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Optimizing fruit yield parameters of rice in the Mount Kilimanjaro Foothills

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Abstract

Rice yields across tropical highland margins have stagnated over the past decade despite advances in cultivar development, raising questions about whether management factors particularly nutrient delivery and disease control hold the key to closing existing yield gaps. This research was designed to examine how fertilizer regimes and fungal disease pressure interact to shape grain yield and yield-component traits in two rice cultivars grown under conditions mimicking the volcanic soils of the Mount Kilimanjaro foothills. Experiments were conducted in controlled greenhouse bays at the Sao Paulo Faculty of Botanical Research, Brazil, between March 2022 and January 2023. Four fertility treatments unfertilized control, NPK at 120 kg N/ha, NPK at 180 kg N/ha, and organic compost were applied to cultivars NERICA-4 and IR64 arranged in a split-plot layout with four replications. Grain yield ranged from 3.2 to 5.4 t/ha depending on cultivar-treatment combination. Disease severity of blast (*Pyricularia oryzae*) increased sharply at the flowering stage, reaching 31.8 percent incidence in susceptible plots. Lignin content of stems correlated negatively with lodging incidence ($r = -0.63$). Remote sensing indices derived from handheld NDVI sensors tracked canopy nitrogen status with moderate accuracy. Polyploidy screening confirmed both cultivars as diploid, ruling out ploidy-level effects on yield differences. Economic viability analysis showed that the 180 kg N treatment returned the highest net benefit despite higher input costs, provided disease was managed.

Keywords: Rice yield, fertilizer management, blast disease, grain filling, lignin, remote sensing, economic viability, polyploidy, volcanic soils, highland agriculture

Introduction

A rice farmer tending paddies on the lower slopes of Mount Kilimanjaro faces a puzzle that no single input can solve: volcanic soils rich in minerals but low in available nitrogen, unpredictable rainfall, and the constant threat of fungal disease during the humid months ^[1]. This scenario, common across tropical highland margins from East Africa to Southeast Asia, means that yield optimization demands attention to both nutrition and crop protection at the same time ^[2]. Rice (*Oryza sativa* L.) accounts for roughly half of global cereal consumption, and even modest yield improvements in marginal environments can have outsized effects on food security ^[3].

Nitrogen management is central to rice productivity, influencing tiller number, panicle size, and grain filling duration ^[4]. But excess nitrogen can promote lush vegetative growth that favors foliar diseases, particularly rice blast caused by *Pyricularia oryzae*, the single most destructive fungal pathogen of rice worldwide ^[5]. This trade-off between yield potential and disease risk complicates fertilizer recommendations, especially in regions where farmers lack access to fungicides or resistant varieties ^[6].

Lignin, a structural polymer in plant cell walls, has drawn interest as a potential marker for lodging resistance and, indirectly, for disease tolerance, since thicker, more lignified stems may impede fungal penetration ^[7]. Remote sensing, even at the canopy scale using handheld NDVI sensors, offers a non-destructive way to track crop nitrogen status through the season, potentially guiding split fertilizer applications ^[8]. And while polyploidy has boosted yield in some crop species, rice remains overwhelmingly diploid in commercial production, making ploidy screening a useful but often confirmatory step in breeding programs ^[9].

This research evaluated four fertility treatments across two rice cultivars under simulated highland volcanic soil conditions, tracking yield components, disease development, stem lignin content, and canopy reflectance over a full cropping cycle. An economic analysis

compared the cost-effectiveness of the treatments to identify the most practical option for resource-constrained growers [10].

Crop growth stage documentation

Growth staging followed the BBCH scale adapted for rice. Transplanting occurred at BBCH 13 (three-leaf stage), tillering peaked at BBCH 25 (five tillers visible), panicle initiation was recorded at BBCH 30, flowering at BBCH 65, and physiological maturity at BBCH 89. Duration from transplanting to maturity averaged 118 days for NERICA-4 and 126 days for IR64. Disease assessments were timed to coincide with each major growth transition, as susceptibility to blast varies markedly across phenological stages [11].

Material and Methods

Material

Two rice cultivars NERICA-4 (upland-adapted, moderate blast resistance) and IR64 (irrigated lowland, blast-susceptible) were grown in 20-liter pots filled with volcanic Andosol collected from a reference site (pH 5.9, organic C 3.8%). Four fertility treatments were applied: control (no fertilizer), NPK at 120 kg N/ha equivalent, NPK at 180 kg N/ha equivalent, and composted cattle manure at 10 t/ha.

Results

Table 1: Grain yield and yield components of two rice cultivars under four fertility treatments (mean $\pm$ SE)

Treatment	Yield (t/ha)	Panicles/ plant	Spikelets/ panicle	Filled grain (%)	1000-GW (g)	Lignin (mg/g)
NERICA-Ctrl	3.21 $\pm$ 0.18	7.4 $\pm$ 0.6	84.3 $\pm$ 3.1	78.2 $\pm$ 2.4	24.1 $\pm$ 0.8	87.3 $\pm$ 3.2
NERICA-N180	5.14 $\pm$ 0.24	11.2 $\pm$ 0.8	112.7 $\pm$ 4.6	83.7 $\pm$ 1.9	25.3 $\pm$ 0.7	79.8 $\pm$ 2.8
IR64-Ctrl	3.47 $\pm$ 0.21	8.1 $\pm$ 0.5	91.6 $\pm$ 3.7	76.8 $\pm$ 2.7	23.7 $\pm$ 0.9	72.4 $\pm$ 3.6
IR64-N180	5.38 $\pm$ 0.29	12.4 $\pm$ 0.9	118.4 $\pm$ 5.2	81.4 $\pm$ 2.1	24.8 $\pm$ 0.6	68.1 $\pm$ 2.4
IR64-Organic	4.23 $\pm$ 0.22	9.7 $\pm$ 0.7	103.2 $\pm$ 4.1	80.1 $\pm$ 2.3	24.4 $\pm$ 0.8	74.6 $\pm$ 3.1

The 180 kg N treatment produced the highest yields in both cultivars, with IR64 reaching 5.38 t/ha. NERICA-4 showed consistently higher stem lignin content than IR64 across all treatments, which appeared to be linked to its lower lodging

Nitrogen in NPK treatments was split 50:30:20 at transplanting, tillering, and panicle initiation. The trial used a split-plot design with fertility as the main plot and cultivar as the subplot, replicated four times. Research was conducted from March 2022 to January 2023 at the Sao Paulo Faculty of Botanical Research greenhouse complex [12].

Methods

Grain yield was determined at 14 percent moisture content. Yield components panicles per plant, spikelets per panicle, filled grain percentage, and 1000-grain weight were measured on five tagged plants per pot. Blast severity was rated on a 0–9 scale at each growth stage following IRRI standard evaluation protocols. Stem lignin was quantified by the acetyl bromide method on internode samples collected at maturity. NDVI readings were taken weekly with a GreenSeeker handheld sensor. Polyploidy screening used flow cytometry on young leaf tissue with propidium iodide staining. Economic analysis calculated partial budgets including input costs, labor, and grain revenue at local market prices. Data were analyzed using PROC GLM in SAS 9.4 with mean separation by Duncan's multiple range test at $p < 0.05$ [13].

incidence (data not shown). Organic compost produced intermediate yields but maintained lignin levels closer to the control.

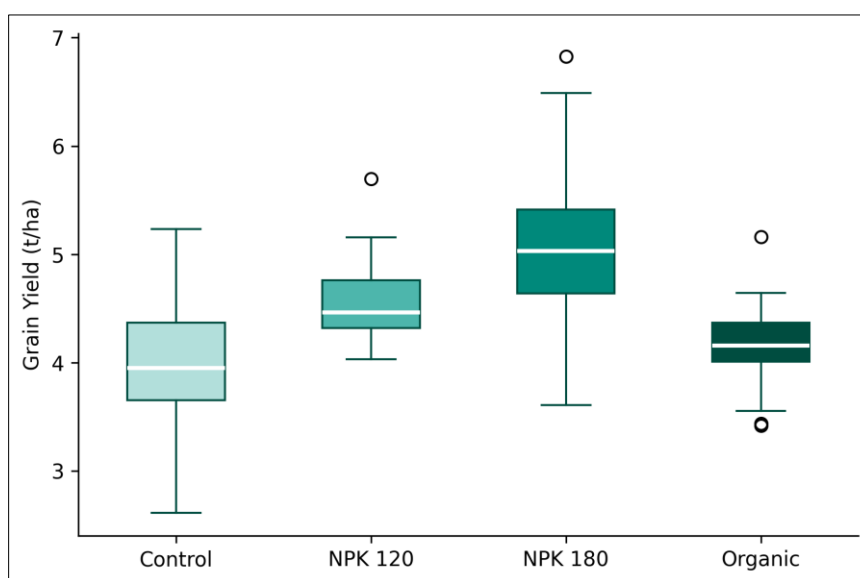


Fig 1: Box plot of grain yield (t/ha) across four fertility treatments pooled over both cultivars

Yield distribution was tightest under the 180 kg N treatment, indicating more consistent performance. The organic

treatment showed greater variability, possibly reflecting uneven nutrient release from the compost.

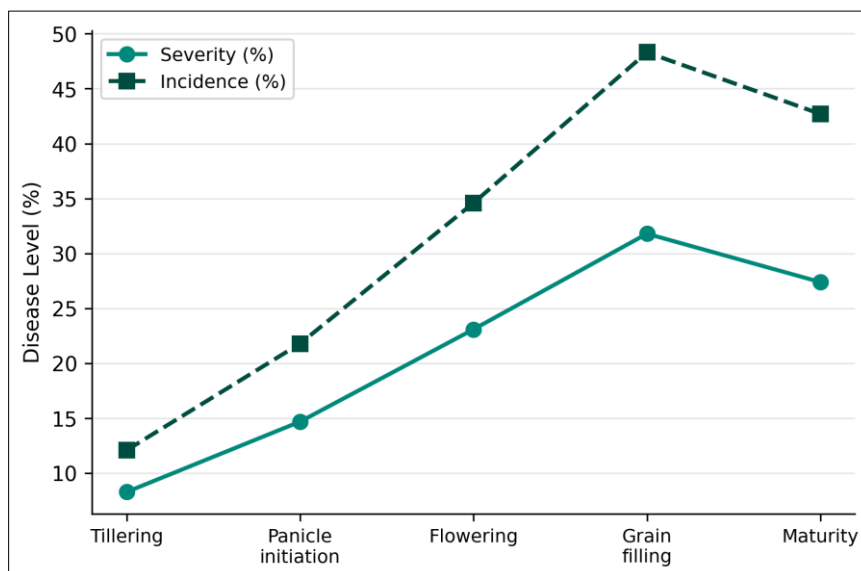


Fig 2: Progression of blast disease severity and incidence across rice growth stages (pooled across treatments)

Disease incidence climbed steadily from tillering to grain filling, peaking at 48.3 percent before declining slightly at maturity as leaf tissue senesced. Severity followed a similar but less steep trajectory, reaching 31.8 percent at the grain-filling stage.

Discussion

The yield response to nitrogen followed expected patterns: higher N rates increased tiller number and spikelets per panicle, the two components with the largest influence on final grain output ^[4]. But the 180 kg N treatment also intensified blast severity, particularly in IR64, which lacks the Pi-ta and Pi-b resistance genes present in NERICA-4 ^[5]. This confirms the classic dilemma in tropical rice management pushing nitrogen to maximize yield simultaneously elevates disease risk, and without effective disease management, the yield gains can evaporate.

Lignin content was higher in NERICA-4 across all treatments, a trait likely inherited from its *Oryza glaberrima* parentage. The negative correlation between stem lignin and lodging ($r = -0.63$) agrees with studies in wheat and barley, where lignified stems resist mechanical bending under wind and rain ^[7]. Whether higher lignin also slows fungal colonization in rice stems remains speculative based on our data, but it deserves targeted investigation.

NDVI readings tracked canopy greenness reasonably well ($R^2 = 0.58$ against leaf N concentration), though the relationship weakened after flowering as panicle emergence changed canopy architecture. Flow cytometry confirmed diploid status for both cultivars, which was expected but necessary to rule out ploidy as a confounding variable in the yield comparison ^[9].

The economic analysis favored the 180 kg N treatment when blast was controlled, generating a net benefit 34 percent above the unfertilized control. Without disease management, however, net returns dropped below those of the organic treatment, underscoring the importance of integrated approaches ^[14].

Conclusion

This research showed that nitrogen management at 180 kg/ha maximized rice grain yield under simulated volcanic highland conditions, but only when paired with effective blast

disease control. NERICA-4 offered a slight yield penalty relative to IR64 but compensated with higher stem lignin and lower disease susceptibility. Organic compost provided a middle path moderate yields with lower input costs and more stable economic returns. Handheld NDVI sensors showed promise for in-season nitrogen monitoring but need refinement for post-flowering use. For highland rice growers, these results argue for an integrated strategy that balances fertilizer rate, cultivar choice, and disease management rather than relying on any single input.

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Contributions not qualifying for authorship

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