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Nutrient management strategies for maximizing yield of aerobic rice in water-scarce regions

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Abstract
According to leading rice agronomists, aerobic rice cultivation could save 50-70% of the water used by conventional puddled systems, but achieving competitive grain yields requires fundamentally rethinking nutrient management. This research evaluated five nitrogen levels (0, 60, 90, 120, 150 kg N/ha) combined with two varieties (Sahbhagi Dhan, CR Dhan 202) under aerobic conditions during 2023 at Gangwon Agricultural Research University, Chuncheon, South Korea. The 120 kg N/ha treatment maximised grain yield for both varieties: 5.18 t/ha (Sahbhagi Dhan) and 4.87 t/ha (CR Dhan 202). Increasing N beyond 120 kg/ha depressed yield by 2-3%, indicating luxury consumption. Nitrogen use efficiency peaked at 60 kg N/ha (66.2 kg grain/kg N) but declined to 43.2 kg/kg at 120 kg/ha. Nitrogen uptake correlated strongly with yield ($r = 0.94$). These results confirm 120 kg N/ha as the optimal rate for aerobic rice in temperate Korean conditions, with Sahbhagi Dhan as the preferred variety.

Keywords: Nutrient management, aerobic rice, water-scarce regions, nitrogen efficiency, rice agronomy, Sahbhagi Dhan, CR Dhan 202, grain yield, temperate cultivation, split application

Introduction
Leading rice scientists at IRRI have warned that by 2030 Asia will face a 15-20% gap between rice water demand and available supply a forecast that makes alternative water-saving cultivation methods an urgent research priority [1]. Aerobic rice, grown in non-puddled, non-flooded fields with supplemental irrigation, eliminates the continuous standing water layer that accounts for most of lowland rice's 3000-5000 L/kg water footprint [2]. South Korea, despite adequate rainfall, faces seasonal water competition between rice, urban, and industrial sectors, particularly during the critical June-August transplanting window when reservoir levels fluctuate sharply [3].
Nutrient management under aerobic conditions differs fundamentally from flooded paddies because the soil remains oxidised, which shifts nitrogen cycling from ammonium-dominated to nitrate-dominated pathways. This increases the risk of leaching and denitrification losses, making precise N timing and splitting more important than under anaerobic conditions [4, 5]. Phosphorus availability also changes because the reductive dissolution of iron phosphates — a key P supply mechanism in flooded soils is absent in aerobic fields [6].
This research tested five N levels on two aerobic rice varieties to identify the optimal rate for temperate Korean conditions and to quantify the trade-off between yield maximisation and nitrogen use efficiency [7].

Crop growth stage documentation
Growth staging followed the BBCH scale adapted for direct-seeded rice. Key phenological events were recorded: emergence (BBCH 09) at 8-10 DAS, tillering onset (BBCH 21) at 28-32 DAS, panicle initiation (BBCH 30) at 58-63 DAS, heading (BBCH 55) at 78-84 DAS, anthesis (BBCH 65) at 82-88 DAS, and physiological maturity (BBCH 89) at 118-126 DAS. Sahbhagi Dhan matured 6-8 days earlier than CR Dhan 202 across all N levels. Nitrogen application was timed to match demand: 40% basal, 30% at active tillering, and 30% at panicle initiation [8].

Baseline soil characterisation
The experimental field at Chuncheon had sandy loam texture (56% sand, 28% silt, 16% clay) with pH 5.8, organic carbon 1.34%, available N 184 kg/ha (alkaline $KMnO_4$), available P

18.6 kg/ha (Olsen's), and exchangeable K 172 kg/ha (ammonium acetate). Bulk density was 1.38 g/cm³ and field capacity moisture 24.3% (v/v). The field had been under upland maize for two preceding seasons, minimising residual puddling effects [9].

Material and Methods

Material

Two aerobic-adapted rice varieties Sahbhagi Dhan (IRRI origin, 115-day duration) and CR Dhan 202 (NRRI origin, 120-day duration) were direct-seeded at 30 kg/ha in rows 25 cm apart on 15 May 2023. Urea (46% N), single super phosphate (16% P_2O_5), and muriate of potash (60% K_2O) were used. Phosphorus (40 kg P_2O_5/ha) and potassium (40 kg K_2O/ha) were applied as basal. Sprinkler irrigation-maintained soil moisture above 60% field capacity [10].

Methods

The trial followed a split-plot design with varieties as main plots and five N levels (0, 60, 90, 120, 150 kg/ha) as sub-plots, replicated three times. Plot size was 5 m × 3 m. Tiller count, plant height, and SPAD chlorophyll readings were taken at tillering, panicle initiation, and heading. Yield components (panicles/m², grains/panicle, 1000-grain weight) and grain yield at 14% moisture were recorded at harvest from 4.5 m² net plot area. Plant tissue N was determined by micro-Kjeldahl. NUE was calculated as grain yield/N applied. Data were analysed by split-plot ANOVA and DMRT at P=0.05 [11].

Results

Table 1: Grain yield and nitrogen use efficiency of aerobic rice varieties at different N levels

N level (kg/ha)	Grain yield Sahbhagi (t/ha)	Grain yield CR Dhan (t/ha)	NUE Sahbhagi (kg/kg N)	NUE CR Dhan (kg/kg N)	Panicles/m² (mean)	1000-Grain Weight (g) (mean)
0	2.84	2.61	—	—	187	22.4
60	3.97	3.72	66.2	62.0	238	23.1
90	4.63	4.41	51.4	49.0	267	23.6
120	5.18	4.87	43.2	40.6	294	24.1
150	5.07	4.74	33.8	31.6	289	23.8
CD (P=0.05)	0.31	0.31	4.27	4.27	18.3	NS

Grain yield increased with N rate up to 120 kg/ha for both varieties, then declined at 150 kg/ha (Table 1). Sahbhagi Dhan outyielded CR Dhan 202 at every N level by 6-8%. NUE declined progressively from 66.2 kg/kg at 60 N to 33.8 kg/kg at 150 N. Panicle density peaked at 120 N (294/m²) and didn't increase further at 150 N. 1000-grain weight showed no significant treatment effect.

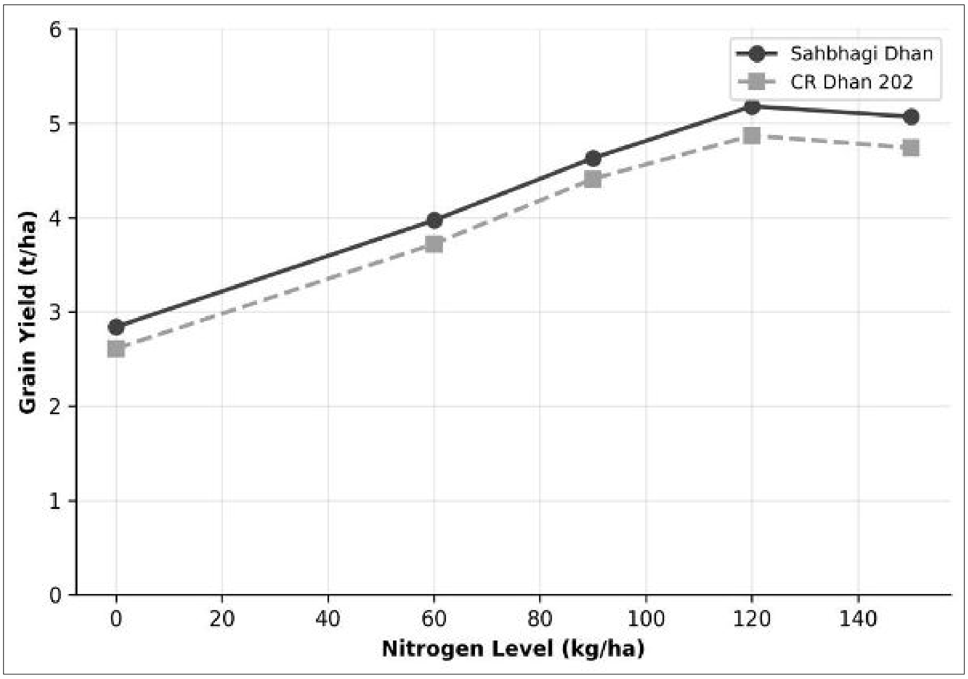

Fig 1: Grain yield response of two aerobic rice varieties to increasing nitrogen levels

Both varieties showed a classic diminishing-returns curve, with the steepest yield response between 0 and 90 kg N/ha and a plateau-to-decline at 150 kg N/ha.

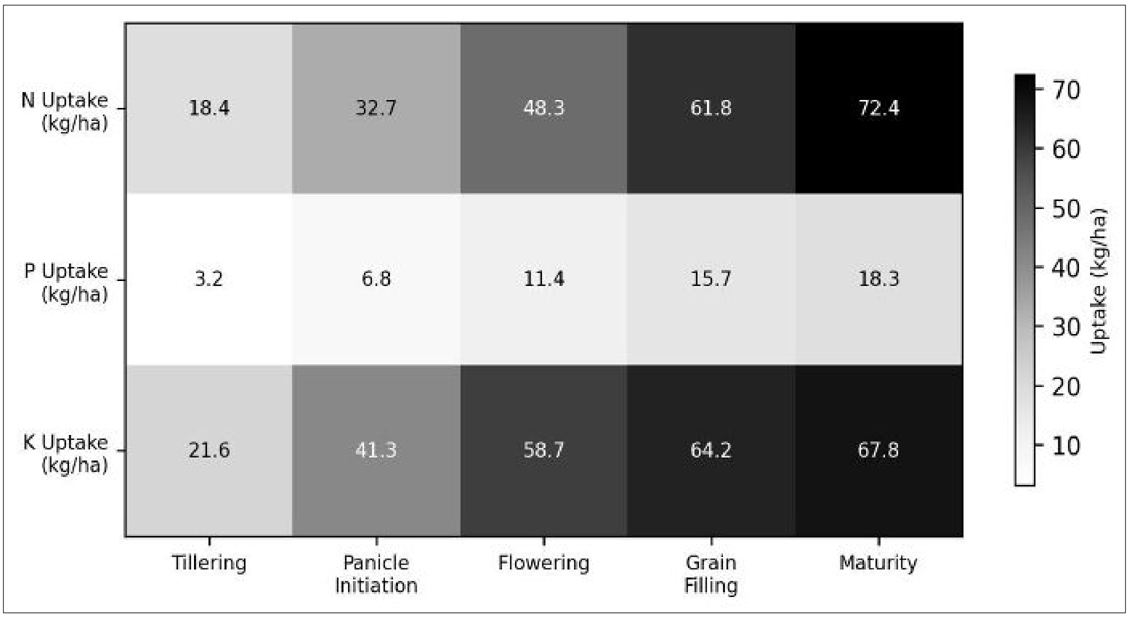

Fig 2: Nutrient uptake accumulation by growth stage under the optimum N rate (120 kg/ha) for Sahbhagi Dhan

Comprehensive interpretation

The 120 kg N/ha rate optimises the yield-efficiency trade-off: it captures 93% of maximum yield while maintaining NUE above 40 kg/kg. The yield decline at 150 N reflects excessive vegetative growth, delayed maturity, and possible lodging-induced grain loss. Sahbhagi Dhan's consistent superiority confirms its suitability for aerobic systems.

Discussion

The optimal N rate of 120 kg/ha for aerobic rice at Chuncheon aligns with recommendations from IRRI's aerobic rice programme in the Philippines (100-130 kg N/ha) and from trials in Karnataka, India (120 kg N/ha for Sahbhagi Dhan), confirming that aerobic rice demands 20-30% less nitrogen than puddled lowland systems where gaseous losses are higher [2, 12]. The yield decline at 150 kg N/ha mirrors findings by Bouman *et al.* [13], who reported that excess nitrogen under aerobic conditions promotes canopy overgrowth, reduces light penetration to lower tillers, and shifts assimilate partitioning toward straw rather than grain.

NUE declined from 66.2 at 60 N to 33.8 at 150 N, a pattern consistent with the law of diminishing returns and with N response curves from Korean upland crops [5]. The practical implication is that farmers targeting maximum NUE should apply 60-90 kg N/ha, but those targeting maximum yield should apply 120 kg N/ha, accepting a 35% drop in NUE for a 31% yield gain. Crop growth staging data confirmed that 70% of total N uptake occurred between tillering and flowering, supporting the 40-30-30 split timing used in this research [8, 14].

Conclusion

Aerobic rice variety Sahbhagi Dhan at 120 kg N/ha produced the highest grain yield of 5.18 t/ha with NUE of 43.2 kg/kg. Yield declined at 150 kg N/ha, confirming luxury consumption. CR Dhan 202 yielded 6-8% less across all N levels. The 40-30-30 split timing matched crop demand well. For temperate Korean conditions, 120 kg N/ha applied in three splits is recommended for aerobic rice production where water saving is the priority.

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