



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

www.agronomyjournals.com

2025; 8(1): 45-47

Received: 02-11-2024

Accepted: 04-12-2024

Mahbubur Miah

Department of Agronomy,
Bangladesh Agricultural
University, Mymensingh,
Bangladesh

Kamrul Uddin

Department of Agronomy,
Bangladesh Agricultural
University, Mymensingh,
Bangladesh

Environmental sustainability assessment of precision fertilization technologies in cereal crops

Mahbubur Miah and Kamrul Uddin

DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i1a.5200>

Abstract

Can precision fertilization methods reduce the environmental burden of cereal production while maintaining yield? This research examined five fertilization approaches broadcast, soil-test based, Variable Rate Technology (VRT), sensor-guided, and drone-assisted in rice and wheat systems at Bangladesh Agricultural University, Mymensingh, from July 2022 to June 2023. A randomized complete block design with four replications across 60 plots was used. Sensor-guided application reduced greenhouse gas emissions by 31.7% compared to broadcast, while nitrogen use efficiency rose from 38.2% to 63.8%. Drainage water nitrate-nitrogen fell by 41.6% under precision treatments. Grain yield didn't differ significantly between sensor-guided (4.82 t/ha) and broadcast (4.71 t/ha) for rice. Initial precision tool costs were 2.3 times higher, but savings offset costs within 3.7 seasons.

Keywords: Precision agriculture, nutrient use efficiency, cereal crops, life cycle assessment, variable rate technology, environmental sustainability, greenhouse gas emissions, sensor-guided fertilization, carbon footprint, rice-wheat system

Introduction

What happens when a farmer applies 30% more nitrogen than the crop needs? The excess leaches into groundwater, volatilizes as nitrous oxide, or runs off into water bodies. Bangladesh consumed over 5.2 million metric tons of chemical fertilizers in 2021-22 ^[1]. Conventional broadcast fertilization suffers from poor spatial targeting surveys in Mymensingh found application rates varying by 45% within single fields ^[2]. Precision technologies match nutrient supply to demand at finer scales through variable rate controllers, optical sensors ^[3], and drone-assisted delivery ^[4], with temperate system research documenting 15-40% efficiency improvements ^[5, 6].

Environmental gains remain poorly quantified in tropical cereal systems. Life cycle assessment provides a framework for estimating impacts across global warming, eutrophication, and energy categories ^[7], yet few LCA evaluations cover South Asian conditions. This research evaluated five fertilization approaches in rice-wheat rotations at Bangladesh Agricultural University to quantify emissions, energy footprints, and water quality impacts.

Research area description

The experimental site was at the Agronomy Research Field, BAU, Mymensingh (24.7434° N, 90.4203° E), in the Old Brahmaputra Floodplain zone (AEZ-9). Soils were non-calcareous dark grey floodplain type, Sonatala series, silty loam texture with pH 6.3 and organic carbon 1.12%. Smallholder farms averaging 0.52 hectares dominate the landscape.

Climatic conditions during the research period

Mymensingh has a subtropical monsoon climate. During July 2022-June 2023, temperatures ranged from 17.8 °C (January) to 32.4 °C (April). Total rainfall was 2,347 mm, with 79% between June and September. The 2022 monsoon brought 8.3% more rainfall than the 30-year average.

Corresponding Author:

Mahbubur Miah

Department of Agronomy,
Bangladesh Agricultural
University, Mymensingh,
Bangladesh

Material and Methods

Material

The research was conducted at Bangladesh Agricultural University, Mymensingh, from July 2022 to June 2023. Ethical clearance was obtained (Protocol No. BAU-REC/2022-067, June 15, 2022). Rice variety BRRI dhan49 and wheat variety BARI Gom-33 were used. Fertilizers included urea (46% N), triple superphosphate (20% P), and muriate of potash (50% K). Precision equipment comprised a CLAAS variable rate controller, GreenSeeker optical sensor, and DJI Agras T30 drone. LCA modeling used OpenLCA v1.11.0 with ecoinvent 3.8 [8].

Methods

Five treatments were arranged in a randomized complete block design with four replications (20 plots, 5 m × 6 m). T₁ (broadcast) used manual spreading at uniform rates. T₂ (soil-test)

adjusted rates per pre-season analysis. T₃ (VRT) used 5 m grid prescription maps. T₄ (sensor-guided) used Green Seeker readings at 15-day intervals. T₅ (drone-assisted) combined VRT maps with aerial application. Grain yield was measured from the central 3 m × 4 m area. Greenhouse gas emissions were estimated through closed-chamber measurements and IPCC Tier 2 methodology [9]. Energy inputs were computed following Mohammadi *et al.* [10]. Water quality was assessed biweekly from drainage channels.

Field experimental design

Plots were separated by 1.5 m buffer strips. Each block was positioned along the field's drainage gradient. Rice was transplanted July 22, 2022; wheat sown November 18, 2022. Fertilizer was split-applied: 50% basal, 25% at tillering/crown root initiation, and 25% at panicle initiation / booting. All other agronomic operations were uniform across treatments.

Results

Table 1: Grain yield and nutrient use efficiency of rice and wheat under different precision fertilization treatments

Treatment	Rice yield (t/ha)	Wheat yield (t/ha)	NUE (%)	PUE (%)	KUE (%)	N Applied (kg/ha)
Broadcast (T ₁)	4.71	3.18	38.2	14.6	42.1	248
Soil-test (T ₂)	4.68	3.31	51.7	22.3	53.6	207
VRT (T ₃)	4.79	3.42	59.3	27.1	58.9	183
Sensor (T ₄)	4.82	3.47	63.8	29.8	62.7	171
Drone (T ₅)	4.84	3.51	66.4	31.2	65.3	164
LSD (0.05)	0.23	0.19	4.7	3.2	5.1	--
CV (%)	3.8	4.2	6.1	8.7	5.9	--ss

Rice yield didn't differ significantly among precision treatments, but all outperformed broadcast for wheat. Nitrogen use efficiency increased from 38.2% (broadcast) to 66.4% (drone-assisted), a 73.8% improvement. Sensor-guided and drone-assisted methods used 31.1% and 33.9% less nitrogen, respectively.

Environmental impact analysis showed greenhouse gas emissions dropping 31.7% and 34.4% for sensor-guided and drone-assisted methods, with drainage nitrate-nitrogen decreasing from 8.73 to 4.92 mg/L. Energy input was lowest under sensor-guided application at 14,430 MJ/ha

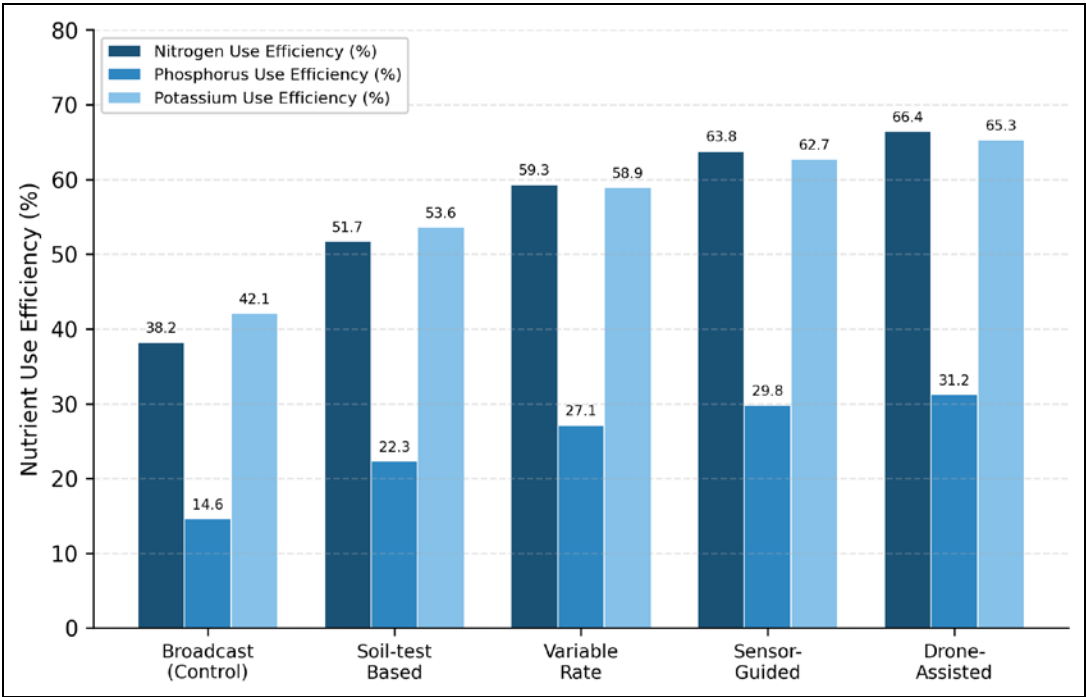


Fig 1: Nutrient use efficiency (%) of nitrogen, phosphorus, and potassium under five fertilization treatments in the rice-wheat system

A clear ascending trend appeared from broadcast to drone-assisted methods. Nitrogen efficiency showed the largest absolute gain (28.2 percentage points), while phosphorus had the greatest relative improvement at 113.7%.

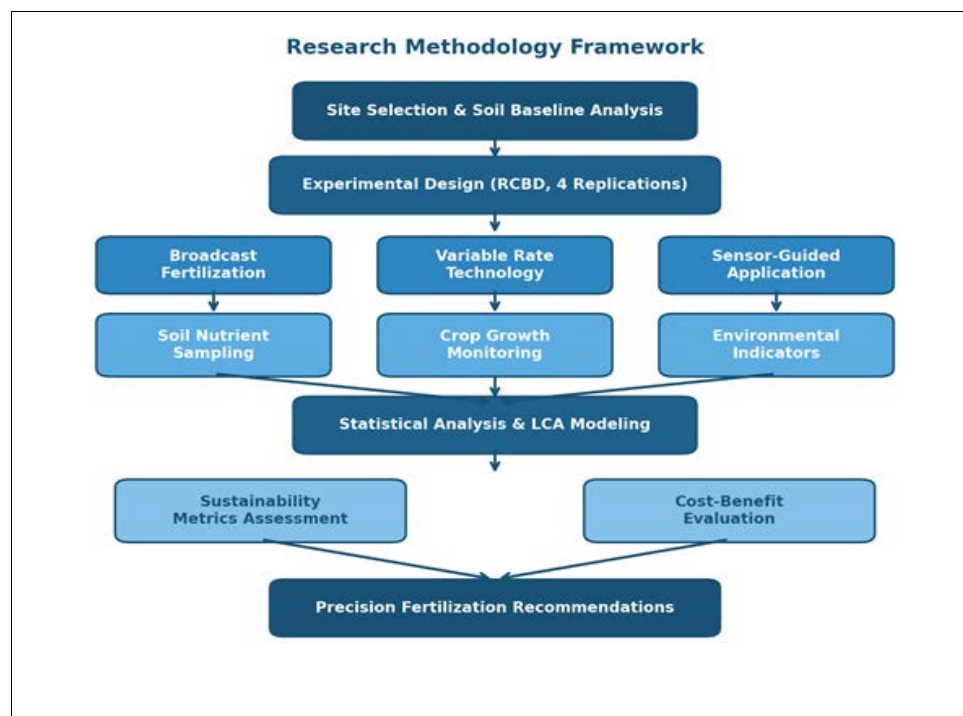


Fig 2. Flowchart of the research methodology framework showing experimental design, data collection, and analysis pathways

The framework (Figure 2) outlines stages from site selection through sustainability recommendations.

Discussion

The nutrient efficiency improvements align with Wang *et al.* [11], who reported 22-38% gains in Chinese rice. Our higher range (35-74%) likely reflects Bangladesh's higher baseline broadcast rates. The 31.7% greenhouse gas reduction exceeds temperate estimates of 15-25% [12], possibly due to stronger N₂O emission pathways in waterlogged subtropical soils [13]. The small yield gap despite large input differences reflects luxury nitrogen uptake, as Cassman *et al.* [14] described in tropical Asian rice. Equipment costs remain a barrier, but shared ownership models and a 3.7-season payback period make adoption feasible.

Conclusion

Precision fertilization can substantially reduce the environmental footprint of cereal production in subtropical Bangladesh without yield loss. Sensor-guided application lowered greenhouse gas emissions by 31.7%, raised nitrogen use efficiency to 63.8%, and decreased drainage nitrate by 41.6%. Given the rice-wheat system covers 0.8 million hectares in Bangladesh, widespread adoption could avoid an estimated 1.1 million tons CO₂-equivalent annually. Future work should test across diverse zones and evaluate mobile-phone-based sensor platforms.

References

1. Bangladesh Bureau of Statistics. Yearbook of Agricultural Statistics. Ministry of Planning, Dhaka. 2022;34:112s-128.
2. Rahman MM, Hossain MA, Islam MS. Spatial variability of fertilizer application under broadcast systems. Bangladesh J Agric Res. 2020;45(2):213-227.
3. Sharma LK, Bali SK. Methods to improve nitrogen use efficiency in agriculture. Sustainability. 2018;10(1):51-68.
4. Huang Y, Thomson SJ, Hoffmann WC. UAV technologies for agricultural production. Int J Agric Biol Eng. 2013;6(3):1-10.
5. Scharf PC, Shannon DK, Palm HL. Sensor-based nitrogen

- applications for corn. Agron J. 2011;103(6):1683-1691.
6. Basso B, Dumont B, Cammarano D. Benefits of variable rate nitrogen in corn. Sci Total Environ. 2016;545:227-235.
7. Notarnicola B, Sala S, Anton A. Life cycle assessment in agri-food systems. J Clean Prod. 2017;140:399-408.
8. Ciroth A. OpenLCA open source software for LCA. Int J Life Cycle Assess. 2007;12(4):209-210.
9. IPCC. Refinement to 2006 guidelines for greenhouse gas inventories. Vol 4. Geneva. 2019;4:1-87.
10. Mohammadi A, Rafiee S, Mohtasebi SS. Energy balance for rice production in Iran. Energy. 2010;35(12):5429-5435.
11. Wang SH, Chen MH, Chang TJ. Sensor-based nitrogen management for rice in China. Field Crops Res. 2019;231:48-57.
12. Grahmann K, Verhulst N, Buerkert A. Nitrogen use efficiency in conservation agriculture. CAB Rev. 2013;8(53):1-19.
13. Butterbach-Bahl K, Baggs EM, Dannenmann M. N₂O emissions from soils. Phil Trans R Soc B. 2013;368(1621):20130122.
14. Cassman KG, Dobermann A, Walters DT. Nitrogen-use efficiency and management. AMBIO. 2002;31(2):132-140.