

Integration of Organic and Inorganic Nutrient Sources on the Yield and Economics of NERICA 4 and Toyohatamochi Upland Rice Varieties

Zainah Kampi¹, Lastone Kanhica², Emmanuel Odama^{3*}, Kisho Miyamoto¹, Hisashi Urayama⁴

¹Eco-PRiDe Project, Japan International Cooperation Agency, Kampala, Uganda

²Ministry of Agriculture, Animals and Fisheries, Luanda, Angola

³Abi Zonal Agricultural Research and Development Institute, National Agricultural Research Organization, Arua, Uganda

⁴Japan International Cooperation Agency, Tokyo, Japan

Email: kampi.zainah@gmail.com, kisho.miyamoto122@gmail.com, lastonekanhica18@gmail.com,

*emmanuel.odama@naro.go.ug, urayama@oada.or.jp

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Abstract

Rice yield in sub-Saharan Africa is still low in contrast to other parts of the globe, and this is mainly attributed to low soil fertility and poor cultivation techniques. The cost of chemical fertilizers is prohibitively high for small-holder farmers in the region. On the other hand, however, organic fertilizer sources like cow dung and chicken waste are freely and readily available to improve soil properties and nutrients for improved plant growth and grain quality. To evaluate the efficiency of organic fertilizer in combination with chemical fertilizer for improved upland rice yield, a field experiment was conducted with two factors: fertilizer (O30, 30% Organic and 70% Chemical; O50, 50% Organic and 50% Chemical; and C, Control having chemical fertilizer only) and variety (NERICA 4 and Toyohatamochi). Results showed that the percentage of ripened grains in the 50% organic treatment was significantly higher than in the 30% organic treatment and Control. Additionally, NERICA 4 exhibited a significantly higher percentage of ripened grains compared to Toyohatamochi. While there was no significant difference in rice yield between fertilizer levels and rice varieties, mean rice yield, ripen grain percentage and net benefit for the 50% organic treatment were the highest, followed by 30% organic, then Control. The cost-benefit analysis results showed that 50% organic fertilizer had the lowest cost of fertilizer input, and the highest net benefit.

Keywords

Upland Rice, Inorganic Fertilizers, Cost-Benefit Analyses, Organic Fertilizers, Compost, Yield

1. Introduction

The demand for rice in sub-Saharan Africa (SSA) is continuously increasing [1] [2]. Rice demand in the region rose from 25 million metric tons in 2000 to 40 million metric tons in 2010, and subsequently to 60 million metric tons in 2020 [2]. The significantly elevated demand for rice is partly attributable to the substantial population growth (+113%) over the past three decades, urbanization, and shifts in consumer preferences in Africa, as numerous individuals are opting for rice instead of their traditional staple foods, such as corn, sorghum, and millet [2]-[4]. The restricted access to wetlands, combined with inadequate irrigation infrastructure, constrains lowland rice production, compelling farmers to adopt upland rice cultivation, as numerous African countries, such as Uganda and Angola, possess substantial potential for upland rice production. However, upland rice production is also facing the challenge of an increasing population, which is exerting pressure on the land, making it a limiting factor of production [5]. Declining soil fertility, resulting from prolonged overcultivation on the same land parcels with limited fertilizer application, combined with inherently poor soil quality, is significantly constraining rice production in SSA [6]-[8]. Ferrallisols and Acrisols, which are the dominant soil types in most parts of the region, have low nutrient content, cation exchange capacity, high leaching and weathering, and a very low water holding capacity that cannot sustainably support rice cultivation [9]-[11].

Despite the poor soil conditions, farmers in Uganda and Angola are investing minimal efforts to improve soil health and quality [7] [8]. Benson *et al.* [12] reported that less than 5% of Ugandan farmers utilize inorganic fertilizers, with notable regional disparities: 1.3% in the central region, 1.1% in the eastern region, 0.7% in the northern region, and 0.6% in the western region. The report further indicated that an average of 61.2% of Ugandan farmers employ organic materials for soil fertility management; however, use of undecomposed materials limits their effectiveness in enhancing soil fertility. Although rice production has increased in the region, this is attributed primarily to the expanded planted area [1] [3] [13]. According to FAO [14], the harvested area increased from 6.9 million ha to 16.6 million ha between 2000 and 2020, whereas there was limited gain in rice yield: increasing from 1.7 to 2.1 t ha⁻¹ only. Because of these factors, SSA remains a net importer of rice, accounting for 40% of the total rice consumed in the region [1] [15].

Several studies have recommended the use of inorganic fertilizers to improve rice productivity in SSA [8] [16]-[18]. However, in Uganda and Angola, local farmers cannot afford chemical fertilizers because of their prohibitively high costs [19]-[21]. Organic fertilizer sources, such as cow dung, chicken manure, and rice straw, are readily and freely available to rice farmers in Uganda and Angola, as over 50% of them have livestock in their homes [22] [23] and have rice straw, which is the raw material for making compost. Compost also improves the physical and chemical properties of soil, but it is required in large quantities [24] [25].

Thus, if farmers use a combination of compost and chemical fertilizers using the spot application method, relatively smaller quantities of compost and chemical fertilizers will be required, reducing the cost of purchasing chemical fertilizers and the labor required to make and carry the compost. Such an approach makes usage and adoption of fertilizers more feasible for farmers.

While extensive research has been conducted on fertilizer application in upland rice cultivation [26] [27], there remains a significant gap in our understanding of the combined use of organic and inorganic fertilizers, particularly when conducting spot application through the drill method. Specifically, the potential benefits of utilizing compost in conjunction with inorganic fertilizers for enhancing rice yields have not been thoroughly explored in this context. The application of compost exerts a regulatory effect on rice plant growth, enhancing both the ripening percentage and grain quality [28] [29]. This beneficial impact stems from compost's characteristic slow-release nutrient profile, which provides a sustained supply of nutrients over time. In contrast, chemical fertilizers exhibit rapid nutrient release immediately following their application. As such, when these two soil amendment methods are used in combination, there is a constant release of nutrients [30]-[32].

NERICA 4 and Toyohamochi rice varieties were used to obtain a broader perspective on how compost affects upland rice varieties with diverse genetic and physiological traits. NERICA 4 is an Indica variety, drought and weed tolerant, tall, middle maturity and panicle weight type variety commonly cultivated upland in Africa, Uganda and Angola. The objectives of this study were: (i) to assess the effects of combining organic and inorganic nutrient sources on the grain yield and yield components of NERICA 4 and Toyohatamochi upland rice varieties, (ii) to identify the most effective nutrient combination for NERICA 4 and Toyohatamochi varieties based on their specific nutrient requirements and adaptability to upland conditions, and (iii) to evaluate the cost-effectiveness and profitability of integrating organic and inorganic nutrient sources compared to standalone application.

2. Materials and Methods

2.1. Description of the Experimental Site

The experiment was conducted at Japan International Cooperation Agency Tsukuba International Centre, Ibaraki Prefecture, Japan (36.0°N, 140.1°E; 25 m a.s.l) in 2023. The overlapping wet season patterns of Tsukuba, such as the high humidity and rainfall in the summer period during which the experiment was conducted, make the results adaptable to tropical contexts such as Uganda and Angola. While the Andisols of Japan differ from the Ferralsols and Nitisols of Uganda, and the Ferralsols and Luvisols of Angola, compost use aligns with global sustainable agriculture and climate resilience goals. Therefore, research conducted in Japan provides robust scientific validation of compost practices before their adaptation and implementation in Africa. Furthermore, a comparable inves-

tigation is scheduled to be conducted in Africa, specifically in Uganda, to evaluate the feasibility and applicability of the study's findings before the implementation of the practice among farmers.

Direct sowing in a drill method was used, and herbicide GO-GO-SAN (Pendimethalin 2%) was applied to the entire experimental field just after sowing. The field was maintained under weed-free conditions throughout the crop's growth. During the growing season, very high temperatures of up to 37°C coupled with high humidity and limited rainfall were experienced (Figure 1). Thus, supplementary irrigation to field condition was done to ensure proper growth of the crop.

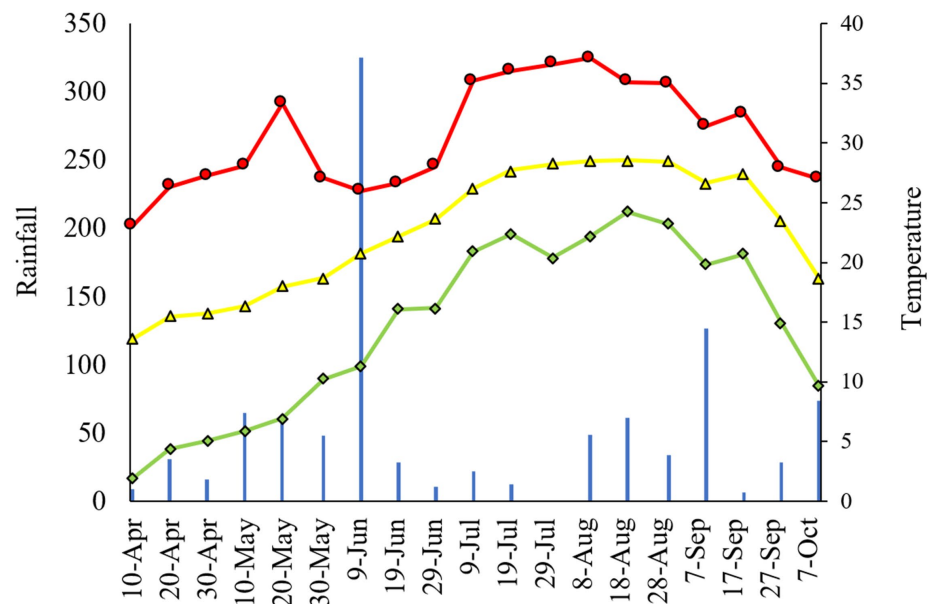


Figure 1. Maximum, average and minimum temperature (°C) and rainfall (mm) received at the experimental site during the period of the experiment in Tsukuba International Centre, Japan.

2.2. Experimental Design

A randomized complete block design (RCBD) with three replications and two factors, fertilizer and variety, was used (Table 1). The drill method was used for planting the rice at a seed rate of 30 kg ha⁻¹; plot sizes were 3 m × 4 m, making 12 m²; and plant spacing was 40 cm between rows. Inorganic fertilizers including Ammonium Sulphate (21% N), Super Phosphate (17.5% P₂O₅) and Potassium Chloride (61% K₂O) were used. The source of organic fertilizer was cow dung with the following nutrient concentrations: Nitrogen 1.4%, Phosphorus 1.6%, and Potassium 2.4%. Cow dung was selected due to its availability in Japan and its accessibility and affordability for farmers in Uganda and Angola, where the study's findings will be applied. Cattle rearing is common in these regions, making cow dung a readily available organic fertilizer—often used alongside chicken manure.

Table 1. Overview of the rice variety and fertilizer treatments.

Varieties	Fertilizers	Experimental plots
NERICA 4 (V4)	C (Control); Chemical only	V4-C
	O30; 30% Organic and 70% Chemical	V4-O30
	O50; 50% Organic and 50% Chemical	V4-O50
Toyohatamochi (Vt)	C (Control); Chemical only	Vt-C
	O30; 30% Organic and 70% Chemical	Vt-O30
	O50; 50% Organic and 50% Chemical	Vt-O50

2.3. Seed Treatment

Rice seeds were floated in water (1.00 specific gravity) to remove empty grains, followed by hot water treatment at 60 °C for 10 min, and then soaked in Benlate-T (Thiuram 20%-benomyl 20% powder) for 24 h. Bird repellent KIHIGEN (Thiuram 80%) was used at a rate of 1% of seed weight to deter birds from eating the seeds at planting.

2.4. Experimental Soil Properties

Before planting, soil samples were collected at 15 cm depth for chemical analysis. A composite soil sample was prepared by combining and homogenizing five random subsamples, air-drying the composite in the laboratory for two weeks, sieving it through a 2-mm mesh, and storing it in a clean container. A subsample of the sieved soil was then mixed with distilled water for subsequent analysis. Soil pH was measured using a pH meter, total Carbon and Nitrogen were determined by dry combustion method in a N-C analyzer, available phosphorus was analyzed using spectrophotometry and exchangeable potassium was measured using atomic absorption spectrometry (**Table 2**).

Table 2. The initial chemical composition of the soil before planting.

pH	Total C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exchangeable K (cmol/kg)	N as a % of Carbon	Carbon as a % of the soil
6.3	32	3.08	73	2	0.262	2.744

2.5. Fertilizer Application Rates and Method

Organic fertilizer rates of 30% and 70% nitrogen replacement rates were used, based on the guidelines by the Japan Ministry of Agriculture, Fisheries and Forestry [33]. Spot application of the compost and the chemical fertilizer was done at planting to minimize wastage and nutrient loss, allowing for use of smaller quantities of compost. This fertilizer application method was adopted to ensure that all the plants had immediate access to the applied fertilizer. Drills were made at depths of 20, 15, and 8 cm for O50, O30, and C treatments, respectively, and the width of the drills was 8 cm for all treatments. Cow dung (1.4% N) was applied, covered with soil, then inorganic fertilizer covered with soil, the seed was sowed

and covered with soil for all treatments. No cow dung was applied for control to ensure a uniform sowing depth of 4 cm for all treatments. The broadcasting method was used to top-dress at panicle initiation stage. For the organic fertilizer, 8.6 and 5.1 kg of cow dung were applied to the O50 and O30 experimental plots, respectively. Standard fertilizer application rates for Japan were used as shown in **Table 3**, and the amounts of chemical fertilizers applied are presented in **Table 4**.

Table 3. Fertilizer application rates of N, P, and K.

Nutrients	Total (kg ha ⁻¹)	Basal (kg ha ⁻¹)	Top dressing (kg ha ⁻¹)
N	60	40	20
P	100	100	0
K	100	80	20

Table 4. Amount of chemical fertilizer applied per plot.

Fertilizer	Control (kg per 12m ² plot)	50% N replacement (kg per 12m ² plot)	30% N replacement (kg per 12m ² plot)
Ammonium Sulphate	0.343	0.171	0.240
Superphosphate	0.686	0.343	0.480
Potassium Chloride	0.197	0.098	0.138

2.6. Data Collection and Statistical Analyses

Plant length and leaf chlorophyll content were collected from 10 plants from the center of the experimental plots. Plant length was measured from the soil surface to the highest part of the plant using a meter rule. The middle part of the leaf next to the flag leaf was identified to measure chlorophyll levels using a SPAD meter (SPAD-502 Plus, Konica Minolta sensing Co., Ltd., Tokyo, Japan). Tiller number per meter squared was determined by counting the number of tillers of the plants in one meter of one of the central lines. Plant length, chlorophyll content, and tiller number data were collected five times: at early growth, 28 days after sowing (DAS); active tillering, 42 DAS; maximum tillering, 56 DAS; panicle initiation, 70 DAS; and at heading, 90 DAS. The Leaf Area Index was determined by cutting rice plants from a 1 m central row in each experimental plot. The leaf area of the harvested plants was then measured using a leaf area meter (LI-COR Biosciences Inc., Nebraska, USA). Dry matter weight was determined by harvesting rice from a 1 m central row of each experimental plot. The rice plants were cut at ground level, collected in situ with all leaves and grains intact, air-dried in a screen house for five days, and subsequently oven-dried for 48 h at 105 °C to achieve constant weight.

Yield and yield components were determined by harvesting plants from a 1 m central row of each experimental plot at maturity (85% ripening). The harvested plants were subsequently dried in a greenhouse for one week. The rice was then threshed to separate the grains, which were subsequently immersed in pure water

to differentiate between empty and filled grains. The grains were weighed and enumerated using an automatic seed counter (SLY-AS/M, Zhejiang Top Instrument Co., Hangzhou, China). Harvest index was determined by dividing the full grain weight by the dry matter weight. Panicle length was obtained by measuring the length of 10 panicles, and the average value was used to represent each treatment plot. Culm length was determined by measuring the length of 10 plants from the bottom of the plant to the panicle node, and the average value was used to represent the plot. Analysis of variance (ANOVA) and multiple range test (Turkey-Kramer: HSD test) at 5% level of probability were used for data analysis with IBM SPSS Statistics (Version 18.0.1.0).

2.7. Cost-Benefit Analysis of Various Fertilizer Types

The cost-benefit analysis was done to help make the right decisions for farmers. Although the experiment was conducted in Japan, prices for the fertilizers and rice were estimated using the Uganda and Angola market prices. Cow dung was considered free of charge since farmers in Uganda and Angola can access it without cost. The costs of loading and transportation were not accounted for in the case of organic fertilizer because the farmers are expected to do the composting in their fields and move the animal wastes using family labor to avoid transportation costs. The chemical fertilizer used in the calculations was NPK 17:17:17, as it is commonly used by rice farmers in Uganda and Angola. The calculations were based solely on nitrogen at a rate of 60 kg ha⁻¹, following both the experimental setup and the recommended application rate in these countries. A total of 353, 247, and 177 kg of NPK 17:17:17 were used for chemical only, O30, and O50 treatments, respectively. The average cost of NPK in Angola and Uganda is US\$ 1 per kilogram. This price was determined based on a market survey conducted in November 2023 among agro-input dealers in Luanda, the capital of Angola, and Kampala, the capital of Uganda. The average cost of paddy rice in Uganda and Angola is US\$ 0.5 per kilogram based on the survey from the farmers in the two countries in November 2023. The exchange rates were: 1 US\$ = 833 Angola kwanza [34] (National Bank of Angola) and 1 US\$ = 3,750 Uganda shillings [35].

3. Results

3.1. Plant Length

Plant height was significantly affected by variety, fertilizer treatments, and the growth stages (Figure 2). The mean plant height for NERICA 4 (62.5 cm) was significantly higher ($p < 0.05$) than the mean value for Toyohatamochi (60.2 cm). Mean plant height under control (62.7 cm) from both rice varieties was significantly higher ($p < 0.05$) than that under the O30 (61.1 cm) and O50 (60.3 cm) compost treatments. Within each of the rice varieties, significant differences in plant height existed only between stages of growth, with significant differences between the EG, AT, and MT growth stages. No significant interaction effects existed between varieties, fertilizer treatments, and growth stages.

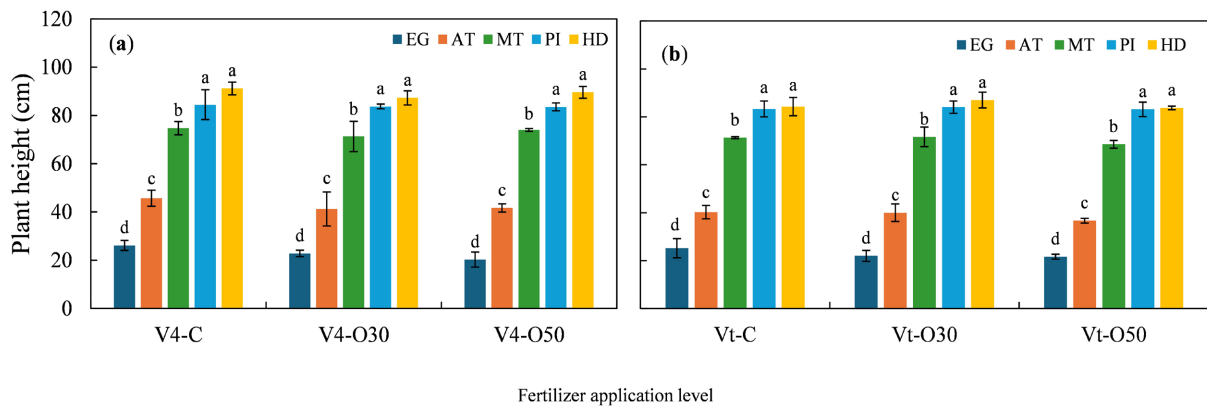


Figure 2. Changes in plant length on NERICA 4 (a) and Toyohatamochi (b) rice varieties under different fertilizer applications and growth stages including Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), and Heading (HD). Different lowercase letters above growth stages indicate significant differences between growth stages within fertilizer application treatment at $p < 0.05$ according to Tukey's HSD test. Error bars show standard deviations ($n = 3$).

3.2. Tiller Number

Rice variety and growth stage significantly affected tiller number m^{-2} but not fertilizer treatment (Figure 3). Mean tiller number m^{-2} for Toyohatamochi (413.2 m^{-2}) was significantly higher than the mean value for NERICA 4 (380.9 m^{-2}) regardless of the growth stage. Though not significantly different, the control (413.9 m^{-2}) showed the highest mean tiller number m^{-2} value than the O30 (396.7 m^{-2}) and O50 (380.5 m^{-2}) treatments. We noted with interest that tiller number m^{-2} for NERICA 4 was not significantly affected by growth stage (Figure 3(a)); but the opposite was true for Toyohatamochi where tiller number m^{-2} significantly increased with growth stage across all the fertilizer treatments (Figure 3(b)). No significant interaction effects existed between variety, fertilizer application, and growth stages.

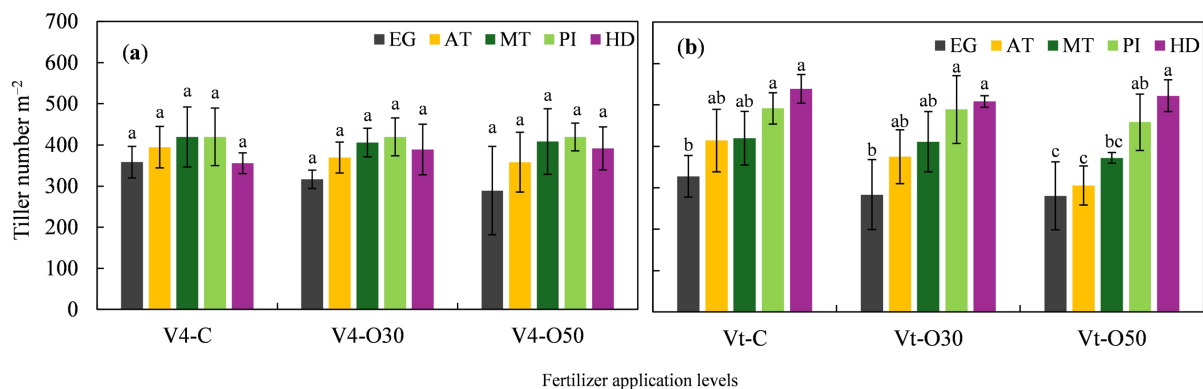


Figure 3. Changes in Tiller number per m^{-2} on NERICA 4 (a) and Toyohatamochi (b) rice varieties under different fertilizer applications and growth stages including Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), and Heading (HD). Different lowercase letters above growth stages indicate significant differences between growth stages within fertilizer application treatment at $p < 0.05$ according to Tukey's HSD test. Error bars show standard deviations ($n = 3$).

3.3. SPAD Value

Changes in SPAD of the two varieties and each fertilizer application method are presented in **Figure 4**. At early growth stage, the SPAD value for chemical fertilizer only was significantly higher than the others for NERICA 4 (**Figure 4(a)**) but not Toyohatamochi, implying that there was interaction between the fertilizer levels and the varieties. At active tillering there was no significant difference in SPAD value between the varieties and the fertilizer levels for both varieties. At maximum tillering, panicle initiation, and at heading the mean SPAD values for Toyohatamochi were significantly higher than that of NERICA 4 at $p < 0.05$ (**Figure 4(b)**). There were no significant interaction effects between the varieties and the fertilizer levels.

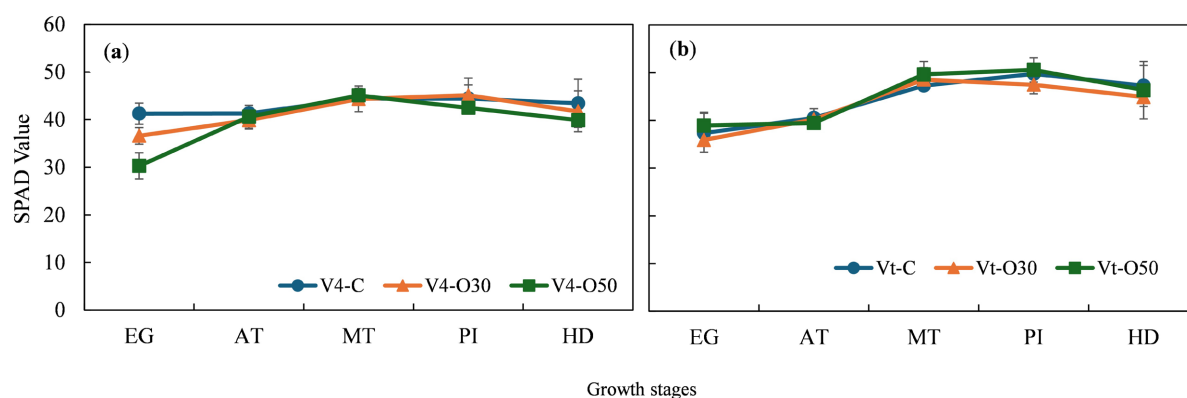


Figure 4. Changes in SPAD on NERICA 4 (a) and Toyohatamochi (b) rice varieties under different fertilizer applications and growth stages including Early Growth (EG), Active Tillering (AT), Maximum Tillering (MT), Panicle Initiation (PI), and Heading (HD). Error bars show standard deviations ($n = 3$).

3.4. Leaf area Index

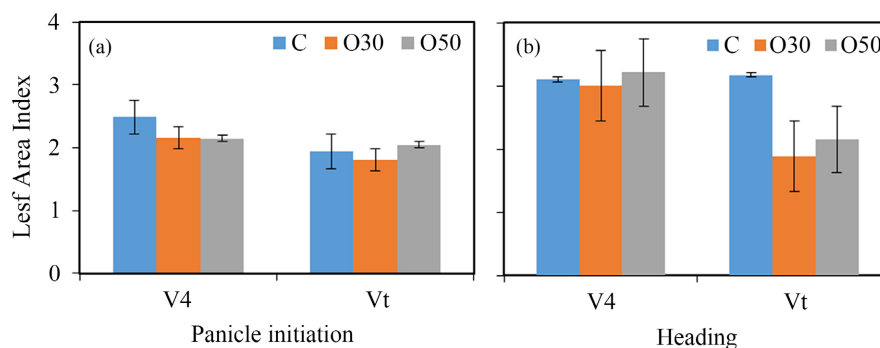


Figure 5. Changes in leaf area index of NERICA 4 (V4) and Toyohatamochi (Vt) rice varieties and fertilizer application methods C, O30, and O50 at Panicle Initiation and Heading growth states. Error bars show standard deviations ($n = 3$).

Figure 5 shows the changes in leaf area index of the two varieties and each fertilizer application method at panicle initiation and heading stage. Leaf area index for NERICA 4 was significantly higher ($p < 0.05$) than that of Toyohatamochi in the two stages and there was no significant difference in the leaf area index among

the different fertilizer levels in the two varieties though the chemical fertilizer-only treatment had a non-significantly high leaf area index followed by O30, and lastly O50 at all stages in the two varieties. There was no interaction in leaf area index between the varieties and the fertilizer levels at both stages.

3.5. Dry Matter

Changes in dry matter weight of different NERICA 4 and Toyohatamochi varieties and various fertilizer application methods at panicle initiation and heading stage are presented in **Figure 6**. There was no significant difference in dry matter weight between the varieties and the fertilizers and no interaction at the two stages.

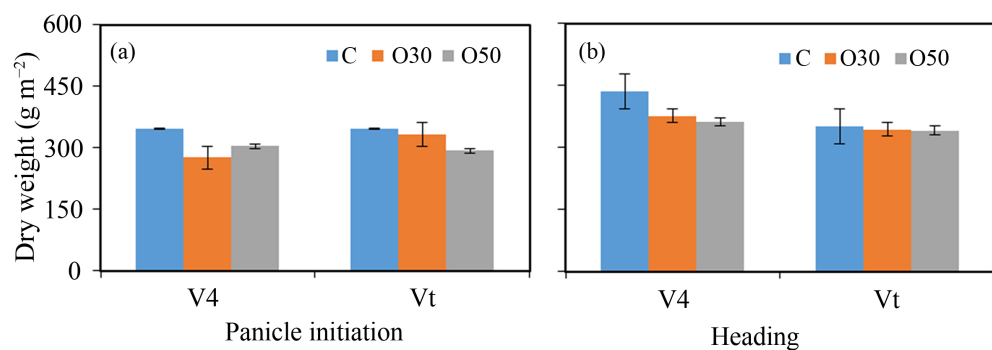


Figure 6. Changes in dry matter weight of NERICA 4 (V4) and Toyohatamochi (Vt) rice varieties and fertilizer application methods C, O30, and O50 at Panicle Initiation and Heading growth states. Error bars show standard deviations ($n = 3$).

3.6. Yield and Yield Components

There was no significant difference in the yield between the varieties and fertilizer levels (**Table 5**). The O50 treatment gave the highest yield, followed by O30, and lastly C. The yield increased with increase in the percentage of organic fertilizer. The percentage of ripened grains for the 50% organic treatments was significantly higher ($p < 0.05$) than that of 30% organic and chemical only. NERICA 4 had a significantly higher ($p < 0.05$) ripening ratio than Toyohatamochi, and the ripening ratio increased with increase in the percentage of organic fertilizer in the two varieties.

There was no significant difference in the panicles m⁻² between the fertilizer levels, but panicle m⁻² for Toyohatamochi was significantly higher ($p < 0.05$) than that of NERICA 4. Panicles m⁻² for Toyohatamochi decreased as the percentage of organic fertilizer increased, which was not the case in NERICA 4. The 1000-grain weight for NERICA 4 was significantly higher than that of Toyohatamochi. NERICA 4 also had a significantly higher number of spikelets per panicle than Toyohatamochi at $p < 0.05$, and there was no significant difference in the number of spikelets per panicle between the fertilizer levels. Surprisingly, Toyohatamochi gave the same number of spikelets per panicle at all fertilizer levels.

Table 5. Yield and yield components of NERICA 4 and Toyohatamochi at different fertilizer application methods.

Variety (V)	Fertilizer levels (F)	Panicle m ⁻²	Spikelets panicle ⁻¹	1000 grain weight (g)	Ripening ratio	Yield (t ha ⁻¹)
NERICA 4	C	194b	92a	25.6a	67a	3.1a
	O30	237b	80a	25.8a	63a	3.1a
	O50	202b	84a	25.7a	73a	3.2a
Toyohatamochi	C	317a	74b	23.9b	50b	2.8a
	O30	301a	74b	24.0b	58b	3.1a
	O50	283a	74b	24.4b	66a	3.4a
Fertilizer levels	C	256a	83a	24.8a	59b	3.0a
	O30	269a	77a	24.9a	61b	3.1a
	O50	243a	79a	25.1a	70a	3.3a
Variety	NERICA 4	211b	85a	25.7a	68a	3.1a
	Toyohatamochi	300a	74b	24.1b	58b	3.1a
2-way ANOVA	F	ns	ns	ns	*	ns
	V	*	*	*	*	ns
	F × V	ns	ns	ns	ns	ns

*, significant difference at $p \leq 0.05$ by Tukey HSD; ns, no significant difference.

3.7. Harvest Index, Panicle Length and Culm Length

Whereas there was no significant difference in the harvest index between the varieties and the fertilizer levels, a significant difference in the panicle length existed between the varieties (Table 6). No significant difference in panicle length existed between the organic fertilizer levels, and no interaction effects were observed. There was also no significant difference and no interactions in the culm length between the varieties and the fertilizer levels.

Table 6. Harvest index, panicle length and culm length.

Variety	Organic fertilizer levels	Harvest index	Panicle length (cm)	Culm length (cm)
NERICA 4	C	0.45a	23.4a	70.2a
	O30	0.47a	22.4a	67.3a
	O50	0.54a	22.9a	67.1a
Toyohatamochi	C	0.49a	16.5b	64.5a
	O30	0.49a	17.4b	62.2a
	O50	0.51a	16.6b	64.6a
Organic fertilizer levels	C	0.46a	20.0a	67.4a
	O30	0.48a	19.9a	64.8a
	O50	0.53a	19.8a	65.9a
Variety	NERICA 4	0.49a	22.9a	68.2a
	Toyohatamochi	0.50a	16.8b	63.8a
2-way ANOVA	F	ns	ns	ns
	V	ns	*	ns
	F × V	ns	ns	ns

*, indicates significant difference at $p \leq 0.05$ by Tukey HSD; ns, no significant difference.

3.8. Cost-Benefit Analysis

Table 6 presents the total cost of fertilizers and the benefit of each fertilizer type. Results showed that 50% organic fertilizer had the lowest cost of fertilizer input, followed by 30% organic, which was US\$ 157 and US\$ 92 cheaper than chemical only, respectively. Use of 50% organic still had the highest benefit, which was on average US\$ 297 more than chemical only, followed by 30% organic, which was US\$ 142 more than that of chemical only (Table 7).

Table 7. Cost-benefit analysis of fertilizer types.

Fertilizer level	Cost of chemical fertilizer (US\$)	Cost of cow dung (US\$)	Total cost of fertilizer	Yield t ha ⁻¹	Total income (US\$)	Benefit (US\$)
Chemical only	352	0	352	3	1,500	1,148
O30	246	14	260	3.1	1,550	1,290
O50	176	19	195	3.3	1,650	1,445

4. Discussion

4.1. Plant Length

The significantly higher plant height observed in the NERICA 4 rice variety compared to Toyohatamochi can be attributed to its genetic composition. NERICA 4 exhibits a potential growth range of 100 - 120 cm at maturity, whereas Toyohatamochi reaches a maximum height of 70 - 90 cm, dependent upon environmental factors such as water and nutrient availability. This is because NERICA 4 was developed to be more resilient and adopted in an African environment, where height is a beneficial trait for competing against weeds and light capture [36] [37]. The significantly longer plant length observed in the control group compared to the 30% compost and 50% compost treatments, particularly during the early growth stage, may be attributed to the plants' underdeveloped root systems, which were insufficient to access nutrients in the organic fertilizer applied to the lower soil layers. An additional factor contributing to the significantly reduced plant length observed in the 30% and 50% compost treatments during early growth stages and subsequent periods may be attributed to the slow-release nature of organic fertilizers; consequently, insufficient nutrients may have been available for optimal crop development [30]. At the early growth stage, the plant focuses on rapid elongation and leaf production to maximize light capture so that all the energy is directed towards cell division and expansion, and hence a significant increase in plant length from early growth to the active tillering stage. From active tillering to maximum tillering, the stem elongates to optimize light absorption to prepare for the reproductive stage and heading and maturity and changes the focus from the vegetative stage to grain filling [36] [37].

4.2. Tiller Number Per Square Meter

The difference in the response of tiller number m⁻² to growth stages between NE-

RICA 4 and Toyohatamochi can be attributed to firstly, their genetic differences and growth partners [38] [39]; NERICA 4 is known for its stability and resilience under various environmental conditions, it exhibits a stable tillering pattern and hence the non-significant variation in tiller number m^{-2} across the different growth stages [39] [40]. Conversely, Toyohatamochi has a genetic composition with a more responsive tillering mechanism to external inputs and environmental conditions, resulting in a significant increase in tillering with the growth stage under fertilization [40]. Secondly, regarding environmental interaction, NERICA 4 exhibits consistent productivity across diverse conditions, while Toyohatamochi's yield is more sensitive to environmental variations [39] [40]. Thirdly, management practices, such as fertilization, play a crucial role. NERICA 4 may have an efficient nutrient uptake and utilization system, allowing it to maintain a steady tiller number even under varying fertilizer treatments. In contrast, Toyohatamochi has a higher nutrient demand during its growth, leading to more pronounced tillering when fertilized appropriately, as organic fertilizer continues to release nutrients over time [38] [41].

4.3. SPAD Value

The interaction in SPAD values between the rice varieties and fertilizer levels at the early growth stage was attributed to the significantly higher SPAD value observed in Toyohatamochi with 50% organic fertilizer compared to NERICA 4 under the same fertilization condition. This finding suggests that Toyohatamochi exhibited a greater physiological response to organic fertilizer than NERICA 4 during the early growth stage. NERICA 4 was bred for poor soils and harsh environmental conditions; therefore, the rate of nutrient uptake under favorable conditions provided by the compost could not compete with that of Toyohatamochi, a Japonica variety whose nutrient demand and uptake pattern match the steady release of essential nutrients by the compost [42].

4.4. Leaf Area Index

Genetically, CG14, the African parent of NERICA 4, is known for its high tolerance to drought, adaptability to poor soil, and harsh environmental conditions. These genetic traits could have caused NERICA 4 to produce a high leaf area index despite the high temperatures, humidity, and drought experienced in Tsukuba during plant growth. However, Toyohatamochi, on the other hand, is a Japonica variety and could have utilized traits such as grain quality and water use efficiency since the water was limited and leaf area index was not crucial; hence, Toyohatamochi had a lower leaf area index [43].

4.5. Dry Matter

All experimental plots were subjected to similar external factors such as water availability, nutrient availability, and sunlight exposure, which could have minimized the genotype effect on dry matter production and hence the non-significant

difference in dry matter weight between the varieties and fertilizer rates. Additionally, there is a possibility that the varieties developed compensatory growth mechanisms to adapt to the drought, high temperature, and humidity experienced during the growing season [42].

4.6. Yield and Yield Components

The findings of our research exhibited a non-significant difference in yield, which could have been because all the treatments received the same amount of essential nutrients for the rice crop, that is, N, P, and K, although 50% compost had the highest yield, followed by 30% compost, and finally chemical only. The non-significance in the yield despite the significantly high ripening ratio of O50 could have been due to the non-significantly high tiller number exhibited by the control, which resulted in a non-significantly higher panicle number per meter squared and non-significantly higher grain number per meter squared and hence the non-significance in the yield. The significantly higher ripening ratio of the 50% compost than that of the chemical only in both varieties ($p < 0.05$). This could have been caused by firstly, the slow release of nutrients by the compost as it has humus, which buffers the nutrients and releases them slowly and evenly for a long period, depending on the organic material used. The slow release of the nutrients by the compost matched the nutrient requirements and uptake by the rice plant at critical stages like at reproductive and grain filling stage and hence the significantly high ripening ratio in O50 [30] [44]. While there was no nutrient monitoring during the growing period, the slow release of nutrients by the compost for a long period was witnessed by the significantly lower plant length of O50 and O30 compared to that of the control at early growth and the significantly higher ripening ratio of the O50 compared to the control. Secondly, compost improves plant physiology by facilitating better root development. This enhanced root system could have led to increased nutrient uptake, boosting crop vigor and tolerance to stresses such as drought, a significant challenge during the experimental period [45]. Thirdly, organic fertilizer, which enhances soil health by improving soil structure, could have increased water retention, aeration, and microbial activity, ultimately enhancing nutrient availability and soil fertility [30] [44]. Furthermore, Zandonadi *et al.* [46] showed that compost lowers salt accumulation and avoids toxicity since organic materials that can easily be broken down by the soil microorganisms. Use of compost is also known to ensure a comprehensive nutrient supply as it provides a wide supply of nutrients both macro and micro, which is not the case with chemical fertilizers that supply only nitrogen, phosphorus and potassium [47]. These results are consistent with those obtained by Kakar [30], when treatments with organic fertilizer gave better grain quality and a higher ripening ratio than those with chemical fertilizers and those obtained from Kita-aoba and Tachijobu rice varieties, which gave high yields when chemical fertilizer was combined with organic manure rather than chemical fertilizer alone [28] [29].

The reason for the significantly higher ripening ratio for NERICA 4 than Toyohatamochi and the decrease in panicle number m^{-2} in Toyohatamochi as the percentage of organic fertilizer increased is because Toyohatamochi is an early maturing variety so maybe it did not take up all the nutrients from the organic fertilizer since it releases its nutrients slowly so the release of the nutrients from the compost did not match the nutrients requirements and uptake by Toyohatamochi variety so there is a possibility at the panicle initiation and grain filling stages in Toyohatamochi the nutrients in the compost were not sufficient [11] [30]. The significantly higher panicle number m^{-2} of Toyohatamochi than NERICA 4, the significantly higher number of spikelets panicle^{-1} and the significantly higher 1000-grain weight of NERICA 4 than Toyohatamochi could be because Toyohatamochi is a panicle number type rice variety and NERICA 4 is a panicle weight type rice variety. Panicle-number type varieties produce a greater number of panicles with a lower number of grains per panicle than panicle-weight type varieties [38] [41].

4.7. Harvest Index, Panicle Length and Culm Length

NERICA 4 exhibited significantly longer panicles than Toyohatamochi, a panicle weight-type rice variety. The longer panicles of NERICA 4 allow for the accommodation of more grains compared to the shorter panicles of Toyohatamochi. In contrast, Toyohatamochi is a panicle number-type variety that produces more panicles, but each panicle is shorter and contains a relatively smaller number of grains than NERICA 4 [36]-[40].

4.8. Cost-Benefit Analysis

Inorganic fertilizers provide rapid nutrient release, promoting fast growth and high yields. However, their continuous application is necessary, which increases production costs over time. In contrast, compost improves soil structure, enhancing water retention and nutrient uptake efficiency. This reduces the need for frequent fertilizer applications, thereby lowering long-term production input costs [48].

5. Conclusion

This study underscores the potential of spot fertilizer application method in the drill method of planting upland rice and integration of organic and inorganic nutrient sources as a viable strategy for integrated soil fertility management in upland rice systems contributing to sustainable agricultural practices. Adopting these technologies could provide an eco-friendly, inexpensive, and adaptable alternative to soil fertility enhancement to promote agricultural sustainability. The major limitation of this study is the method of fertilizer application that was used; it is labor-intensive and time-consuming. Further research should explore other sources of organic fertilizers and the long-term impact of compost on soil health, growth, development, and yield of upland rice.

Authors' Contributions

Zainah Kampi: Conceptualization, project administration, methodology, data curation, formal analysis, writing—original draft, writing—review and editing. **Lastone Kanhica:** Project administration, methodology, writing—review and editing. **Emmanuel Odama:** Conceptualization, methodology, data curation, writing—review and editing. **Kisho Miyamoto:** Methodology, writing—review and editing. **Hisashi Urayama:** Resources, supervision, writing—review and editing. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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