

Full Length Research Paper

Evaluation of blended fertilizer rates for improving irrigated lowland rice (*Oryza sativa* L.) productivity in Uganda

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The gap between the potential yield of 7-8 t ha⁻¹ and the actual yield of 3.1 t ha⁻¹ for irrigated rice in Uganda is primarily due to declining soil fertility caused by repeated harvests without sufficient site-specific nutrient replenishment. Two main factors limit fertilizer use: high prices and limited access, along with farmers' limited knowledge about fertilizers use. Farmers must often combine different types of mineral fertilisers to meet the recommended application rates, which can be confusing. Blended fertilisers, which combine several nutrients into a single formulation, are easier to apply, saving time and labour. Field trials at Doho and National Crops Resources Research Institute (NaCRRI) evaluated seven blended fertilizer treatments using a randomized complete block design (RCBD) replicated three times to determine their effectiveness in boosting irrigated lowland rice yields. Blended fertilizers boosted irrigated rice yields by 1.2 t ha⁻¹ at NaCRRI and by 1.6 t ha⁻¹ at Doho. Irrigated rice production was most profitable in Doho, with a gross margin of UGX 13.5 million per acre, compared to UGX 8.4 million at NaCRRI. Using 125% of Basal plus a top dress resulted in the highest average gross margin of UGX 14.7 million, making this the most effective blended fertilizer application rate for farmers.

Key words: Soil fertility, soil nutrients, rice yield.

INTRODUCTION

Rice has emerged as a critical food staple and a major source of income for many Ugandans (Kilimo Trust, 2018; Hong et al., 2021). About 80% of rice farmers in Uganda are smallholder, working on less than 2 ha with basic tools and limited irrigation, often without fertilizers (International Soil Reference and Information Centre [ISRIC], 2022; Ministry of Agriculture, Animal Industry and Fisheries [MAAIF], 2023), which could significantly boost

their rice yields. While fertilizers have been shown to enhance rice yields (Senthilkumar et al., 2018; Kwesiga et al., 2020; Awio et al., 2021, 2022a; Johnson et al., 2023), the use of fertilizers in Uganda is extremely low, even below the already low average for sub-Saharan Africa (SSA), which is around 8 to 10 kg ha⁻¹ (Okoboi and Barungi, 2012). The main hurdle is high costs. Fertilizer prices in Uganda are among the highest in the region,

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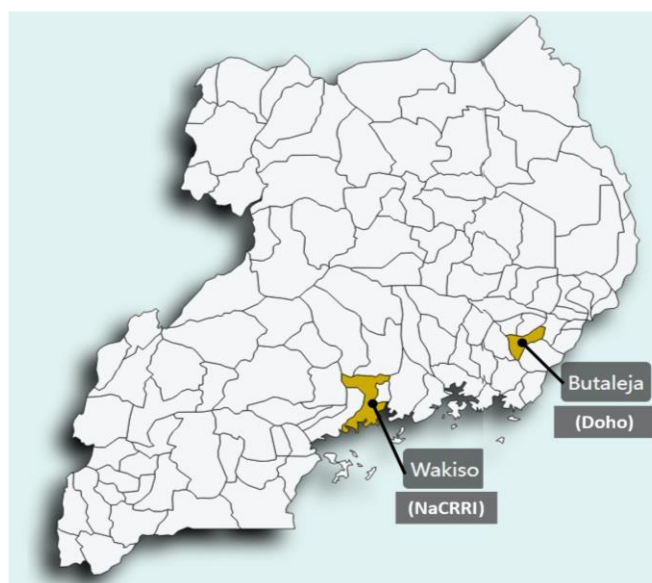


Figure 1. Map of Uganda highlighting the districts of Wakiso and Butaleja, where the experimental sites of NaCRRRI and Doho are located, respectively.

with urea priced at approximately \$1.49 per kg significantly higher than in neighboring Kenya (\$0.97) and Nigeria (\$0.99).

Nitrogen (N), Phosphorus (P), and Potassium (K) fertilizer is even pricier, costing up to \$1.63 per kg, while it's available for around \$0.85 in Ghana and about \$1.02 in Nigeria (Bonilla Cedrez et al., 2020). The high cost of fertilizers compels farmers to continuously grow rice on the same land without fertilizing, thereby depleting essential soil nutrients (Goswami et al., 2020; Uma et al., 2022) and losing up to 72 kg N, 23 kg P, and 43 kg K per hectare each year (ISRIC, 2022). As a result, farmers are harvesting only 1.5 to 2.5 t ha⁻¹ of paddy (MAAIF, 2023), which falls well below the SSA regional average of 4.6 t ha⁻¹ (Johnson et al., 2023) and the national yield potential of 5 to 7 t ha⁻¹ (Hong et al., 2021).

This low yield reduces farmers' income and affects their livelihoods, ultimately impacting the growth of Uganda's rice industry. Given these limitations, it is essential to explore innovations that assist farmers in utilizing traditional mineral fertilizers more efficiently. Blended fertilizers, created by combining solid finished fertilizer materials such as urea, diammonium phosphate, and muriate of potash, offer the potential for local customization of fertilizers to match specific soil and crop requirements, while precisely supplying the limiting nutrients identified through soil tests. They provide a cost-effective way to deliver a balanced mix of macro- and micronutrients in one application, eliminating the need for farmers to buy multiple fertilizer types. A study on upland rice in Uganda found that a rice-specific NPK fertilizer

blend produced a higher paddy yield of 4.3 t ha⁻¹, compared to 3.4 t ha⁻¹ from conventional Diammonium Phosphate (DAP) and urea. The net benefits were also higher for the blended fertilizer, at UGX 1,329,400 versus UGX 1,117,900 for the conventional method (Kaizzi et al., 2024). Additionally, a study in Kenya showed that the blended fertilizer for tea led to consistently higher yields and economic returns while providing environmental benefits (Sitienei et al., 2018). A study in China found that a single application of controlled-release nitrogen fertilizer (CRN) at rates of up to 200 kg N ha⁻¹ boosted rice yield, nitrogen-use efficiency (NUE), and economic profit compared to the same rates of split-applied conventional nitrogen fertilizers (Yuan et al., 2024). However, there is limited data on optimized fertilizer blends and rates for irrigated rice in Uganda. The objective of this study was to determine the effect of blended fertilizers on the growth and yield of irrigated lowland rice, in addition to recommending blended fertilizer application rates for irrigated lowland rice. The findings of this study will contribute to the realization of the outcomes of Uganda's National Fertilizer Policy of higher and sustainable agricultural productivity and improve farm income (Benson et al., 2012).

METHODOLOGY

Description of the experimental sites

The study was conducted in the second season of 2023 at NaCRRRI and Doho (Figure 1) and extended into 2024. The Doho rice

Table 1. Soil properties at the experimental sites prior to establishment of the experiment.

Site	E.C	pH	O.M	N	P	K	Na	Ca	Mg	CEC
	$\mu\text{S/cm}$	H_2O	%	%	mg/kg			meq/100 g		
NaCRRRI	40.8	5.9	1.6	0.2	4.3	0.2	0.2	5.4	0.9	9.0
Doho	97.3	6.0	6.2	0.6	20.0	0.2	0.8	4.9	0.6	9.0

Table 2. Actual blended fertilizer application rates converted to kg/ha and kg/acre.

Fertilizer treatment	Time of application	Amount of blended fertilizer applied	
		kg/ha	kg/acre
F-1 No fertilizer	Basal	0	0
	Top dress	0	0
F-2 Basal only	Basal	126	51
	Top dress	0	0
F-3 (50% of Basal + Top dress)	Basal	65	26
	Top dress	126	51
F-4 (75% of Basal + Top dress)	Basal	95	38
	Top dress	126	51
F-5 (100% of Basal + Top dress)	Basal	126	51
	Top dress	126	51
F-6 (125% of Basal + Top dress)	Basal	157	64
	Top dress	126	51
F-7 (150% of Basal + Top dress)	Basal	189	76
	Top dress	126	51

irrigation scheme is located in Eastern Uganda in the Butaleja district (34°02' E, 0°56' N, and is at an altitude of 1100 m above sea level). It is the largest public rice irrigation scheme in Uganda (Wanyama et al., 2017; Awio et al., 2021). The annual average rainfall in the Doho is 1,186 mm, distributed over two rainy seasons, from March to May and from August to October. The annual average temperature here is 22.7°C, with daily mean temperatures ranging from 15.4 to 30.7°C (Namyanya et al., 2014).

Located at an altitude of 1160 m above sea level, NaCRRRI is characterized by a tropical, humid and dry climate with a long-term mean annual precipitation of 1280 mm. The rainfall pattern is bimodal with two distinct wet and dry seasons. December, January and February are dry, followed by rain in March, April and May. June and July are dry while August, September, October and November are wet. The average minimum and maximum temperatures are 25 and 31°C, respectively. The soils at NaCRRRI consist of umbric Gleysols, gleyian Fluvisols, and Histosols, with a predominantly silty loam soil texture (Gabiri et al., 2018). Soil properties at the two experimental sites, Doho and NaCRRRI, were evaluated just before the start of the experiment, as detailed in Table 1.

Experimental design

The experiment was designed as a RCBD with seven treatments (Figure 1) replicated three times. The rice variety used in the experiment was WITA-9, which matures 135 days after sowing and is commonly grown by lowland rice farmers in Doho, Butaleja and eastern Uganda in general. WITA-9 is particularly appreciated by farmers for its improved grain yield and resistance to common rice diseases in Uganda, namely bacterial late blight, Rice Yellow Mottle Virus (RYMV) and rice blast (Saito et al., 2019). Four 3-week-old seedlings of WITA-9 were transplanted per hill at a distance of 30 cm between rows and 15 cm between plants in a row in experimental plots measuring 3.7 m × 3 m. The blended fertilizer used in the experiments had the composition of NPK 23:17:12, along with 3% sulfur trioxide, 2% magnesium oxide, and 1% sodium oxide (Grainpulse Limited, 2023). No other fertilizer was used in this experiments. Basal fertilizer was applied to the rice by broadcasting 10 days after transplanting, while the top dress was applied 56 days after transplanting. Table 2 shows the actual amount of fertilizer blend applied in the various experimental treatments, while Figure 2 shows the corresponding N, P-K rates applied in the base and top

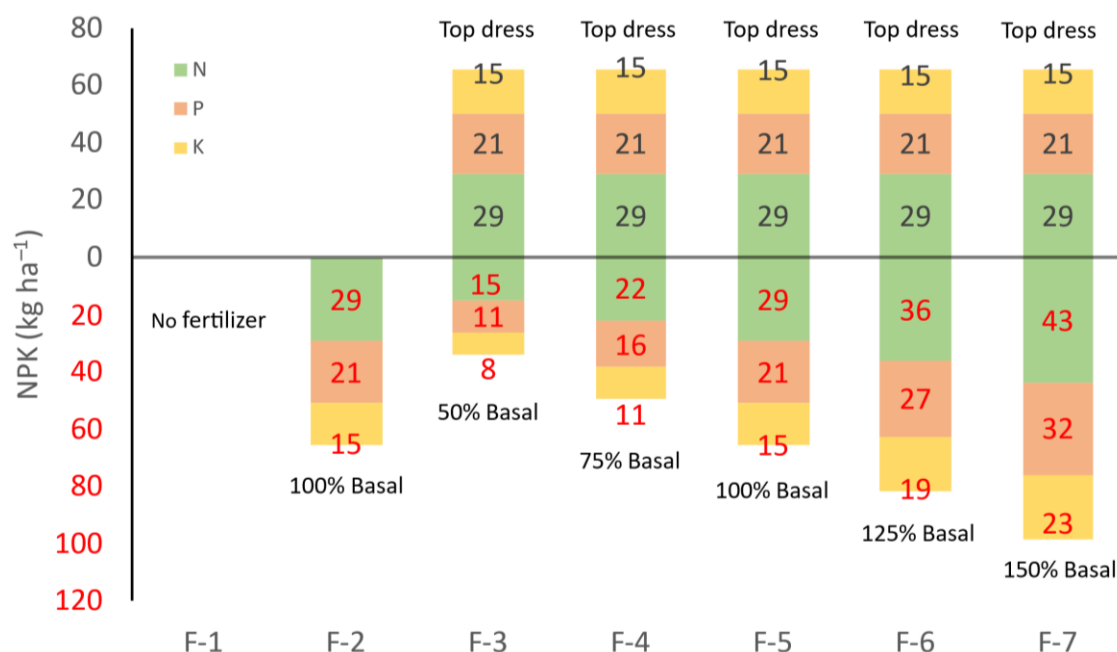


Figure 2. Experimental treatments with fertilizer amounts applied and the timing of application.

dressing. The formulation of the fertilizer blend used was 23:17:12 percent N, P and K. Standing water was maintained in the experimental plots throughout the growing season.

Data collection and analysis

Relative leaf chlorophyll content (SPAD) measurements were taken on 20 hills 4 and 8 weeks after transplanting using a Minolta SPAD-502 chlorophyll meter on the uppermost, fully expanded leaf halfway between tip and collar. Plant height (cm) was measured at three, six, and nine weeks after transplanting and at harvest from 20 hills chosen from the inner rows of each plot. The first two rows and the first two plants in a row were excluded to minimize the border effect (Sato and Takahashi, 1983). The height of the plants was measured from the base above the ground to the tallest part of the plant, which could be the tip of the leaf or panicle. The same plants used to determine plant height were also harvested, and the panicles were counted to calculate the panicle number per square meter. All panicles harvested from each plot were then dried, threshed, and immersed in plain tap water to separate the floating unfilled grains from the filled ones that sink below. The filled and unfilled grains were dried and weighed separately to give the total weight of the empty grain and the total weight of the filled grain. Three five-gram samples of the filled grains were then drawn and counted, and their average number was used to calculate the 1000 grain weight and the total number of filled grains. Similarly, three one-gram samples of the empty grains were drawn and counted, and their average number was used to calculate the total number of empty grains. The total number of filled grains and empty grains was then used to calculate the grain filling ratio expressed as a percentage. The moisture content of the filled grains was measured (Riceter Grain Moisture Meter, Kett Electric Laboratory, Tokyo, Japan) and the yield was determined from the weight of the filled grains and expressed in kg per hectare at 14% moisture content. All the data collected was summarized in Microsoft excel and

subjected to a analysis of variance (ANOVA) in randomized blocks using Statistical Tool for Agricultural Research (STAR) (International Rice Research Institute [IRRI], 2013). Data from each experimental site was analyzed separately due to distinct geographical locations, with varying soil and environmental factors. The post-hoc test use to separate treatment he means was Tukey's Honestly Significant Difference (HSD) test.

Estimation of the benefit cost ratio

The calculation of benefit-cost ratio involves dividing the present value of benefits by the present value of costs (Project Management Institute, 2017). To arrive at the present value of costs, we factored in the expenses associated with planting and harvesting one acre of land at two experimental sites during the second season of 2023. These expenses included the cost of setting up a nursery, uprooting seedlings, seeding, plowing, puddling, transplanting, fertilizers (excluding the cost of application), insecticides, weeding, harvesting, bags, transportation, bird control, and irrigation fees. Except for the cost of fertilizers, which varied depending on the experimental treatment, all other expenses remained constant within a particular experimental site. On the other hand, the present value of benefit was calculated based on the value of milled rice, which accounted for 65% of the paddy harvested. We used a flat rate of UGX 3,500 for milled rice, based on producer prices at the two trial sites in March 2024.

RESULTS AND DISCUSSION

Yield and yield components

The use of blended fertilizer resulted in higher rice-paddy yields both in the Doho and NaCRRRI experimental sites.

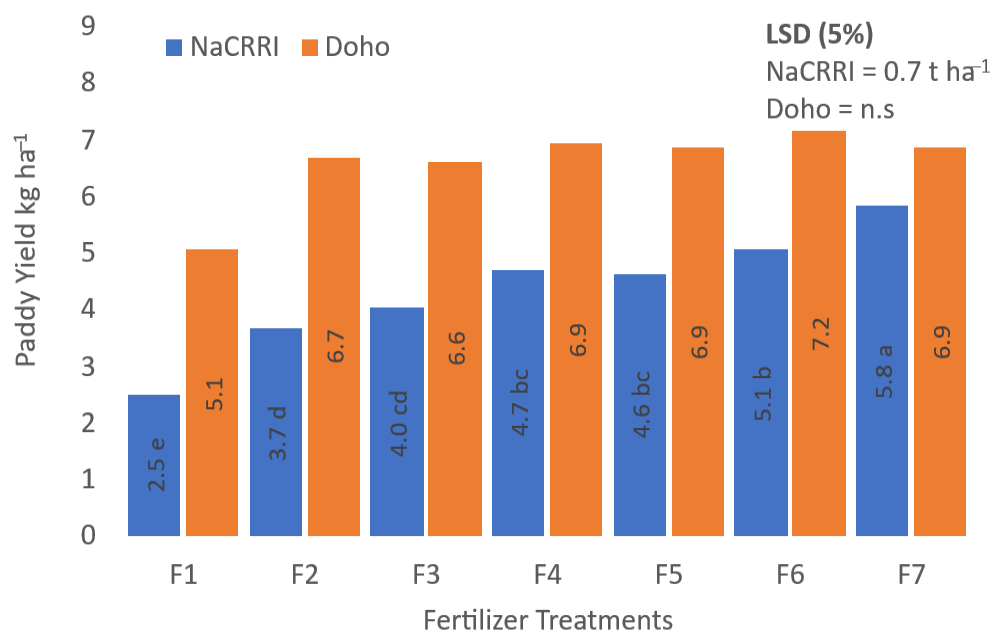


Figure 3. Comparison of paddy yield at different locations and fertilizer levels.

The yield increase calculated as the yield above that of the control treatment was statistically significant at NaCRRI, as illustrated in Figure 3 and appreciable at Doho. At NaCRRI, the paddy yield increased by 1.2 to 3.3 t ha⁻¹, while at the Doho irrigation system, it increased by 1.6 to 2.1 t ha⁻¹. The F-7 fertilizer treatment (150% of Basal + Top Dress) at NaCRRI recorded the highest percentage increase in yield of 133%, while at Doho, the F-6 fertilizer treatment (125% of Basal + Top Dress) recorded the highest percentage increase in yield of 41%. Another study in northern Uganda showed that using a rice-specific NPK blended fertilizer increased paddy rice yield by 2.2 t ha⁻¹, while the recommended DAP and urea only resulted in a 1.3 t ha⁻¹ increase (Kaizzi et al., 2024). A similar study on upland rice in Ethiopia found that applying blended fertilizer increased paddy yield from 2.2 t/ha in the control treatment to 5.3 t/ha with up to 100 kg of N/ha. No additional yield increase was observed with rates exceeding 100 kg N/ha (Abate and Bobo, 2022). The highest yield in this study in Doho was 7 t ha⁻¹, surpassing the 4.75 t ha⁻¹ reported in another study using the same variety and management (Awio et al., 2022a; Alibu et al., 2022). While the highest yield for NaCRRI in this experiment was 5.8 t ha⁻¹, a similar study recorded a yield of 4.6 t ha⁻¹ (Alibu et al., 2022). The two studies referenced support this study's findings that irrigated lowland rice yields in Uganda, as in the rest of sub-Saharan Africa, can be boosted significantly by using blended fertilizers. These fertilizers provide more balanced nutrition compared to the previously recommended DAP and Urea (Barungi and Odokonyero,

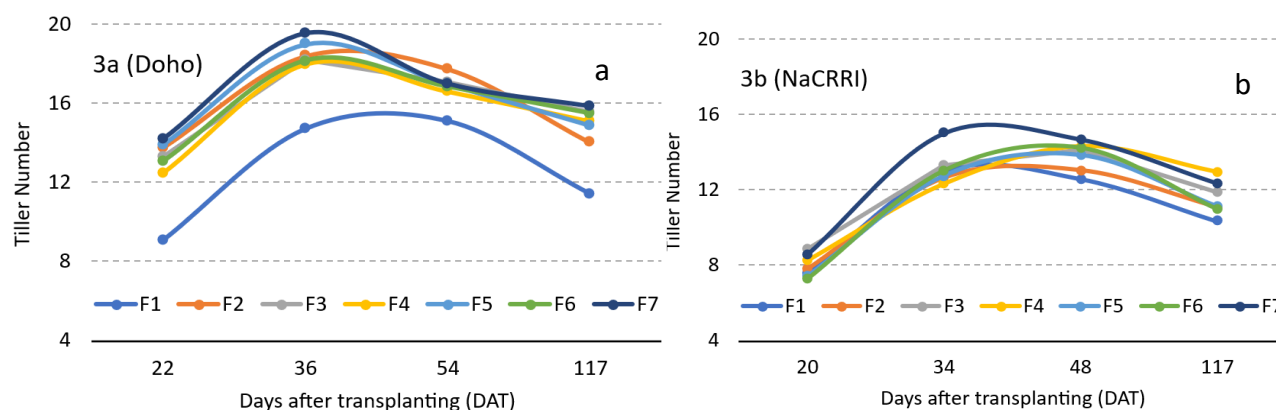
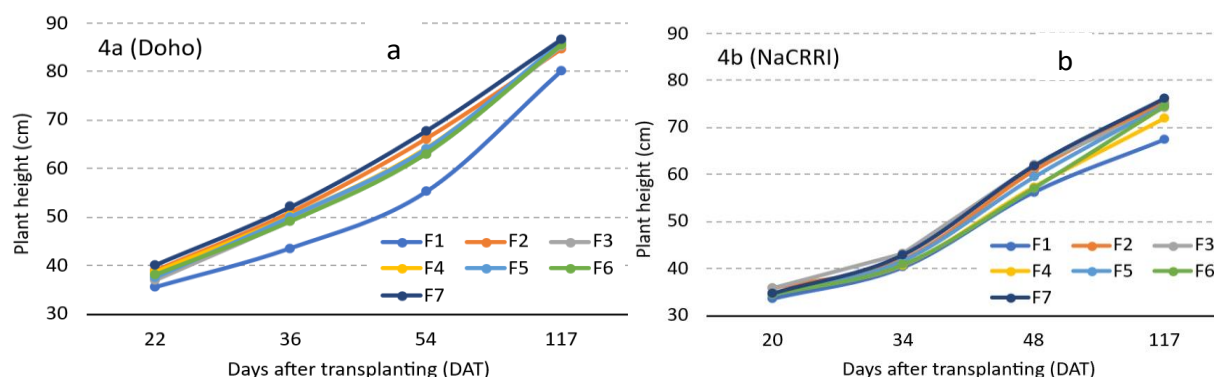
2016; Awio et al., 2022b). The increase in yield is likely due not only to the N, P, and K ratios in the blended fertilizer but also to the additional micronutrients: 3% sulfur trioxide, 2% magnesium oxide, and 1% sodium oxide. The enhanced yield from blended fertilizers can be largely attributed to potassium (K), which was missing from previous recommendations of DAP and urea fertilizers and is crucial for rice production in Uganda, as shown by nutrient omission trials (Kaizzi et al., 2024).

Blended fertilizer application had a greater positive effect on the number of panicles per square meter (related to tillering), which largely increased yield. Among the yield component metrics, we found that the number of panicles per square meter was the most highly correlated with paddy yield, *that is*, a very strong positive coefficient of correlation $r = 0.91$ for NaCRRI and 0.88 for Doho. Similar studies conducted in Doho and Olweny, it was observed that the yield of rice was directly proportional to the number of panicles per square meter (Awio et al., 2022a; Alibu et al., 2022). Tillering is a crucial agronomic trait in rice because the number of tillers directly affects the number of panicles, which is a key determinant of grain yield (Park et al., 2020). A moderate positive correlation was observed between 1000-grain weight and paddy yield, with $r = 0.53$ at NaCRRI and $r = 0.56$ at Doho.

The 1000-grain weight varies considerably between varieties (Chen et al., 2021) and can be influenced by environmental conditions, particularly during the grain-filling stage (Okamura et al., 2023; Gasparis and Miłoszewski, 2023). Table 3 shows the yield components of irrigated lowland rice grown with different fertilizer

Table 3. Yield components of irrigated lowland rice grown with different fertilizer levels.

Treatment	Panicles/m ²		Grains/Panicle		Grain Filling (%)		1000 Grain Weight	
	NaCRRi	Doho	NaCRRi	Doho	NaCRRi	Doho	NaCRRi	Doho
F1	152 ^c	235 ^b	94	111	81	84 ^a	21.4 ^b	22.7 ^b
F2	171 ^{bc}	312 ^{ab}	130	120	76	76 ^b	21.4 ^b	23.0 ^{ab}
F3	222 ^{abc}	366 ^a	110	101	78	77 ^{ab}	21.7 ^b	23.2 ^{ab}
F4	227 ^{abc}	357 ^a	122	108	78	76 ^b	21.5 ^b	23.3 ^a
F5	245 ^{ab}	332 ^a	109	113	78	78 ^{ab}	22.0 ^{ab}	23.3 ^a
F6	235 ^{ab}	350 ^a	113	115	83	77 ^{ab}	22.7 ^a	22.9 ^{ab}
F7	254 ^a	374 ^a	134	98	76	81 ^{ab}	21.8 ^b	22.9 ^{ab}
Mean	215	332	116	109.5	79	79	21.8	23.1
Turkey's HSD 5%	81	81	<i>n.s</i>	<i>n.s</i>	<i>n.s</i>	73	0.8	0.5
CV (%)	13.2	8.5	14.7	12.4	3.99	3.3	1.3	0.8

**Figure 4.** (a, b) Tilling progress of irrigated lowland rice grown with different levels of blended fertilizers.**Figure 5.** (a, b) Growth of irrigated lowland rice grown with different levels of blended fertilizers.

levels.

While there were no significant effects of fertilizer application on plant height and tillering, it was clear that height and tillering were higher in fertilized treatments,

particularly in Doho (Figure 4a and b). In both trial sites, rice growth and tillering improved in T7 compared to other treatments, although the differences were not statistically significant (Figure 5a and b).

Table 4. The cost-benefit ratio of growing rice with different amounts of blended fertilizer in the Doho irrigation scheme.

Variable	F-1	F-2	F-3	F-4	F-5	F-6	F-7
Total paddy yield	5.070	6.700	6.630	6.930	6.870	7.170	6.870
Total milled rice (TY)	3.296	4.355	4.310	4.505	4.466	4.661	4.466
Average price/kg (UGX)	3.500	3.500	3.500	3.500	3.500	3.500	3.500
Total revenue (TR) × 1000	11.534	15.243	15.083	15.766	15.629	16.312	15.629
Gross margin (TR - TVC) × 1000	10.336	13.841	13.577	14.212	14.023	14.654	13.923
Benefit-cost ratio (TR/TVC)	9.6	10.9	10.0	10.1	9.7	9.8	9.2
Unit cost of production (UGX)	364	322	349	345	360	356	382

Table 5. The cost-benefit ratio of growing rice with different amounts of blended fertilizer at NaCRRI.

Variable	F-1	F-2	F-3	F-4	F-5	F-6	F-7
Total paddy yield	2.500	3.670	4.030	4.700	4.630	5.070	5.830
Total milled rice (TY)	1.625	2.386	2.620	3.055	3.010	3.296	3.790
Average price/kg (UGX)	3.500	3.500	3.500	3.500	3.500	3.500	3.500
Total revenue (TR) × 1000	5.688	8.349	9.168	10.692	10.533	11.534	13.263
Gross margin (TR - TVC) × 1000	4.490	6.947	7.662	9.139	8.927	9.876	11.557
Benefit-cost ratio (TR/TVC)	4.7	6.0	6.1	6.9	6.6	7.0	7.8
Unit cost of production (UGX)	737	588	575	509	534	503	450

Benefit cost analysis of rice farming using blended fertilizer

The benefit cost ratio (BCR) is a relative measure which is used to determine benefit per unit cost and helps farmers in decision making activities. The average total production of milled rice was significantly higher in Doho at 4,294 kg compared to NaCRRI at 2,826 kg (Tables 4 and 5). This was due to the higher soil fertility and reliable irrigation facilities in Doho (Alibu et al., 2022). The experimental results show that rice production in Doho had an average gross margin of UGX 13.5 million per acre, which was significantly higher than NaCRRI's UGX 8.4 million per acre (Tables 4 and 5). The findings indicate that utilizing blended fertilizer for lowland irrigated rice cultivation is highly advantageous. The BCR (Benefit-Cost Ratio) was consistently positive for all treatments and at both experimental sites, indicating that the benefits of using fertilizer mixtures significantly outweigh the production costs (Tables 4 and 5). Specifically, farmers in Doho can expect to receive a benefit of UGX 10 for every UGX 1 spent, while those in NaCRRI can anticipate a benefit of UGX 6 for every UGX 1 of cost. The highest BCR at NaCRRI was achieved with fertilizer treatment F-7 (150% of Basal + Top Dress), in which 76 kg of mixed fertilizer was applied 10 days after transplanting (basal application) and an additional 51 kg of mixed fertilizer was applied 56 days after transplanting. In Doho, where the average benefit-cost ratio (BCR) was

10, and minor differences were observed between treatments, the selection of the best fertilizer treatment was made based on gross margins. A study on upland rice in Uganda found that using blended fertilizers yielded a benefit-to-cost ratio of 1.34, which falls short of the FAO-recommended minimum of 2 for farmer technology adoption (Kaizzi et al., 2024). The low ratios in upland rice may be due to water limitations affecting the response to fertilizer. In contrast, this study on irrigated lowland rice, where water was sufficient, reported higher benefit-to-cost ratios. Among all the treatments, the F-6 treatment showed the highest gross margin of UGX 14.7 million. This treatment involved applying 64 kg of blended fertilizer 10 days after transplanting (basal application) and an additional 51 kg of blended fertilizer 56 days after transplanting. A similar study conducted in Doho in 2019 found that following recommended agronomic practices, even without fertilizer application, resulted in a significant increase in yields and income (Alliance for a Green Revolution in Africa [AGRA], 2018; Awio et al., 2022b). This suggests that the soils in Doho are fertile enough to support high rice yields. However, the study also found that the distribution of net revenue from improved management practices shifted towards the lower side of NPK fertilizer application due to high fertilizer costs. This suggests that the nutrient content of 100:50:50 kg NPK ha⁻¹ was not economically viable at current rice and fertilizer prices due to the risk of little or no return on fertilizer investment. This finding supports our fertilizer

recommendation of F-6 (65:48:34 kg NPK ha⁻¹) for Doho.

CONCLUSION AND RECOMMENDATIONS

This study was conducted to evaluate the effectiveness of blended fertilizers in enhancing the productivity of irrigated lowland rice in Uganda and to develop recommended fertilizer application rates. Blended fertilizers increased irrigated rice yields by 1.2 to 3.3 t ha⁻¹, depending on the application rate. In Doho, applying 125% of the basal fertilizer 157 kg ha⁻¹ for basal and 126 kg ha⁻¹ for top-dress resulted in the highest average gross margin of UGX 14.7 million, making it the most effective rate for farmers in that area. At NaCRRI, applying 150% of the basal fertilizer 189 kg ha⁻¹ for basal and 126 kg ha⁻¹ for top-dress yielded the highest gross margin of UGX 11.6 million, making it the best option for farmers there. Overall, blended fertilizers can significantly increase yields in irrigated lowland rice farming, enhancing profitability and competitiveness. They offer a cost-effective solution by delivering a balanced mix of macro- and micronutrients in a single application, thereby reducing the need for multiple fertilizer types.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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