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Research Article

The Performance of Three Submergence-Tolerant Rice Varieties at Different Agro-ecological Submergence Zones in a Riverine Grassland

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Abstract

The study was conducted in a riverine grassland along the river Taia/Jong, Njala university, Southern Sierra Leone. It was undertaken with the aim of investigating the performance of three submergence-tolerant rice varieties at different elevation zones in a Riverine grassland. The experimental design had two factors (three rice varieties and six elevation zones) arranged in a Randomized Complete Block Design (RCBD) in each of two blocks. The rice varieties were Indochine Blanc (Deepwater Floating Rice), FARO 66 and FARO 67 respectively. Yield responses to submergence depth were non-linear and variety-specific: FARO 66 and FARO 67 peaked at intermediate depths (76–143 cm), while Indochine Blanc shows a flatter, lower response with slight improvement under deep water. The study concluded that the strong variety-by-submergence interaction ($p < 0.05$) revealed that flooding did not act as a blanket constraint, but rather as a filter that distinguished genotypes by their tolerance capacity. While the FARO varieties generally performed best at 143 cm, these average trends were conditional on statistical context. For growers in flood-variable environments, the path to optimal yield lay in deliberately pairing water-depth management with the natural submergence-tolerance strengths of the chosen rice variety. FARO 66 is recommended for areas with stable shallow to medium flooding (up to 150 cm), while FARO 67 is preferable where water levels fluctuate frequently. Indochine Blanc is not suitable for commercial production under the tested conditions due to consistently low yields.

Keywords

Submergence Variety, FARO 66, FARO 67, Deepwater Floating Rice

1. Introduction

Rice (*Oryza sativa* L.) is one of the oldest and most important staple foods, serving as a dietary cornerstone for over half of the world's population [1, 2]. As one of the three most produced crops globally, alongside sugarcane and maize, it holds considerable strategic significance across much of Africa [3]. Nutritionally, rice provides 32–59% of dietary energy and comprises up to 40% of dietary protein in some regions [4, 5]. In Sub-Saharan Africa (SSA), consumption has risen

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sharply, from 9.2 Mt in 1990 to 31.5 Mt in 2019 [6].

Rural populations rely heavily on rain-fed agriculture for their food and income [2], and rain-fed paddy rice, with its puddled soil and near-continuous water availability, holds strong yield potential. Across SSA, over 70% of the rice area is rainfed, with cultivation spanning nearly 10 million hectares across 40 African countries, where rainfed upland and lowland systems are the most ubiquitous and dominant [7-9]. Rainfed lowland rice is the largest contributor to production, accounting for 48% of the total, followed by irrigated (33%) and rainfed upland (19%); however, productivity varies considerably, with irrigated systems generally achieving higher yields [10].

A major constraint across African rice-growing areas is flooding, with varying water depths, crop stages at flood onset, and durations of water accumulation [11]. Deepwater rice (*Oryza sativa*) is specifically defined as varieties grown in flooded conditions where water exceeds 50 cm for at least one month during the season; intermediate floodplains range from 30–100 cm, while deepwater areas surpass 1 m at peak rainy periods [12, 13]. Globally, such flooded rice areas cover about 11 million ha, yet average yields remain low at just 1.5 t/ha [14, 15].

Sierra Leone covers 72,325 km^2, of which nearly 75% is arable distributed between upland (78%) and lowland (22%) ecologies. The lowland comprises 690,000 ha of Inland Valley Swamps, 145,000 ha of Bolilands, 130,000 ha of Riverine grasslands, and 200,000 ha of Mangrove Swamps. Within this, the southern province holds about 2,000 ha of shallow and 7,000 ha of deep riverine grassland, while the northern province has 4,000 ha of shallow floodplains [16, 17]. The largest expanse of riverine grassland lies in the Tormabum area of Bonthe and Pujehun Districts. This is a true deepwater system, closely resembling the deepwater rice areas of southern Sierra Leone: it floods to depths of 3–4 m during the rainy season because a raised sandbar at the mouths of the Waanje and Sewa Rivers blocks their flow, forcing both into a single stream that runs parallel to the shore for 30–50 km before reaching the sea.

Submergence stress is one of the primary factors limiting rice production, making investigations into varietal growth responses critical for safeguarding yield sustainability and stability [18, 19]. Deepwater floating rice (DW-FR), such as the variety Indochine Blanc, has long been a staple for millions living in flood-prone river basins and deltas across Asia and Africa [12, 20, 21]. When floodwaters rise, the stems of Indochine Blanc elongate at an extraordinary rate of 20–25 cm per day, keeping the plant's head afloat hence the terms "floating" or "deepwater" rice [20]. This trait offers a biological solution to the highly variable flood depths that farmers face during the rainy season. Nevertheless, average rice yields in SSA still hover around 2 t/ha and have shown signs of stagnation from 2012 to 2023 [22], far below the region's potential. In this context, the varieties FARO 66 and FARO 67 have become widely popular in West Africa, demonstrating a 1–3 t/ha yield advantage over recurrent parents under submergence stress [23]. This study was undertaken to investigate the performance of three submergence-tolerant rice varieties, namely Indochine Blanc, FARO 66, and FARO 67, at different water level zones in a riverine grassland.

2. Materials and Methods

2.1. Study Site

Figure 1. *Google earth image of the Experimental Site, with inset map of Sierra Leone.*

The experiment was conducted in a riverine grassland (08°12' N latitude and 12°06' W longitude) situated between the former West Africa For Oil palm Research (WAFOR) plantation and Kaniya village, across the Taia/Jong River. The riverine grassland is located close to the bank of the river and it is mostly flooded during the rainy season when the river spills over into the grassland. The research site is a typical Riverine grassland comprising a clayey alluvia soil, sandy clay loam texture which is a characteristics of the Gbesebu series soil type classification which make up the major portion of the current alluvial floodplain of the Taia River. The parent material of clayey alluvium is always more than 120 cm thick with texture of silty clay in the topsoil and usually clay in the subsoil. The silt content is moderately high, 35-45 percent. The adjacent upland consists of thick forest over which runoff is generated after rainfall events. The valley system has a topography that effectively enables the capture and storage of runoff, as is common around big rivers in many parts of Sierra Leone. The region is semi-humid to humid with a unimodal rainfall pattern that ranges between 2000-4000mm annually. The area of the experimental site comprises 15.4 acres/ 6.24 hectares, as shown in Figure 1.

2.2. Experimental Design

The field experiment was conducted from May to November 2020. The site was cleared of vegetation and ploughed manually using hoes. The site was well developed with two constructed micro dams at the upstream areas and a berm was also constructed at the downstream very close to the mouth of river Taia, to reduce the entry of river water into the experimental site for controlling flooding. The experiment was replicated at two locations, one upstream and the other downstream of the micro-dams. Each location was divided into three zones based on the difference between the minimum and maximum elevation (Figure 2). Each zone was planted with three replicates of each variety using a randomized complete block design (RCBD). The upstream section was constantly underwater with but little change in water depth over time, while the downstream section experienced wide fluctuations in water depth at near cyclical two-week intervals. The berm consisted of two main gates which were used to control the movement of water from the site to the Taia River when necessary. A 3.6 m staff with 1 cm graduations was designed and placed in each zone for collecting daily water level data. Growth parameters were measured throughout the growing season. Ploughing and seeding were done on two occasions. Indochine Blanc was first planted on May 3rd, 2020, due to its long growing season, while FARO 66 and FARO 67 were planted on June 1st, 2020, due to their short growing seasons. The experiment comprised three replications of three rice varieties at each of two sites, in three depth zones, yielding a total of fifty-four plots.

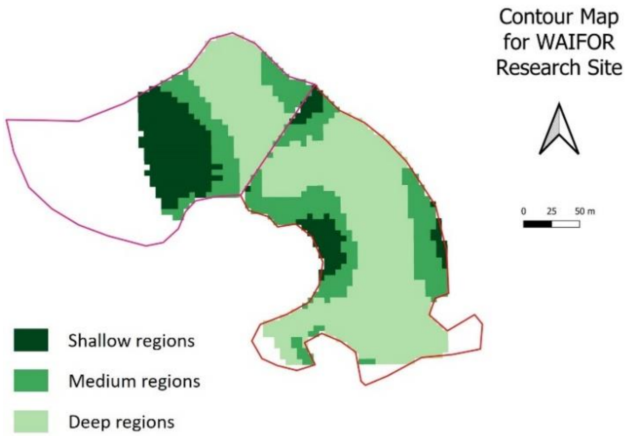

Figure 2. Elevation zones across the study area.

2.3 Data Collection

2.3.1. Soil, Topographic and Water Level Data

A topographic reconnaissance survey was conducted using GPS receivers, laser measures, levels, and tripods to determine ground elevations.

Three composite topsoil samples (0–20 cm) were collected per plot with a soil auger immediately after the survey.

Daily upstream and downstream water levels were recorded to the nearest centimeter using local staff gauges, with continuous measurement even during flooding (extended staff in deep areas when needed).

2.3.2. Crop Performance

Plant Height: Four weeks after direct seeding, measurements were taken at two-week intervals, except when the plants were completely inundated (Weeks 8, 10, and 12). In each plot, five plants were randomly selected and tagged with a blue plastic rope for taking plant height measurements. Plant height was measured from ground level to the tip of the highest leaf, to the nearest centimeter.

Tiller Numbers: The number of individual tillers were manually counted for every tagged plant in all of the plots at the same time that plant height measurements were made.

Number of panicle per m^2

The total number of panicles was counted manually from the 1 m^2 harvested in each plot. The total number of spikelets per panicle was counted manually from the panicles in the m^2 areas.

2.3.3. Rice Grain Yield

At harvest, yield components (fresh and dry grain weights, initial and final grain moisture, and 1000-grain weights) were obtained from the panicles harvested from every plot. Fresh grain weights were obtained by using an electronic measuring scale to record the weight of the freshly harvested and threshed panicles from all plots and the same procedure was followed to get dry grain weights after the grains were properly sun-dried. Grain yields were reported at a moisture content of 13 - 14 percentage. Initial grain moisture content was obtained by using the electronic moisture meter to determine the amount of moisture in the grain when freshly harvested and threshed; the same procedure was followed to determine the final grain moisture content after the grains were properly sun-dried. One thousand (1000) grains were evenly selected from each of the plot grains and weighed using an electronic scale to determine the 1000-grain weights

2.4. Data Analysis

Data was analyzed using excel 2016 Version and various results were presented in graphs and Scatter diagram. The data were analyzed in SPSS (Statistical Package for Social Sciences) version 26. SPSS was preferred over other statistical packages in this study because of its ready availability, wide global application and high reliability. The data from the randomized block design in three replicates were evaluated for two factors (water levels and Rice varieties). The analysis of variance (ANOVA) test was done to isolate the effects of each treatment and treatment interaction effects on yield. For cases with significant ANOVA effects (at $p \leq 0.05$), the means were separated using the Least Significant Difference (LSD) test. To determine whether the yield response across the six water depths (32, 76, 143, 188, 234, and 259 cm) differed significantly among the three rice varieties (FARO 66, FARO 67, and Indochine Blanc), a two-way ANOVA was conducted.

3. Results

3.1. Upstream Water Levels

During Sierra Leone's rainy season peak (July–September), the Taia River overflows onto the experimental site. Daily water level monitoring tracks flooding patterns, zone conditions, and rising/falling trends, while upstream berms help mitigate the flooding. Figure 3 shows the daily trend of water levels at different elevations ranging from June to November. Several changes behind this trend result from differences in elevation. From 20th June to 4th July, the water depth at the shallow level was zero (0 cm), while at both the medium and deep levels, the water depth was slightly above fifty centimeters (50 cm). The trend increased from 4th July to 18th July, where the depth at both shallow and medium levels was above 200 cm, and at the deep level, the depth was above 300 cm.

Similarly, from 18th July to 1st August, flooding continued on the three rice varieties but with a slight decrease in depth: at the shallow plots, the depth was 100 cm; at the medium level, 150 cm; and at the deep plots, between 250 cm and 300 cm. However, from 1st August to 15th August, the flooding pattern changed at each level. At the shallow level, depth decreased from 100 cm to 0 cm; at the medium level, from 150 cm to 50 cm; and at the deep level, from 300 cm to 150 cm.

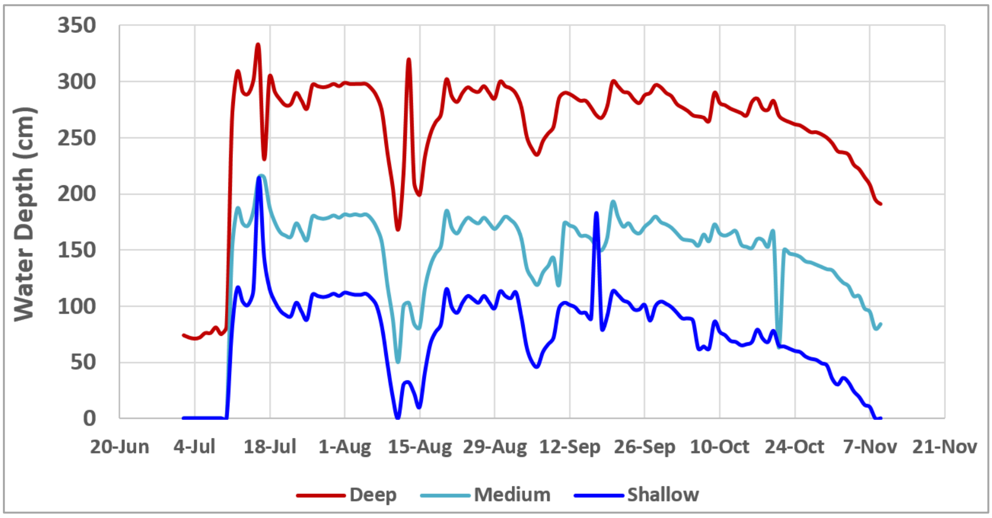

Figure 3. *Water levels in upstream plots.*

Notwithstanding, from 20th August to 24th October, water levels increased across the three levels and remained at an equilibrium state at each level for over a month. The shallow level was within 100–150 cm depth, the medium within 150–200 cm, and the deep level within 250–300 cm. Nevertheless, from 7th October to 21st November, the trend in water depth changed: at the shallow level, there was little or no water during that period, while both medium and deep levels reduced to a depth of 50 cm or below.

Meanwhile, the highest figures were recorded in July (16th July) with a depth of 331 cm, followed by 13th August with 320 cm, and 28th September with 297 cm for the deep level. Similarly, for both shallow and medium levels, the highest points were also recorded on the above dates.

3.2. Downstream Water Levels

The downstream plots were under non-structural measures of flood management, which resulted in a high increase in flooding at each elevation. At the end of the downstream area, a berm was constructed at the mouth of the Taia River which would have helped reduce flooding at the experimental site, but sadly, the berm broke down when the first flood occurred on 11th July 2020. However, from the graph above, the same daily water level data was collected under non-structural measures, and the flooding patterns were also different.

From the results, the water level varied based on elevation (Figure 4). From 20th June to 4th July, the water depth at shallow plots was 0 to 22 cm, at medium plots 32 to 149 cm, and at deep plots 76 to 192 cm respectively. From 4th July to 18th July, the water level at shallow plots increased from 22 cm to 213 cm and then decreased within the same period to 0 cm. At the medium plots, the depth increased from 149 to 215 cm and then decreased within the same weeks to 126 cm. At the deep plots, the depth continued increasing from 192 to 457 cm but later reduced to 172 cm.

However, upon critical observation of the graph, the flooding trends increased for a period of two weeks and started decreasing within the same weeks. This rise-and-fall pattern of flooding at the downstream site induced stress conditions on the rice varieties, especially at the shallow plots where flooding lasted for almost a week. Notwithstanding, the highest flooding occurred in July: on 17th July, a depth of 457 cm was recorded; on 4th August, the highest depth was 420 cm; and on 13th September, the depth was 380 cm for the deep plots. The above dates were recorded as the highest peak flooding periods at each water level at the experimental site.

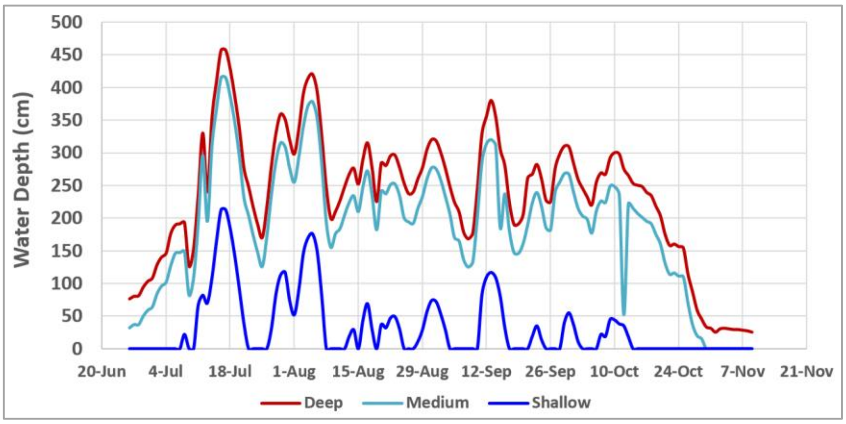

Figure 4. *Water levels in downstream plots.*

3.3. Effect of Submergence Depth on Productive Panicles

Productive panicle number, also known as productive tiller number, is an important trait that influences yield performance and is a specialized character that directly regulates grain yield, as shown in Figure 5. The productive panicle number was counted manually from 1 m^2 harvested plots, and averages were recorded for each replication. The highest average productive panicle number was recorded in FARO 66 + medium, with an average of 304 at a depth of 143 cm, followed by FARO 66 + shallow with an average of 267.67 at a depth of 76 cm for the upstream. From Figure 10, grain yield was consistent with the yield components in terms of water level and the high values recorded in the above plots. Meanwhile, from a critical observation of Figure 5, it can be seen that a low productive panicle number for the downstream was recorded at shallow + Indochine Blanc, with an average of 94.33 at a depth of 234 cm, followed by FARO 66 + deep with an average of 153.33 at a depth of 234 cm, as reflected in the yield in Figure 10 This resulted from continuous flooding of the varieties, which led to waterlogging for an extended period, and most varieties were unable to develop to their normal stand.

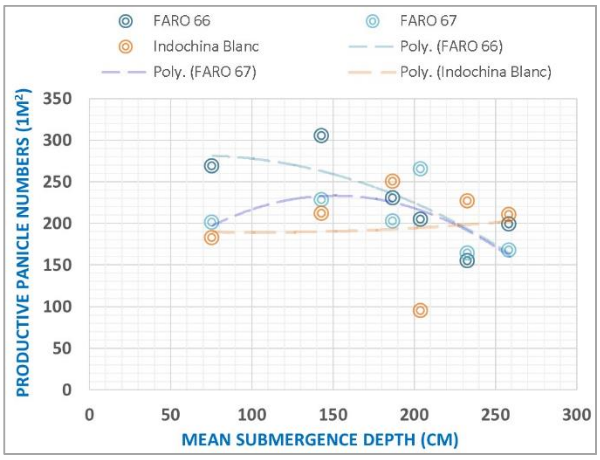

Figure 5. *Productive Panicle number.*

3.4. Effect of Submergence Depth on Non-Productive Panicle Number

Non-productive panicles (unproductive tillers) reduce yield and were manually counted from 1 m^2 plots. As shown in Figure 6, the highest count (78.67) occurred in shallow-water Indochine Blanc at 32 cm depth downstream, due to waterlogging and pest damage that destroyed panicles and produced empty grains. The same figure also shows that prolonged deep flooding increased non-productive panicles upstream at 259 cm for FARO 66 (30), FARO 67 (32), and Indochine Blanc (49). Additionally, Figure 6 illustrates that downstream deep and medium water levels produced higher counts than shallow conditions, further confirming the link between water level extremes and poor yield performance.

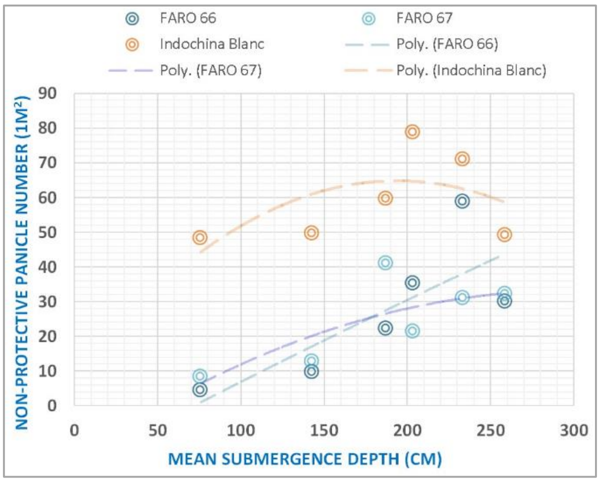

Figure 6. *Effect of Submergence Depth on Non-Productive Panicle Number.*

3.5. Effect of Submergence Depth on Spikelet Numbers per Panicle

The trend of increasing submergence depth on the three rice varieties has a negative effect on spikelet number per panicle, except at some depths where excellent performance was observed in the 1 m^2 harvested plots. However, the maximum spikelet number was recorded only at shallow + FARO 67, with an average of 14.77 at a depth of 76 cm, followed by FARO 66 + medium with an average of 13.47 at a depth of 188 cm. Meanwhile, as the depths continued to increase at the various levels, the spikelet number per panicle became lower, ranging from an average of 10–12 at depths of 259 cm and 234 cm, respectively. This trend of water reduces grain yield performance, as shown in Figure 7.

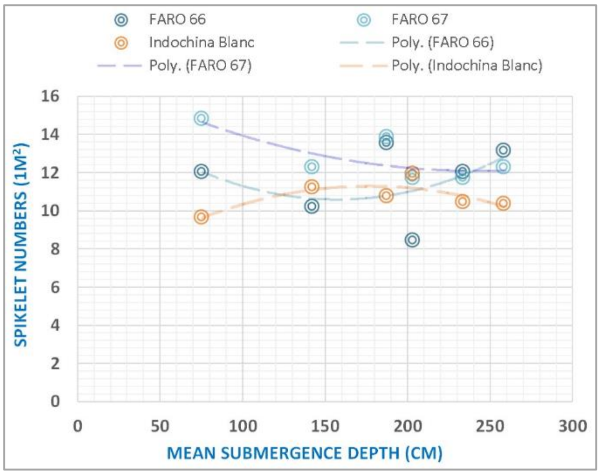

Figure 7. *Effects of Submergence depth on spikelet number.*

3.6. Effect of Submergence Depth on Plant Height

Plant height, a critical yield determinant, was recorded across six water depths at 4, 6, and 14 weeks after planting (WAP), though weeks 8–12 were omitted due to peak flooding. As shown in Figure 7, final heights at 14 WAP, when flooding receded and plants entered the reproductive stage, trended upward across all varieties. Indochine Blanc showed little early variation at 4 and 6 WAP, but by 14 WAP it surged dramatically with depth, reaching 302 cm at 259 cm and 243 cm at 234 cm, while shallow depths (32 cm and 76 cm) produced only 115.9 cm and 124.3 cm, confirming its strong preference for deep and medium water over shallow conditions.

For FARO 66, early gains aligned with rising water (peaking at 66.8 cm at 259 cm by 6 WAP), but the 14 WAP graphs reveal a shift where maximum height moved to 134 cm (145.8 cm), while the 259 cm depth dropped to 135.9 cm, proving this variety cannot sustain extreme flooding. FARO 67 followed a similar pattern, recording its tallest average at 188 cm (145.2 cm) before declining at 259 cm (120.5 cm), though it generally tracked the increasing-water trend. Overall, Figure 7 illustrate that while intermediate depths boost height, extreme deep flooding reduces performance for FARO 66 and 67, whereas Indochine Blanc thrives under deeper conditions.

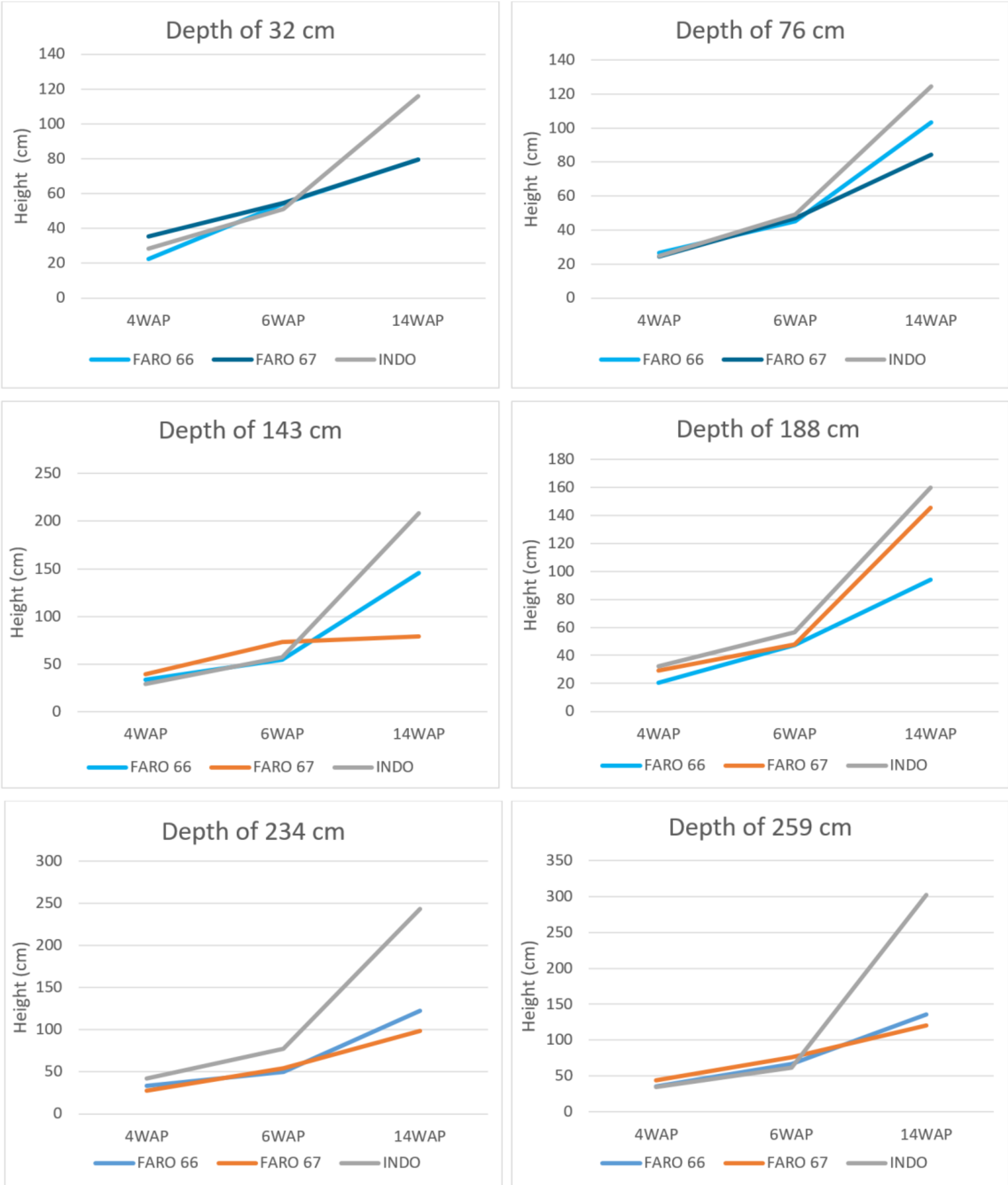

Figure 8. *Plant height at six different depths and three different varieties.*

Across all measured depths, Indochine Blanc shows significantly greater plant height at 4, 6, and 14 WAP than FARO 66 and FARO 67, because Indochine Blanc grows progressively taller as water depth increases.

The Effects of Tiller Numbers on each Rice Varieties at 6 water depths

At 4 WAP, there was no significant difference in tillering observed among the three varieties (Indochine Blanc, FARO 66, and FARO 67) at the six water depths. Notwithstanding, at 6 WAP, a significant difference was observed. The maximum tiller number for Indochine Blanc at 6 WAP was recorded at a depth of 32 cm with an average tiller number of 7 for FARO 67, followed by a depth of 234 cm with an average of 6 tillers. At 14 WAP for Indochine Blanc, the highest tiller number was recorded at a depth of 234 cm with an average of 10 tillers. This shows that Indochine Blanc had a more significant effect at depths of 234 cm and 32 cm when compared to depths of 259 cm, 188 cm, 134 cm, and 76 cm. However, it can be clearly observed (Figure 9) that the more variety grows up with water, the fewer the tiller numbers.

Similarly for FARO 66 at 6 WAP, a significant difference was observed, wherein the highest average tiller was recorded at a depth of 188 cm with a tiller number of 8. On the other hand, at 14 WAP, the highest tiller number was recorded at a depth of 76 cm with an average of 25 tillers. From the graph, it shows a sudden change in tillers from a depth of 188 cm to a depth of 76 cm, with a greater significant difference between them. However, it could be concluded that FARO 66 produces more tillers at a depth of 76 cm when compared to the other depths.

Moreover, for FARO 67 at 6 WAP, a maximum tiller number was recorded at a depth of 32 cm with 10 tillers, and the variety continued the trend of increasing tillers at shallow depths. The highest tiller number was recorded at a depth of 76 cm at 14 WAP with an average of 27 tillers. From the result, it was observed that FARO 67 produces more tillers at 32 cm and 76 cm when compared to higher depths.

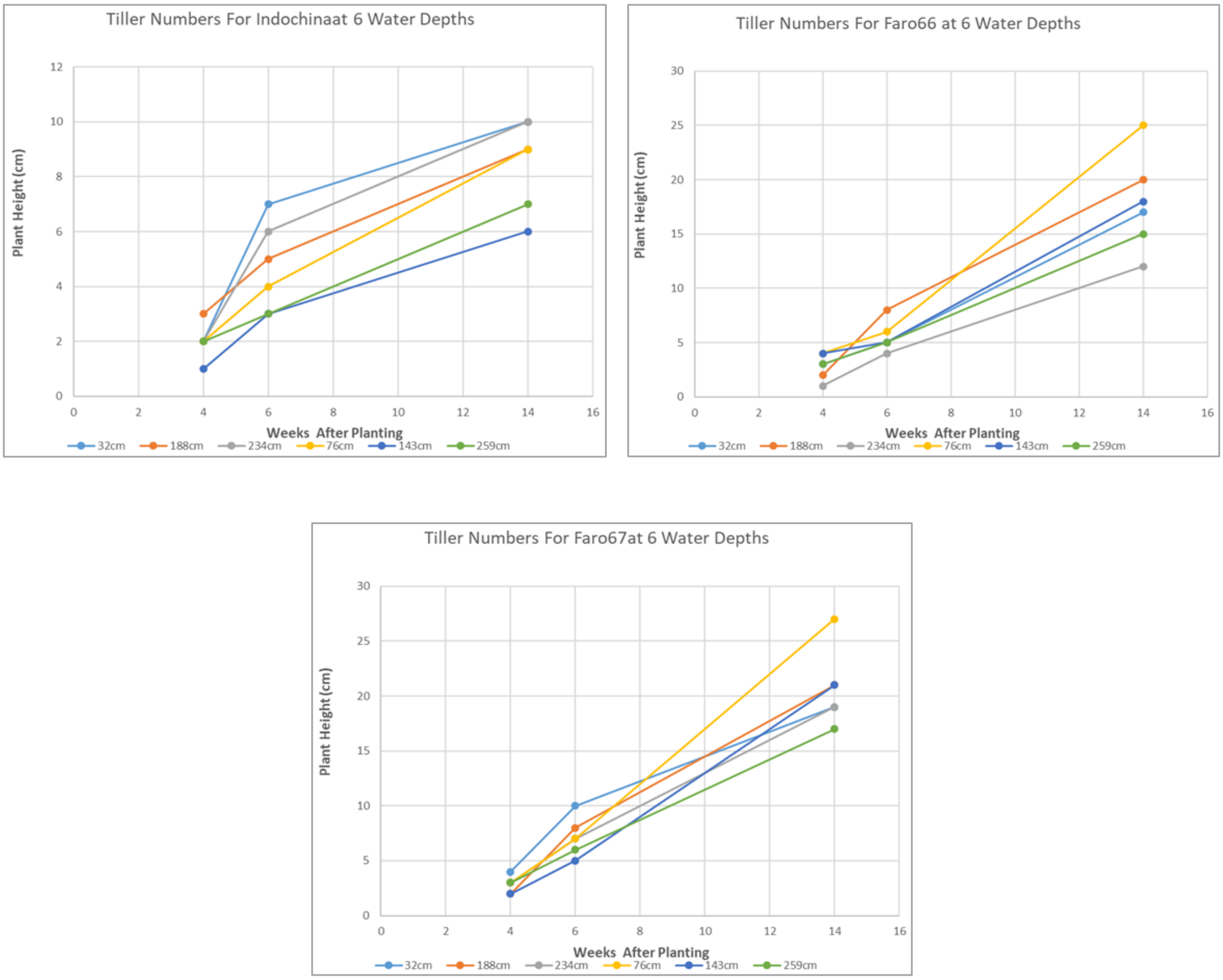

Figure 9. *Tillers numbers from the different rice varieties.*

The analysis presented in Figure 8 clearly illustrates the varietal response patterns across the different water depths. FARO 67 demonstrated superior performance at 76 cm, 134 cm, and 259 cm, maintaining significant progress throughout the observation period (4, 6, and 14 weeks after planting). Across these depths, it recorded average tiller counts of 19, 21, and 19, respectively, outperforming both FARO 66 and Indochine Blanc. Furthermore, FARO 66 also exhibited a significantly higher tiller count relative to Indochine Blanc. These findings suggest that the tiller reduction observed in Indochine Blanc is likely associated with its increased plant height in response to deeper water levels.

3.7. Effect of Submergence Depth on Yield

At the upstream location, FARO 66 recorded its maximum average grain yield (3903 kg/ha) at a mean depth of 76 cm (Figure 10), substantially outperforming FARO 67 (2287 kg/ha) and Indochine Blanc (497 kg/ha) at the same depth. This confirms FARO 66's superior tolerance at 76 cm. At 143 cm, FARO 66 again performed best (3533 kg/ha), followed closely by FARO 67 (3173 kg/ha) and Indochine Blanc (2453 kg/ha). At 259 cm, all varieties showed reduced yields, with 1360 kg/ha for FARO 66, 1667 kg/ha for FARO 67 and 1637 kg/ha for Indochine Blanc due to prolonged flooding lasting nearly a month. Notably, Indochine Blanc performed relatively better at 259 cm than at 76 cm, suggesting greater deepwater tolerance.

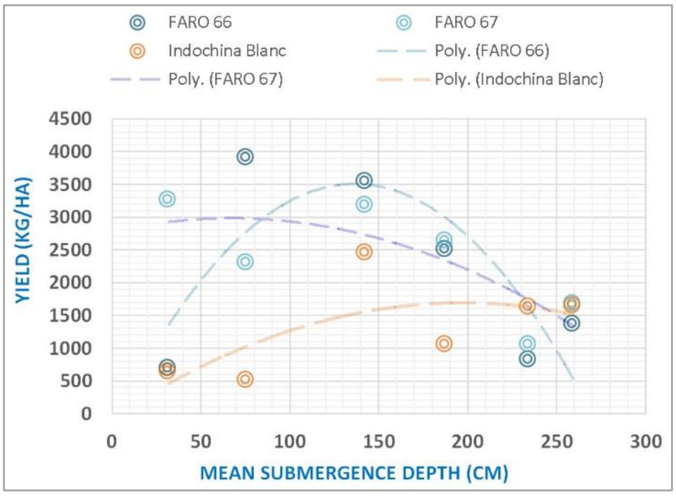

Figure 10. Effect of Submergence depth on yield.

At the downstream location, yields were generally lower due to fluctuating flood patterns lasting one to two weeks, which induced stress on the varieties. At 32 cm, FARO 66 yielded only 683 kg/ha and Indochine Blanc 640 kg/ha, while FARO 67 performed much better with 3240 kg/ha. At 188 cm, FARO 67 recorded 2623 kg/ha, demonstrating tolerance to rise-and-fall flood patterns compared to the other varieties. Additional yield losses downstream were attributed to fish and crab damage to vegetative parts following the breakdown of the berm at the mouth of the River Taia.

Table 1. Results of the two-way analysis of variance (ANOVA) for the effects of variety, depth, and their interaction on Yield.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	58717992.59	17	3453999.564	11.145	0.00
Intercept	201067407.4	1	201067407.4	648.767	0.00
VARIETY	10615125.93	2	5307562.963	17.125	0.00
DEPTH	20333748.15	5	4066749.63	13.122	0.00
VARIETY * DEPTH	27769118.52	10	2776911.852	8.96	0.00
Error	11157200	36	309922.222		
Total	270942600	54			
Corrected Total	69875192.59	53			

a. R Squared = 0.840 (Adjusted R Squared = 0.765)

The overall two-way ANOVA model (Table 1) was highly significant ($F(17,36) = 11.145$, $p < 0.001$) and explained 84.0% of the total variance in yield (Adjusted $R^2 = 0.765$). Furthermore, the interaction effect between VARIETY and DEPTH was also highly significant ($F(10,36) = 8.96$, $p < 0.001$), indicating that the effect of depth on yield varies significantly depending on the specific variety.

Table 2. Pairwise Comparisons of Mean Grain Yield (kg/ha) Among the Three Rice Varieties.

(I) VARIETY	(J) VARIETY	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
FARO 66	FARO 67	-210.00	185.569	0.265	-586.35	166.35
	Indochine	817.78*	185.569	0.000	441.43	1194.13
FARO 67	FARO 66	210.00	185.569	0.265	-166.35	586.35
	Indochine	1027.78*	185.569	0.000	651.43	1404.13
Indochine	FARO 66	-817.78*	185.569	0.000	-1194.13	-441.43
	FARO 67	-1027.78*	185.569	0.000	-1404.13	-651.43

Error bars (Figure 11) confirm significant differences at key depths. At 32 cm, FARO 67 significantly outyields both FARO 66 and Indochine Blanc, while at 76 cm, FARO 66 demonstrates superior performance. At 143 cm, the three varieties converge with no significant differences, and at 259 cm, all varieties perform poorly with no statistical differences. These findings underscore the need for depth-specific variety selection: FARO 67 is recommended for shallow areas (≤50 cm), FARO 66 for medium-depth zones (70–150 cm), and either FARO 67 or Indochine Blanc for deep areas (>200 cm), despite generally low yields under such conditions.

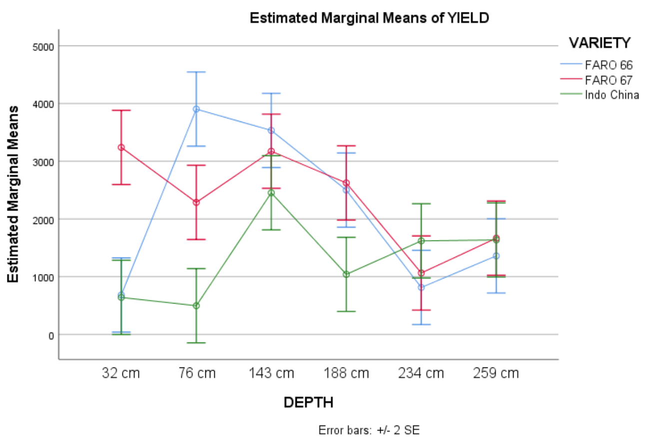

Figure 11. Estimated marginal means of yield.

4. Discussion

4.1. Comparative Yield Performance

The average grain yield of FARO 67 (2.34 t/ha) was marginally higher than that of FARO 66 (2.13 t/ha), but the mean difference between these two varieties was not statistically significant (Table 2 at $p = 0.05$. Both FARO 66 and FARO 67, however, showed significant yield differences when compared to Indochine Blanc (1.31 t/ha). The overall analysis revealed a highly significant interaction between variety and water depth ($p < 0.001$), indicating that the yield response of each variety varied considerably across the six submergence depths.

When compared to the general benchmark of 2–3 t/ha for rainfed lowland rice under optimum conditions [12], FARO 66 and FARO 67 performed within this range at their optimal depths (76 cm and 32 cm, respectively). However, the average yields across all depths (2.13–2.34 t/ha) were consistent with Catling's benchmark. Similarly, the yields of these two varieties agreed with findings from the Philippines, where average rice yields from small farm reservoirs ranged from 4.05 to 4.25 t/ha [24] under optimal management conditions. In contrast, Indochine Blanc recorded the lowest average yield (1.31 t/ha), which was below the Catling benchmark, indicating poor adaptation to the tested submergence conditions.

4.2. Depth-specific and Yield Patterns

The polynomial trendlines in Figure 10 confirm that yield responses to submergence depth are non-linear and variety-specific. For FARO 66 and FARO 67, yield peaks at intermediate depths (76–143 cm) and declines at both very shallow and very deep levels, whereas Indochine Blanc exhibits a flatter, lower response curve with slight improvement under deep water.

FARO 67 (3240 kg ha^{-1}) far outyielded FARO 66 (683) and Indochine Blanc (640). The significant ANOVA ($p = 0.001$) shows that FARO 67 is very much adapted to very shallow water or even near-saturated conditions. This may be due to its ability to tiller profusely in shallow water and maintain efficient nutrient uptake, whereas FARO 66 and Indochine Blanc suffer from either suboptimal moisture or early competition.

At a depth of 76 cm, FARO 66 peaked (3903 kg ha^{-1}), significantly outperforming FARO 67 and Indochine Blanc ($p = 0.010$). This depth appears optimal for FARO 66's growth habit, allowing full expression of its deep-rooting and elongation capacity without excessive flood stress. The result confirms earlier observations that FARO 66 is a "medium-depth specialist".

There were no significant differences among varieties (p =

0.412) at 143 cm. All three achieved moderate yields (3533, 3173, 2453 kg ha^{-1} respectively). At this depth, the stresses of partial submergence become similar for all varieties, possibly because each employs different but equally effective adaptive strategies (e.g., FARO 66 elongation, FARO 67 tillering, Indochine Blanc modest tolerance). For farmers in areas with water depths around 140 cm, any of the three varieties could be used, though FARO 66 gives the highest numerical yield.

At 188 cm and 234 cm, the univariate ANOVAs were only marginally significant ($p = 0.115$ and 0.078 respectively). The means shows that at 188 cm, FARO 67 (2623) and FARO 66 (2500) are close, while Indochine Blanc lags (1040). At 234 cm, Indochine Blanc (1620) and FARO 67 (1667) are similar and higher than FARO 66 (813). This suggests that Indochine Blanc begins to show relative tolerance to deep water, consistent with its reputation as a deep-water rice. At 259 cm, all yields are low and not significantly different ($p = 0.517$), indicating that extreme submergence (>250 cm) uniformly reduces yield regardless of variety.

5. Conclusions

Submergence depth has a profound effect on rice grain yield, with the optimal range depending on the variety. FARO 66 is recommended for areas with stable shallow to medium flooding (up to 150 cm), while FARO 67 is preferable where water levels fluctuate frequently. Indochine Blanc is not suitable for commercial production under the tested conditions due to consistently low yields. Future breeding efforts should focus on combining the high yield potential of FARO 66 with the flood-fluctuation tolerance of FARO 67. Additionally, protective measures against fish and crab damage are necessary for downstream sites to avoid yield losses.

Based on the depth-specific yield patterns observed, clear practical recommendations emerge for variety selection under different submergence regimes. For shallow floodplains with water depths not exceeding 50 cm, FARO 67 is the recommended variety due to its superior performance. In areas characterized by stable, medium-depth flooding between 70 and 150 cm, FARO 66 provides the highest grain yield. Where deep water conditions (>200 cm) prevail with prolonged flooding, none of the three varieties are ideal; however, Indochine Blanc or FARO 67 are preferable to FARO 66. Notably, the absence of a significant yield difference among varieties at 143 cm suggests that in environments where water depth is highly variable but often settles near 140 cm, any of the three varieties can be grown with acceptable results.

Abbreviations

SSA	Sub-Saharan Africa
RCBD	Randomized Complete Block Design
WAFOR	West Africa For Oil palm Research
DW-FR	Deepwater Floating Rice
ANOVA	Analysis of Variance

Author Contributions

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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