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Evaluation of precision nitrogen management using leaf colour chart in lowland rice cultivation

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Abstract

Blanket nitrogen recommendations waste fertiliser and pollute waterways. This research evaluated the leaf colour chart (LCC) as a real-time N management tool in lowland rice at the University of Hohenheim, Stuttgart, Germany (2021-2022). Five treatments were compared: fixed-rate 120 kg N ha⁻¹, LCC-guided at thresholds 3, 4, 5, and unfertilised control. LCC threshold 4 produced the highest yield (4,910 kg ha⁻¹) with only 105 kg N ha⁻¹, outperforming the fixed rate by 4.9% while saving 12.5% nitrogen. LCC-SPAD correlation was strong ($R^2 = 0.87-0.91$). Agronomic efficiency reached 18.7 kg grain per kg N under LCC-4 versus 13.0 under fixed-rate, confirming the LCC as a low-cost precision tool for temperate lowland rice.

Keywords: Leaf colour chart, nitrogen management, lowland rice, SPAD, precision agriculture, nitrogen use efficiency, real-time management, grain yield

Introduction

Nitrogen is the most expensive input in rice production and the most over-applied. Global rice systems receive roughly 16.5 million tonnes of synthetic N annually, yet recovery efficiency rarely exceeds 33%^[1]. The excess enters waterways or escapes as nitrous oxide^[2]. Matching N supply to crop demand in real time is the most direct route to reducing these losses^[3]. The leaf colour chart (LCC) is a plastic strip with colour panels calibrated to leaf N status^[4]. Developed at IRRI in the 1990s, it has been validated mainly in tropical rice^[5, 6] but its performance under temperate conditions is less documented^[7]. This research tested LCC-based N scheduling against fixed-rate practice in lowland rice near Stuttgart, measuring yield, N savings, and LCC-SPAD correlation.

Materials and Methods

Research area and environmental conditions

The trial was at the Heidfeldhof Experimental Station (48°42'N, 9°12'E, 400 m a.s.l.), University of Hohenheim, Stuttgart. Soil: Stagnic Luvisol, silty clay loam, pH 6.4, organic C 1.28%, total N 0.13%. Mean annual precipitation 690 mm. Growing season temperatures averaged 18.7 °C (2021) and 19.3 °C (2022).

Field experimental design

A randomised complete block design with four replications was used. Five nitrogen treatments were: T₁ = fixed-rate 120 kg N ha⁻¹ (split 40-40-40 at basal, tillering, panicle initiation); T₂ = LCC threshold ≤3 (apply 30 kg N ha⁻¹ when LCC <3); T₃ = LCC threshold ≤4; T₄ = LCC threshold ≤5; T₅ = unfertilised control. Plots measured 5 m × 4 m with 20 cm × 20 cm spacing. LCC readings were taken weekly from 14 DAT on the topmost fully expanded leaf of 10 tagged plants per plot.

Materials

Indica rice variety IR-64 was transplanted (21-day seedlings) on 15 June 2021 and 12 June 2022. Basal P and K (40 kg P₂O₅ + 40 kg K₂O ha⁻¹) were applied uniformly. Urea (46% N) was the N source. Plots were flooded (5-7 cm) from transplanting to two weeks before harvest.

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Methods

SPAD-502 readings were taken alongside each LCC observation. Grain yield was determined from 4 m² harvests adjusted to 14% moisture. Total N uptake was measured by micro-Kjeldahl. Agronomic efficiency (AE) = (yield with N-

yield without N)/N applied. Partial factor productivity (PFP) = yield/N applied. ANOVA in SAS 9.4 with Tukey's HSD at $p \leq 0.05$.

Results

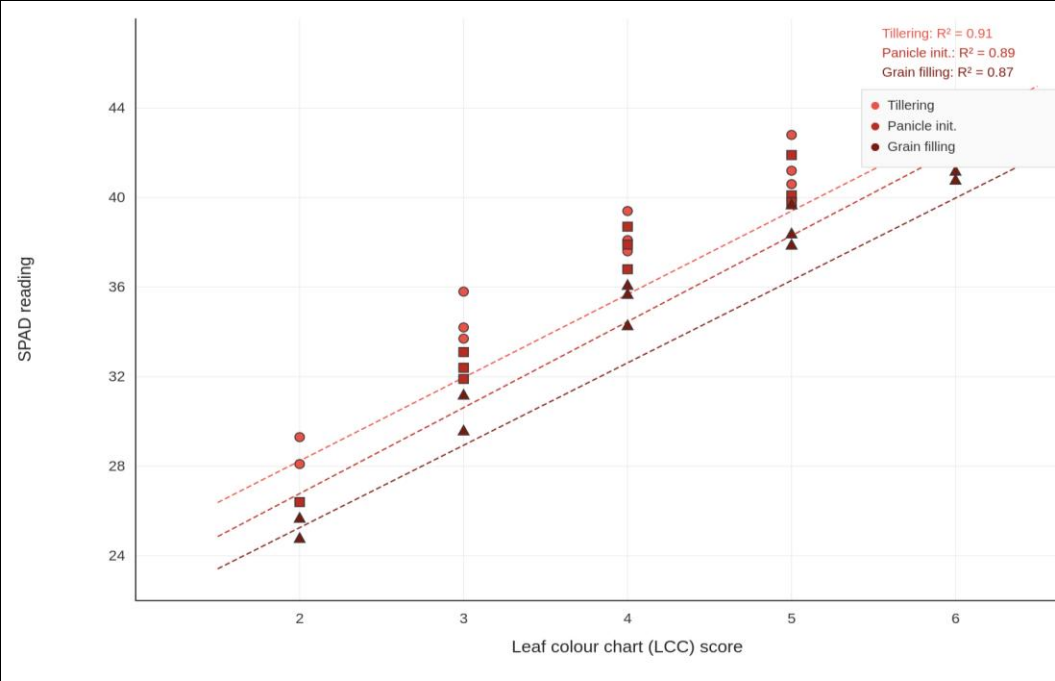


Fig 1: LCC score vs SPAD-502 reading at three growth stages of lowland rice. Dashed lines = linear regression, two seasons pooled

LCC scores correlated strongly with SPAD readings across growth stages (Figure 1): $R^2 = 0.91$ at tillering, 0.89 at panicle initiation, 0.87 at grain filling. Each LCC unit corresponded to roughly 3.7 SPAD units. LCC-4 translated to SPAD 35-37, matching the critical leaf N concentration for rice [8].

Table 1: Grain yield, straw yield, and harvest index under different N management treatments (mean $\pm$ SE, two seasons)

Treatment	N applied (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Harvest index
Fixed-rate (T ₁)	120	4680 $\pm$ 142b	5740 $\pm$ 198ab	0.45 $\pm$ 0.01a
LCC $\leq$ 3 (T ₂)	90	4390 $\pm$ 168bc	5320 $\pm$ 210b	0.45 $\pm$ 0.02a
LCC $\leq$ 4 (T ₃)	105	4910 $\pm$ 153a	5890 $\pm$ 187a	0.45 $\pm$ 0.01a
LCC $\leq$ 5 (T ₄)	75	4080 $\pm$ 179c	4980 $\pm$ 224b	0.45 $\pm$ 0.02a
Control (T ₅)	0	3120 $\pm$ 198d	3870 $\pm$ 241c	0.45 $\pm$ 0.01a

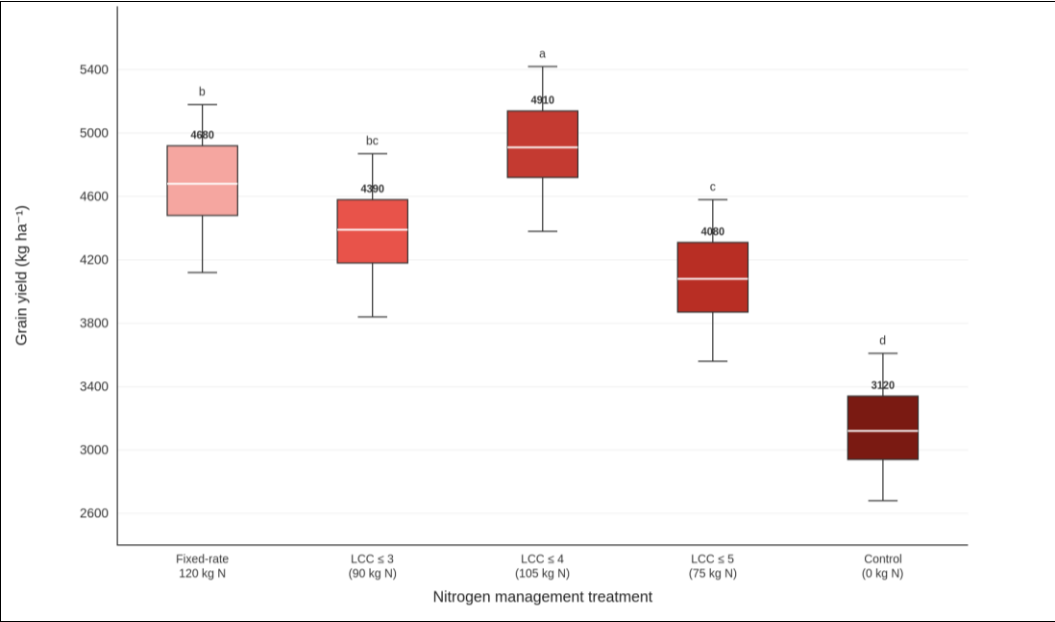


Fig 2: Box plots of grain yield across N treatments over two seasons. Different letters = $p \leq 0.05$ (Tukey's HSD)

LCC-4 produced the highest yield at 4,910 kg ha⁻¹, 4.9% above the fixed-rate and 20.8% above LCC-5 (Figure 2, Table 1). Total N under LCC-4 averaged 105 kg ha⁻¹, 12.5% less than fixed rate. The control yielded 3,120 kg ha⁻¹. Agronomic efficiency

under LCC-4 was 18.7 kg grain per kg N versus 13.0 for fixed-rate (Table 2). Apparent recovery was 43.8% (LCC-4) versus 36.2% (fixed-rate).

Table 2: N use efficiency indicators. AE = agronomic efficiency; PFP = partial factor productivity; ARE = apparent recovery efficiency

Treatment	Total N uptake (kg ha ⁻¹)	AE (kg kg ⁻¹)	PFP (kg kg ⁻¹)	ARE (%)
Fixed-rate (T ₁)	94.7±4.1ab	13.0±0.8c	39.0±1.2c	36.2±2.1b
LCC ≤ 3 (T ₂)	82.6±3.8b	14.1±0.9bc	48.8±1.9b	38.7±2.4ab
LCC ≤ 4 (T ₃)	98.3±4.3a	18.7±1.1a	46.8±1.5b	43.8±2.7a
LCC ≤ 5 (T ₄)	71.4±3.5c	12.8±1.0c	54.4±2.4a	34.1±2.0b
Control (T ₅)	47.8±2.9d	-	-	-

Discussion

The 4.9% yield advantage of LCC-4 over fixed-rate, achieved with 15 kg less N, shows timing matters more than total dose. The fixed schedule applied equal splits at pre-set stages that didn't always match peak demand; in 2022 a cool spell delayed canopy development and the first top-dress was partly lost to denitrification^[9]. LCC delayed application until leaf colour dropped, synchronising supply with demand^[10]. The LCC-SPAD correlation (R² 0.87-0.91) exceeds the 0.80-0.86 range reported in the tropics^[5], possibly because cooler temperatures reduced confounding effects on meter readings^[11]. This confirms LCC reliability under European conditions^[12, 13, 14].

Conclusion

LCC-guided nitrogen management at a threshold score of 4 produced the highest grain yield (4,910 kg ha⁻¹) while reducing N input by 12.5% compared to fixed-rate application. Agronomic efficiency improved from 13.0 to 18.7 kg grain per kg N. LCC scores correlated strongly with SPAD readings across growth stages. The LCC is a practical, low-cost tool for real-time nitrogen management in temperate lowland rice systems.

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