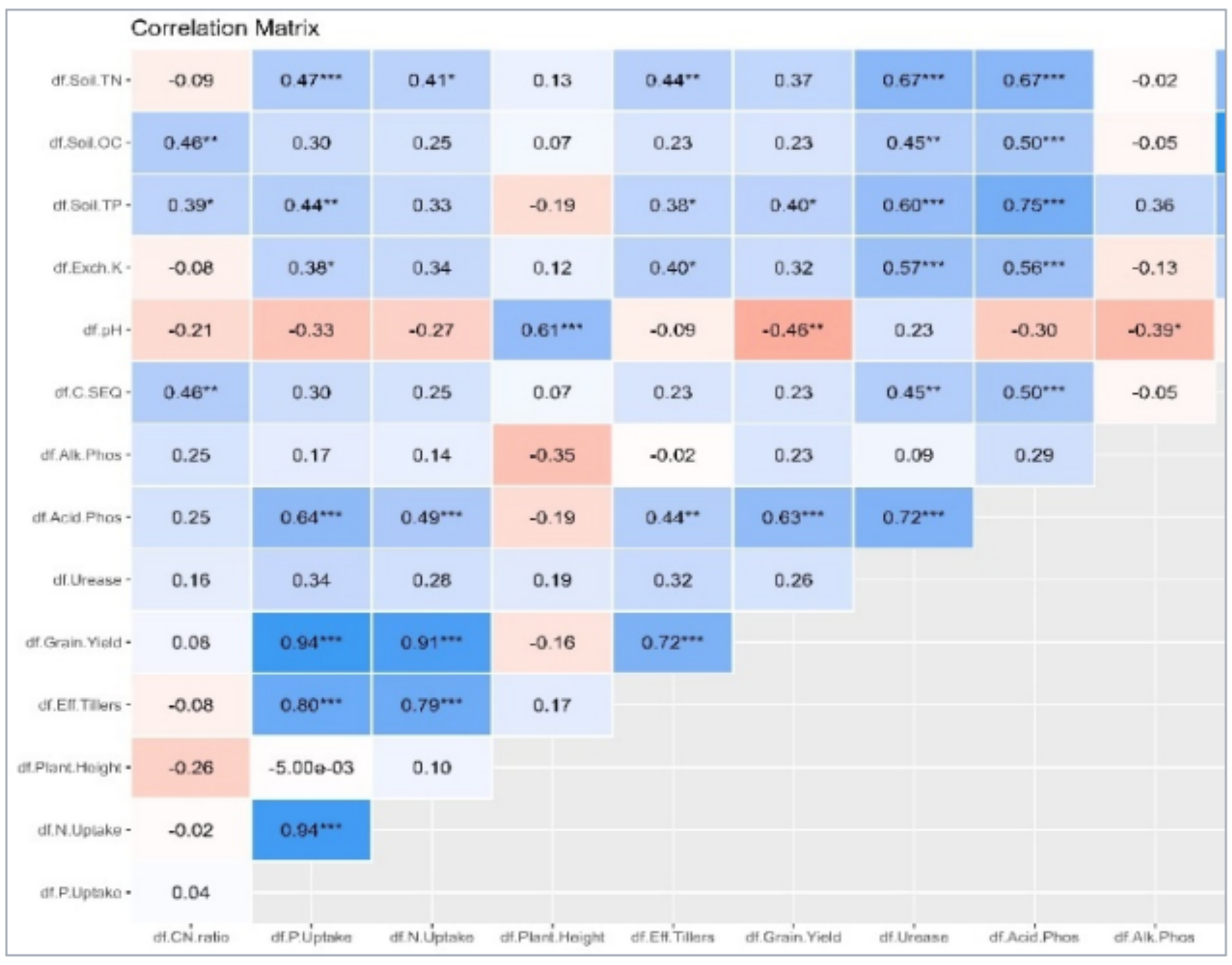
Assessment of Azolla and Rice Straw Management on Agronomic Efficiency and Soil Properties under Flooded Rice Production System

Said H. Marzouk*, Hamis J. Tindwa, Nyambilila A. Amuri
(binmarzouk@gmail.com)
Sokoine University of Agriculture, Tanzania

Introduction

Nitrogen use efficiency (NUE) in rice systems remains low globally, contributing to environmental degradation and unsustainable fertilizer demand. While Azolla and rice straw have been studied independently, their combined application under reduced synthetic nitrogen regimes in tropical lowland soils—especially in sub-Saharan Africa—remains underexplored. This study fills that gap by evaluating their synergistic effects on NUE, soil health, and carbon sequestration in Tanzania's Kilombero Valley.

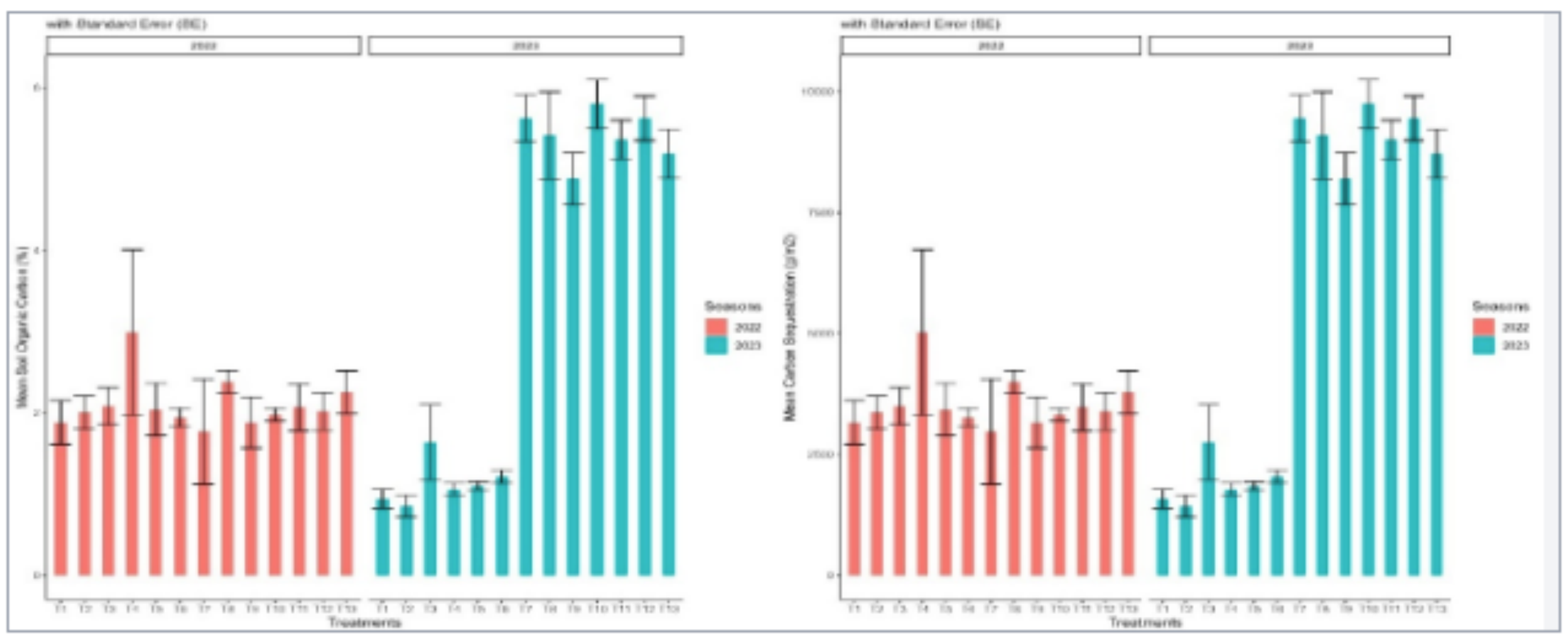


Treatment Combination and Field Layout

Code	Azolla application	Rice straw	Nitrogen application	Other synthetic fertilizers
T1	-	-	-	-
T2	-	-	100 kg urea-N ha^{-1}	-
T3	-	-	100 kg urea-N ha^{-1}	30 kg P ha^{-1}
T4	-	-	100 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K
T5	-	-	100 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}
T6	-	-	50 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}
T7	-	6.9-ton rice straw ha^{-1}	-	30 kg P ha^{-1}
T8	3.4-ton dry Azolla ha^{-1}	-	-	30 kg P ha^{-1}
T9	-	6.9-ton rice straw ha^{-1}	50 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}
T10	3.4-ton dry Azolla ha^{-1}	-	50 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}
T11	3.4-ton dry Azolla ha^{-1}	6.9-ton rice straw ha^{-1}	-	30 kg P ha^{-1}
T12	3.4-ton dry Azolla ha^{-1}	6.9-ton rice straw ha^{-1}	50 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}
T13	3.4-ton dry Azolla ha^{-1}	6.9-ton rice straw ha^{-1}	100 kg urea-N ha^{-1}	30 kg P ha^{-1} + 30 kg K ha^{-1} + 20 kg S ha^{-1}

Methodology

The study was conducted over two rice-growing seasons (2022–2023) at the Mkula Irrigation Scheme in Kilombero Valley, Tanzania, using a randomized complete block design with 13 treatment combinations and three replications. Treatments included varying nitrogen levels (50 and 100 kg N/ha), phosphorus, potassium, and sulphur fertilizers, and organic amendments of Azolla (3.4 t/ha) and rice straw (6.9 t/ha). Soil and plant samples were analyzed for nutrient content, enzyme activity, and carbon sequestration using standard laboratory methods. Nitrogen use efficiency metrics were calculated, and statistical analyses (ANOVA, PCA, correlation matrix) were applied to assess treatment effects.



Results

Integrated application of Azolla, rice straw, and NPKS fertilizers produced strong synergistic effects on soil fertility, nitrogen agronomic efficiency, and rice yield across two consecutive seasons. Soil organic carbon (SOC) increased substantially, reaching 5.79% under the Azolla + 50% N + PKS treatment, while total nitrogen (TN) rose to 0.65% in Azolla-amended plots. Available P peaked at 2.95 mg kg^{-1} and exchangeable K reached 122.12 ppm under combined Azolla + rice straw + full NPKS inputs. Although soil pH remained generally stable, a small but significant seasonal decline was observed ($p = 0.036$). Soil enzyme activities responded strongly to organic inputs: urease activity increased from 85.4 to 188.5 µg urea-N g^{-1} soil $5h^{-1}$, and acid phosphatase reached 136.38 µg pNP g^{-1} soil h^{-1}. All enzyme activities were significantly higher in integrated treatments ($p < 0.001$), indicating enhanced nutrient mineralization dynamics. Agronomic performance improved markedly. The highest grain yield (5,333 kg ha^{-1}), P uptake (81.45 kg ha^{-1}), and P use efficiency (271.5%) were obtained in the Azolla + rice straw + full NPKS treatment. Notably, Azolla + 50% N + PKS produced comparable yields, indicating the possibility of reducing synthetic N while maintaining productivity. Grain yield exhibited strong positive correlations with agronomic N efficiency ($r = 0.990$), P uptake ($r = 0.895$), and PUE ($r = 0.895$*). Azolla contributed substantial biologically fixed nitrogen. In season one, fresh biomass additions (1,956 and 1,503 kg ha^{-1}) with N concentrations of 2.2% and 1.9% supplied 71.4 kg N ha^{-1}. In season two, biomass inputs (1,784 and 1,640 kg ha^{-1}) with N contents of 1.8% and 2.2% contributed 68.7 kg N ha^{-1}. These inputs significantly enhanced soil N availability and agronomic efficiency. Carbon sequestration increased significantly ($p < 0.05$) in treatments receiving Azolla or rice straw, particularly when combined with reduced NPKS—demonstrating the role of organic residues in improving SOC and long-term soil health. Treatments lacking organic materials showed no increase relative to the control. Multivariate analyses confirmed these trends. PCA positioned Azolla + rice straw + NPKS (T13) as the most influential treatment, strongly associated with SOC, TN, enzyme activity, and yield. Heatmap clustering grouped T13, T12, and T10 with high-performing soil and plant indicators. Correlation analysis showed grain yield correlating strongly with TN ($r = 0.94$), SOC ($r = 0.80$), and exchangeable K ($r = 0.72$), while urease and acid phosphatase were tightly linked to TN ($r = 0.67$) and available P ($r = 0.60$), respectively.

Comprehensiveness: Trade-offs Analysis

Yield Benefits:

71% yield increase (2.1 to 3.6 t/ha) with organic amendments matching full-dose synthetic N treatments

Cost-Benefit:

- **Savings:** 50% reduction in synthetic N (50 kg/ha vs 100 kg/ha)
- **Input costs:** Azolla (locally cultivated), rice straw (farm residue)
- **Net benefit:** Reduced input costs + higher yields

Environmental Benefits:

- 48% increase in soil organic carbon (8.5 to 12.6 t/ha)
- Enhanced soil biological activity and enzyme levels
- Reduced fertilizer-related emissions

Practical Relevance

Farmers	Policy	Environment
Higher yields with 50% less synthetic N	Eco-friendly nutrient management	Carbon sequestration + soil health

Novelty: First study testing Azolla + rice straw synergy in acidic tropical lowland soils of sub-Saharan Africa under reduced synthetic nitrogen regimes

Scalability for Smallholders:

- Uses locally available, low-cost materials
- Simple application methods compatible with existing practices
- Immediate yield benefits with long-term soil improvement

Conclusion & Way Forward

Integrated use of Azolla, rice straw, and balanced NPKS fertilizers significantly improved soil fertility, nitrogen use efficiency, and rice productivity in acidic lowland soils. Organic inputs increased soil organic carbon, total nitrogen, and nutrient-cycling enzyme activities, while maintaining high yields even with 50% reduced synthetic nitrogen. Treatments combining Azolla and rice straw performed best, demonstrating strong synergies in nutrient supply and carbon sequestration. This approach offers a low-cost, climate-smart, and scalable strategy for enhancing rice production and soil health in sub-Saharan African paddy systems.

Acknowledgments: *Salma A. Salim, Direct Aid Association, Department of Soil and Geological Sciences, Sokoine University of Agriculture*