


The potential of aquatic vegetation as a growth medium for floating rice cultivation in lowland swamps

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ABSTRACT

Floating farming systems have emerged as a promising adaptive technology for rice cultivation in lowland swamps, where chronic waterlogging renders conventional agriculture challenging. These systems typically employ local aquatic vegetation as a growth substrate; however, a comprehensive evaluation of its agronomic potential has been lacking. This study quantifies the efficacy of this aquatic vegetation medium in supporting the growth and yield of two rice varieties, Ciherang and NutriZinc, within a floating farming system. The varieties were cultivated on floating rafts, and a comprehensive analysis of the growth medium and plant production was conducted at 120 days after planting. Results demonstrated that the substrate provided an optimal physicochemical environment for rice. The pH was ideal for both Ciherang (5.78–6.54) and NutriZinc (5.98–6.87). Essential nutrients were available at sufficient levels: phosphorus (81–167 mg P kg⁻¹) and nitrogen in the forms of NH₄⁺ (68–148 mg N kg⁻¹) and NO₃⁻ (23–67 mg N kg⁻¹). Furthermore, supportive levels of organic carbon, total nitrogen, and exchangeable cations (K, Ca, Mg) were recorded. These favourable conditions directly translated to high yields, with Ciherang and NutriZinc producing 271.3 g plant⁻¹ and 443.1 g plant⁻¹, respectively – a yield comparable to conventional cultivation. This study confirms that aquatic vegetation from lowland swamps is a highly effective growth medium, capable of supplying optimal nutrient levels to sustain high rice productivity, thereby validating floating farming as a viable and productive solution for waterlogged environments.

Keywords: microbial decomposition, nutrient availability, leaching, ammonification, nitrification.

INTRODUCTION

Lowland swamps in Indonesia, which are inland wetlands characterized by prolonged seasonal inundation from rainfall and river overflow, represent a significant yet underutilized agricultural resource. Spanning approximately 13.3 million hectares, primarily in Sumatra, Kalimantan, and Papua (Lakitan et al., 2019). While these swamps offer vital agricultural potential during dry-season water shortages, they become unproductive under the permanent inundation of the rainy season (Hatta et al., 2023).

The inundation of these lowland swamps during the rainy season, with water depths of 2–3 meters, effectively precludes the cultivation of standard agricultural crops. Consequently, developing agricultural systems adapted to permanent flooding is essential for unlocking their year-round productivity.

Floating farming is an adaptive agricultural practice designed for long-term flooded lands, enabling crop cultivation on buoyant rafts that float on the water's surface. This mechanism, which allows the rafts to rise and fall with fluctuating water levels, is ideally suited to the conditions of

flooded lowland swamps. While this system has been successfully implemented for multi-crop cultivation in the swampy regions of South Kalimantan and Sumatra (Diansari and Endah, 2019; Wulandari et al., 2024), the system has recently been adapted for rice production (Srivastava et al., 2017; Van Vo and Huynh, 2015). This innovation enables year-round rice cultivation in these challenging environments.

One significant challenge facing floating farming systems is the perception that their organic growing media cannot sustain long-term productivity. This view is supported by evidence that the media's capacity to supply nitrogen – a crucial nutrient – diminishes over successive planting cycles (Hammad et al., 2020; Yavitt et al., 2021). This perception persists due to a critical knowledge gap: a lack of comprehensive data on the nutrient availability within these unique systems. Specifically, there is an absence of detailed information on how nitrogen cycles in media composed of lowland swamp vegetation – such as *Eichornia crassipes*, *Pistia stratiotes*, and *Neptunia oleracea* – when used for rice cultivation on floating rafts.

The growing medium in floating farming systems is typically sourced from local swamp vegetation, chosen for its availability and buoyancy. However, selection is often made without rigorous consideration of the vegetation's inherent biochemical characteristics and quality. This oversight is critical, as the choice of substrate directly dictates its ability to support optimal plant growth. The foundational scientific issue lies in the varying chemical structures of organic carbon between plant species, which fundamentally govern nitrogen nutrient dynamics through mineralization and immobilization processes (Elrys et al., 2021; Priatmadi et al., 2023a). Consequently, a medium derived from vegetation with a high carbon-to-nitrogen (C:N) ratio may tie up nitrogen, making it unavailable for crops, whereas a medium with a more balanced ratio can efficiently release it. Since rice growth and productivity in these floating systems are predominantly determined by the medium's capacity to supply plant-available nitrogen (Elrys et al., 2021; Priatmadi et al., 2023b), the uncritical selection of vegetation ultimately risks low nutrient use efficiency and compromised yields.

The effectiveness of a floating cultivation system is fundamentally governed by the nutrient

dynamics of its organic growing media, where the biochemical composition of the source vegetation dictates the mineralization, release, and plant availability of essential nutrients. Consequently, media derived from different plant species exhibit markedly different nutrient-supplying capacities, directly influencing crops (Oo-Thae et al., 2022). For instance, while *Salvinia cucullata* may offer superior physical stability, *Salvinia molesta* has been shown to enhance yields more effectively (Karmaker et al., 2023). Nitrogen, as a primary macronutrient demanded in large quantities by plants, is also of particular importance in this context (Anas et al., 2020; Ye et al., 2022). Consequently, the nitrogen-supplying capability of the organic substrate is a key determinant in selecting materials for floating cultivation media. These findings underscore a critical research gap: the selection of vegetation for growing media must be informed by a detailed understanding of its inherent nutrient dynamics. While a full nitrogen cycle model is beyond the scope of this work, the data presented on nitrogen availability, speciation, and potential loss mechanisms constitute critical foundational knowledge for understanding nutrient dynamics in floating cultivation. To address this need and advance the sustainability of floating farming, this study aims to quantitatively evaluate the potential of predominant aquatic vegetation to supply essential nutrients, specifically for rice cultivation in floating farming of lowland swamp environments.

MATERIALS AND METHODS

Study site

This research was conducted in Parigi Village, within the Daha Selatan District of Hulu Sungai Selatan Regency, South Kalimantan Province, Indonesia (2.638478° S, 115.080289° E). The area predominantly consists of lowland swamps, situated adjacent to the Amandit River, which significantly influences its hydrology. The swamp in Parigi Village is characterized as shallow to intermediate in depth and experiences seasonal inundation for 4–6 months annually, particularly during the rainy season from November to March. The study site receives substantial annual rainfall, ranging between 2.470 and 2.510 mm. Precipitation peaks from January

to March, with monthly averages of 300–400 mm, while the period from June to August is markedly drier, receiving only 80–100 mm per month. Average daily temperatures vary from 22 °C to 34 °C, with the highest temperatures recorded between September and October. Relative humidity remains consistently high throughout the year, ranging from 88% to 89%. These conditions contribute to perpetually saturated soils and frequent flooding, defining the hydrologic regime of the area.

Construction of floating raft and growing media

The floating rafts were constructed using a bamboo frame measuring 1.8 × 12 meters, overlaid with polyethylene (PE) netting. Wooden planks were installed at three-meter intervals to partition the raft into four distinct experimental plots, each measuring 1.5 × 3.0 meters. A layered organic growing medium was systematically applied to each plot. The base layer consisted of 30 kg of chopped and rolled *Neptunia oleracea* stems and leaves, forming a 15 cm thick substrate. Above this, a second layer of 30 kg of rolled *Neptunia oleracea* roots was added. Two kilograms of chicken manure were then evenly distributed over the root layer to supply baseline nutrients and stimulate organic decomposition. The third and final layer comprised a 30 kg mixture of *Eichornia crassipes* and *Pistia stratiotes*, to which 1.8 kg of NPK fertilizer was incorporated per plot. Following assembly, the growing medium was allowed to incubate in an open area for two weeks to facilitate partial decomposition prior to planting.

For the purpose of chemical characterization, the aquatic vegetation used as growing media was analyzed for key properties. Samples were first oven-dried at 60 °C for 72 hours and then ground to a fine consistency with a particle size of less than 0.5 mm. Organic carbon content was determined using the Walkley-Black method (Nelson and Sommers, 1996), total nitrogen was measured via the Kjeldahl method (Bremer and Mulvaney, 1982), while total P was quantified through digestion with 60% HClO₄ and measured at 660 nm using a spectrophotometer (Olsen and Sommers, 1982). Additionally, the contents of lignin, cellulose, and hemicellulose were analyzed using the sodium hydroxide method (Chesson, 1981).

Rice planting and observations of growing media, growth and yield parameters

Rice seedlings of two superior varieties, Cihorang and NutriZinc, were prepared using an established protocol to ensure vigorous initial growth before transplantation to the floating rafts. Seeds were first soaked in water for 24 hours to stimulate germination. They were then sown into a growth medium composed of a 2:1 soil-to-manure mixture, which has been demonstrated to support optimal development. The seeds were distributed evenly and covered with a 1–2 cm layer of the medium to conserve moisture and protect against pests. The seedlings were maintained under these conditions for 30 days to develop a robust root system and sufficient biomass, providing a strong physiological foundation for subsequent growth on the floating cultivation system.

Upon completion of the two-week incubation period, 30-day-old rice seedlings were carefully transplanted onto the prepared growing medium of the floating rafts. The seedlings were placed in planting holes at a density of two seedlings per hole, with a systematic spacing of 20 × 30 cm between holes to ensure adequate room for growth and resource availability. Agronomic management included regular irrigation, adjusted according to weather conditions and crop water requirements, as well as consistent monitoring and control of pests to minimize damage and prevent the spread of disease.

Nutrient availability was assessed when the rice plants reached 120 days after planting. Growing medium samples were collected by subsampling approximately 500 grams at a depth of 20 cm from four distinct points on each floating raft to ensure representative characterization. The collected samples were oven-dried at 60 °C for 72 hours, then ground to a particle size of ≤ 2.0 mm using a mechanical grinder. Chemical analyses were performed on the prepared samples, including: soil pH (McLean, 1982), organic carbon content (Nelson and Sommers, 1996), ammonium content (Kempers and Zweers, 1986), nitrate content (Yang et al., 1998), available phosphorous (Jackson, 1967), and exchangeable cations (Ca, Mg, and K) (Knudsen and Peterson, 1982; Lanyon and Heald, 1982).

Rice growth and yield parameters were assessed at physiological maturity, 120 days after planting. The evaluated parameters included

plant height, tiller number, shoot-dried weight, and grain yield. To determine the shoot-dried weight, the above-ground biomass was harvested, oven-dried at 70 °C for 72 hours, and then weighed. Similarly, the grain yield was determined by threshing all panicles and oven-drying the grains at 70 °C for 72 hours prior to final weighing.

Statistical analysis

The observational data were systematically tabulated and organized using Microsoft Excel. To evaluate differences in nutrient availability within the growing media used for the Ciherang and NutriZinc rice varieties, a paired samples t-test (also known as a dependent samples t-test) was conducted. This statistical comparison was appropriate as the measurements were taken from the same floating raft units under two different planting conditions. All statistical analyses were performed using GenStat 13th Edition.

RESULTS AND DISCUSSION

Characteristics of aquatic plants

The three types of vegetation used as growing media exhibited organic carbon contents ranging from 311 to 376 g C kg⁻¹, while total nitrogen levels varied between 20 and 22 g N kg⁻¹ (Table 1). The combination of these organic C and total N values resulted in C/N ratios within a narrow range of 15 to 18 (Table 1), indicating favorable conditions for decomposition and nutrient mineralization. Total phosphorus content across the vegetation types ranged from 558 to 613 g P kg⁻¹ (Table 1), reflecting relatively high phosphorus reserves in the plant biomass.

Lignin content, an important indicator of decomposition rate, was highest in *N. oleracea* (382 g kg⁻¹) and lowest in *E. crassipes* (69 g kg⁻¹). In contrast, cellulose – a major structural component of plant cell walls – showed the opposite trend, with the highest concentration observed in *E. crassipes* and the lowest in *N. oleracea* (Table 1). Furthermore, analytical results indicated that *E. crassipes* contained the highest hemicellulose content among the aquatic vegetation types studied, highlighting substantial interspecific variation in structural carbohydrate composition.

Chemical characteristics of growing media

The pH of the growing medium used for the Ciherang variety ranged from 5.78 to 6.54, with a mean value of 6.16, while the medium supplemented for NutriZinc exhibited a slightly higher and broader range of 5.98 to 6.87, with a mean pH of 6.45 (Figure 1A). These findings indicate that the growing medium derived from aquatic vegetation in lowland swamps provides a pH environment highly conducive to rice cultivation. The observed pH levels align well with established optimal ranges for rice productivity. Specifically, the results corroborate findings by Minarsih et al. (2021), who reported that Ciherang achieves optimum production at pH values exceeding 6.0. Furthermore, the measured pH conditions in this study fall within the ideal range of 6.0–6.25 for maximal rice yields (Ahmed et al., 2020). This range is also consistent with the findings of Urmi et al. (2022), who demonstrated that optimal rice production under integrated nutrient management (combining inorganic and organic fertilizers) occurred at pH levels between 5.47 and 6.25. The slightly elevated pH associated with the NutriZinc treatment may suggest a varietal-specific interaction with the organic growing medium, warranting further investigation into the biochemical influences of different rice genotypes on substrate properties.

The organic carbon (C) content in the growing media showed no significant difference ($p > 0.05$) between the Ciherang and NutriZinc cultivation systems. For the Ciherang variety, organic C content ranged from 218 to 268 g C kg⁻¹ with a mean value of 246 g C kg⁻¹, while the NutriZinc variety exhibited a similar range of 226 to 265 g C kg⁻¹, also averaging 246 g C kg⁻¹ (Figure 2B). According to the soil chemical property assessment criteria established by the Soil Research Centre (1983) the organic C content in both growing media was classified as very high. A very high organic C content is very supportive for optimal rice growth and production (Qaswar et al., 2020; Yu et al., 2020). Yuan et al. (2021) showed that returning rice litter to the field for 6 years increased organic C content by 80–250 g C kg⁻¹, which resulted in increased rice growth and yield. These research results demonstrate the importance of organic C content in the growing medium in supporting growth and yield in rice cultivation.

Nutrient availability in the growing medium is a critical factor influencing rice growth and

Table 1. Chemical characteristics of aquatic plant-based growing media

Chemical characteristics	<i>Eichornia crassipes</i>	<i>Pistia stratiotes</i>	<i>Neptunia oleracea</i>
Organic C (g kg ⁻¹)	376.5	311.4	352.2
Total N (g kg ⁻¹)	22.0	20.3	19.8
Total P (g kg ⁻¹)	558.3	613.2	593.2
C/N ratio	17.1	15.3	17.8
Lignin (g kg ⁻¹)	69.2	181.2	382.4
Cellulose (g kg ⁻¹)	351.4	216.4	210.3
Hemicellulose (g kg ⁻¹)	271.3	18.7	6.3

productivity. The results of this study demonstrate substantial levels of key nutrients in the planting media. Phosphorus (P) availability ranged from 95 to 167 mg P kg⁻¹ (average: 135 mg P kg⁻¹) in the Ciherang growing medium, while the NutriZinc medium contained 81–144 mg P kg⁻¹ (average: 113 mg P kg⁻¹) (Figure 1C). These nutrient levels are particularly significant when evaluated against established rice production requirements. The phosphorus availability (112–135 mg P kg⁻¹) falls within the medium to high range considered optimal for rice growth (Susanti et al., 2024).

The content of exchangeable bases (K, Ca, and Mg) in the growing media showed no

significant differences between the Ciherang and NutriZinc varieties. For exchangeable potassium, values ranged from 1.9 to 3.2 cmol kg⁻¹ (mean: 2.38 cmol kg⁻¹) in the Ciherang medium, compared to 1.2–3.7 cmol kg⁻¹ (mean: 2.50 cmol kg⁻¹) for NutriZinc (Figure 1D). Exchangeable magnesium levels were 2.6–4.1 cmol kg⁻¹ (mean: 3.21 cmol kg⁻¹) and 1.9–3.9 cmol kg⁻¹ (mean: 3.10 cmol kg⁻¹) for Ciherang and NutriZinc, respectively (Figure 1F). Exchangeable calcium content ranged from 3.9 to 5.5 cmol kg⁻¹ (mean: 4.4 cmol kg⁻¹) in the Ciherang medium and 3.6–5.3 cmol kg⁻¹ (mean: 4.3 cmol kg⁻¹) in the NutriZinc medium (Figure 1E).

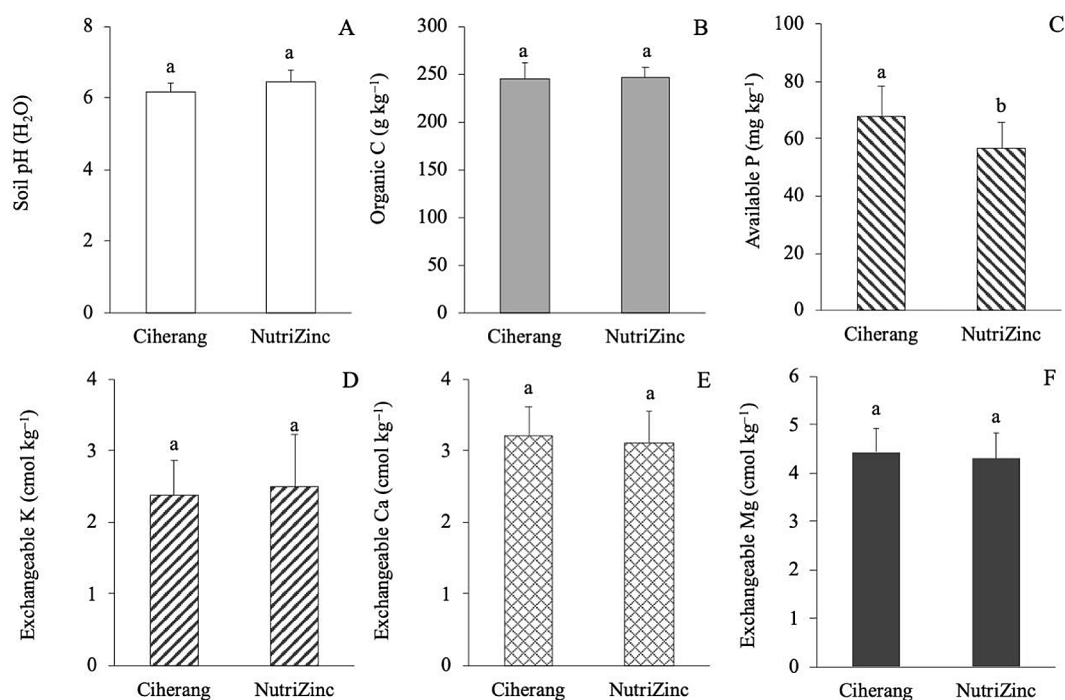


Figure 1. Chemical properties of growing media planted with Ciherang and NutriZinc rice varieties: (A) pH, (B) organic carbon content, (C) available phosphorous, (D) exchangeable potassium, (E) exchangeable calcium, and (F) exchangeable magnesium. Error bars represent the standard deviation of the mean (n = 16).

Bars sharing the same letter within each panel indicate no significant difference between varieties based on a t-test ($p \leq 0.05$)

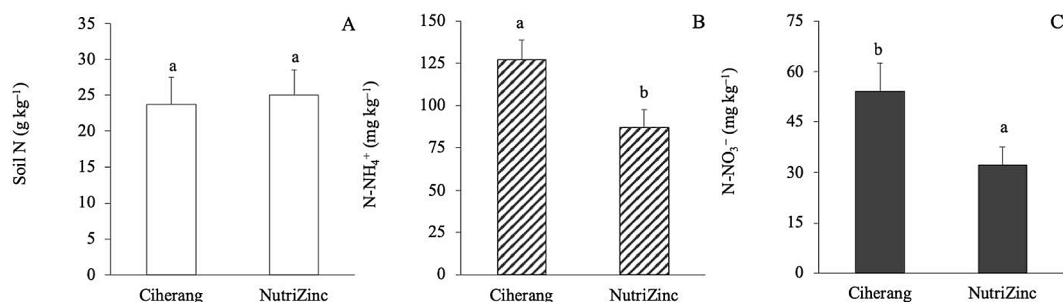


Figure 2. Contents of total nitrogen (A), ammonium (B), and nitrate (C) in the growing media planted with Ciherang and NutriZinc rice varieties. Error bars represent the standard deviation of the mean ($n = 16$). Bars sharing the same letter within each panel indicate no significant difference between varieties based on a t-test ($p \leq 0.05$)

The analysis revealed no significant difference in nitrogen (N) content within the growing medium between the Ciherang and NutriZinc varieties. Specifically, the average N content was 23.7 g kg^{-1} (range: $19.2\text{--}29.3 \text{ g kg}^{-1}$) for Ciherang and 25.0 g kg^{-1} (range: $19.3\text{--}32.4 \text{ g kg}^{-1}$) for NutriZinc (Figure 2A). Consequently, under these equivalent N conditions, the observed disparities in growth, yield, and the uptake of other nutrients between the two crops are not attributable to differential nitrogen availability. Instead, these differences are more likely driven by the intrinsic genetic characteristics of each variety or their distinct physiological responses to specific nutrients.

Analysis of the growing media revealed a clear divergence in the availability of inorganic nitrogen forms, with ammonium (NH_4^+) and nitrate (NO_3^-) ion content being significantly higher in the media for the Ciherang variety compared to that for NutriZinc (Figures 2B and 2C). Specifically, the average NH_4^+ and NO_3^- content was 127 mg kg^{-1} and 54.1 mg kg^{-1} , respectively, for Ciherang, but only 87.0 mg kg^{-1} and 32.3 mg kg^{-1} for NutriZinc. This pattern is a direct consequence of NutriZinc's superior nitrogen uptake efficiency; this variety absorbs NH_4^+ and NO_3^- from the medium more rapidly and completely, thereby leaving a lower residual nutrient concentration. In contrast, the lower uptake efficiency of Ciherang results in a greater accumulation of these ions in its growth medium. This finding is consistent with the principle that high-productivity varieties typically possess a greater nutrient acquisition capacity (Wang et al., 2023). The direct agronomic implication of this efficient uptake is demonstrated in NutriZinc's enhanced plant growth and production (Figure 3), confirming that efficiently utilized nitrogen is a primary driver of biomass

and yield (Vishwakarma et al., 2023). Nitrogen availability from the growing medium reached levels sufficient for supporting rice plant development. Remarkably, the available nitrogen (NH_4^+ and NO_3^-) provided by the growing media in this study reached $238\text{--}362 \text{ kg N ha}^{-1}$ across both varieties, substantially exceeding conventional fertilization requirements. According Susanti et al. (2024), achieving a yield of 8 tons ha^{-1} typically requires 158 kg N ha^{-1} through fertilization.

These findings demonstrate that the growing medium derived from locally sourced aquatic vegetation is capable of supplying substantial quantities of nitrogen (N) to support rice growth and production. The availability of these essential nutrients originates primarily from the decomposition of organic matter within the growing medium. Specifically, *P. stratiotes*, utilized as the top layer of the growing medium, contains elevated levels of total phosphorus and total nitrogen (Table 1), which are subsequently converted into plant-available forms (NH_4^+ , NO_3^- , and available P) through microbial decomposition. The efficient mineralization of organic matter in this system is facilitated by the favorable C/N ratio, which ranged from 15 to 18 across the vegetation types (Table 1). This ratio is a critical parameter governing the decomposition process and subsequent nutrient release, as established in previous studies (Li et al., 2020; Priatmadi et al., 2023a). A C/N ratio below 20 generally promotes net nitrogen mineralization rather than immobilization. Specifically, (Gale et al., 2006) indicate that a C/N ratio ≥ 15 typically represents the threshold for organic nitrogen mineralization, while Calderón et al. (2005) recommend 16–19 as the upper limit for nitrogen immobilization. Similarly, Lazicki et al. (2020) use a C/N ratio of

19 as the critical value for net N immobilization, noting that organic matter with a C/N ratio ≥ 14 tends to undergo nitrogen mineralization. Thus, the C/N ratios observed in this study fall within the optimal range for promoting nutrient release and availability.

The high nitrogen content within the growing medium, while beneficial for plant nutrition, poses a significant risk of loss via multiple pathways if not promptly absorbed by crops. Primarily, the medium's constant contact with water – a defining feature of the floating system – creates conditions prone to water saturation. This facilitates the leaching of nitrate, especially during periods of heavy rainfall or over-irrigation. Effective water and fertilization management has been shown to mitigate such losses substantially, with potential reductions of over 40% (Bai et al., 2020). Furthermore, the saturated conditions often lead to localized anaerobic zones, which promote denitrification – a microbial process that converts nitrogen into gaseous nitrous oxide (N_2O), resulting in irreversible nutrient loss (Pan et al., 2022; Qasim et al., 2022). Thus, managing the hydrological environment is crucial for conserving nitrogen in this cultivation system.

Analysis of the growing media revealed a persistent disparity in nitrogen forms, with ammonium (NH_4^+) concentrations consistently exceeding nitrate (NO_3^-) levels for both rice varieties (Figures 3C and 3D). This pronounced NH_4^+ dominance strongly indicates an inhibition of the nitrification process – the biological conversion of ammonium to nitrate, which requires oxygen.

The most probable cause is the unique hydrological setting of the floating cultivation system. Positioned directly above the water, the medium experiences constant upward water diffusion, maintaining high moisture and creating nearly anaerobic conditions. This oxygen-deficient environment suppresses the activity of ammonium-oxidizing microbes, thereby curtailing nitrification. Our findings align with established principles; for instance, Lin and Hernandez-Ramirez (2020) documented a significant decrease in nitrification rates as soil water content approaches saturation. Consequently, the observed nitrogen dynamics can be directly attributed to the oxygen-limited conditions inherent to the floating media.

Growth and Yield of Rice

The growth and production of two rice varieties, Ciherang and NutriZink, were observed in a floating farming system within a swamp at harvest time (120 days after planting). The results indicated a clear trade-off between plant height and yield-related components. While Ciherang achieved a greater average plant height (83.3 cm, range 78–92 cm) compared to NutriZink (80.5 cm, range 75–87 cm) (Figure 3A), NutriZink demonstrated superior performance in other parameters. Specifically, NutriZink produced a significantly higher number of tillers, with an average of 41.3 (range 35–52) versus 29.5 (range 24–37) for Ciherang (Figure 3B). This advantage translated directly to yield, as NutriZink also exhibited a greater shoot-dried weight (average 422.8 g plant⁻¹, range 276–484 g plant⁻¹) and rice

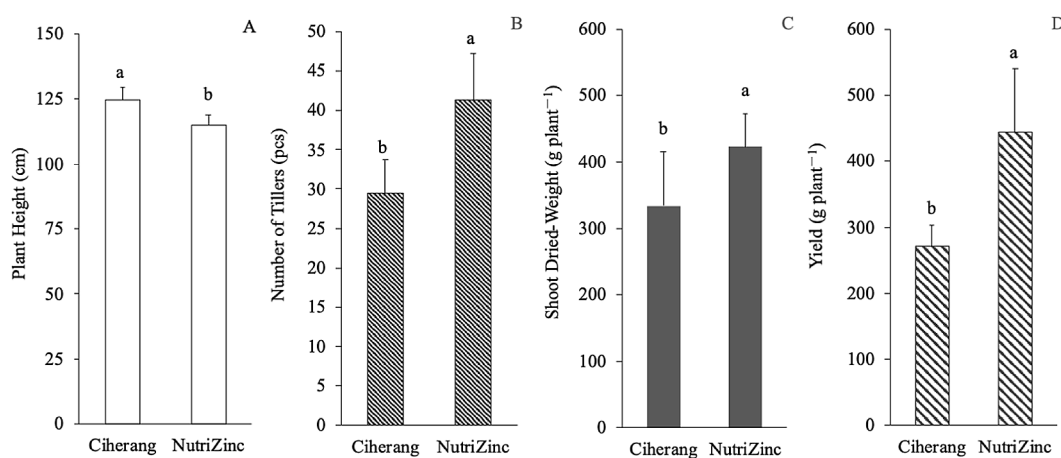


Figure 3. Plant height (A), number of tillers (B), shoot-dried weight, and yield (D) of Ciherang and NutriZink rice varieties growing in floating farming system. Error bars represent the standard deviation of the mean ($n = 16$). Bars sharing the same letter within each panel indicate no significant difference between varieties based on a t-test ($p \leq 0.05$)

production (average 444.3 g plant⁻¹, range 205–715 g plant⁻¹), both of which were higher than the respective values for Ciherang at 333.8 g plant⁻¹ (range 147–488 g plant⁻¹) and 271.3 g plant⁻¹ (range 204–325 g plant⁻¹) (Figure 3C and 3D).

The observed differences in growth and production between the Ciherang and NutriZinc varieties within the floating farming system could be primarily attributed to their divergent nutrient uptake efficiencies. NutriZinc's superiority in key yield components – including tiller number, plant dry weight, and final grain production – is directly correlated with its enhanced ability to absorb essential nutrients, particularly phosphorus and nitrogen. This is compellingly evidenced by the lower residual levels of these nutrients in NutriZinc's growth medium compared to Ciherang's (Figures 1C, 2B, and 2C), indicating a more effective absorption and utilization of resources to fuel its growth. This phenomenon aligns with the findings of Weih et al. (2018), who identified nutrient uptake efficiency as a major determinant of plant productivity, often governed by superior root systems and physiological mechanisms in elite varieties. Consequently, these results underscore the importance of tailoring fertilization strategies to varietal efficiency, as emphasized by Singh et al. (2024), to maximize yield while minimizing nutrient waste in such agricultural systems.

The Ciherang and NutriZinc varieties in this study, cultivated under a floating farming system in a swamp, demonstrated a distinct growth and yield profile. When compared to standard performance data, the results from this floating system show both alignments and notable deviations. The plant height of Ciherang observed in this study (83.3 cm) is consistent with, or slightly shorter than, the typical range of 90–95 cm reported for Ciherang under conventional irrigated lowland conditions (Sasmita et al., 2019). However, the average number of tillers of Ciherang (29.5) appears lower than the common expectation of 15–20 productive tillers per hill in optimal environments, though the reported range (24–37) suggests high variability within the experimental system.

The most significant point of comparison lies in the yield. The average Ciherang yield of 271.3 g plant⁻¹ from this study is notably high. To provide a standard comparison, this equates to approximately 6.5 tons ha⁻¹, assuming a planting density of 24 plants per m². This calculated yield

falls within the upper range of, or even exceeds, Ciherang's typical yield potential of 5.0–6.5 tons ha⁻¹ under standard intensive cultivation (Zulkifli et al., 2021). This suggests that the floating system, despite its unique challenges (e.g., anaerobic conditions), can be a highly productive environment for the Ciherang variety. The high shoot-dried weight, coupled with a lower tiller count but strong yield, indicates that the plants may have allocated resources more efficiently to panicle development and grain filling rather than excessive vegetative growth or tillering, a common adaptive response in suboptimal environments (Tirtalistyani et al., 2022).

The yield of the NutriZinc variety in this study were excellent, reaching to 444.3 g plant⁻¹ (equal to 10.7 tons ha⁻¹), demonstrating performance that was comparable to, and in several aspects superior to, existing reports from conventional cultivation systems. For instance, Pratiwi et al. (2024) and Endriani et al. (2024) reported yields of 248 g plant⁻¹ and 220 g plant⁻¹, respectively, under standard paddy conditions with various management practices. Notably, a study by Kartinaty et al. (2021) documented a much lower production range of 153–163 g plant⁻¹ in a different planting system. In contrast, the yield achieved in the present floating farming system significantly surpassed these values. This superior performance can likely be attributed to the enhanced nutrient uptake efficiency, particularly for nitrogen, that was identified as a key characteristic of NutriZinc in this agro-ecosystem. The results strongly suggest that the floating system provides a highly favourable environment for unlocking the full genetic yield potential of the NutriZinc variety.

The research results confirm that locally sourced aquatic vegetation serves as an effective growing medium capable of supporting rice growth and yield. Its efficacy is directly tied to the inherent biochemical composition of the source plants; media derived from vegetation with higher initial nutrient content can sustain crops for longer durations. This is exemplified by its ability to support short-cycle horticultural crops, such as bok choy, for up to three consecutive growing cycles. Critically, our nutrient analysis revealed persistently high levels of nitrogen and phosphorus at harvest, indicating that the medium retains sufficient fertility to support at least two cycles of rice cultivation without supplementation. These findings collectively

demonstrate the sustainable potential of aquatic vegetation media to support multiple production cycles, reducing dependence on external fertilizer inputs.

This study indicates that floating rice cultivation holds significant potential for large-scale adoption by smallholder farmers. The system's reliance on locally abundant aquatic vegetation as a growth medium enables the year-round cultivation of food and horticultural crops at relatively low cost, using readily available resources. However, scaling this practice widely presents distinct implementation challenges, which are primarily educational rather than material. Success depends on providing farmers with targeted training in two key areas: the technical construction of durable floating rafts and the preparation of effective planting media. Furthermore, farmers require guidance in selecting appropriate crop species that are well-suited to the unique conditions of floating cultivation, ensuring both productivity and long-term sustainability.

CONCLUSIONS

The findings of this study demonstrate that growing media derived from aquatic vegetation in lowland swamps exhibit favourable chemical properties for supporting rice cultivation in floating farming systems. The pH of the media consistently fell within the optimal range for rice growth and productivity, providing a suitable biochemical environment for nutrient availability and root development. With a C/N ratio of 15–16, the organic matter underwent efficient mineralization, facilitating the release of plant-available nitrogen and phosphorus. The quantities of mineral nitrogen (NH_4^+ and NO_3^-) supplied by the media significantly surpassed the agronomic requirements for rice, reducing or eliminating the need for supplemental nitrogen fertilization. Similarly, phosphorus availability was maintained at medium to high levels, sufficient to sustain robust plant development. Furthermore, the presence of essential exchangeable bases (K, Ca, Mg) was within ranges conducive to optimal rice growth and yield formation. These results underscore the potential of locally sourced aquatic vegetation as an effective, sustainable, and nutrient-rich growing medium for floating rice farming systems. By utilizing such organic resources, farmers can enhance

productivity in flood-prone ecosystems while reducing dependence on external inputs. This approach offers a promising strategy for adapting agriculture to waterlogged conditions and supporting food security in lowland swamp regions.

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