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Impact of Sugar Pressmud Compost and Rice Husk Ash on the Productivity of Upland Rice (Nerica 1)

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Authors' contributions

This work was carried out in collaboration among all authors. Author MGK designed the study, performed the statistical analysis and wrote the first draft of the manuscript. The remaining authors analyzed the study results and managed the literature searches. All authors read and approved the final manuscript.

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Abstract

Factory waste products were evaluated at the National Agricultural Research Organization, Ikulwe satellite station, in Uganda to establish their efficacy as source of nutrients for rice. A potted study was conducted in CRB, replicated four times during 2022 and 2023 while, a field experiment was conducted in RCBD during 2023. The eleven treatments tested included: (i) 100 kg Di-Ammonium Phosphate (DAP) ha^{-1} (FDAP), (ii) sugarcane press mud compost (SPC) (iii) rice husks (RH) (iv) rice husk ash (RHA) (v) SPC + Cymbopogon compost (CC) (vi) RH + CC (vii) RHA + CC (viii) SPC + 50 kg DAP hectare^{-1} (HDAP) (ix) RHA + HDAP (x) RH + HDAP (xi) control (No amendments). Baseline soil physico-chemical properties were determined prior to planting, while nutrient uptake by rice was assessed at harvest. Growth attributes including height,

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leaf length, leaf width, leaf number and tillers were determined. Yield components, comprising panicles and grain and were quantified, and grain yield determined. Data were analyzed using GenStat package and Fischer's significant test applied. SPC had significant NPK, Ca, Mg & Fe while; RH and RHA recorded high K, Si, and Ca with deficiency in Mg & Fe. Treatments given FDAP, RHA + HDAP or SPC + HDAP, registered high NP in stover, growth parameters, yield attributes and yield relative, to RHA and RH amendments while, FDAP, RH and control produced shorter rice plants. Based on the current study, SPC + HDAP, RHA + HDAP and FDAP are hereby recommended as nutrients for increased productivity of upland rice in Uganda and similar ecosystems.

Keywords: Amendments; efficacy; factory waste products; nutrients; organic fertilizers.

1. Introduction

Farmers in the Uganda`s South Eastern Agro-Ecological Zone, grow upland rice, especially New Rice for Africa (NERICA) under various cropping systems using poor soil fertility management options. But there are no recommendations for the readily available and relatively abundant organic factory wastes being utilized as fertilizers for rice production in the country. The average yields under rainfed conditions are low (1.5 Mtha^{-1}) relative to the higher (3.5 Mtha^{-1}) yields under irrigated conditions (Odogola, 2006). Rice (*Oryza sativa* L.) has been ranked the most important cereal after maize in Uganda (Kilimo Trust, 2014; UBOS, 2023) and yet the productivity is still low. Choi & Hinkle, (2019) reported that the rice yields in Uganda are remarkably low at 2.5 Mtha^{-1} for both rainfed and irrigated conditions compared to other neighboring countries such as Rwanda (4.7 Mtha^{-1}) and Kenya (4.9 Mtha^{-1}). The global average is 4.7 Mtha^{-}1 (FAO, 2021). Alibu *et al.* (2016) & Barungi and Odokonyero, (2016), reported that the low yields are largely attributed to drought, low soil fertility, poor weed management, pests and diseases In the last 2 decades, the Uganda National Agricultural Research Organization (NARO) released NARIC (1 & 2) that were introduced and tested with international support, before Uganda's own breeding programs expanded local releases of New Rice for Africa (NERICA) 1, 4 & 10 varieties in 2002 to increase rice production and productivity. These rice varieties had a potential to produce better and stable yield of more than 4 Mtha^{-1}across seasons in 110-120 days. This consistency is highly valued by Ugandan smallholders who are risk averse. Kishine *et al.* (2008) reported that Nerica are interspecific cultivated rice crosses between Asia rice (*Oryza sativa* L.) and (African rice (*O. glaberrima*) (while NARIC are *Oryza sativa* types. The *O. glaberrima* rice varieties are drought tolerant and compete very well with weeds, while the *O. sativa* have high yield potential and grain quality. Some NERICA lines like NERICA 4 are reported to be tolerant to drought and low phosphorus under upland conditions. NERICA cultivars have shown resistance / tolerance to parasitic Striga species under field conditions, and moderate resistance to other stresses such as weeds and diseases (Rodenburg et al., 2015). These attributes confer on NERICA varieties a high degree of tolerance to intermittent drought, adaptability to non-flooded soils, and resilience under erratic rainfall conditions that are increasingly common in Uganda. With a relatively short growth cycle of approximately 90–120 days—shorter than many traditional rice varieties—NERICA cultivars enable farmers to escape terminal drought and integrate effectively into bimodal cropping systems. Their adaptability also reduces production risk in marginal rainfall environments. Moreover, NERICA varieties are characterized by rapid establishment and vigorous early growth, which enhances weed suppression, thereby lowering labor requirements, reducing production costs, and minimizing yield losses associated with weed competition. There is high demand for NERICA varieties which have spread all over Uganda. The popularity is associated with their high yields, but the crop requires fertile soil for high productivity. Fertilizer use is a rare practice among the rural Ugandan poor farmers and higher productivity has been associated with use of virgin land which has declined overtime. This is worsened by lack of organic fertilizer recommendations for newer upland varieties in Uganda (Onaga et al., 2012). Natural soil nutrient supplies are often insufficient to sustain high crop yields, especially with modern intensive agriculture. Jones (2023) reported that balanced application of fertilizers increases total nutrient content in soils and enhances crop production. Fertilizers, thus, maintain soil fertility and productivity and therefore, make a vital contribution to economic crop production (Johnson et al., 2023). Nitrogen (N), phosphorus (P), and potassium (K) are fundamental macronutrients governing rice growth and productivity.

The significance of organic fertilizers for improving yields of agricultural products is paramount in many countries including Uganda. Shu and Chung (2006), reported that the growth and nutrient accumulation of rice plants given the pea-rice hull compost were higher than under chemical fertilizer. The nutrient accumulation of the rice plants positively correlated with the dry matter yield. Fertilizers, thus, maintain soil fertility and productivity and therefore, make a vital contribution to economic crop production. He *et al.,*(2024), noted that Nitrogen is one of the most important nutrients that determine rice growth and yield, and optimizing nitrogen fertilizer management has been shown to enhance key productivity metrics such as grain yield, biomass accumulation, and nitrogen use efficiency. It positively influences tiller development, yield and yield components (Djaman et al., 2016). Nitrogen is vital for vegetative growth, photosynthesis, and yield, increasing tillers, panicles and grain count. Phosphorus is essential for roots development, energy (ATP) production, and early plant vigor. Phosphorus improves tillering, panicle formation, grain filling and enhances stress resistance. Potassium regulates photosynthesis, water/nutrient transport, enzyme activation and disease resistance. It increases filled grains, grain weight and yield especially under shading. Potassium promotes early flowering, improves nutrient content and cooking quality. Nitrogen and Phosphorus frequently limit crop growth, and Potassium can also be limiting depending on soil history and crop removal. Tirkey *et al.* (2024) reported that application of 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 40 kg K_20 ha^{-1} significantly increased plant height, produced maximum number of tillers, dry matter, leaf area index and maximum grain yield. Although Silicon (Si) has not been classified as an essential element for higher plants growth, it has been reported by Meena et al. (2014) to increase the number of rice spikelets per panicle, spikelet fertility, harvest index and rice N use efficiency. Saranya *et al.* (2018) recorded maximum maize leaf area and plant height under treatments with rice husk ash. Liang *et al.,* (2025) reported that nitrogen is one of the most important nutrients for rice growth and yield, and optimizing nitrogen fertilizer management has been shown to enhance key productivity metrics such as grain yield, biomass accumulation, and nitrogen use efficiency. Korotkova *et al.* (2016), reported that rice husk contains a significant amount of silicon dioxide (14.8%) and an adequate supply of silica is essential for good paddy yield. Suwarto and Suryono, (2015) noted that application of waste from rice husk ash brick factory, enriched with fertilizer N, P and K, increased production, quality and quantity of rice grain. Puppe (2023), reported that silicon application consistently mitigates heavy metal (including Zn) induced stress and enhances photosynthetic efficiency and chlorophyll concentrations in plants under abiotic metal stress conditions. Silicon was observed by Gharineh and Karmollachaab (2013), to reduce leaf transpiration and water flow rate in the xylem vessels and thus, increases water use efficiency and imparts mechanical resistance to pest and disease penetration by enhancing cell wall thickness below the cuticle. Rice husk ash is a major source silicon and is therefore recommended under intensive cropping or highly weathered tropical soils like many in Uganda.

Sugarcane Pressmud Compost (SPC), a by-product of the sugarcane industry, represents a promising source for enhancing soil fertility. Uganda has 16 sugar mills that generate about 7-8 million tons of sugar and 210-240 tons of SPC annually (UBOS, 2023). This by-product, rich in organic and essential nutrients, has gained attention as a valuable source for bio-fortification in agriculture. Compositing, stabilizes organic matter and transforms pressmud into a nutrient rich biofertilizers. The process involves microbial decomposition of organic material, resulting in the formation of humic substances. Soil properties, nutrient availability and rice yield, significantly, increased by application of nitrogen and sugar cane press mud compost (SPC), resulting in significant increases of N, P and K uptake in grain and straw compared with control treatments (Sajid et al., 2024). Interestingly, (Djaman et al., 2016) found lower nitrogen fertilizer requirement for aromatic (90 kg N ha^{-1}) than non-aromatic (120 kg N ha^{-1}) rice varieties at maximum grain yield. SPC is a rich source of organic carbon, N, P, K Ca, Mg, Fe and Si. Some studies have been conducted on SPC for its suitability in agriculture and for energy production (Kalaivanan and Hattab, 2008). The high ion (Fe) in SPC is usually more available to plants than iron in acidic soils because organic acids from composting help chelate iron, giving improved soil pH and Cation exchange capacity which enhances micronutrient uptake. Therefore, SPC can help to reduce iron deficiency symptoms in crops grown on sandy or alkaline soils. Considering the abundance and steady production of organic apparently waste products in Eastern Uganda such as rice and sugarcane factory products, use of some selected soil amendments is a good option for improved soil nutrient management, livelihoods and basic service support. Regulations against open burning of crop residues often accompany policies that promote sustainable reuse rather than disposal by fire. Crop residue management policies typically explicitly list composting and soil amendment production as desirable alternatives to burning, helping to maintain soil organic matter and nutrient cycling (Kalindi et al., 2025). A systematic and evidence-based approach is required to harness factory-derived organic waste products as reliable sources of high-quality organic manure capable of delivering consistent nutrient supply in Uganda. Against this background, the present study was conducted at the National Agricultural Research Organization (NARO), Ikulwe Research Station, during the 2022 and 2023 seasons to (i) evaluate effects of organic amendments on rice growth and yield performance and (ii) compare the efficacy of organic amendments with conventional fertilizer in improving rice productivity.

2. Materials and Methods

A screen house pot study was conducted at NARO, Ikulwe station, Uganda during 2022 and 2023, followed by a field experiment at the same station during 2023.

2.1 Screen House during 2022 and 2023

2.1.1 Amendment Details

Fresh rice husks (RH) and Sugarcane pressmud composts (SPC) were sourced from rice and sugar factories respectively. Fifty kilograms of dry rice husks were placed in a closed drum with a lid and lit with fire. The husks were burnt with limited air supply to complete combustion to produce white rice husk ash (RHA) after cooling inside the drum. The RHA was stored in an air tight container.

2.1.2 Preparation of Amendments

The RH, RHA and SPC were applied as sole or in equal proportions of the mixtures (1:1) and at a rate of 8 Mtha^{-1} or 0.8kg per square meter under field conditions.

2.1.3 Treatments and Experimental Design

The potted study aimed at establishing effects and efficacy of organic amendments on rice productivity. The eleven treatments arranged in a Complete Randomized Design (CRD), replicated four times with even light intensity, temperature, humidity, similar pots watered uniformly and rotated regularly included; (i) sugarcane press mud compost (SPC) (ii) rice husks (RH) (iii) rice husks ash (RHA) (iv) SPC + Cymbopogon compost (CC) (v) RH + CC (vi) RHA + CC (vii) SPC + 50 kg Di-Ammonium Phosphate (DAP) fertilizer ha^{-1} (viii) RHA + 50 kg DAP ha^{-1} (ix) RH + 50 kg DAP ha^{-1} (x) 100 kg DAP ha^{-1} (xi) Control. Half (0.5 kg) a kilogram of NERICA 1. All the amendments were applied basal at planting in the pots (Potted study) and in the hills for the field experiment. Rice seeds, sourced from the Uganda National Crop Resources Research Institute, Namulonge, were washed with distilled water and kept for 14 days after germination (DAG) in a wooden box (0.5 m (length) x 0.5 m (width) x 0.1m (high) filled with sandy-clay soil which was given 2 liters of water daily. The soil was excavated from land that had been under fallow for three years, filled in forty four, 3-liter plastic pots each with diameter 30 cm (top) x 15 cm (bottom) x 25 cm (height), bearing a hole at the bottom. All the nutrient amendments per treatment were mixed in the potted soil as basal. Two, uniform, healthy, 15 days old rice seedlings were transplanted to each pot that was watered with 0.5 liters of rain water every 4 days after till harvest at 75 days after transplanting. No nitrogen (N) was top dressed after transplanting.

2.1.4 Data Collection

Air-dried soil samples were collected and subjected to chemical analysis for organic matter, textural class and pH of the soil before the pot study. Air-dried soil and whole plant samples collected at harvest were subjected to chemical N, P, K nutrient uptake using standard Kjeldahl and molybdenum blue methods described by Saez-Plaza et al. (2013) & Yokota et al. (2003). Data were also recorded on the levels of N, P, K, Ca, Mg, Fe and Si in the amendments using standard methods and the pH was measured by a pH meter. The organic matter was determined by oxidation and calculating the percent ash as described by Masood et al. (2022). Plant height, leaf length and width were measured every two weeks on transplanted rice and the number of leaves and tillers were counted at the same time interval, till 50% panicle initiation (40 DAT), in all the treatments. At harvest (75 DAT), data were collected on the number of panicles per plant, filled panicles and grains per panicle for all the treatments.

2.2 Field Study

A field experiment was conducted at Ikulwe station during 2023 to establish effects and efficacy of organic amendments on rice yields.

2.2.1 Study Site and Rainfall

The field site was located at 00º 26’ 23.2’’N 033º 28’ 40.9’’ E, at 1209 meters above sea level. The area received a total of 815 mm of the total 1240 mm annual rainfall with minimum and maximum temperatures of 19.8^{0}C and 30 ^{o} C respectively during the cropping season of 2023 (Fig. 1).

2.2.2 Experimental Design and Treatments

The study was arranged in a Randomized Complete Block Design (RCBD) with similar treatments used in the pot study, replicated three times with each hill having 3 rice plants. The experimental units measured 5 x 5 m with 2 m space between the plots. NERICA 1 was planted by drill method at a seed rate of 50 kg ha^{-1}, under spacing of 30 cm x 12.5 cm (3 seeds) in a clean field that had been ploughed twice and disc hallowed. N and P nutrients were applied as basal fertilizers at planting and no additional fertilizers were top dressed. The sources of N & P were DAP (18% N & 46% P). The crops were thinned to 2 plants per hill at 14 days after emergence (DAE) and hand hoeing was done uniformly at 21 and 42 DAE in all the treatments. There were no pests and disease incidences; thus, no control measures were administered.

2.2.3 Data Collection

Fifteen plants from individual net plots of each crop were randomly selected and tagged at 15 DAE for biometric observations. The plant heights were measured from the ground to the base of the last fully opened rice flag leaf. The length and width of the plant leaves were taken by measuring the longest leaf and widest leaf parts, respectively. Data were also collected weekly on the number of tillers and green leaves of tagged plants in all the treatments. Data collection during the vegetative stage ended at 50% flowering of rice. At harvest, 2 boarder rows together with two plants at both ends of rows in all plots were harvested as guard rows and net plot crops were considered for yield data collection. The number of panicles per plant, filled and empty panicles per plant, total grains and filled grains per panicle were determined on 15 earmarked plants. The yield per hectare was determined using harvested grain rice in net plots each measuring 20 m^2 at 90 DAE.

2.2.4 Data Analysis

Collected data were subjected to analysis of variance (ANOVA) using GenStat statistical package (13th edition, 2013). The significant differences between treatments means were separated using Fischer's least significant difference (LSD) test at P=0.05.

3. Results

3.1 Properties of the Site and Soil at the Experimental Site

During 2022 in the pot experiment at Ikulwe station, where the field study was also conducted, the minimum and maximum temperatures were 19.2^{0}C and 31^{0}C respectively, during the cropping season. The average annual minimum and maximum temperatures were 19^{0}C and 32^{0}C. The properties of the luvisol soil established before conducting the study indicated the organic matter as 3%, pH was 5.7 with textural sand (57%), silt (20%) and clay (23%).

3.2 Rainfall during the Cropping Season of 2023

The weekly rainfall for the cropping season is indicated in Fig. 1. A total of 649.7mm of rainfall was received between September and December (2023) with monthly totals of 141.7mm (September), 220.7mm (October), 155.1mm (November) and 132.2mm (December).

3.3 Nutrients in the Soil and Amendments

The amounts of available nitrogen, exchangeable phosphorus and exchangeable potassium for the soil used in the pot and field studies are indicated in Table 1. The soil had low levels of available nitrogen (N), phosphorus (P), potassium (K) and low exchangeable calcium (Ca), magnesium (Mg) and iron (Fe). Sugarcane press mud compost recorded high levels of available NPK, with substantial levels of available silicon (Si) and exchangeable calcium (Ca), magnesium (Mg) and iron (Fe). The rice husks (RH) had higher N than rice husk ash (RHA), but the latter gave higher available K, Si, exchangeable Ca, Mg and Fe. Rice husks were highly deficient in exchangeable Mg and Fe. Cymbopogon compost recorded higher levels of N and K with low exchangeable Fe.

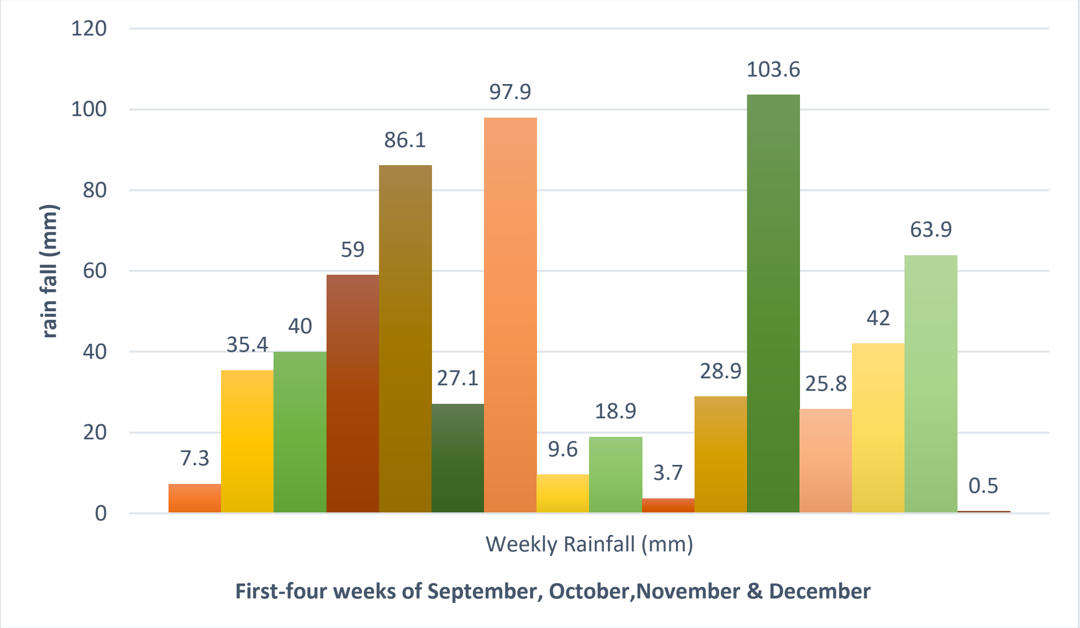

Fig. 1. Rainfall during September – December 2023

Table 1. Nutrients in the soil and the amendments

Treatment	**Available nitrogen (mg kg^{-1})**	**Available phosphorus (mg kg^{-1})**	**Available potassium (mg kg^{-1})**	**Available silicon (mg kg^{-1})**	**Ex. calcium (ppm)**	**Ex. Mg (ppm)**	**Ex. iron (ppm)**
Soil	1,500	30	310	40	51	245	20
SPC	19,000	20,000	2,000	90,000	25,000	15,000	7,500
Rice husks	4,000	500	8,500	15,000	4,000	500	150
Rice husk ash	600	400	16,000	800,000	9,000	1,500	800
CC	30,000	4,000	20,000	20,000	10,000	4,000	30

Note: Ex=Exchangeable, Mg =Magnesium, mg kg^{-1} = Milligrams per Kilogram, ppm= Parts per million

3.4 Nutrient Uptake by NERICA 1 Stover at Harvest

The data on nutrient uptake by NERICA 1 Stover as influenced by field treatments during 2023 are indicated in Table 2. Treatments given the recommended (100 kg ha^{-1}) DAP fertilizer or Sugar pressmud compost (SPC) + half DAP (50 kg ha^{-1}) recorded high NP uptake in the Stover. High P and K uptake were observed under RHA + HDAP. Rice husks + HDAP recorded lower NPK uptake. SPMC and CC treatments recorded medium uptake levels of P and K, with low N uptake in the rice Stover. Rice amended with RHA recorded higher uptake of Potassium (34.5 mg/plant). RHA, RH + CC and sole RH scored lower NPK uptake in rice Stover at harvest while, the lowest observations were under the control.

3.5 Effects of Different Amendments on Growth Attributes of Potted NERICA 1 during 2022

Results on the growth attributes for potted NERICA 1 during 2022 are given in Table 3. Application of all the treatments except FDAP fertilizer and sole RH significantly ($P \leq 0.05$), increased the height of rice.

Table 2. Nutrient uptake by NERICA 1 rice Stover at harvest during 2023

	Nutrient uptake (mg/plant)		
Treatment	**Nitrogen (N) (mg/plant)**	**Phosphorus (P) (mg/plant)**	**Potassium (K) (mg/plant)**
FDAP	5.60a	1.03a	12.60d
HDAP	5.30a	0.94a	30.50b
Rice husk ash + HDAP	4.30b	0.89a	31.50a
Rice husks + HDAP	4.50b	0.78b	11.40d
SPC + Cymbopogon compost	3.80c	0.76b	28.50b
Sugarcane Press mud compost	3.78c	0.72b	28.40b
Rice Husks Ash + Cymbopogon Compost	3.79c	0.68b	23.70c
Rice Husk Ash	3.50c	0.63b	34.50a
Rice husks + Cymbopogon Compost	3.26d	0.62b	13.60d
Rice husks	3.65c	0.56b	7.60e
Control	2.97d	0.50c	7.30e
P-value	<0.001	0.05	<0.001
LSD (P=0.05)	0.30	0.19	3.14
CV (%)	3.5	2.0	4.5

Values with different letters in a column are significantly different at P≤0.05, SPC = Sugarcane Press Mud Compost. FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare

Table 3. Growth parameters of potted NERICA 1 at 50 days after transplanting during 2022

Treatments	**Plant height (cm)**	**Leaf number**	**Leaf length (cm)**	**Leaf width (cm)**	**Tiller numbers**
FDAP	30.57b	4.87	45.27a	2.00a	2.88a
HDAP	46.33a	4.88	38.77a	2.20a	3.20a
Rice husks + HDAP	39.87a	5.20	38.60a	2.00a	2.37a
Rice husk ash + HDAP	43.10a	5.13	42.73a	2.10a	3.40a
SPC + Cymbopogon Compost	47.97a	5.73	38.53a	2.10a	2.53a
Sugarcane Pressmud Compost	49.07a	5.67	32.07b	2.00a	2.27a
Rice Husk Ash + CC	46.83a	4.87	32.07b	2.00a	2.53a
Rice Husk Ash	39.33a	4.60	28.47c	2.00a	1.87b
Rice husks + CC	45.27a	5.40	28.47c	1.90b	1.40b
Rice husks	36.37b	5.13	28.13c	1.90b	0.53c
Control	35.73b	5.27	28.43c	1.60c	0.67c
P-value	<0.001	NS	<0.001	0.01	<0.001
LSD (P=0.05)	9.84	0.89	6.81	0.02	0.84
CV (%)	3.80	–	4.80	3.23	5.60

Values with different letters in a column are significantly different at P=0.05, NS = Not significant, SPC = Sugarcane Pressmud Compost. FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare

The height under the later 2 treatments was at par with the control, which recorded the shortest plants. Application of RHA, RH + CC or sole RH recorded low leaf length and width. The number of tillers per rice plant was high under DAP or SPMC, but significantly reduced (<0.001) under RH and RHA amendments. The control produced shorter plants, lower leaf length and width with the least number of tillers per rice plant. The number of leaves was not significant under the treatments.

Table 4. Growth parameters of potted NERICA 1 in the field at 50 days after transplanting during 2023

Treatments	Plant height (cm)	Leaf number	Leaf length (cm)	Leaf width (cm)	Tillers
FDAP	30.70b	5.10	37.73a	1.97a	3.53a
SPC + HDAP	47.40a	4.77	31.18a	1.57a	2.53a
Rice husks + HDAP	45.50a	5.32	34.38a	1.67a	2.58a
RHA + HDAP	40.60a	4.37	31.32a	1.58a	2.77a
SPC + CC	44.60a	5.17	30.98a	1.47a	2.53a
SPC	38.20a	3.45	27.47b	1.23b	2.10b
RHA + CC	38.70a	3.25	24.42b	1.07b	1.63b
Rice Husk Ash	39.70a	3.63	27.45b	1.04b	2.07b
Rice husks + CC	39.60a	4.27	20.40c	1.26b	1.73b
Rice husks	33.70b	4.27	22.85b	0.94b	1.25b
Control	33.50b	3.85	22.15c	0.71c	0.42c
P-value	0.043	NS	<0.001	0.004	0.001
LSD (P=0.05)	10.01	2.1	6.75	0.54	1.42
CV (%)	5.60	–	4.80	5.20	4.87

Values with different letters in a column are significantly different at P=0.05, NS = Not significant, DAP = Di-Ammonium Phosphate, SPC = Sugarcane Pressmud Compost. FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare, RHA= Rice Husk Ash, Cymbopogon Compost

Table 5. Yield attributes of potted NERICA 1 at harvest during 2022 and 2023

		2022			2023		
Treatments	**PP (Panicles)**	**GP (Grains)**	**PFGP (%)**	**PP (Panicles)**	**PFPP (%)**	**GP (Grains)**	**PFGP (%)**
FDAP	3.2a	58.4a	58.5g	2.93a	57.6b	51.8a	70.5
SPC + HDAP	2.9a	64.9a	65.5e	3.13a	65.5b	63.4a	87.6
Rice Husk Ash + HDAP	3.0a	52.0a	51.0h	3.13a	45.1c	46.2a	72.5
Rice husk + HDAP	2.3b	69.1a	79.5a	2.40b	88.7a	67.3a	72.1
SPC + CC	3.0a	47.4a	71.0c	2.87a	55.3b	47.5a	82.7
SPC	2.5b	42.6a	73.5b	2.67b	56.0b	43.5a	79.5
Rice Husk Ash	2.4b	29.3b	71.5b	2.67b	52.2b	23.8b	73.7
RHA + CC	2.5b	30.0b	62.5f	2.40b	42.9d	25.2b	69.2
Rice husks + CC	1.3c	31.0b	68.5d	1.53c	66.1b	22.8b	81.5
Rice husks	1.6c	38.7b	80.5a	1.87c	57.6b	26.8b	92.8
Control	1.6c	31.0b	72.5b	1.00d	86.7a	20.2b	76.4
P-value	<0.001	0.04	<0.001	<0.001	<0.001	0.003	NS
LSD (P=0.05)	0.63	28.76	2.40	0.61	21.80	22.78	23.7
CV (%)	6.0	5.80	4.30	5.30	6.20	5.80	–

Values with different letters in a column are significantly different at P≤0.05, FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare, SPC = Sugarcane Pressmud compost, NS = Not significant, PP = Mean Panicles per plant, PFPP = Percent filed panicles per plant, GP = Mean grains per panicle, PFGP = Percent filled grains per panicle, CC= Cymbopogon Compost

3.6 Effects of Different Nutrient Amendments on Growth Attributes and Yield Attributes of Rice in the Field During 2023

3.6.1 Growth Parameters

The results on the growth parameters for potted NERICA 1 during 2023 are indicated in Table 4. All the treatments applied recorded significantly (0.04) high plant height compared to the FDAP, RH and the control. There was significantly higher leaf length (*P*=0.001), leaf width (*P*=0.004) and number of tillers (*P*=0.001) under the treatments with FDAP, SPC + CC relative to other treatments. RH and RHA produced rice with low leaf length, width and tillers, while the control treatment scored the lowest parameters.

3.6.2 Yield Attributes

The data on yield attributes for potted NERICA 1 under different nutrient amendments during 2022 and 2023 are indicated in Table 5. Application of FDAP, SPC + HDAP and RHA + HDAP, produced significantly *(P*=0.05), high panicles per plant (PP), percent filled panicles per plant (PFPP) and grains per panicle (GPP) during the two years. Introduction of RHA, RH and the control gave lower PP and GP during the 2 years. Intermediate PP and GP were recorded under sole SPC, RHA and RHA + CC during 2022 and 2023. The PFGP and PFPP significantly (*P*=0.001), increased for RH (80.5%) and the control (86.7%) during 2022 and 2023 respectively. PFGP was not significant during 2023.

3.7 Effects of Nutrient Amendments on Growth and Yield of NERICA 1 in the Field During 2023

3.7.1 Growth Parameters

The growth parameters for NERICA 1 as influenced by nutrient amendments under field conditions are presented in Table 6. Application of FDAP (100 kg ha^{-1}), sugarcane press mud compost (SPMC) + HDAP fertilizer (50 kg ha^{-1}), RHA + HDAP fertilizer or SPC + CC as amendments to the field rice, significantly, (*P*=0.05) increased the rice leaf length by 6 cm, 1.8 cm, 1.8 cm and 1.3 cm respectively over the control (5.08 cm). Application of sole SPMC, RH alone or RH with either CC or HDAP amendments, RHA alone or RHA + CC, did not influence the rice plant leaf length. The rice plant height, leaf number, leaf width and number of tillers were not significant under field conditions.

3.7.2 Yield Attributes and Yield

The data in Table 7 indicated that application of the FDAP fertilizer, SPMC) + HDAP fertilizer, RHA + HDAP fertilizer or SPC + CC significantly, (*P*=0.05), increased the number of total panicles per square meter (TP m^{-2}) and grains per panicle (GPP). Lower TP m^{-2} and GPP were observed under sole RH, RH + CC, RHA and RHA + CC, sole SPC and RH + HDAP fertilizer during 2023. High grain yield (3.45 Mt ha^{-1}) was produced by rice treated with the FDAP fertilizer which was similar to the grain yield (3.27 t ha^{-1}) under SPC + HDAP fertilizer. This was followed by low grain yield of 2.87 Mt ha^{-1} under RHA + HDAP, SPMC + CC (2.86 kg ha^{-1}), RH + HDAP (2.64 Mt ha^{-1}) and SPMC (2.57 Mt ha^{-1}), which were similar. Application of sole RH, RH + CC, sole RHA and RHA + CC produced significantly lower (*P*=0.001) rice grain yield. The control treatment recorded the lowest (1.85 Mt ha^{-1}) rice grain yield, while the percent filled panicles per square meter did not differ amongst the applied soil amendments.

Table 6. Growth parameters of field NERICA 1 at 65 DAE under nutrient amendments (2023)

Treatments	**Plant height (cm)**	**Leaf number (leaves)**	**Leaf length (cm)**	**Leaf width (cm)**	**Tillers -**
FDAP	34.00c	5.00	37.08a	0.16	3.23a
SPC + HDAP	41.50a	4.80	32.87a	0.15	3.43a
Rice husk ash + HDAP	43.69a	5.00	32.83a	0.15	2.69b
SPMC + CC	41.69a	4.58	32.31a	0.15	3.56a
Rice husks + HDAP	37.86b	4.83	30.55b	0.18	3.14a
SPC	42.92a	4.48	29.53b	0.16	3.22a
Rice Husk Ash + CC	43.19a	4.94	30.53b	0.15	3.02b
Rice Husk Ash	41.07a	5.01	29.58b	0.18	3.02b
Rice husks + CC	40.88b	5.06	31.06b	0.16	3.03b
Rice husks	39.25b	4.10	25.02c	0.14	2.47c
Control (No amendment)	38.64b	5.08	31.06b	0.15	2.31c
P-value	0.66	NS	0.02	0.06	0.03
LSD (P=0.05)	5.82	0.99	5.00	NS	0.46
CV (%)	5.80	–	5.20	–	5.60

Values with different letters in a column are significantly different at $P \leq 0.05$, SPC = Sugarcane press mud compost, FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare, NS = Not significant

Table 7. Yield attributes and yield for field NERICA 1 at harvest under nutrient amendments (2023)

Treatments	**TP m^{-2} (Panicles)**	**% FP m^{-2} (Percent)**	**GPP (Grains)**	**Yield (Mt ha^{-1})**
FDAP	226.3a	77.3	107.3a	3.45a
SPC + HDAP	245.3a	87.9	105.2a	3.27a
Rice husk ash + HDAP	229.0a	91.0	109.9a	2.87b
SPC + Cymbopogon compost	215.0a	85.8	98.6a	2.86b
Rice husks + HDAP	199.0b	80.4	89.8b	2.64b
SPC	162.0b	83.8	89.1b	2.57b
Rice Husk Ash + CC	188.0b	86.4	88.2b	2.36c
Rice Husk Ash	171.3b	83.4	72.4c	2.28c
Rice husks + CC	163.3b	81.8	88.8b	2.44c
Rice husks	179.3b	60.4	94.8a	2.16c
Control	121.3c	76.5	74.9b	1.85d
P-value	0.03	NS	0.05	<0.001
LSD (P=0.05)	39.10	14.60	16.63	0.48
CV (%)	11.50	–	4.78	10.30

Values with different letters in a column are significantly different at P=0.05, FDAP = 100 kg Di-ammonium phosphate fertilizer per hectare, SPC = Sugarcane Pressmud Compost, HDAP = 50 kg Di-ammonium phosphate fertilizer per hectare, CC = Cymbopogon compost, FP = filled panicles, % = percent, m^{-2} = per square meter, GPP = grains per panicle, Mt ha^{-1}= Metric tons per hectare

4. Discussion

4.1 Properties of the Site and Soil for the Pot and Field Studies

During 2022 and 2023 when the pot experiment and field study were conducted at Ikulwe station, the weather conditions favored both studies and the properties for the luvisol soil indicated the moderate organic matter, near neutral pH with textural sand, silt and clay soil.

4.2 Nutrient Uptake by NERICA 1 Stover at Harvest

The soil had low levels of available nitrogen (N), phosphorus (P), potassium (K) and small levels of exchangeable calcium (Ca), magnesium (Mg) and iron (Fe). Low to medium nutrient availability in Luvisol significantly limits rice productivity in Uganda, leading to poor crop growth, reduced tillering, weak root development, poor grain filling, and ultimately low yields. Upland rice systems are more constrained by nitrogen and phosphorus deficiencies due to leaching and strong P fixation, while lowland systems are mainly affected by nitrogen losses and potassium related grain filling constraints. The present discussion highlights how deficiencies of these nutrients differentially affect upland rice systems, with implications for crop growth, yield components, and fertilizer use efficiency. Nitrogen deficiency was pronounced due to aerobic soil conditions and possibly caused by N losses through leaching and erosion. On Luvisol, which are typically low in organic matter and total nitrogen, inadequate N supply would have resulted in poor early vigor, reduced tillering, and limited leaf area development if amendments were not applied (control). These findings underscore the importance of synchronizing N supply with crop demand production systems.

Phosphorus deficiency exerts a stronger limitation on upland rice compared to lowland rice. Under aerobic conditions, P availability is often restricted due to strong fixation by ion and aluminum oxides, a common characteristic of Luvisol in the tropics. Poor P availability adversely affected root development, tiller survival, and early crop establishment of upland rice (control), resulting in delayed phonological development and reduced grains per panicle for the control treatment (sections 3.6.1 & 3.6.2).

Potassium deficiency negatively affected upland rice performance, although its impact was more evident during reproductive and grain filling stages in control treatment (section 3.6.2). On Luvisol, continuous cropping and the removal of straw progressively deplete exchangeable K reserves. In upland rice, low K availability reduces drought tolerance and increased susceptibility to lodging under high biomass conditions. Moreover, inadequate K supply reduces the efficiency of applied N, highlighting the importance of balanced nutrient management rather than single nutrient fertilization strategies. Rice husk ash and Cymbopogon extracts under the current study possibly contributed greatly to improved rice growth and development given the high levels of K (section 3.3) as soil amendments. The results in the current study are consistent with reports that emphasize nutrient imbalance and soil fertility depletion as major causes of yield stagnation in smallholder rice systems across sub-Saharan Africa and particularly in Uganda by Awio et al. (2021); Saito et al. (2015); Kyalo et al. (2025). Sugarcane press mud compost (SPC) recorded high levels of available NPK, with substantial levels of available silicon (Si) and exchangeable calcium (Ca), magnesium (Mg) and iron (Fe). Based on the results of the current study, SPC, could have accounted for significant NPK uptake levels by rice under treatments given SPC amendments (section 3.4) and the high plant height and leaf length (section 3.5) in the potted plants. The results also showed significantly high plant height, leaf length, leaf width, and number of tillers under field ecosystems with SPC (section 3.6.1) and high panicles per plant and grains per panicle under the same treatment (section 3.6.2).

Despite the rice husks (RH) having a higher level of N than rice husk ash (RHA), and the later giving the highest silicon (Si) level among the amendments, the two treatments resulted in poor rice growth and yield performance. This may be attributed to the high deficiency of exchangeable Mg and Fe in RH. Rice husks are mainly high in lignin and silica, not readily available plant nutrients. They are slow to decompose and release nutrients. Because of the high carbon content, microbes break down the husks slowly and can immobilize nitrogen (microbes use soil N to decompose the husks), making less nitrogen available to the crop. This could have limited the rice growth where no other amendment was added. RHA is mostly silica (SiO_2) after burning. While silicon is beneficial for rice, it is not a micronutrient like N, P, or K, so RHA alone generally doesn’t supply the primary nutrients rice needs for high productivity. Rice needs silicon (Si) as a beneficial element for strength, disease resistance and strass tolerance. However, in RH, much of the silica is insoluble, dissolves very slowly and unavailable to plants. Silicon is also reported to increase the number of rice spikelets per panicle, spikelet fertility, harvest index and rice N use efficiency by Gharineh and Karmollachaab (2013); Meena et al. (2014); Detmann et al. (2012); Ahmed et al. (2012).

Research indicates that when RH or RHA is used without adequate NPK or other amendments, neither raw husks nor RHA provides the right nutrient balance for good rice growth. RHA has high silica but burning at high temperatures makes it less soluble. RHA is only beneficial if properly processed or added in combination with other sources. Phyo *et al.,* (2024), reported that RHA alone did not outperform the control and the highest yield was with RHA + potassium fertilizer. The results are also supported by Sekifugi et al. (2019) & Jeer et al. (2018). Cymbopogon compost (CC) recorded higher levels of N and K in Stover under the current study. The potted rice crop with CC amendment produced longer and wider leaves when combined with SPMC, relative to sole SPC (section 3.5). The potted study also recorded more panicles per plant, grains per panicle and percent filled grains per panicle (section 3.42). The current results further indicated that SPMC + CC amendment to rice in the field produced taller plants with more tillers, panicles per unit area and grains per panicle relative to sole SPC (sections 3.6.1 & 3.6.2), indicating nutritional benefits from CC amendments. Olasan *et al.* (2025) indicated increased productivity of cowpea from *Cymbopogon Citrates*. Overall, for best rice responses, we need to combine plant-based compost with balanced fertilization or nutrient sources. The differential responses of upland rice to NPK and micronutrients availability require site specific nutrient management approaches tailored to the soil type and water regime, using organic amendments. Without such interventions, continued nutrient mining will further degrade soil fertility and undermine the long-term viability of rice-based production systems in Uganda.

4.3 Effects of Different Nutrient Amendments on Potted and Field NERICA 1 During 2022 and 2023

4.3.1 Growth Parameters

The rice plant height and tillers per plant significantly increased when DAP fertilizer, sugarcane press mud compost, rice husk ash and Cymbopogon compost were applied as soil amendments. The results could have resulted from various physiological processes of cell division and elongation of the plant. This may be attributed to availability of Phosphates from the amendments, which is essential for roots development, energy (ATP) production, and early plant vigor, besides, improving tillering, panicle formation, grain filling and enhancement of stress resistance. All the above benefits from phosphorus could have directly contributed to the rice plant stem initiation and development. The results are supported by Tirkey et al. (2024); Tsukru et al. (2023), who observed similar results at high phosphorus levels. The reduced rice plant height under 100 kg DAP fertilizer per hectare, sole rice husks and the control treatments were possibly due to the observed significantly low NPK uptake by rice (section 3.4) under the control and rice husks treatment. There was reduction in rice plant height on application of DAP fertilizer which was at par with data for the control and treatment given rice husks. This could be attributed to early stimulation of root growth than shoot elongation by phosphorus. Rice plants develop shorter but sturdier stems, allocate assimilates to roots and tillers rather than vertical growth under conditions of high levels of phosphorus and this condition is reflected in compact plants but not poor growth. Applied DAP supplies nitrogen mainly as ammonium (NH_4^+). High ammonium concentrations reduce gibberellic acid activity, which controls stem elongation and favors short internodes. This effect is desirable for reduced rice lodging under paddy conditions. The lower rice height could have also resulted from reduced Zinc availability due to P-Zn antagonism. Excess phosphorus from DAP fertilizer reduces plant height, bronzing or causing pale young leaves and delayed maturity. When DAP is used as the main source of N, without top dressing with Urea as was adopted in the current study, DAP provides more P relative to N and N becomes limiting. Nitrogen is vital for vegetative growth, photosynthesis, and yield, increasing tillers, panicles and grain count. A possible imbalance in P relative to N possibly could have caused reduced cell division with shorter plants during vegetative and reproductive stages. The NERICA rice varieties also have a genetic response that prioritizes tillering and panicle number over height. Nesution *et al.* (2021) observed formation of new cells in growing tissue due to increased levels of phosphorus for nitrogen.

Sugarcane press mud compost as amendments to the potted and field rice, significantly, (P=0.05) increased the rice leaf length over the control under the current study (section 3.5 & 3.6). SPC has high levels of $Ca^{2+,}$ Mg^{2+} and Fe^{2+}/Fe^{3+}. Exchangeable Calcium strengthens cell walls and membranes, leading to healthy root tips and better root penetration. It also improves tiller survival and reduces rice lodging by strengthening stems. Ca^{2+} also enhances tolerance to salinity, acidity and toxic levels of Al^{3+} and Fe^{3+}, which creates favorable conditions for nutrient availability. Exchangeable Mg^{2+} is a central component of chlorophyll, hence essential for photosynthesis. It improves leaf area development, leaf greenness and biomass accumulation. It also activates many enzymes involved in energy transfer (ATP) and carbohydrate metabolism. Exchangeable Mg^{2+}similarly, supports grain filling by enhancing translocation of photosynthates to rice panicles. Exchangeable Fe^{3+}, is essential for chlorophyll synthesis and electron transport in photosynthesis and respiration. It promoted vigorous early growth and rice is generally tolerant to high Fe, but still requires adequate levels for optimal metabolism. The results showed low scores of leaf length, leaf width and number of tillers per plant with the application of the RHA, RH + CC and RH soil amendments. This may be attributed to low levels of available N and P (section 3.3) in the amendments that would not synergistically influence rice growth. Nitrogen is a major component of chlorophyll, amino acids and proteins. Adequate N increases cell division and cell elongation, especially in young leaves. Nitrogen promotes lateral expansion of leaf cells, increases protein synthesis, and enhances leaf blade thickness and width. It also stimulates axillary bud initiation and out growth, and improves cytokines production, which breaks apical dominance. This results into more tillers per hill, especially if N is available at early vegetative stages. Phosphorus supports energy transfer (ATP) needed for cell division, enhances early root growth, improving nutrient and water uptake, while P ensures efficient carbohydrate metabolism and transport with support to balanced leaf expansion. Phosphorus is critical for early tiller initiation, promotes strong root systems that transport multiple tillers. N and P have a synergistic effect and when they are deficient, the crop develops short leaves, narrow canopies and develops low tiller numbers. Shorter plants with lower leaf length, width and number of tillers per plant were observed under the control treatment. This may be attributed to the lower NPK nutrient uptake by rice plants (section 3.4). Similar results were reported by Murthy et al. (2015) on rice plant height with increased levels of Nitrogen.

4.3.2 Yield Parameters

The 100 kg DAP fertilizer per hectare, SPC + HDAP and RHA + HDAP fertilizer, produced significantly (P=0.05), high panicles per plant, percent filled panicles per plant and grains per panicle during the two years. The increases may be attributed to increased photosynthetic rates due to increased translocation of photosynthates to the sinks. Similar observations were reported by Singh et al. (2017); Singh et al. (2017) due to increased NPK fertilizer applications. Maurya *et al.* (2021) observed higher growth, yield attributes and nutrient uptake by different rice varieties following increased levels of nitrogen. Tirkey *et al.* (2024) similarly, reported that application of 120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1} significantly increased plant height, and produced maximum number of tillers, dry matter, leaf area index and maximum grain yield. The data (Section 3.3) recorded high available Nitrogen (19,000 mg kg^{-1}) and Phosphorus under SPMC (20,000 mg kg^{-1}).

Phosphorus was additionally supplied through the applied DAP fertilizer, which could have enhanced multiple metabolic and physiological processes throughout the plant's life cycle. Archana *et al.* (2017) reported that higher yields associated at increased levels of phosphorus were possibly due to better root growth and increased uptake of nutrients favoring better crop growth. Higher grain yield with application of K_2O relative to the control was registered by Brahi et al. (2000); Ola et al. (2019). Rice uptake for P and K under RHA amendment was high (Section 3.4). This may be associated with influences of the high Silicon (800,000 mg kg^{-1}) in RHA recorded under the current study (Section 3.3). The lower PP and GP under sole RHA, rice husks and the control during the 2 years, may be attributed to the low NPK uptake by rice recorded under the treatments (Section 3.4) and associated with the lower available NPK and micro nutrients (section 3.3) in the treatments. The higher Percent filled grains per panicle (PFGP) and Percent filled panicles per plant (PFPP) for RH and the control treatments during 2022 and 2023, relates to the lower Panicles per plant and grains per panicle recorded (Section 3.6.2 & 3.7.2).

5. Conclusion and Recommendations

Sugar cane pressmud compost had significant NPK, Ca, Mg & Fe while rice husks recorded higher N than rice husk ash, which recorded high K, Si, Ca but significantly lower Mg & Fe. In the screen and field conditions, treatments given 100 kg DAP (FDAP) or SPC + 50 kg DAP (HDAP) per hectare, recorded high NP in Stover, longer leaf length, leaf width and more tillers relative to RHA and RH amendments. High PK uptake was recorded under RHA + HDAP and FDAP or SPC + HDAP beside RHA + HDAP amendments recorded high panicles per plant, percent filled panicles per plant, grains per panicle and grain yield. RH + HDAP, SPC + CC, RHA, RH + CC and RH amendments recorded low PK uptake with low N levels in Stover, low leaf length, low leaf width, tillers and yield. All other amendments produced taller rice than FDAP, RH treatments and the control. It could be concluded from the current study that SPC and RHA (8.0 $Mtha^{-1}$) amendments should be promoted for increased upland rice productivity but need to be supplemented with 50 $kgha^{-1}$ Di-ammonium phosphate fertilizer since the treatments produced higher rice growth, yield parameters and yield under both the controlled screen house and field conditions, and both treatments recorded similar results to the recommended Di-ammonium phosphate fertilizer (100 $kgha^{-1}$) for upland rice ecosystems. The three treatments could be recommended for increased productivity of upland rice in Uganda and similar ecosystems.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

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