) regarding the application of rice mill waste and NPK fertilizer.

Table 3. Impact of rice mill waste and NPK fertilizer on soil pH (H_2O), soil organic carbon, and total nitrogen.

Soil pH (H_2O)						**Soil organic carbon (%)**					**Total nitrogen (%)**				
RMW (t ha^{-1})						**RMW (t ha^{-1})**					**RMW (t ha^{-1})**				
NPK (kg/ha)	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**
0	5.61	5.85	5.87	5.92	5.81	0. 673	1.453	1.730	2.263	1.530	0.098	0.140	0.144	0.190	0.143
200	5.85	5.85	5.88	5.94	5.88	1. 173	1.517	1.863	2.340	1.723	0.127	0.142	0.146	0.196	0.153
400	5.84	5.85	5.88	5.97	5.88	1. 253	1.597	1.920	2.977	1.937	0.130	0.142	0.149	0.201	0.156
600	5.85	5.88	5.88	5.99	5.90	1. 407	1.653	2.007	3.043	2.027	0.132	0.143	0.171	0.203	0.165
Mean	5.79	5.85	5.87	5.95		1. 127	1.555	1.880	2.656		0.122	0.142	0.153	0.200	
LSD (0.05) for RMW = 0.04467						LSD (0.05) for RMW = 0.0641					LSD (0.05) for RMW = 0.0031				
LSD (0.05) for NPK = 0.04467						LSD (0.05) for NPK = 0.0641					LSD (0.05) for NPK = 0.0031				
LSD (0.05) for RMW * NPK = 0.08934						LSD (0.05) for RMW * NPK = 0.1281					LSD (0.05) for RMW * NPK = 0.0062				

Note: Interaction between NPK and RMW.

Table 4. Impact of rice mill waste and NPK fertilizer on available phosphorous, exchangeable acidity, and total exchangeable bases.

Available phosphorous (mg/kg)						**Exchangeable acidity (cmol+/kg)**					**Total exchangeable bases (cmol+/kg)**				
RMW (t ha^{-1})						**RMW (t ha^{-1})**					**RMW (t ha^{-1})**				
NPK (kg/ha)	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**
0	22.80	28.10	31.87	33.03	28.95	3.383	2.513	2.400	2.283	2.6450	6.44	7.31	7.47	7.64	7.215
200	25.00	30.17	32.50	33.23	30.22	2.626	2.453	2.400	2.273	2.4383	7.24	7.42	7.48	7.64	7.424
400	26.60	31.23	32.80	33.37	31.00	2.566	2.433	2.346	2.200	2.3867	7.25	7.43	7.56	7.67	7.477
600	26.73	31.60	32.90	33.80	31.26	2.553	2.426	2.306	2.193	2.3700	7.28	7.45	7.62	7.68	7.507
Mean	28.58	30.27	32.52	33.36		2.782	2.456	2.363	2.237		7.053	7.40	7.53	7.66	
LSD (0.05) for RMW = 0.163						LSD (0.05) for RMW = 0.05643					LSD (0.05) for RMW = 0.004022				
LSD (0.05) for NPK = 0.163						LSD (0.05) for NPK = 0.05643					LSD (0.05) for NPK = 0.004022				
LSD (0.05) for RMW * NPK = 0.326						LSD (0.05) for RMW * NPK = 0.11286					LSD (0.05) for RMW * NPK = 0.008044				

Note: Interaction between NPK and RMW.

3.3.2. Impact of Rice Mill Waste and NPK Fertilizer on Available Phosphorus, Exchangeable Acidity and Total Exchangeable Bases

The impact of rice mill waste and NPK fertilizer on the available phosphorus, exchangeable acidity, and total exchangeable base content of the soil are displayed in Table 4. The results revealed that the available phosphorus, exchangeable acidity, and total exchangeable bases of amended plots increased significantly ($P<0.05$) compared to the control. Soil available phosphorus, exchangeable acidity, and total exchangeable bases increased with increasing rate of treatment application, with the highest values obtained at the rate of 6 t ha^{-1} RMW + 600 kg ha^{-1} NPK.

The increased soil available phosphorous may be attributed to the fact that the organic wastes have liming effects because of the presence of calcium and magnesium, which increase soil pH, thereby releasing adsorb phosphorous presence in organic wastes. The increase in available phosphorous may also be due to the dissolution and mineralization of the applied chemical fertilizer. Similar results were obtained by Oguike et al. (2006); Ohaekweiro (2016) and Chukwu et al. (2004) with the application of rice mill waste and NPK fertilizer.

The reduction in exchangeable acidity in treatment-amended plots could be attributed to the removal or precipitation of AL $(OH)^3$ from the soil exchangeable sites through the process of dissolution and mineralization of the inorganic and organic amendments. This is consistent with the result obtained by Oguike et al. (2006); Ohaekweiro (2016) and Chukwu et al. (2004) with the application of rice mill waste and NPK fertilizer.

The increased total exchangeable bases may be due to the ability of the treatments, especially the rice mill waste to act as a liming material. Similar results were obtained by Chukwu et al. (2004) on higher total exchangeable bases value in amended plots over control and Ojikpong and Kekong (2019) with the application of N-fortified rice mill waste on a maize and cassava intercrop.

3.3.3. Impact of Rice Mill Waste and NPK Fertilizer on Effective Cation Exchange Capacity (ECEC) and Percentage Base Saturation (%BS)

Table 5 presents the impact of rice mill waste and NPK fertilizer on effective cation exchange capacity and percentage base saturation. The results showed a highly significant ($P < 0.05$) improvement in amended plots over control in both ECEC and percentage base saturation, with the highest value obtained at 6 t ha-1 RMW + 600 kg ha-1 NPK application rate.

The increase in the ECEC of the soil over control may be due to the buffering effect of the amendments, while the increased percentage of base saturation could be due to the presence of basic cations in the treatments. A similar result was obtained by Oguike et al. (2006); Chukwu et al. (2004) and Ojikpong and Kekong (2019) with the application of RMW and NPK fertilizer.

Table 5. Effect of rice mill waste and NPK fertilizer on effective cation exchange capacity and percentage base saturation.

Effective cation exchange capacity (cmol+/kg)						**Percentage base saturation (%BS)**				
RMW (t ha^{-1})						**RMW (t ha^{-1})**				
NPK (kg/ha)	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**
0	9.83	9.83	9.87	9.96	9.87	65.90	74.36	75.68	76.70	73.16
200	9.84	9.86	9.88	9.96	9.89	73.56	75.25	75.71	76.70	75.31
400	9.80	9.87	9.89	9.97	9.88	73.67	75.48	76.44	76.93	75.63
600	9.82	9.85	9.95	9.98	9.90	74.13	75.63	76.58	76.95	75.82
Mean	9.82	9.85	9.90	9.97		71.82	75.18	76.10	76.82	
LSD (0.05) for RMW = 0.01686						LSD (0.05) for RMW = 0.03731				
LSD (0.05) for NPK = 0.01686						LSD (0.05) for NPK = 0.03731				
LSD (0.05) for RMW * NPK = 0.03372						LSD (0.05) for RMW * NPK = 0.07461				

Note: Interaction between NPK and RMW.

3.4. Impact of Rice Mill Waste and NPK Fertilizer on Growth and Yield of Orange-Fleshed Sweet Potato

3.4.1. Impact of Rice Mill Waste and NPK Fertilizer on Number of Branches of Orange-Fleshed Sweet Potato at 4, 8, and 12 Weeks after Treatment Application (WATA)

The impact of rice mill waste and NPK fertilizer on the number of branches of orange-fleshed sweet potato at 4, 8, and 12 WATA is presented in Table 6. The results showed an increased number of OFSP branches over control with no significant ($P<0.05$) difference in the interaction between rice mill waste and the NPK fertilizer at 4, 8, and 12 WATA. The number of branches increased with the increasing rate of treatment application with the highest number of branches obtained at 600 kg ha^{-} NPK fertilizer + 6 t ha^{-1} RMW application rate.

This could be due to the dissolution of the NPK fertilizer and the decomposition of the rice mill waste material, releasing nutrients for crop uptake. An increase in the number of branches of sweet potato following the application of soil organic and inorganic amendment has been recorded by Akpaninyang, Okpara, Njoku, and Ogbologwung (2014) and Nwankwo, Nwankwo, and Abah (2023).

3.4.2. Impact of Rice Mill Waste and NPK Fertilizer on Number of Leaves of Orange-Fleshed Sweet Potato at 4, 8 and 12 Weeks after Treatment Application

The effect of rice mill waste and NPK fertilizer on the number of leaves of orange-fleshed sweet potato at 4, 8, and 12 WATA as presented in Table 7. The results showed a significant ($P<0.05$) increase in the number of OFSP leaves over control with rice mill waste and NPK fertilizer at 4, 8, and 12 WATA. The number of leaves increased with increasing rate of treatment application with the highest number of leaves obtained at 600 kg ha^{-} NPK fertilizer + 6 t ha^{-1} RMW application rate.

This could be due to the dissolution of the NPK fertilizer and the decomposition of the rice mill waste material, releasing nutrients for crop uptake. An increase in the number of leaves of OFSP following the application of organic and inorganic amendment has been recorded by Akpaninyang et al. (2014); Nwankwo et al. (2023) and Ojikpong and Kekong (2019) reported an increase in a number of leaves over control with the application of N-fortified rice mill waste on maize plant.

3.4.3. Impact of Rice Mill Waste and NPK Fertilizer on Vine Length (cm) of Orange-Fleshed Sweet Potato at 4, 8, and 12 Weeks after Treatment Application

The effect of rice mill waste and NPK fertilizer on the length of orange-fleshed sweet potato vine at 4, 8, and 12 WATA is presented in Table 8. The results showed an increase in vine length of OFSP over control with rice mill waste and NPK fertilizer at 4, 8, and 12 WATA. The vine length increased with increasing rate of treatment application with the highest value obtained at 600 kg ha^{-} NPK fertilizer + 6 t ha^{-1} RMW application rate.

Increased OFSP vine length could be attributed to the dissolution of the NPK fertilizer in the soil, as well as the decomposition of the rice mill waste material, leading to the release of nutrients for the plants. This aligned with the findings of Akpaninyang et al. (2014); Nwankwo et al. (2023) and Ojikpong and Kekong (2019) reported an increase in a number of leaves over control with the application of N-fortified rice mill waste on maize plant.

Table 6. Impact of rice mill waste and NPK fertilizer on a number of branches of orange-fleshed sweet potato at 4, 8, and 12 weeks after treatment application (WATA).

4 WATA						8 WATA					12 WATA				
RMW (t ha^{-1})						RMW (t ha^{-1})					RMW (t ha^{-1})				
NPK (kg/ha)	0	2	4	6	Mean	0	2	4	6	Mean	0	2	4	6	Mean
0	2.00	2.33	3.00	3.67	2.83	2.33	5.00	6.00	8.00	5.33	11.33	8.67	12.00	17.33	12.33
200	2.67	3.33	4.67	5.00	3.92	5.00	7.00	9.00	10.00	7.75	15.33	11.33	16.00	22.00	16.17
400	4.33	5.00	5.33	7.00	5.52	7.00	10.00	10.00	14.00	10.25	18.67	14.00	20.00	25.33	19.50
600	6.33	6.67	7.67	9.00	7.42	9.00	13.00	14.00	17.00	13.23	25.00	20.37	25.00	31.00	25.33
Mean	3.92	4.33	5.17	6.17		5.83	8.75	9.75	12.25		17.58	13.58	18.25	23.92	
LSD (0.05) for RMW = 1.312						LSD (0.05) for RMW = 0.120					LSD (0.05) for RMW = 3.164				
LSD (0.05) for NPK = 1.312						LSD (0.05) for NPK = 0.120					LSD (0.05) for NPK = 3.164				
LSD (0.05) for RMW * NPK = 2.624						LSD (0.05) for RMW * NPK= 0.240					LSD (0.05) for RMW * NPK = 6.329				

Note: Interaction between NPK and RMW.

Table 7. Impact of rice mill waste and NPK fertilizer on a number of leaves of orange-fleshed sweet potato at 4, 8, and 12 weeks after treatment application (WATA).

4 WATA						8 WATA					12 WATA				
RMW (t ha^{-1})						RMW (t ha^{-1})					RMW (t ha^{-1})				
NPK (kg/ha)	0	2	4	6	Mean	0	2	4	6	Mean	0	2	4	6	Mean
0	28.0	24.7	27.7	34.0	28.6	41	45.3	51.3	62.7	50.08	156.3	164.3	198.7	208.7	182.0
200	49.7	42.7	37.7	57.0	46.8	71.7	73.3	81.3	87.3	78.42	202.7	222.3	281.3	292.0	249.6
400	55.0	57.7	66.3	71.0	62.5	101.7	110	123.3	136.7	117.92	232.3	303.3	344.3	370.0	312.5
600	69.0	78.0	86.3	89.7	80.8	137.7	143.7	158	166.7	151.50	334.3	394.3	425.7	442.0	399.1
Mean	50.4	50.8	54.5	62.9		88.	93.1	103.5	113.3		231.4	271.1	312.5	328.5	
LSD (0.05) for RMW = 8.89						LSD (0.05) for RMW = 4.430					LSD (0.05) for RMW = 25.35				
LSD (0.05) for NPK = 8.89						LSD (0.05) for NPK = 4.430					LSD (0.05) for NPK = 25.35				
LSD (0.05) for RMW * NPK = 17.77						LSD (0.05) for RMW * NPK = 8.860					LSD (0.05) for RMW * NPK = 50.70				

Note: Interaction between NPK and RMW.

Table 8. Impact of rice mill waste and NPK fertilizer on plant height of orange-fleshed sweet potato at 4 and 8 weeks of treatment application (WATA).

4 WATA						**8 WATA**					**12 WATA**				
RMW (t ha^{-1})						**RMW (t ha^{-1})**					**RMW (t ha^{-1})**				
NPK (kg/ha)	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**
0	10.13	25.07	27.53	29.63	23.09	31.33	46.67	64.33	74.33	54.17	63.0	76.3	96.3	99.7	83.8
200	19.80	32.07	38.00	38.43	32.07	47.67	54.67	74.67	86.33	65.83	120.0	126.0	134.7	132.7	128.3
400	28.23	51.50	53.60	58.63	47.99	50.67	77.33	86.67	97.67	78.08	145.7	155.3	155.0	150.0	151.5
600	39.60	65.50	68.63	75.70	62.36	100.3	117.67	128.67	136.67	120.83	178.3	195.7	187.0	193.7	188.7
Mean	24.44	43.53	46.94	50.60		57.50	74.08	88.58	98.75		126.8	138.3	143.2	144.0	
LSD (0.05) for RMW = 0.580						LSD (0.05) for RMW = 0.582					LSD (0.05) for RMW = 9.80				
LSD (0.05) for NPK = 0.580						LSD (0.05) for NPK = 0.582					LSD (0.05) for NPK = 9.80				
LSD (0.05) for RMW * NPK = 1.160						LSD (0.05) for RMW* NPK = 1.164					LSD (0.05) for RMW * NPK = 19.60				

Note: Interaction between NPK and RMW.

3.4.4. Impact of Rice Mill Waste and NPK Fertilizer on Weight of Root (kg Plot^{-1}) and Total Yield (t ha^{-1}) at Harvest

The effect of rice mill waste and NPK fertilizer on root weight and total storage yield of orange-fleshed sweet potato at harvest is presented in Table 9. The results showed a significant ($P<0.05$) increase in OFSP yield of amended plots over control with the application of rice mill waste and NPK fertilizer at 600 kg ha^{-} NPK fertilizer + 6 t ha^{-1} RMW recording the highest values.

Increased OFSP yield could be attributed to the dissolution of the NPK fertilizer in the soil, as well as the decomposition of the rice mill waste material, leading to the release of nutrients for the plant's uptake. This aligns with the findings of Chukwu et al. (2004); Akpaninyang et al. (2014); Nwankwo et al. (2023) and Ojikpong and Kekong (2019), who reported an increase in the number of leaves over control with the application of the N-fortified rice mill waste on maize plants.

Table 9. Impact of rice mill waste and NPK fertilizer on total yield of orange-fleshed sweet potato at harvest.

Weight of root (kg/plot)						**Total root yield (kg/ha)**				
RMW (t ha^{-1})						**RMW (t ha^{-1})**				
NPK (kg/ha)	**0**	**2**	**4**	**6**	**Mean**	**0**	**2**	**4**	**6**	**Mean**
0	0.47	0.61	0.83	0.90	0.70	0.937	1.017	1.530	1.500	1.246
200	0.73	0.83	0.96	1.00	0.88	1.217	1.373	1.600	1.680	1.462
400	0.89	0.99	1.00	1.20	1.02	1.463	1.653	1.660	2.000	1.694
600	1.25	1.30	1.20	1.40	1.29	2.090	2.163	2.000	2.330	2.146
Mean	0.84	0.93	1.00	1.12		1.427	1.552	1.697	1.872	
LSD (0.05) for RMW = 0.2022						LSD (0.05) for RMW = 0.102				
LSD (0.05) for NPK = 0.2022						LSD (0.05) for NPK = 0.102				
LSD (0.05) for RMW * NPK = 0.4044						LSD (0.05) for RMW * NPK = 0.204				

Note: Interaction between NPK and RMW.

4. CONCLUSION

The field experiment was conducted at the Teaching and Research Farm of Alex Ekwueme Federal University, Ndufu-Alike, to study the impact of rice mill waste and NPK fertilizer on soil chemical properties, growth, and yield of orange-fleshed sweet potato. The results showed that the various levels of rice mill waste, NPK fertilizer, and their combinations improved soil pH, soil organic carbon, available phosphorus, total nitrogen, total exchangeable bases, and percentage base saturation. The various levels of rice mill waste, NPK fertilizer, and their combinations increased the number of leaves, branches, plant height, total yield, and weight of storage roots of orange-fleshed sweet potato. Yield increased linearly with the highest rates of rice mill waste and NPK fertilizer, suggesting that the rates applied were not optimum. Rice mill waste is not frequently considered by farmers because of its high carbon-nitrogen ratio. Based on these findings, it is an important organic waste in the ecosystem because of its high organic carbon. The supply of nitrogen from the NPK fertilizer prevented nitrogen immobilization, and the high organic carbon content of rice mill waste produced great benefits to soils with low organic matter content.

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