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Improvement of water quality and food production via nutrient recovery in climate-vulnerable wetlands through nature-based floating rice cultivation

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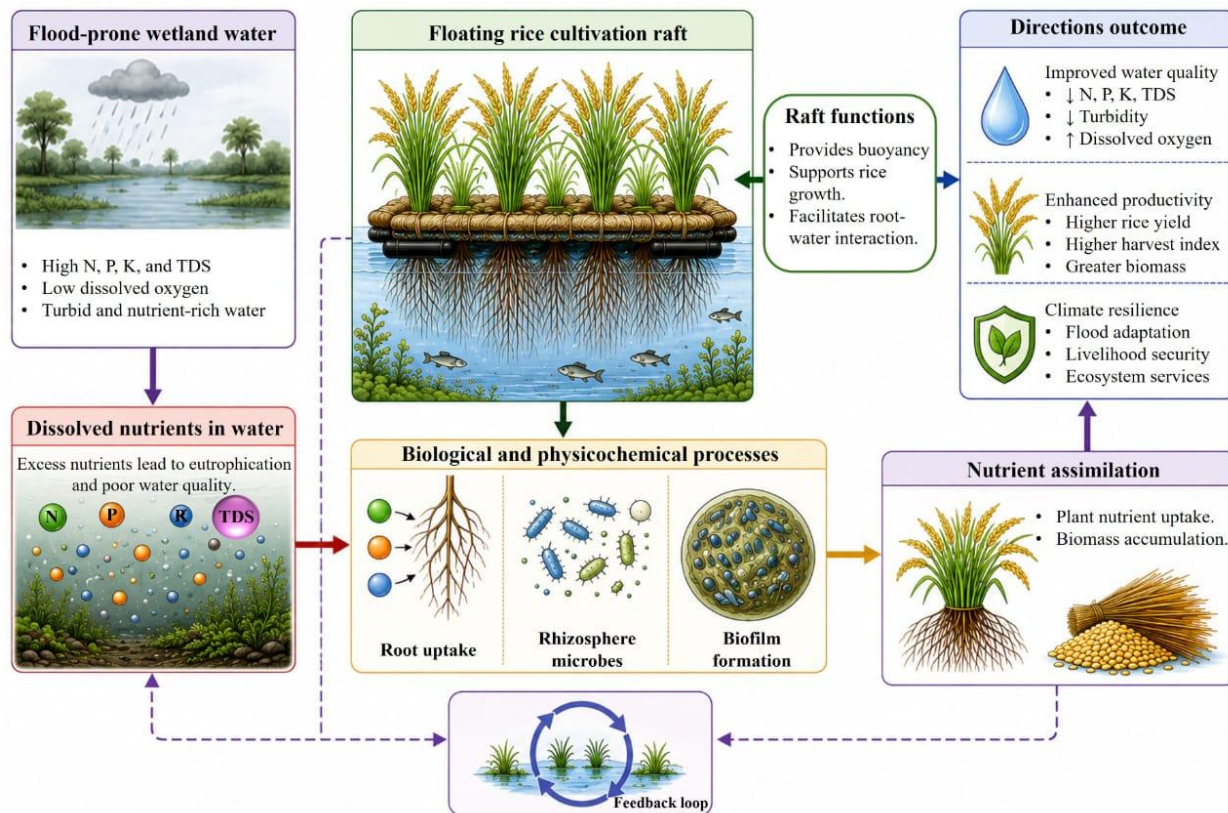
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ABSTRACT:

Flood-prone wetlands in Bangladesh present a major challenge to sustaining rice production while maintaining water quality under a changing climate. Nature-based floating rice cultivation offers a promising climate adaptation strategy, yet its capacity to simultaneously enhance nutrient recovery and food production remains poorly quantified. This study evaluated floating cultivation systems using two high-yielding rice cultivars (BRRI Dhan-79 and BRRI Dhan-51) and one indigenous cultivar (Maloti) to assess their agronomic performance and ecological functions. Floating rafts constructed from locally available materials supported rice growth while facilitating the recovery of dissolved nutrients from floodwater through plant uptake and rhizosphere-

mediated processes. BRRI Dhan-79 and BRRI Dhan-51 reduced dissolved nitrogen by 80.9% and 79.1%, phosphorus by 84.6% and 81.5%, potassium by 40.9% and 39.5%, and total dissolved solids by 39.2% and 37.2%, respectively, whereas Maloti exhibited limited nutrient removal and increased total dissolved solids by approximately 9%. Enhanced nutrient recovery translated into significantly higher grain yields (0.271 and 0.263 kg m^{-2}), harvest indices (46.9% and 45.9%), and total biomass production than the indigenous cultivar. Nutrient mass balance analysis further indicated greater nutrient recovery per unit biomass in the hybrid cultivars, reflecting higher nutrient use efficiency and more effective conversion of recovered nutrients into grain and straw biomass. Regression analysis revealed significant negative relationships between residual nutrient concentrations and grain number at the raft scale, demonstrating that improved nutrient recovery was closely linked to enhanced reproductive productivity. These findings show that floating cultivation with high-yielding rice cultivars simultaneously improves water quality and enhances rice production, providing a scalable nature-based solution for climate-resilient agriculture and sustainable wetland management in flood-vulnerable regions.

KEYWORDS: Floating Cultivation, Sustainable Agriculture, Water Quality, Nutrient Removal, Biofilter



Graphical Abstract: Nutrient Recovery and Floating Rice Cultivation for Improved Water Quality and Food Production

1. INTRODUCTION

As a densely populated, agrarian nation situated within the world's most extensive flood-prone river delta, Bangladesh faces a fundamental climate adaptation challenge (Hossain et al., 2020). Its agricultural system is uniquely vulnerable to monsoon-driven flooding, which consistently threatens national food security and the livelihoods of millions (Sheikh & Pervez, 2025; Paszkowski et al., 2024). Climate change jeopardizes agricultural production, with rice yields anticipated to decrease by 8.8–32% and wheat by 36–40% by 2050, a susceptibility highlighted by previous flash floods (Amin et al., 2015; Kaium et al., 2025). Recent major flood events starkly illustrate this vulnerability. For example, the 2017 flood destroyed more than 219,000 hectares of

48 Boro rice, causing losses exceeding BDT 10.6 billion (Mondal et al., 2021; Islam et al., 2024). The
49 Haor ecosystem of northeastern Bangladesh is extremely flood-prone. Around six million hectares
50 went underwater in 2024, causing heavy losses to rice fields and disrupting rural livelihoods (Khan
51 & Islam, 2025). One promising response is floating paddy cultivation, which allows rice to be
52 grown directly on water surfaces. This practice uses land that would otherwise remain
53 unproductive during floods and avoids the need to expand traditional farmland (Chen et al., 2025).
54 Beyond producing rice, floating agriculture also supports food security, stabilizes wetland ecology,
55 and benefits local communities. Studies suggest that in flood-prone regions, the availability of
56 cultivable land could increase by up to 50% through this approach (Sarker et al., 2025).
57 Conventional rafts are insufficient under extreme flooding conditions, necessitating more robust
58 designs (Haseeb, 2018). Floating agriculture has been successfully practiced in the Mekong Delta
59 of Vietnam and the Ayeyarwady Delta of Myanmar, where it has helped farmers cope with both
60 salt intrusion and seasonal flooding while maintaining crop yields (Aung, 2018; Tho & Umetsu,
61 2022). It reduces the need for heavy tillage while improving land utilization efficiency (Cao &
62 Zhang, 2014; Hossain, 2014). Simultaneously, these systems enhance overarching ecological
63 functions. The floating rafts enhance water quality through direct nutrient assimilation by roots
64 and rhizospheric microbial activity (Keilhauer et al., 2019). Oxygen release from roots supports
65 nitrification, while the substrate filters particulates and recycles organic matter, creating a
66 sustained phytoremediation system (White & Cousins, 2013). Floating beds enhance biodiversity
67 and serve as natural biofilters; current research indicates that floating treatment wetlands (FTWs)
68 can reduce nutrient loads, curtail bacterial contamination, and create aquatic habitats (Deng & Ni,
69 2013; Rome et al., 2023). Large-scale adoption, however, remains limited by high input costs, a
70 lack of technical expertise, socio-economic constraints, and weak institutional support (Islam et

al., 2019; Majumder et al., 2024). Research has primarily concentrated on agronomic and socio-economic aspects, although comprehensive examinations of ecological balance and water quality are rare (Chowdhury et al., 2022). In particular, fewer than 20% of published studies assess water quality across multiple cropping cycles, leading to substantial uncertainty regarding long-term sustainability (Abdullah Al Pavel et al., 2014). Although research on floating agriculture is growing, crop and water-quality outcomes are rarely integrated, limiting design guidance and constraining the development of sustainable systems (Ghosh et al., 2024; Nair et al., 2025). To the best of our knowledge, this study is among the first in Bangladesh to incorporate systematic monitoring of water quality (N, P, K, and TDS) alongside rice performance in floating farming. Previous studies have predominantly focused on agronomic or socio-economic factors, although few have measured weekly fluctuations in nutrients and solutes over a complete cropping cycle. This research indicates that floating rice varieties can serve as both food sources and natural biofilters, reducing nutrient loads while sustaining grain output. Therefore, this study aims to investigate changes in, and compare, water quality parameters (N, P, K, and TDS) across three floating rice cultivation systems to determine how nutrient removal is linked to paddy yield in floating water systems.

2. MATERIALS AND METHODS

2.1. Experimental site and climate

The research was carried out in the Geo-Hydraulic and Water Resources Laboratory of Sylhet Agricultural University, Bangladesh (24°51' N, 91°50' E). The study area exhibits a tropical monsoon climate, with an average annual temperature of 25.2 °C and a relative humidity of 78% (Bangladesh Bureau of Statistics 2023). Clay soils were collected from a nearby hillock. Such soils are recognized for their high water-holding capacity and nutrient-sorption properties, which

minimize nutrient leaching and make them suitable for paddy cultivation (Easton & Bock, 2016). The soil was finely pulverized to avoid clod formation and subsequently amended with vermicompost to enhance nutrient availability and overall fertility.

2.2.Experimental design

Floating cultivation modules were constructed from expanded polystyrene (EPS) sheets with a surface area of 0.46 m² (Figure 1). Each unit contained 21 evenly spaced openings (3.8 cm diameter) designed to hold 350 mL plastic pots, which were treated as subsamples within the raft. Each pot contained 350 g of soil and was planted with three rice seedlings. The paired-raft configuration was chosen to provide structural stability and buoyancy while adhering to parameters aligned with prior floating bed research (Islam & Atkins, 2007) and (Ghosh et al., 2024). Buoyancy was achieved by affixing empty 2-L plastic bottles beneath the units, thereby supporting the combined weight of soil, water, and fully grown plants. Three independent raft modules were maintained per treatment as replicates, with treatments comprising three rice varieties: the local landrace Maloti, the hybrid BRRI Dhan-51, and the hybrid BRRI Dhan-79. This resulted in a total of nine floating rafts across all treatments. Each raft system received 80 liters of water from the central lake at Sylhet Agricultural University to replicate natural pond conditions. The water was not replenished during the experimental period because the setup was conducted in the shade, which minimized evaporation losses. The design of the floating beds was derived from previous floating agricultural methods in Bangladesh and adjusted for controlled pond environments (Hossain, 2014). Experimental ponds were prone to eutrophication under high nutrient loads, so floating rafts were also tested for their role in mitigating nutrient enrichment (Jones et al., 2017; Hernández-Vásquez et al., 2024).

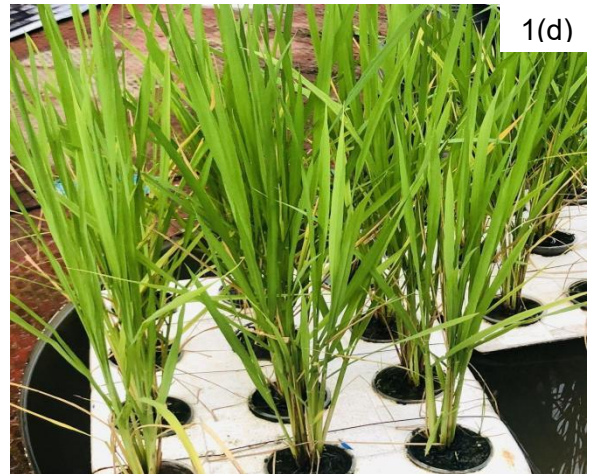


Figure 1. Experimental setup of floating rice cultivation: (a) seedlings planted in soil cups, (b) initial floating tray system in water tank, (c) early-stage plant establishment, (d) mid-stage vegetative growth, (e) reproductive stage, and (f) panicle initiation and grain filling.

2.3. Treatments and crop management

Three seedlings were placed into each pot on 24 August 2023. Crop nutrition was solely administered via foliar spray of Nutra-Phos-N fertilizer (2 g L⁻¹) at three critical phenological stages: panicle initiation (30 days after transplanting, DAT), flowering (46 DAT), and milk stage (60 DAT). This method was chosen to improve nutrient absorption while reducing the risk of water pollution, in accordance with foliar feeding techniques documented in flooded rice systems (Muthukrishanan et al., 2024; Yogi et al., 2024). The crop had been harvested on 4 December 2023 (102 DAT).

2.4. Water quality analysis

Weekly water samples were collected from the experimental site and field-filtered through 0.45 µm membranes. To preserve their quality, samples were maintained at ≤4 °C and tested within 48 hours. Total dissolved nitrogen (TDN, mg L⁻¹) and total dissolved phosphorus (TDP, mg L⁻¹ P) were determined after alkaline persulfate digestion at 120°C for 30 min using 0.5g K₂S₂O₈ per 50 mL of sample. Nitrate (NO₃⁻) was assessed using the cadmium reduction colorimetric method, ammonium (NH₄⁺) through the indophenol blue method, and orthophosphate (PO₄³⁻-P) via the molybdenum blue method. Standard calibration curves were established with R²>0.995. The method detection limit (LOD) was 0.01 mg L⁻¹ for NO₃⁻-N, 0.005 mg L⁻¹ for NH₄⁺-N, and 0.002 (LOQ) was 0.015 mg L⁻¹. We calibrated the ICP-OES using multi-element standards ranging from 0.1 to 10 mg L⁻¹, yielding a straight-line response with R²> 0.999. To check precision, all

measurements were repeated three times, and the variation stayed within $\pm 3\%$. Every sample was measured in triplicate to ensure reliable results. All steps were done following the standard methods for the Examination of water and wastewater (Bridgewater et al., 2017). Total dissolved solids (TDS) were quantified with a calibrated AQUASEARCHER™ AB33M1 benchtop meter. The weekly nutrient removal rate was calculated based on the average nutrient concentration in the water. The variation in nutritional content between successive weeks was computed as:

$$\Delta N_i = N(i - 1) - N_i \quad (1)$$

where $N(i - 1)$ is the average nutrient concentration at week $(i - 1)$ and N_i is the concentration at week i . The total nutrients removed per week were calculated as:

$$\text{Total removed (mg week}^{-1}\text{)} = \Delta N_i \times V \quad (2)$$

where V is the water volume (80 L).

Removal efficiency was expressed as:

$$\text{Removal Efficiency (\%)} = \frac{\Delta N_i}{N(i-1)} \times 100 \quad (3)$$

2.5. Nutrient mass balance and nutrient use efficiency

To quantify nutrient recovery in floating rice cultivation, a nutrient mass-balance approach was employed to estimate the amount of dissolved nutrients removed from the water column over the experimental period. The total nutrient removed from each floating cultivation unit was calculated as:

$$N_{\text{removed}} = (C_i - C_f) \times V \quad (4)$$

where N_{removed} is the total nutrient removed (mg), C_i is the initial nutrient concentration in the water (mg L⁻¹), C_f is the final nutrient concentration at the end of the cultivation period (mg L⁻¹), and V is the volume of water in each floating cultivation unit (80 L).

The percentage nutrient recovery efficiency was calculated as:

$$NRE(\%) = \frac{C_i - C_f}{C_i} \times 100 \quad (5)$$

To assess the efficiency with which recovered nutrients were converted into crop biomass, nutrient use efficiency (NUE) was calculated as:

$$NUE = \frac{N_{\text{removed}}}{B_g + B_s} \quad (6)$$

where NUE is the nutrient use efficiency (mg g⁻¹ biomass), B_g is the dry grain biomass (g), and B_s is the dry straw biomass (g). This index represents the amount of nutrient recovered from the water per unit of harvested aboveground biomass, thereby providing a quantitative measure of the coupling between nutrient recovery and biomass production under floating cultivation. Higher NUE values indicate greater efficiency of converting dissolved nutrients into productive plant biomass while simultaneously improving water quality.

2.6. Agronomic measurements

Primary agronomic data of rice, including tiller number, spike number, and grain number per plant, were recorded directly from the experimental plots. Pot weight and aboveground dry biomass were measured using a calibrated digital scale (capacity: 2 g–30 kg). In contrast, grain weight was determined with an electronic precision balance (Model EK-600i, A&D Company Ltd., Tokyo,

Japan). The harvest index (HI), an indicator of the efficiency of biomass partitioning into grain yield, was calculated as:

$$\text{Harvest Index, HI (\%)} = \frac{GY}{GY + SY} \times 100 \quad (7)$$

where GY is the grain yield, and SY is the straw yield (Singha et al., 2024).

2.7. Statistical analysis

Nutrient concentrations (N, P, K, and TDS) were expressed as mean $\pm$ standard error (SE). Weekly differences among rice varieties were analyzed using a one-way analysis of variance (ANOVA), with variety treated as the fixed factor. Post-hoc comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level. All statistical analyses were performed using SPSS version 27.0. Descriptive statistics and tabular formatting were conducted in Microsoft Excel 2019.

2.8. Integrated ecosystem performance analysis

To compare the multifunctional agronomic and ecological performance of floating rice cultivars, an integrated ecosystem performance analysis was performed using seven indicators: grain yield, harvest index, nitrogen recovery, phosphorus recovery, potassium recovery, total dissolved solids (TDS) reduction, and total aboveground biomass. Because these variables were measured in different units and scales, each indicator was normalized to a common 0–100 scale using min–max normalization:

$$X_{norm} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \times 100 \quad (8)$$

where X_i represents the observed value of each cultivar, while X_{min} and X_{max} denote the minimum and maximum values for each indicator among cultivars. The normalized values were used exclusively for visualization in the radar plot and did not replace the original statistical analyses performed on the raw data.

3. RESULTS

3.1. Variation of Nutrient Concentrations and TDS

Weekly variations in nutrient and TDS concentrations differed significantly among cultivars (Figure 2a–d). Nitrogen concentrations declined steadily in BRRI Dhan-79 and BRRI Dhan-51, from 6.7–7.0 mg L⁻¹ at week 1 to 2.6–2.8 mg L⁻¹ at week 15, whereas Maloti increased from 7.1 mg L⁻¹ to 8.3 mg L⁻¹. From week 7 onward, both hybrids consistently belonged to group a, significantly lower than Maloti (b/c). Phosphorus concentrations also declined sharply in the hybrids, decreasing from 9.0 mg L⁻¹ to 3.5–3.8 mg L⁻¹, while Maloti showed only a slight change, remaining near 8.3 mg L⁻¹. Similar trends were seen in potassium, where Maloti slightly reduced from 20.3 mg L⁻¹ to 18.6 mg L⁻¹, while BRRI Dhan-79 and BRRI Dhan-51 fell from 19.4–20.1 mg L⁻¹ to 12.6–13.3 mg L⁻¹. BRRI Dhan-79 and BRRI Dhan-51 reduced TDS concentrations from 136 mg L⁻¹ to 92–93 mg L⁻¹, whereas Maloti increased them from 138 mg L⁻¹ to 151 mg L⁻¹. Significant differences among cultivars became evident from week 7 onward ($a < b < c$). Maloti exhibited poor nutrient uptake and a tendency to accumulate solutes, indicating limited potential to improve water quality under floating rice culture. In contrast, BRRI Dhan-79 and BRRI Dhan-51 maintained consistently lower nutrient and TDS concentrations.

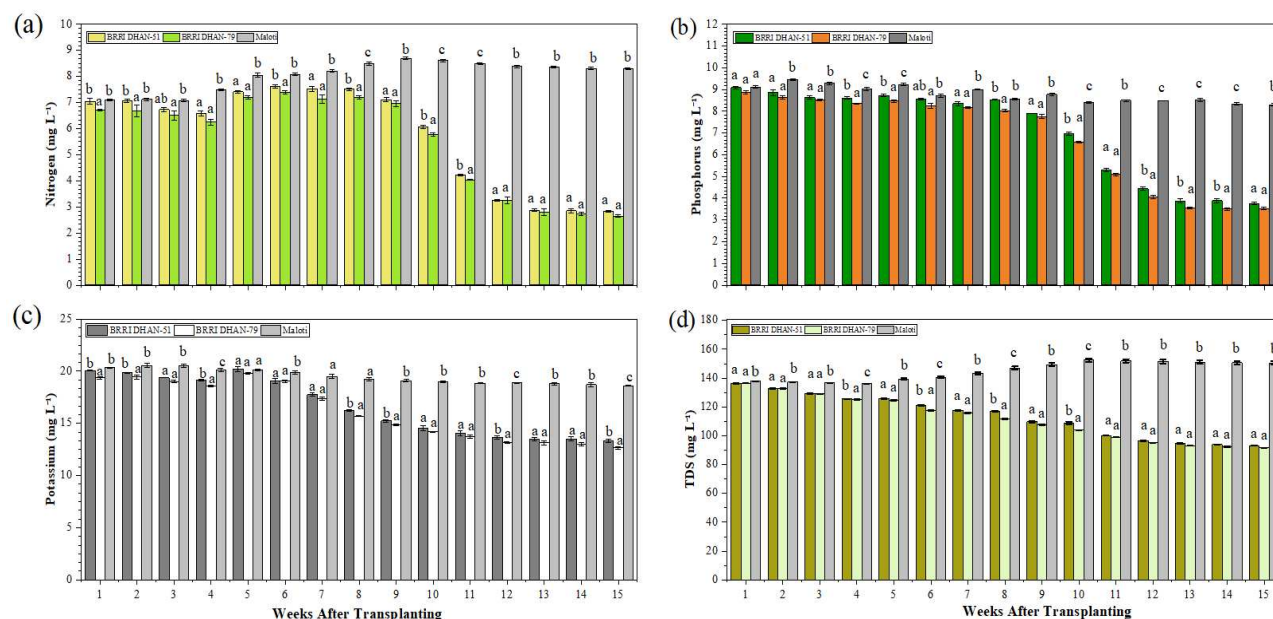


Figure 2. Weekly variation in nutrient and TDS concentrations under floating rice cultivation: (a) nitrogen, (b) phosphorus, (c) potassium, and (d) total dissolved solids (TDS).

3.2. Variation in nutrient (N, P, K) and TDS removal efficiency

Under floating rice production, weekly nutrient and TDS removal efficiencies showed significant cultivar and time-dependent changes (Figure 3a-d; Supplementary Table 1). Across the study period, nitrogen removal efficiency (Figure 3a) showed clear differences among the cultivars. In week 11, BRRI Dhan-79 recorded a marked rise, reaching about 29.9% (137,9 mg N), while BRRI Dhan-51 removed slightly more, at 30.6% (148.8 mg N). For BRRI Dhan 51, earlier increases were already visible in week 10 (14.6%, 83 mg) and week 9 (5.3%, 32 mg), roughly matching the post-tillering phase, when nutrient uptake accelerates. By the fifteenth week, the two hybrids had extracted roughly 420-450 mg N from the system. Maloti behaved quite differently: its efficiencies fluctuated between -15% and +1%, a sign of weak nutrient absorption and gradual solute build-up in the water column. By the end of the trial, this resulted in a total nitrogen removal efficiency of 80.9% for BRRI Dhan-79 and 79.1% for BRRI Dhan-51, conclusively identifying them as

235 effective phytoremediators, in stark contrast to Maloti, which had a net negative efficiency (-
 236 16.0%). Phosphorus removal followed a similar temporal trend (Figure 3b). Efficiencies in BRRI
 237 Dhan-51 increased sharply after week 9, reaching 23.8% (132 mg P) in week 11, 20.2 % (82 mg
 238 P) in week 12, and maintaining >10 % thereafter. BRRI Dhan-79 showed nearly identical peaks
 239 of 22.5% (118 mg P) in week 11 and 20.2% (82 mg P) in week 12, culminating in cumulative
 240 removals of 430-450 mg P. Maloti's efficiency mainly remained below 2%, occasionally turning
 241 negative (-4% to -5%), suggesting nutrient release instead of uptake. This resulted in a total
 242 phosphorus removal efficiency of 84.6% for BRRI Dhan-79 and 81.5% for BRRI Dhan-52,
 243 confirming their high remediation potential, whereas Maloti's net removal was negligible at 8.6%.
 244 For potassium (Figure 3c), both BRRI hybrids exhibited their strongest biofiltration and nutrient-
 245 removal performance between week 7-9, with BRRI Dhan-79 reaching 9.7% (135 mg K) in week
 246 8 and BRRI Dhan-51 attaining 8.6% (122 mg K) the same week. Their cumulative removals were
 247 400-430 mg K, while Maloti never exceeded 2% efficiency and contributed <70 mg in total. The
 248 total potassium removal was significantly higher in BRRI Dhan-79 (40.94%) and BRRI Dhan-51
 249 (39.54%) than in Maloti (8.79%). TDS removal efficiency (Figure 3d) displayed clear positive
 250 patterns for BRRI Dhan-79 and BRRI Dhan-51 but negative trends for Maloti. BRRI Dhan-51
 251 performed best in TDS removal, achieving 8.2% (711.9 mg) in week 11. BRRI Dhan-79 followed
 252 closely, with 4.7% (388 mg) in week 10. In contrast, Maloti maintained negative efficiencies
 253 throughout most of the middle period, from week 5 to 10, ranging from -1.5% to -3.0%, indicating
 254 a continuous solute buildup of roughly 178-303 mg per week. Over the 15 weeks, BRRI Dhan-79
 255 and BRRI Dhan-51 reduced TDS by 39.17% and 37.22%, respectively, whereas Maloti increased
 256 TDS by 9.00%. Taken together, Figure 3 and Supplementary Table 1 clearly show that the two

BRRI hybrids maintained positive nutrient and TDS removal throughout the season, whereas Maloti often lost nutrients back to the medium.

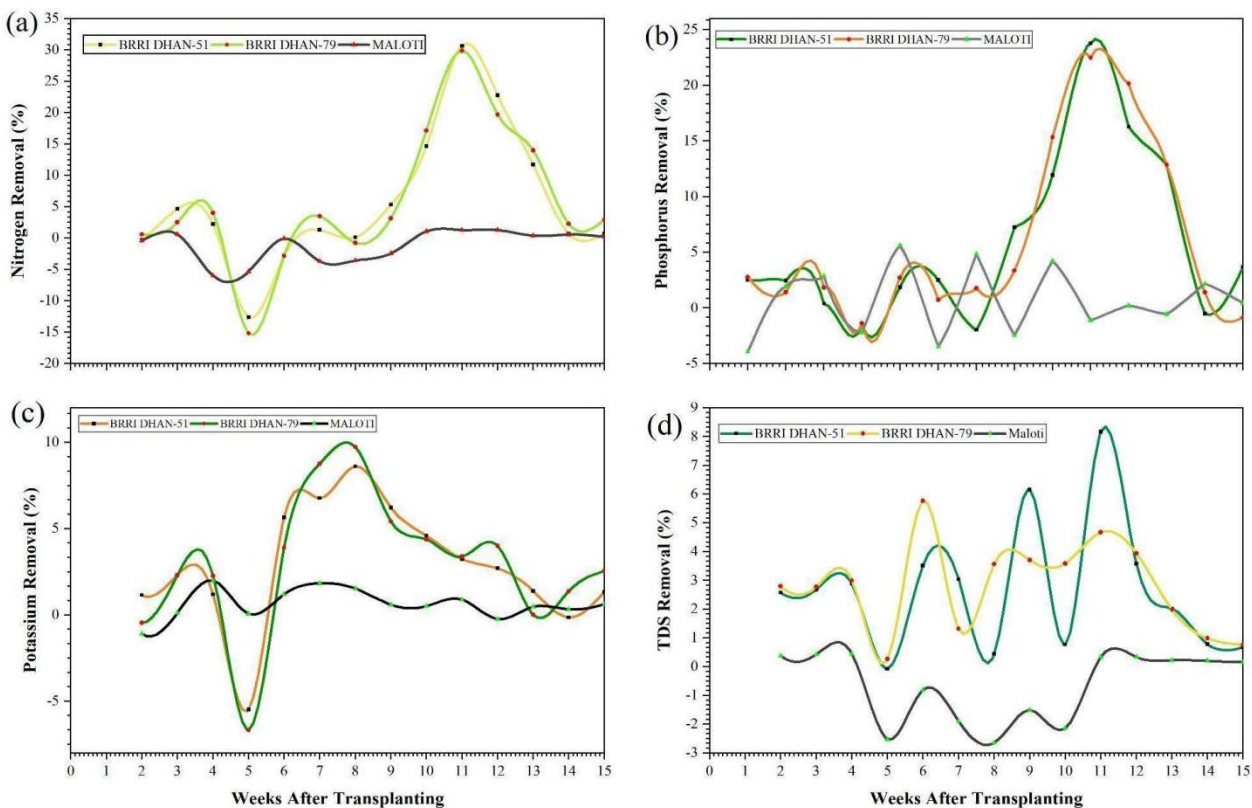


Figure 3. Weekly removal efficiency (%) of nutrients and total dissolved solids (TDS) under floating rice cultivation: (a) nitrogen, (b) phosphorus, (c) potassium, and (d) total dissolved solids.

3.3. Pot-wise comparison of grain number among three rice varieties

Varietal differences in grain yield were consistent across all 21 pots (Supplementary Table 2). Maloti recorded the lowest values (109–164 grains pot⁻¹), while BRRI Dhan-79 (264–290 grains pot⁻¹) and BRRI Dhan-51 (257–290 grains pot⁻¹) produced significantly higher yields. One-way ANOVA revealed significant effects of variety on all yield components ($F = 14.68 - 1227.32$; $p < 0.005$). Hybrids did not differ significantly from each other, but both produced higher grain yield and harvest index than Maloti.

269 **Table 1.** Yield performance and Harvest Index (HI) of three rice varieties

Paddy	Total	Grain	Area (m²)	Grain	Straw	Harvest
Variety	Grain	Weight (g)		Yield	(kg	Yield
	No.			m⁻²)	m⁻²)	Index (%)
Local Maloti	2863	34	0.46	0.074a	0.819	20.8a
BRRI Dhan-51	5738	121	0.46	0.263b	1.26	45.9b
BRRI Dhan-79	5791	124.5	0.46	0.271b	1.45	46.9b

270 Values are the sum of the average of three replications per pot (21 pots per variety).
 271 Significant differences among varieties are indicated by superscript letters within a column
 272 (Tukey's HSD, $p < 0.05$).

273 The yield performance and harvest index (HI) of the three rice varieties under floating cultivation
 274 are summarized in Table 1. The local Maloti exhibited the lowest performance, with a grain yield
 275 of 0.074 kg m⁻², a straw yield of 0.819 kg m⁻², and an HI of 20.8%. Conversely, BRRI Dhan-79
 276 and BRRI Dhan-51 demonstrated significantly superior results ($p < 0.05$). Their grain yields (0.271
 277 and 0.263 kg m⁻²) were over 3.5 times higher than Maloti, while their straw yields (1.45 and 1.26
 278 kg m⁻²) exceeded Maloti by 1.5–1.8 times. The hybrids also demonstrated a higher biomass
 279 partitioning efficiency, with HIs of 46.9% and 45.9%, which is more than double that of Maloti.
 280 The two hybrids did not exhibit substantial differences; however, they consistently outperformed

the local variety, highlighting the superior yield potential and resource-use efficiency of BRRI varieties under floating-bed conditions.

3.4. Integrated ecosystem performance of floating rice cultivars

The integrated ecosystem performance analysis synthesized seven agronomic and ecological indicators into a single multidimensional comparison of floating rice cultivars (Figure 4). BRRI Dhan-79 exhibited the largest normalized performance envelope, reflecting the highest grain yield, harvest index, nitrogen, phosphorus, and potassium recovery, TDS reduction, and total biomass productivity. BRRI Dhan-51 displayed a comparable but slightly smaller performance profile across most indicators. In contrast, Maloti consistently exhibited the lowest normalized scores due to poor nutrient recovery, lower biomass accumulation, and a negative TDS reduction. The radar plot demonstrates that the high-yielding cultivars simultaneously maximize water-quality improvement and crop productivity, highlighting their superior multifunctional performance under floating cultivation.

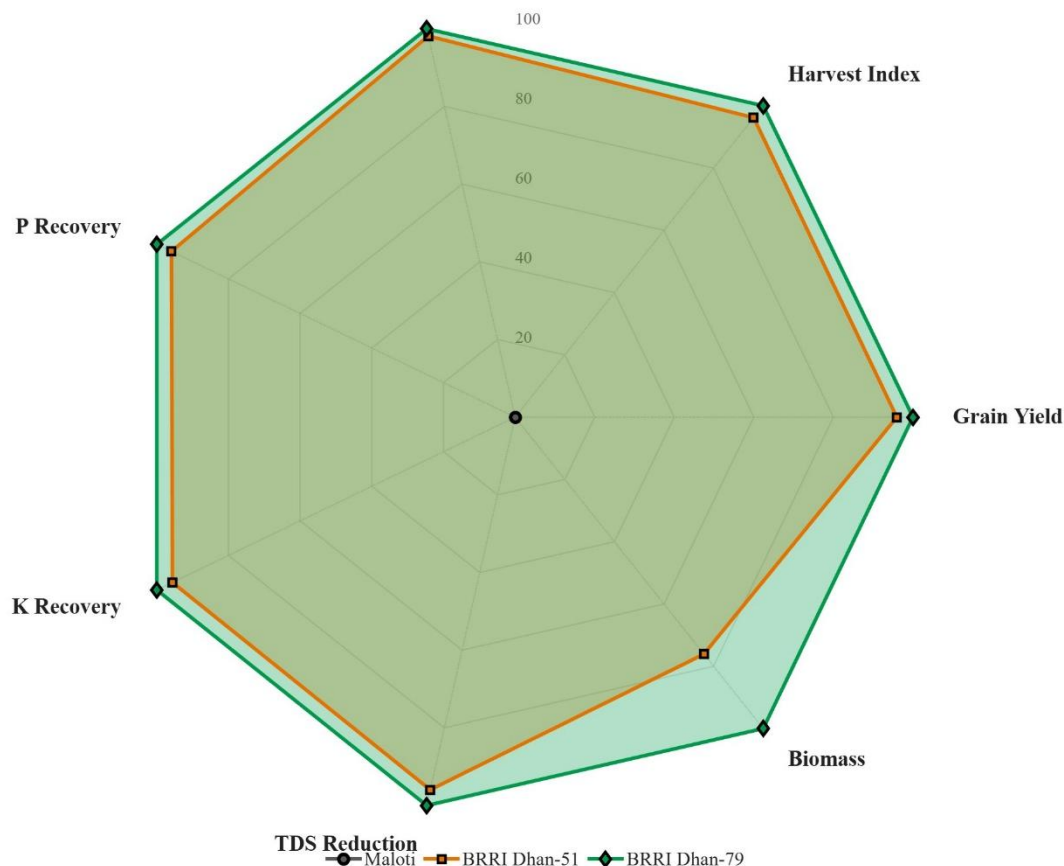


Figure 4. Integrated ecosystem performance of floating rice cultivars under floating cultivation.

3.5. Linear regression of nutrient concentrations

The regression analysis (Figure 5a-c) revealed a strong, highly significant negative relationship between water nutrient concentrations and average grain number ($p < 0.001$, $R^2 = 0.983-0.994$). As nutrient levels declined, grain number increased sharply, demonstrating that better nutrient removal was directly associated with enhanced yield performance. The slopes of the regression lines (-57.58, -72.32, and -45.21 for nitrogen, phosphorus, and potassium, respectively) indicate that even small decreases in waterborne nutrient concentrations corresponded to substantial gains in grain formation. When the regression results are compared with the weekly nutrient dynamics (Figure 3) and pot-wise, grain data (Supplementary Table 2), a consistent pattern emerges across

all parameters. Pot containing BRRI Dhan-79 and BRRI Dhan-51 generally showed a lower residual nutrient concentration and a higher removal efficiency (up to 30 % N, 24% P, and 10% K; Supplementary Table 1). These reductions were consistently associated with higher grain production, reaching 270-290 grains per pot. In contrast, Maloti retained higher N-P-K concentrations (8.29, 8.30, and 18.61 mg L⁻¹) and yielded only 110-160 grains per pot. This pattern clearly indicates that yield improvement in floating conditions depends strongly on the plant's capacity to remove and utilize dissolved nutrients from the water. Taken together, the regression findings confirm that nutrient removal behavior is relevant for water quality enhancement and a strong predictor of yield performance. The very high coefficients of determination ($R^2 > 0.98$) show that nutrient concentration alone explained more than 98% of the variation in grain number. This close connection between nutrient uptake and productivity underscores that cultivars that maintain low residual nutrient levels, such as BRRI Dhan-79 and BRRI Dhan-51, perform better under floating culture. Conversely, nutrient buildup in Maloti indicates inefficient nutrient uptake and lower agronomic potential.

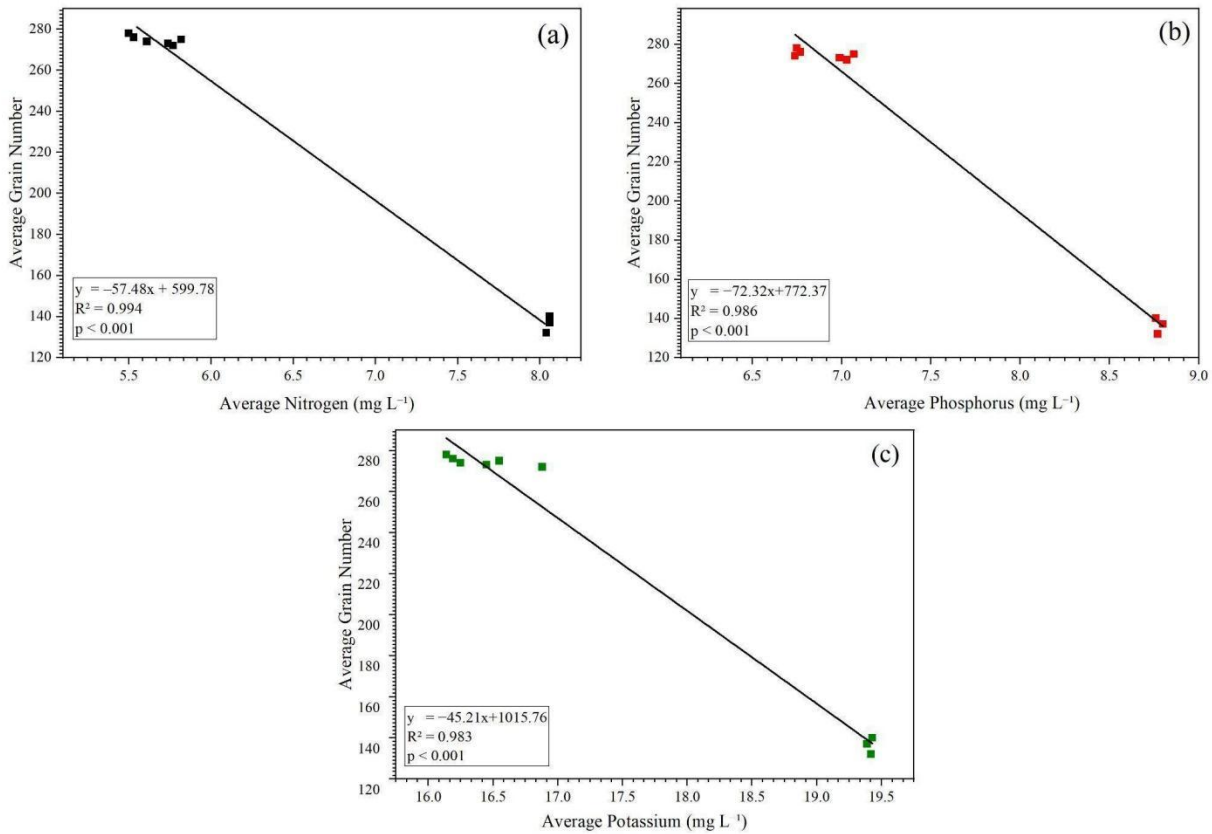


Figure 5. Linear Regression between Average Grain Number and Nutrient Concentrations: (a) nitrogen, (b) phosphorus, and (c) potassium.

4. DISCUSSION

The three rice cultivars exhibited distinct variations in biofiltration efficiency and yield performance. BRRI Dhan-79 regularly surpassed BRRI Dhan-51 and the conventional Maloti, highlighting the enhanced resilience of high-yielding varieties (HYVs) under aquatic stress. The nitrogen removal efficiencies of BRRI Dhan-79 (80.9%) and BRRI Dhan-51 (79.1%) were significantly higher than those of most treatment wetlands (Figure 3), which typically achieve 40–55% removal (Vymazal, 2011). Global assessments of rehabilitated wetlands indicate a median nitrogen removal effectiveness of around 37% (Moreno-Mateos et al., 2012). Well-managed free-

330 water surface wetlands can sometimes remove more than 60% of nitrogen (Gaballah et al., 2024).
331 In comparison, floating treatment wetlands (FTWs) often perform even better, achieving nitrate
332 reductions of nearly 80% under heavy nutrient loads and maintaining this level of removal for
333 several growing seasons (Rathour et al., 2020; McCoy et al., 2024). These outcomes suggest that
334 floating rice systems could play a comparable role in providing clean water while producing food.
335 Oxygen that leaks from the rice roots helps turn ammonium into nitrate and also keeps phosphorus
336 and trace metals from dissolving too much in the water. These processes together help clean and
337 stabilize the water naturally (Nawaz et al., 2014). The patterns of nutrient uptake corroborate this
338 hypothesis. The high-yielding varieties (HYVs) extracted over 40% of the available potassium and
339 more than 82% of the available phosphorus, while Maloti absorbed just over 9% of the available
340 phosphorus. This contrast reflects the greater nutrient-use efficiency of modern cultivars, which is
341 linked to higher metabolic demand, denser panicle formation, and improved grain filling (Akhtar
342 et al., 2011). Beyond plant physiology, the rhizoplane acts as a biofilm habitat where nitrifiers,
343 denitrifiers, and polyphosphate-accumulating organisms coexist and regulate nutrient
344 transformations, particularly under intermittent oxygen conditions (Shahid et al., 2020). The
345 pattern also aligns with established crop–nutrient dynamics, in which nitrogen stimulates tillering
346 (Reyes-Cabrera et al., 2017). In contrast, phosphorus is essential for spikelet initiation and grain
347 development (De Bauw et al. 2018). The pronounced decline in nutrient levels after the ninth week
348 corresponded with the onset of reproductive growth, emphasizing the importance of matching
349 nutrient availability to developmental stages. This synchronized nutrient drawdown results from
350 source-to-sink remobilization, in which nutrients are translocated from roots and shoots to the
351 developing panicle, a process regulated by complex hormonal signaling (Wang et al., 2020). By
352 contrast, the traditional landrace Maloti exhibited imbalanced nutrient uptake and poor

reproductive output, producing only 100–170 grains per pot (Supplementary Table 2). This performance is typical of classic landraces with shallow root systems and restricted rhizosphere oxygenation, which may even release nitrogen under eutrophic stress (Su et al., 2019). Limited aerenchyma development and weak internal oxygen transport in such landraces reduce redox buffering and microbial nitrification potential, thereby increasing ammonium accumulation and potential N₂O emissions (Iqbal et al., 2023). Despite Maloti's cultural and historical importance, its insufficient absorption efficiency and low yield suggest it is unsuitable for integrated food-water systems in flood-prone areas. From a pragmatic perspective, floating rice systems with high-yield varieties (HYVs) produced modest but considerable yields while functioning as effective nutrient sinks. Yields between 0.074 and 0.271 kg m⁻² (Table 1) were lower than those of conventional field-based rice production (0.48 kg m⁻²; Al Mamun et al., 2024); yet they are relevant in regions where terrestrial agriculture is infeasible. Moderate yields, although inferior to field output, are crucial during floods because they mitigate overall crop losses and enhance household resilience (Ismail et al., 2013). Integrating HYVs into floating systems enhances circular nutrient use and ecosystem stability, aligning with nature-based adaptation frameworks that couple plant, microbial, and hydrological processes (Canet-Martí et al., 2021). The integrated ecosystem performance assessment demonstrates that nutrient recovery and crop productivity are closely coupled in floating rice cultivation systems. Unlike single-indicator evaluations, the radar plot integrates provisioning ecosystem services (grain yield and biomass production) with regulating ecosystem services (nutrient recovery and TDS reduction), providing a holistic assessment of cultivar performance. BRRI Dhan-79 achieved the greatest multidimensional performance, indicating its greater capacity to recover dissolved nutrients while maintaining superior biomass production and water-quality improvement. This integrated assessment supports

the interpretation of floating rice cultivation as a nature-based solution for climate-resilient wetland agriculture. These findings corroborate the notion that floating rice may function as a nature-based climate adaptation strategy. By integrating high-yielding cultivars into floating cultivation, farming communities can simultaneously safeguard food production, limit nutrient losses to surrounding waters, and build resilience against recurring floods (Chowdhury & Moore, 2017).

5. CONCLUSIONS

In this study, we grew both hybrid and local rice varieties on floating rafts to assess their grain yield and their effects on water quality in climate-vulnerable floodplain wetlands of Bangladesh. The results demonstrate that floating rice cultivation is a multifunctional, nature-based solution capable of simultaneously enhancing agricultural productivity and improving aquatic environmental quality under prolonged flooding conditions. Among the evaluated cultivars, BRRI Dhan-79 and BRRI Dhan-51 consistently outperformed the indigenous cultivar Maloti, achieving substantially greater grain yield, harvest index, biomass production, and nutrient recovery from floodwater. These cultivars removed up to 80.9% of dissolved nitrogen, 84.6% of phosphorus, 40.9% of potassium, and nearly 40% of total dissolved solids, whereas Maloti exhibited limited nutrient uptake and reduced water quality improvement.

Nutrient mass balance analysis further revealed that the high-yielding cultivars converted recovered nutrients more efficiently into harvestable grain and straw biomass, demonstrating a strong linkage between nutrient recovery and crop productivity. The significant negative relationships between residual nutrient concentrations and grain production indicate that enhanced nutrient assimilation is a key mechanism driving improved performance in floating cultivation

systems. Collectively, these findings highlight the dual provisioning and regulating ecosystem services provided by floating rice cultivation, including food production and nutrient remediation.

The study provides robust evidence that cultivar selection is critical for maximizing the ecological and agronomic benefits of floating agriculture. By integrating nutrient recovery with climate-resilient rice production, floating cultivation offers a scalable and low-cost adaptation strategy for flood-prone wetlands across Bangladesh and other deltaic regions facing increasing hydrological variability. Future research should evaluate long-term multi-season performance, greenhouse gas emissions, carbon sequestration potential, microbial nutrient transformation, and socio-economic feasibility to support the wider adoption of floating rice cultivation as a sustainable wetland management and climate adaptation strategy.

AUTHOR CONTRIBUTIONS (CrediT Statement)

Author Contributions: Ashutus Singha: Conceptualization, Methodology, Investigation, Supervision, Project administration, Writing – review & editing. Setu Roy: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. Md. Jouadul Hasan: Conceptualization, Methodology, Formal analysis, Writing – review & editing. A. K. Mohibul Islam: Conceptualization, Methodology, Writing – review & editing. Ayman Intiser: Writing – review & editing. Mohammad Abdul Kader: Writing – review & editing. Suchitra Mitra: Visualization, Writing – review & editing. All authors read and approved the final version of the manuscript.

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420 **AVAILABILITY OF DATA AND MATERIALS**

421 The dataset used in this study will be made available from the corresponding author upon
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423 **ETHICS APPROVAL AND CONSENT TO PARTICIPATE**

424 Not applicable.

425 **CONSENT FOR PUBLICATION**

426 Not applicable.

427 **CONFLICT OF INTEREST**

428 The authors declare that they have no conflicts of interest.

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580

SUPPLEMENTARY TABLE-1

581

Nutrient Removal Efficiency

582

			BRRI DHAN-51_N			
Week	Treat ment	Avg Nitrogen (mg/L)	Nitrogen Removed, ΔNi = Avg N(i-1) - Avg N(i)	Total Removed (mg) = $\Delta Ni \times V$ (80L)	Removal Efficiency (%) = $(\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -51	7.04				
2	BRRI DHAN -51	7.06	-0.02	-1.6	-0.28	79.11
3	BRRI DHAN -51	6.73	0.33	26.4	4.67	
4	BRRI DHAN -51	6.58	0.15	12	2.23	
5	BRRI DHAN -51	7.41	-0.83	-66.4	-12.61	
6	BRRI DHAN -51	7.62	-0.21	-16.8	-2.83	
7	BRRI DHAN -51	7.52	0.1	8	1.31	
8	BRRI DHAN -51	7.51	0.01	0.8	0.13	
9	BRRI DHAN	7.11	0.4	32	5.33	

	-51					
10	BRRI DHAN -51	6.07	1.04	83.2	14.63	
11	BRRI DHAN -51	4.21	1.86	148.8	30.64	
12	BRRI DHAN -51	3.25	0.96	76.8	22.80	
13	BRRI DHAN -51	2.87	0.38	30.4	11.69	
14	BRRI DHAN -51	2.85	0.02	1.6	0.70	
15	BRRI DHAN -51	2.83	0.02	1.6	0.70	

583

			BRRI DHAN-79_N			
Week	Treat ment	Avg Nitrogen (mg/L)	Nitrogen Removed, ΔNi = Avg N(i-1) - Avg N(i)	Total Removed (mg) = $\Delta Ni \times V$ (80L)	Removal Efficiency (%) = $(\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -79	6.71				
2	BRRI DHAN -79	6.67	0.04	3.2	0.60	80.92
3	BRRI DHAN -79	6.50	0.17	13.33	2.50	
4	BRRI	6.24	0.26	21.07	4.05	

	DHAN -79					
5	BRRI DHAN -79	7.19	-0.95	-75.73	-15.17	
6	BRRI DHAN -79	7.39	-0.20	-16.27	-2.83	
7	BRRI DHAN -79	7.13	0.26	20.53	3.47	
8	BRRI DHAN -79	7.19	-0.05	-4.27	-0.75	
9	BRRI DHAN -79	6.96	0.23	18.13	3.15	
10	BRRI DHAN -79	5.77	1.19	95.47	17.15	
11	BRRI DHAN -79	4.04	1.72	137.87	29.88	
12	BRRI DHAN -79	3.25	0.80	63.73	19.70	
13	BRRI DHAN -79	2.79	0.45	36.27	13.96	
14	BRRI DHAN -79	2.73	0.06	5.07	2.27	
15	BRRI DHAN -79	2.65	0.08	6.40	2.93	

			MALOTI_N			
Week	Treat ment	Avg Nitrogen (mg/L)	Nitrogen Removed, ΔNi = Avg N(i-1) - Avg N(i)	Total Removed (mg) = $\Delta Ni \times V$ (80L)	Removal Efficiency (%) = $(\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	MALO TI	7.10				
2	MALO TI	7.12	-0.03	-2.13	-0.38	-16.04
3	MALO TI	7.08	0.04	3.47	0.61	
4	MALO TI	7.50	-0.42	-33.87	-5.98	
5	MALO TI	7.90	-0.40	-32.00	-5.33	
6	MALO TI	7.91	-0.01	-0.53	-0.08	
7	MALO TI	8.20	-0.29	-23.47	-3.71	
8	MALO TI	8.50	-0.29	-23.47	-3.58	
9	MALO TI	8.70	-0.21	-16.53	-2.43	
10	MALO TI	8.61	0.09	7.47	1.07	
11	MALO TI	8.50	0.11	8.80	1.28	
12	MALO TI	8.39	0.11	8.80	1.29	
13	MALO TI	8.36	0.03	2.67	0.40	
14	MALO TI	8.31	0.05	3.73	0.56	
15	MALO	8.29	0.02	1.60	0.24	

	TI					
			BRRi DHAN-51_K			
Week	Treat ment	Avg Potassiu m (mg/L)	Potassium Removed, $\Delta Ni = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRi DHAN -51	20.06				
2	BRRi DHAN -51	19.83	0.23	18.40	1.15	39.54
3	BRRi DHAN -51	19.37	0.46	36.80	2.32	
4	BRRi DHAN -51	19.14	0.23	18.40	1.19	
5	BRRi DHAN -51	20.19	-1.05	-84.00	-5.49	
6	BRRi DHAN -51	19.05	1.14	91.20	5.65	
7	BRRi DHAN -51	17.76	1.29	103.20	6.77	
8	BRRi DHAN -51	16.23	1.53	122.40	8.61	
9	BRRi DHAN -51	15.22	1.01	80.80	6.22	
10	BRRi	14.52	0.7	56.00	4.60	

	DHAN -51					
11	BRRI DHAN -51	14.05	0.47	37.60	3.24	
12	BRRI DHAN -51	13.67	0.38	30.40	2.70	
13	BRRI DHAN -51	13.48	0.19	15.20	1.39	
14	BRRI DHAN -51	13.5	-0.02	-1.60	-0.15	
15	BRRI DHAN -51	13.32	0.18	14.40	1.33	

586

			BRRI DHAN-79_K			
Week	Treat ment	Avg Potassiu m (mg/L)	Potassium Removed, $\Delta Ni = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -79	19.36				
2	BRRI DHAN -79	19.45	-0.09	-7.20	-0.46	40.94
3	BRRI DHAN -79	19	0.45	36.00	2.31	
4	BRRI DHAN -79	18.57	0.43	34.40	2.26	

5	BRRI DHAN -79	19.81	-1.24	-99.20	-6.68	
6	BRRI DHAN -79	19.04	0.77	61.60	3.89	
7	BRRI DHAN -79	17.37	1.67	133.60	8.77	
8	BRRI DHAN -79	15.68	1.69	135.20	9.73	
9	BRRI DHAN -79	14.83	0.85	68.00	5.42	
10	BRRI DHAN -79	14.18	0.65	52.00	4.38	
11	BRRI DHAN -79	13.7	0.48	38.40	3.39	
12	BRRI DHAN -79	13.15	0.55	44.00	4.01	
13	BRRI DHAN -79	13.15	0	0.00	0.00	
14	BRRI DHAN -79	12.97	0.18	14.40	1.37	
15	BRRI DHAN -79	12.64	0.33	26.40	2.54	

			MALOTI_K			
Week	Treat ment	Avg Potassiu m (mg/L)	Potassium Removed, $\Delta N_i = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta N_i \times V (80L)$	Removal Efficiency (%) $= (\Delta N_i / N_{i-1}) \times 100$	Total Removal Efficiency
1	MALO TI	20.33				
2	MALO TI	20.55	-0.22	-17.87	-1.10	8.79
3	MALO TI	20.53	0.03	2.00	0.12	
4	MALO TI	20.12	0.41	32.53	1.98	
5	MALO TI	20.11	0.01	1.07	0.07	
6	MALO TI	19.87	0.24	19.33	1.20	
7	MALO TI	19.50	0.36	29.07	1.83	
8	MALO TI	19.21	0.30	23.87	1.53	
9	MALO TI	19.09	0.11	9.07	0.59	
10	MALO TI	19.00	0.10	7.73	0.51	
11	MALO TI	18.83	0.17	13.60	0.89	
12	MALO TI	18.87	-0.05	-3.60	-0.24	
13	MALO TI	18.78	0.09	7.20	0.48	
14	MALO TI	18.72	0.06	4.80	0.32	

15	MALO TI	18.61	0.11	9.20	0.61	
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			BRRI DHAN-51_P			
Week	Treat ment	Avg Phospho rus (mg/L)	Phosphorus Removed, $\Delta Ni = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -51	9.08				
2	BRRI DHAN -51	8.85	0.23	18.40	2.53	81.46
3	BRRI DHAN -51	8.63	0.22	17.33	2.45	
4	BRRI DHAN -51	8.60	0.03	2.67	0.39	
5	BRRI DHAN -51	8.73	-0.13	-10.67	-1.55	
6	BRRI DHAN -51	8.57	0.16	13.07	1.87	
7	BRRI DHAN -51	8.35	0.21	17.07	2.49	
8	BRRI DHAN -51	8.52	-0.16	-13.07	-1.96	
9	BRRI DHAN -51	7.90	0.62	49.33	7.24	

10	BRRI DHAN -51	6.96	0.94	75.47	11.94	
11	BRRI DHAN -51	5.30	1.65	132.27	23.77	
12	BRRI DHAN -51	4.44	0.86	69.07	16.28	
13	BRRI DHAN -51	3.87	0.57	45.60	12.84	
14	BRRI DHAN -51	3.89	-0.02	-1.60	-0.52	
15	BRRI DHAN -51	3.75	0.14	11.47	3.68	

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			BRRI DHAN-79_P			
Week	Treat ment	Avg Phospho rus (mg/L)	Phosphorus Removed, $\Delta Ni = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -79	8.88				
2	BRRI DHAN -79	8.63	0.25	19.73	2.78	84.64
3	BRRI DHAN -79	8.51	0.12	9.87	1.43	
4	BRRI DHAN -79	8.35	0.16	12.53	1.84	

5	BRRI DHAN -79	8.47	-0.12	-9.33	-1.40
6	BRRI DHAN -79	8.24	0.23	18.40	2.72
7	BRRI DHAN -79	8.18	0.06	4.80	0.73
8	BRRI DHAN -79	8.03	0.15	11.73	1.79
9	BRRI DHAN -79	7.76	0.27	21.60	3.36
10	BRRI DHAN -79	6.57	1.19	95.20	15.34
11	BRRI DHAN -79	5.09	1.48	118.13	22.48
12	BRRI DHAN -79	4.07	1.03	82.13	20.16
13	BRRI DHAN -79	3.54	0.52	41.87	12.87
14	BRRI DHAN -79	3.49	0.05	4.00	1.41
15	BRRI DHAN -79	3.52	-0.03	-2.40	-0.86

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			MALOTI_P		
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Week	Treatment	Avg Phosphorus (mg/L)	Phosphorus Removed, $\Delta Ni = \text{Avg } N(i-1) - \text{Avg } N(i)$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) = $(\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	MALO TI	9.11				
2	MALO TI	9.46	-0.36	-28.53	-3.92	8.58
3	MALO TI	9.28	0.18	14.67	1.94	
4	MALO TI	9.02	0.26	21.07	2.84	
5	MALO TI	9.22	-0.20	-16.00	-2.22	
6	MALO TI	8.70	0.52	41.33	5.61	
7	MALO TI	9.00	-0.30	-24.00	-3.45	
8	MALO TI	8.56	0.44	34.93	4.85	
9	MALO TI	8.77	-0.21	-16.80	-2.45	
10	MALO TI	8.40	0.37	29.60	4.22	
11	MALO TI	8.50	-0.09	-7.47	-1.11	
12	MALO TI	8.48	0.02	1.33	0.20	
13	MALO TI	8.53	-0.05	-3.73	-0.55	
14	MALO TI	8.34	0.19	14.93	2.19	
15	MALO TI	8.30	0.04	2.93	0.44	

			BRRI DHAN-51_TDS			
Week	Treatment	Avg TDS (mg/L)	TDS Removed, $\Delta Ni = \text{Avg N(i-1)} - \text{Avg N(i)}$	Total Removed (mg) = $\Delta Ni \times V (80L)$	Removal Efficiency (%) = $(\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -51	136.343				
2	BRRI DHAN -51	132.831	3.512	280.99	2.58	37.22
3	BRRI DHAN -51	129.264	3.567	285.33	2.69	
4	BRRI DHAN -51	125.547	3.717	297.37	2.88	
5	BRRI DHAN -51	125.636	-0.089	-7.12	-0.07	
6	BRRI DHAN -51	121.208	4.429	354.29	3.52	
7	BRRI DHAN -51	117.521	3.687	294.93	3.04	
8	BRRI DHAN -51	117.004	0.517	41.37	0.44	
9	BRRI DHAN -51	109.793	7.211	576.88	6.16	
10	BRRI DHAN -51	108.943	0.850	68.00	0.77	

11	BRRI DHAN -51	100.044	8.899	711.89	8.17	
12	BRRI DHAN -51	96.467	3.577	286.17	3.58	
13	BRRI DHAN -51	94.523	1.944	155.54	2.02	
14	BRRI DHAN -51	93.777	0.746	59.66	0.79	
15	BRRI DHAN -51	93.152	0.625	50.04	0.67	

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			BRRI DHAN-79_TDS			
Week	Treat ment	Avg TDS (mg/L)	TDS Removed, $\Delta Ni =$ Avg N(i-1) - Avg N(i)	Total Removed (mg) = $\Delta Ni \times V$ (80L)	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency
1	BRRI DHAN -79	136.45				
2	BRRI DHAN -79	132.63	3.82	305.33	2.80	39.17
3	BRRI DHAN -79	128.95	3.68	294.67	2.78	
4	BRRI DHAN -79	125.08	3.87	309.87	3.00	
5	BRRI DHAN -79	124.74	0.33	26.67	0.27	

6	BRRI DHAN -79	117.54	7.20	576.27	5.77	
7	BRRI DHAN -79	115.99	1.55	124.27	1.32	
8	BRRI DHAN -79	111.85	4.14	331.20	3.57	
9	BRRI DHAN -79	107.70	4.15	332.00	3.71	
10	BRRI DHAN -79	103.83	3.87	309.33	3.59	
11	BRRI DHAN -79	98.98	4.85	388.00	4.67	
12	BRRI DHAN -79	95.07	3.91	313.07	3.95	
13	BRRI DHAN -79	93.19	1.88	150.40	1.98	
14	BRRI DHAN -79	92.26	0.93	74.13	0.99	
15	BRRI DHAN -79	91.56	0.70	56.00	0.76	

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			MALOTI_TDS			
Week	Treat ment	Avg TDS (mg/L)	TDS Removed, $\Delta Ni =$ Avg N(i-1) - Avg N(i)	Total Removed (mg) = $\Delta Ni \times V$ (80L)	Removal Efficiency (%) $= (\Delta Ni / Ni-1) \times 100$	Total Removal Efficiency

1	MALO TI	137.76				
2	MALO TI	137.24	0.52	41.60	0.38	-9.00
3	MALO TI	136.65	0.59	47.20	0.43	
4	MALO TI	136.04	0.61	48.80	0.45	
5	MALO TI	139.47	-3.43	-274.40	-2.52	
6	MALO TI	140.58	-1.11	-88.80	-0.80	
7	MALO TI	143.24	-2.66	-212.80	-1.89	
8	MALO TI	147.03	-3.79	-303.20	-2.65	
9	MALO TI	149.26	-2.23	-178.40	-1.52	
10	MALO TI	152.45	-3.19	-255.20	-2.14	
11	MALO TI	151.93	0.52	41.60	0.34	
12	MALO TI	151.42	0.51	40.80	0.34	
13	MALO TI	151.08	0.34	27.20	0.22	
14	MALO TI	150.78	0.30	24.00	0.20	
15	MALO TI	150.55	0.23	18.40	0.15	

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SUPPLEMENTARY TABLE-2

596

Grain Number

Pot	Maloti (Mean $\pm$ SE)	BRRi Dhan-79 (Mean $\pm$ SE)	BRRi Dhan-51 (Mean $\pm$ SE)	F-value	p-value
Pot1	116 $\pm$ 13.30 a	278 $\pm$ 10.17 b	260 $\pm$ 4.91 b	78.11	<0.001
Pot2	112 $\pm$ 5.29 a	270 $\pm$ 6.69 b	283 $\pm$ 6.12 b	247.65	<0.001
Pot3	163 $\pm$ 1.20 a	264 $\pm$ 4.91 b	282 $\pm$ 12.67 b	66.66	<0.001
Pot4	142 $\pm$ 6.89 a	274 $\pm$ 6.49 b	277 $\pm$ 5.90 b	144.14	<0.001
Pot5	109 $\pm$ 1.20 a	279 $\pm$ 2.73 b	259 $\pm$ 3.48 b	1227.32	<0.001
Pot6	148 $\pm$ 27.39 a	278 $\pm$ 13.68 b	270 $\pm$ 12.60 b	14.68	0.005
Pot7	164 $\pm$ 13.01 a	281 $\pm$ 9.35 b	260 $\pm$ 3.71 b	42.08	<0.001
Pot8	154 $\pm$ 5.17 a	282 $\pm$ 6.66 b	290 $\pm$ 3.48 b	211.58	<0.001
Pot9	133 $\pm$ 17.63 a	273 $\pm$ 9.64 b	270 $\pm$ 9.07 b	39.66	<0.001
Pot10	141 $\pm$ 23.13 a	286 $\pm$ 6.17 b	278 $\pm$ 2.03 b	34.54	<0.001

Pot11	154 ± 20.54 a	269 ± 9.74 b	265 ± 5.86 b	23.41	0.001
Pot12	113 ± 15.07 a	277 ± 12.12 b	287 ± 5.90 b	70.02	<0.001
Pot13	118 ± 17.64 a	286 ± 4.04 b	290 ± 1.45 b	89.25	<0.001
Pot14	155 ± 9.21 a	284 ± 7.88 b	284 ± 3.48 b	103.58	<0.001
Pot15	125 ± 17.57 a	271 ± 4.63 b	267 ± 5.36 b	57.54	<0.001
Pot16	163 ± 7.62 a	267 ± 10.91 b	278 ± 11.46 b	39.41	<0.001
Pot17	131 ± 6.17 a	274 ± 12.81 b	257 ± 3.79 b	84.71	<0.001
Pot18	123 ± 13.74 a	264 ± 5.77 b	270 ± 6.89 b	77.57	<0.001
Pot19	127 ± 18.50 a	285 ± 5.13 b	271 ± 12.91 b	43.14	<0.001
Pot20	123 ± 17.62 a	274 ± 5.78 b	268 ± 7.54 b	55.00	<0.001
Pot21	152 ± 7.94 a	274 ± 12.20 b	271 ± 7.31 b	54.79	<0.001

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599 Local, BRRI Dhan-79, and BRRI Dhan-51 are the rice varieties.

600 Values represent mean $\pm$ standard error (SE) based on three replications.

601 F and P values are derived from one-way ANOVA.