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Growth Responses and Weed Control of Upland Rice Varieties under Different Weed Management Strategies and Fertilizer Types

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Abstract

Rice (*Oryza sativa*) is a vital staple crop for over half of the global population, yet its productivity is constrained by weed competition. A field experiment was conducted from July to November 2023 at the Teaching and Research Farm, University of Abuja, to evaluate the growth performance of three upland rice varieties (FARO 55, FARO 56, and FARO 59) under weed management strategies [herbicide at standard rate (M1), reduced rate (M2), manual weeding (M3), and no weeding (M4)] and fertilizer types [organic (F1), inorganic (F2), and no fertilizer (F3)]. A split-split plot design was employed with rice varieties as main plots, weed management as sub-plots, and fertilizer types as sub-sub plots. Growth parameters measured were plant height, tiller number, and leaf area index (LAI) at 4, 8, and 12 weeks after sowing (WAS). Data were analyzed using SPSS version 27. Results revealed that FARO 55 significantly ($p<0.05$) outperformed FARO 56 and FARO 59 in plant height (54.94 cm), tiller number (5.21), leaf number (9.79), LAI (2.84), root length (5.84 cm), and biomass (1.81 g). FARO 59, however, showed competitive relative growth (0.02) and strong weed suppression ability. Treatments combining reduced herbicide with inorganic fertilizer (M2F2) and manual weeding with inorganic fertilizer (M3F2) notably enhanced plant height (50.44, 50.64 cm) and LAI (2.48, 2.45). Effective weed control was also observed under treatments combining herbicides (standard or reduced) with organic, inorganic, or no fertilizer. It could be concluded from these findings that appropriate variety selection combined with integrated weed-nutrient management is essential for improving upland rice growth and ensuring sustainable productivity.

Keywords: Upland rice, reduced herbicide, sustainable farming, weed management

Introduction

Rice (*Oryza sativa*) is a global vital staple food crop, providing food for more than half of the world's population (Kingra *et al*., 2019; Verma *et al.*, 2021; Asma *et al.*, 2023). Its cultivation plays an important role in ensuring food security and economic stability, particularly in many developing nations (Bandumula, 2018). Rice is cultivated across various ecosystems, including irrigated, rainfed lowland, and upland environments. Upland rice is especially significant in areas where water resources are scarce or where irrigation infrastructure is lacking (Fahad *et al*., 2019). The cultivation techniques for upland rice differ considerably from those used for lowland rice, necessitating careful soil and water management to achieve satisfactory growth and yield (Datta *et al*., 2017; Liu *et al*., 2019). Upland rice fields are often more susceptible to weed infestations and nutrient deficiencies due to the absence of standing water, which in lowland fields naturally suppresses weeds and aids nutrient uptake. Weeds pose a significant challenge in rice production, competing with crops for essential resources like nutrients, water, and light, which can drastically reduce yields if not effectively managed (Rana and Rana, 2016; Kaur *et al*., 2018; Kumar *et al*., 2023). Weed management in rice involves various strategies such as chemical control with herbicides, manual weeding, and integrated approaches that combine multiple methods (Jabran and Chauhan, 2015; Nagargade *et al*., 2018). Chemical control is effective and reduces labour demands, but it raises issues regarding environmental impact, the potential for herbicide resistance, and residual effects on future crops while manual weeding is environmentally sustainable, it is labor-intensive and may not be feasible for large-scale farming operations (Peterson *et al.*, 2017; Imoloame *et al.*, 2021).

Fertilizers play a significant role in supplying essential nutrients to rice plants and come in two main types: organic and inorganic (Shrestha *et al.*, 2020). Organic fertilizers, such as manure and compost improve soil structure, boost microbial activity, and provide a gradual release of nutrients. In contrast, inorganic fertilizers, including Urea and NPK (Nitrogen, Phosphorus, Potassium), deliver nutrients that are quickly available and can rapidly enhance crop growth. The choice between these fertilizers can greatly influence the growth, yield, soil health, and sustainability of upland rice (Sharma and Chetani, 2017; Ghosh and Devi, 2019; Ilahi *et al.*, 2021).

Weed management and fertilization are interconnected practices that are essential for upland rice productivity, uncontrolled weeds can lead to substantial yield reductions by competing for nutrients, light, and water (Tshewang *et al.*, 2016; Shrestha *et al.*, 2020). Effective weed management minimizes this competition, allowing rice plants to use available resources more effectively while fertilization supplies the nutrients necessary for plant growth, development, and yield (Jabran *et al.*, 2018; Shrestha *et al.*, 2020). The type and timing of fertilizer application can impact the success of weed management strategies; for example, proper fertilization can improve the vigor of rice plants, making them more competitive against weeds (Rao *et al*., 2017; Ilahi *et al.*, 2021; Monteiro and Santos, 2022). This study aims to explore how different weed management strategies and fertilizer types affect the growth performance of upland rice varieties, providing practical recommendations for integrated weed and nutrient management to boost upland rice productivity.

Materials and Methods

Description of Experimental Site and Conditions

The research was carried out from July to November 2023 at the Teaching and Research Farm of the Faculty of Agriculture, University of Abuja, located in Abuja, which experiences a tropical savanna climate with distinct wet and dry seasons. The experimental site lies at an elevation ranging from 360 to 490 meters above sea level. The area receives an average annual rainfall between 1,200 mm and 1,500 mm, primarily occurring from April to October, with temperatures during the wet season averaging between 22°C and 30°C (NiMet, 2021). The soil at the site is sandy loam, composed of 71% sand, 14% silt, and 15% clay, with a pH of 6.5 and a carbon content of 9.8 g/kg (University of Uyo Lab.). Before the experiment commenced, the site was left fallow for a year to ensure uniform soil conditions and to minimize any residual effects from previous crops.

Experimental Treatments and Design

Three upland rice varieties (FARO 55, FARO 56, and FARO 59) were sourced from National Cereals Research institute (NCRI), Badeggi based on their agronomic traits and their relevance to upland rice cultivation in the region. The study also involved four weed management strategies (chemical application at the manufacturer recommended rate of 500 ml/ha (standard rate), chemical application at a reduced rate of 300 ml/ha, manual weeding, and a control), as well as two types of fertilizers (organic and inorganic). The experiment was designed using a split-split plot layout. replicated three times. The total experimental area covered 259 square meters, with each plot measuring 1 square meter. Plots were separated by 0.25 meters, and there was a 1-meter gap between different varieties and replicates. In total, 108 plots were used in the study The main plots were designated for rice varieties, sub-plots for weed management strategies, and sub-sub plots for fertilizer types, resulting in 12 treatment combinations: M1F1 (standard herbicide rate with organic fertilizer), M1F2 (standard herbicide rate with inorganic fertilizer), M1F3 (standard herbicide rate with no fertilizer), M2F1 (reduced herbicide rate with organic fertilizer), M2F2 (reduced herbicide rate with inorganic fertilizer), M2F3 (reduced herbicide rate with no fertilizer), M3F1 (manual weeding with organic fertilizer), M3F2 (manual weeding with inorganic fertilizer), M3F3 (manual weeding with no fertilizer), M4F1 (control with organic fertilizer), M4F2 (control with inorganic fertilizer), and M4F3 (control with no fertilizer).. The total experimental area covered 259 square meters, with each plot measuring 1 square meter. Plots were separated by 0.25 meters, and there was a 1-meter gap between different varieties and replicates.

Agricultural Practices

The site was cleared of existing vegetation using manual labour and mechanical tools to remove weeds, grasses, and other plant residues, which was essential for minimizing weed competition and facilitating subsequent tillage operations. Tillage was performed in two stages: Primary tillage involved plowing the soil to a depth of 20-25 cm with a tractor-mounted moldboard plow, which helped break up compacted soil layers, incorporate organic matter, and improve soil aeration and drainage. Secondary tillage followed, using a harrow to refine the soil by breaking down large clods and creating a fine seedbed. Harrowing was conducted twice, with a week between operations, to ensure thorough soil pulverization and uniformity. The field was then leveled with a leveling board to create an even surface, crucial for uniform water distribution during irrigation and efficient planting. Each plot was clearly marked and labeled for accurate data collection and management. Sowing was carried out on July 21, 2023, with three seeds dibbled at a depth of 2 cm and spaced 20 cm x 20 cm apart, ensuring optimal plant density. Three weeks after sowing, seedlings were thinned to one hill per stand. Sowing was done manually to achieve uniform seed placement. Three fertilizer treatments: organic, inorganic, and control were applied to evaluate their effects on rice growth. HELIN-1-FARM organic liquid fertilizer was applied at the rate of 6L/ha at 3 and 8 weeks after sowing (WAS). Inorganic fertilizer was applied at a rate of 120 kg N/ha, 60 kg P/ha, and 60 kg K/ha (200 kg/ha of NPK 15:15:15 at 3 WAS and urea at 65 kg/ha at 8 WAS). The control plots were left without fertilizer application, serving as a baseline for comparison. Weed management was conducted at 4, 8, and 12 WAS using Agriforce, a selective post-emergence herbicide containing Bispyribac sodium at 100 g/L, applied at 500 ml/ha for the standard rate and 300 ml/ha for the varied rate. Manual weeding was done on the plots requiring it, while control plots were left unmanaged, allowing weeds to grow naturally throughout the experiment

Data Collection

Data were taken at 4, 8, and 12 weeks after sowing (WAS) for: plant heigh which was determined by measuring from the base of the plant to the tip of its tallest leaf using a meter rule, tiller number was determined by visually inspecting each plant and recording the number of side shoots that had emerged from the main stem, leaf number, leaf area index (LAI) was assessed according to the method proposed by Gomez (1972), root number was determined by counting the number of adventitious roots emerging from the base of the stem of a destructive sample manually, root length was measured from the base of the plant to the tip of the longest root using a meter rule, relative growth rate, weed density was calculated as the number of individual weed plants per square meter, weed biomass was measured using standard destructive sampling procedures, weed species richness was determined using systematic quadrat sampling, applying ecological survey methods adapted from Magurran (2013), weed cover was determined by employing a visual rating method based on the percentage of ground area covered by weeds., and weed competitive index was calculated using the relative dry matter method described by Moody (1991) and Rao *et al*. (2000). Standard procedures established by the International Rice Research Institute (IRRI, 2002) were used for growth parameters, with similar protocols applied for weed parameters. The data collected were analyzed using analysis of variance (ANOVA) in the Statis tical Package for the Social Sciences (SPSS) version 27 to evaluate the significance of the treatments. Means were separated using Duncan's Multiple Range Test (DMRT) at the 5% significance level. Significant differences among treatments were identified, and the interaction effects were analyzed to understand the combined influence of rice varieties, weed management strategies, and fertilizer types.

Results

FARO 55 had the highest values for plant height (54.94 cm), tiller number (5.21), leaf number (9.79), Leaf Area Index (LAI) (2.84), root length (5.84 cm), and biomass (1.81 g), significantly surpassing FARO 56 and FARO 59. However, FARO 55 had a lower root number (16.11) compared to FARO 56 and FARO 59. FARO 56 exhibited the highest root number (19.42) but had a comparatively shorter root length (5.09 cm). Both FARO 55 and FARO 59 showed a competitive relative growth rate (RGR) of 0.02. Treatments M2F2 and M3F2 resulted in the highest plant heights (50.44 cm and 50.64 cm, respectively), while M3F1 had the lowest (40.02 cm). Treatments like M2F1, M2F2, and M3F1 supported a higher leaf number (9.62 each), and treatments M2F2 and M3F2 significantly enhanced LAI. Root number did not differ significantly among the treatments, but the M4F3 treatment showed greater root length. The M2F3 treatment produced the highest biomass (1.74 g), and RGR remained relatively stable across treatments despite variations in other parameters. The interaction between variety and treatment significantly influenced tiller number, leaf number, weed density, weed richness, and weed biomass (Table 1).

FARO 55 had the highest weed density (19.79 plants/m^2), while FARO 59 had the lowest (15.40 plants/m^2). Weed height was fairly consistent across varieties, with FARO 55 having slightly taller weeds (17.22 cm). FARO 55 also had the highest weed richness (4.57 %), weed biomass (1.07g), and slightly higher weed cover (20.09 cm), whereas FARO 59 had the highest Weed Competitive Index (WCI) (2.86). Treatments M4F1, M4F2, and M4F3 showed the highest values across all weed parameters (weed density (42.51plants/m^2, 46.85 plants/m^2, 47.89 plants/m^2 respectively), weed height (36.53 cm, 38.30 cm, 38.38 cm respectively) , weed richness (6.37 %, 6.48 %, 6.93 % respectively) ,weed biomass (1.86 g, 1.70 g, 1.89 g respectively), weed cover (50.48 %, 51.78 %, 52.37 % respectively), and WCI (7.35, 10.46, 9.30 respectively) compared to other treatments (Table 2).

Discussion

Taller plants like FARO 55 may have an advantage in light capture, which is essential for photosynthesis and overall growth. However, this increased height could also make them more prone to lodging under challenging conditions (Gu *et al.*, 2017; Falster *et al.*, 2018). The superior tillering ability seen in FARO 55 might contribute to its potential for higher yield, aligning with findings by Wang *et al.* (2017) and Nurhasanah *et al.* (2017) that suggest higher tillering is often linked to increased grain yield due to a greater number of panicle-bearing tillers. The higher leaf number and Leaf Area Index (LAI) observed in FARO 55 indicate more robust vegetative growth compared to FARO 56 and FARO 59, as LAI is a key factor in determining canopy structure and light interception, which influences photosynthetic efficiency and biomass production according to Xue *et al.* (2016) and leads to high yield (Shi *et al.*, 2019). The greater root number and length produced by FARO 56 and FARO 55 respectively, are associated with better nutrient and water uptake, which is crucial for plant growth and stress tolerance (Falster *et al*., 2019). The higher biomass recorded in FARO 55 reflects its superior growth performance according to Falster *et al*. (2018). Despite FARO 59's lower plant height and tiller number, it displayed a competitive Relative Growth Rate (RGR) similar to FARO 55, indicating efficient growth relative to its size as reported by Rajput *et al*. (2017). This also aligns with reports that biomass is a direct indicator of plant productivity, and a higher RGR suggests faster biomass accumulation, potentially leading to higher yield (Pittaro *et al*., 2024). The taller plant heights observed in treatments M2F2 and M3F2, along with the greater tiller numbers in treatments M1F1, M2F1, and M3F1, suggest that these treatment combinations significantly influence vegetative growth, with some promoting taller plants and increased tillering (Kaur *et al*., 2018; Kumar *et al*., 2024). The treatments M1F1, M2F1, M2F2, and M3F1, that supported higher leaf numbers, and the treatments M2F2 and M3F2, which enhanced LAI, may be linked to optimized nutrient availability or other favorable growth conditions, leading to improved leaf development and better canopy coverage (Farooq *et al*., 2019; Soares *et al*., 2019). The longer root length observed in treatment M4F3 suggests enhanced root growth under stress and overall plant vigor (Shi *et al*., 2020). According to Lamont *et al*. (2023), the relatively stable RGR across treatments indicates consistent growth rates despite differences in biomass accumulation efficiency. The higher biomass produced by M2F3 indicates that this treatment combination may offer optimal conditions for biomass accumulation (Pittaro *et al*., 2024).

The higher weed density observed in FARO 59 plots may indicate either lower competitiveness of the variety or higher nutrient availability benefiting both rice and weeds which supports the findings by Dass *et al*. (2017). FARO 55, having slightly taller weeds, suggests that certain treatment combinations may influence weed growth dynamics in these plots (Adigun *et al*., 2017).

The taller weeds and higher weed richness recorded for FARO 55 indicated that the weed species are slightly more vigorous when grown alongside with this variety, potentially due to its agronomic practices or environmental adaptations (Rana and Rana, 2016) while the lower weed richness in FARO 59 suggested better weed suppression or more efficient nutrient use by the rice plants themselves, reducing weed competition (Nagargade *et al*., 2018). Highly competitive index suggests that either the variety's competitiveness is poor or there is high nutrient availability that benefits both rice and weeds (Dass *et al*., 2017). The lower weed biomass recorded in FARO 59 could be that this variety is either more competitive against weeds or benefits more from weed management practices as reported by Choudhary *et al.* (2022). Treatments M4F1, M4F2, and M4F3, which showed the higher values across multiple weed parameters, may be less effective at controlling weeds or may create conditions that are more conducive to weed growth (Jehangir *et al*., 2021). On the other hand, treatments M1F1, M1F2, M1F3, M2F1, M2F2, and M2F3, which exhibited the lower values for weed parameters, appear to have a more significant impact on reducing weed density and biomass. This could be attributed to either more effective weed control methods or enhanced competitiveness of the rice plants under these treatments according to Ahmed *et al*. (2020).

Conclusion

FARO 55 generally outperforms FARO 56 and FARO 59 in most growth parameters, indicating its potential as a high-yield variety under the given conditions. However, FARO 56's superior root number suggests it may be more resilient under conditions where root efficiency is critical. The treatments, particularly M2F2 (varied herbicide rate with inorganic fertilizer), and M2F3 (varied herbicide rate with no fertilizer) and M3F2, significantly enhance certain growth parameters, suggesting that tailored agronomic practices can optimize rice growth and yield. FARO 59 combined with treatments M1F1, M1F2, M1F3, M2F1, M2F2 and M2F3, appeared to be the most effective combination for weed control. This highlights the importance of selecting appropriate rice varieties and treatments for effective weed management.

Table 1: Influence of weed management strategies and fertilizer types on growth of upland rice cultivars.

Variables	**PH (cm)**	**TN**	**LN**	**LAI**	**RN**	**RL(cm)**	**BM**	**RGR**
Variety								
FARO 55	54.94[a]	5.21[a]	9.79[a]	2.84[a]	16.11[c]	5.84[a]	1.81[a]	0.02[a]
FARO 56	43.60[b]	4.74[b]	9.60[b]	1.65[b]	19.42[a]	5.09[b]	1.42[b]	0.01[b]
FARO 59	37.18[c]	4.43[c]	8.96[c]	1.40[b]	17.87[b]	4.50[c]	1.39[b]	0.02[a]
SEM±	1.26	0.02	0.01	0.11	0.45	0.12	0.05	0.01
Treatment								
M_1F_1	43.84[abc]	5.20[a]	9.62a	1.71[b]	16.62	4.74b[c]	1.42[ab]	0.01
M_1F_2	43.01[abc]	4.78c	9.55[ab]	2.04[ab]	17.88	5.11[abc]	1.50[ab]	0.02
M_1F_3	45.79[abc]	4.51f	9.39[c]	2.14[ab]	18.44	5.17[abc]	1.55[ab]	0.01
M_2F_1	46.58[abc]	5.18a	9.62[a]	1.99[ab]	17.59	5.27[abc]	1.49[ab]	0.02
M_2F_2	50.44[a]	4.72cd	9.62[a]	2.48[a]	18.18	5.36[ab]	1.61[ab]	0.01
M_2F_3	47.90[abc]	4.48f	9.32[d]	2.12[ab]	18.93	5.20[abc]	1.74[a]	0.02
M_3F_1	40.02[c]	5.28a	9.59[a]	1.71[b]	17.25	4.57[c]	1.52[ab]	0.01
M_3F_2	50.64[a]	4.55ef	9.40[c]	2.45[a]	17.48	4.92[bc]	1.57[ab]	0.01
M_3F_3	48.63[ab]	4.59def	9.20[e]	2.02[ab]	17.93	5.43[ab]	1.49[ab]	0.02
M_4F_1	41.26b[c]	5.02b	9.51[b]	1.75[b]	17.78	5.29[abc]	1.58[ab]	0.01
M_4F_2	41.10b[c]	4.55ef	9.39[c]	1.52[b]	17.37	4.81[bc]	1.40[b]	0.01
M_4F_3	43.68[abc]	4.67cde	9.20[e]	1.59[b]	18.11	5.84[a]	1.55[ab]	0.01
SEM±	2.53	0.04	0.02	0.22	0.90	0.24	0.10	0.01
V x T	Ns	<0.001	<0.001	Ns	Ns	Ns	Ns	Ns

Mean value of figures with the same superscript in a column are not significantly different (p<0.05%). Plant height=PH, tiller number=TN, leaf number=LN, leaf area index=LAI, root number=RN, root length=RL, biomass=BM, relative growth rate=RGR.

Table 2: Effect of weed management strategies and fertilizer types on weed growth in upland rice field.

Variable	WD	WH (cm)	WR (%)	WC (%)	WB (g)	WCI
Varieties						
FARO 55	19.79^{a}	17.22	4.57^{a}	20.09	1.07^{a}	2.08
FARO 56	17.56^{b}	16.49	3.96^{b}	18.86	0.87^{b}	2.66
FARO 59	15.40^{c}	15.29	3.62^{c}	18.46	0.74^{c}	2.86
SEM±	0.53	0.78	0.09	0.61	0.03	0.33
Treatment						
M_1F_1	6.93e	6.76c	2.82de	4.11d	0.52de	0.10c
M_1F_2	7.44^{e}	$8.10b^{c}$	2.59^{def}	4.26^{d}	0.39^{e}	0.12^{c}
M_1F_3	6.59^{e}	7.55^{c}	2.19^{f}	4.48^{d}	0.42^{e}	0.11^{c}
M_2F_1	7.04^{e}	7.85^{c}	2.93^{de}	4.93^{d}	0.47^{e}	0.11^{c}
M_2F_2	7.11^{e}	10.20^{bc}	3.11^{d}	6.70^{d}	0.51^{de}	0.22^{c}
M_2F_3	6.59^{e}	8.08^{bc}	2.48^{ef}	6.37^{d}	0.52^{de}	0.15^{c}
M_3F_1	10.70^{c}	9.74^{bc}	4.22^{c}	13.37^{c}	0.70^{cd}	0.62^{c}
M_3F_2	11.03^{c}	13.00^{b}	4.41^{c}	18.07^{b}	1.03^{b}	1.26^{c}
M_3F_3	10.25^{cd}	11.34^{bc}	4.11^{c}	12.70^{c}	0.72^{c}	0.56^{c}
M_4F_1	42.51^{b}	36.53^{a}	6.37^{b}	50.48^{a}	1.86^{a}	7.35^{b}
M_4F_2	46.85^{a}	38.30^{a}	6.48^{ab}	51.78^{a}	1.70^{a}	10.46^{a}
M_4F_3	47.89^{a}	38.38^{a}	6.93^{a}	52.37^{a}	1.89^{a}	9.30^{a}
SEM±	1.05	1.55	0.18	1.2	0.06	0.66
V x T	<0.001	Ns	0.007	Ns	0.002	Ns

Mean value of figures with the same superscript in a column are not significantly different (p<0.05%). Weed density=WD, weed height=WH, weed richness=WR, weed cover=WC, weed biomass=WB, weed competitive index=WCI.

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