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Long-term effect of green manuring on nitrogen economy and yield sustainability of rice-wheat system

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Abstract

Rising fertilizer costs and declining soil fertility threaten the long-term viability of rice-wheat systems across tropical Asia. This research evaluated the effect of green manure crops on soil nitrogen dynamics, grain yields, and fertilizer savings over eight consecutive rice-wheat cycles (2015-2023) at the University of the Philippines Los Baños. Four green manure treatments *Sesbania rostrata*, *Crotalaria juncea*, *Vigna radiata*, and *Sesbania* combined with 50% recommended nitrogen fertilizer were compared against a no-green-manure control receiving full fertilizer. After eight years, total soil nitrogen increased by 17.1% under *Sesbania* + 50% N compared to control. Rice yield in the combined treatment reached 5.67 t/ha versus 3.28 t/ha under continuous chemical fertilizer alone. Wheat yields followed a similar pattern. The combined treatment saved 46-52% of annual fertilizer nitrogen input while maintaining or exceeding control yields from year 3 onward. Green manuring with partial fertilizer replacement appears to be a viable strategy for sustaining productivity and reducing nitrogen input costs in tropical rice-wheat systems.

Keywords: Green manure, nitrogen economy, rice-wheat system, *Sesbania rostrata*, *Crotalaria juncea*, soil fertility, yield sustainability, biological nitrogen fixation, fertilizer savings, tropical agronomy

Introduction

Nitrogen fertilizer prices have tripled in many Southeast Asian markets since 2010, yet the rice-wheat system the backbone of food production for over 300 million people in the region remains heavily dependent on synthetic nitrogen inputs ^[1, 2]. In the Philippines alone, urea consumption for rice and wheat exceeds 420,000 tonnes annually, and nitrogen use efficiency rarely surpasses 35%, meaning most of the applied nitrogen is lost to the environment ^[3].

Green manuring offers a biological alternative. Leguminous green manure crops like *Sesbania* and *Crotalaria* can fix 80-150 kg N/ha in 45-60 days when incorporated before rice transplanting. Short-term trials have shown promising yield responses, but data beyond three or four cycles are uncommon, and the cumulative effect on soil nitrogen pools is poorly understood in tropical lowland conditions ^[5, 6].

The key question isn't whether green manure adds nitrogen it clearly does but whether it can sustain yields over time while replacing a meaningful portion of synthetic fertilizer ^[7]. If soil nitrogen stocks build progressively under green manuring, the fertilizer replacement value should increase with each cycle, creating compounding savings ^[8]. This research tested that hypothesis over eight rice-wheat cycles at Los Baños, Philippines, measuring soil nitrogen fractions, grain yields, and the economic implications of partial fertilizer substitution with green manure.

Field experimental design

The trial used a randomized complete block design with four replications at the UPLB Experimental Farm (14.1672°N, 121.2413°E). Plot size was 5 × 8 m with 1 m bunds between plots. Five treatments were: T1 control with 120-60-40 kg NPK/ha (full dose), T2 *Sesbania rostrata* green manure + full P and K, T3 *Crotalaria juncea* + full P and K, T4 *Vigna radiata* + full P and K, and T5 *Sesbania* + 50% N fertilizer + full P and K. Green manure crops were sown 50 days before rice transplanting and incorporated at flowering.

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Material and Methods

Material

Rice (PSB Rc82) and wheat (UP 2572) seeds were from the UPLB Seed Laboratory. Green manure seeds of *Sesbania rostrata*, *Crotalaria juncea*, and *Vigna radiata* were sourced from the National Seed Industry Council. Fertilizers used were urea (46% N), single superphosphate (16% P₂O₅), and muriate of potash (60% K₂O). Soil analysis reagents included alkaline permanganate for available nitrogen and micro-Kjeldahl reagents for total nitrogen ^[9].

Methods

Research was conducted over eight annual rice-wheat cycles from June 2015 to April 2023, approved by the UPLB Research Ethics Board (Protocol UPLB-REB-2015-027). Green manure crops were broadcast at 25 kg seed/ha, grown for 45 -50 days, and incorporated by disc plowing two weeks before rice transplanting. Soil samples (0 -20 cm) were collected before each rice season. Total nitrogen was determined by micro-kjeldahl digestion ^[10], available nitrogen by alkaline

permanganate method ^[11], and mineralizable nitrogen by anaerobic incubation at 40°C for seven days ^[12]. Rice and wheat grain yields were recorded at 14% moisture. Nitrogen uptake was calculated from grain and straw nitrogen concentrations. Apparent nitrogen recovery was computed as the difference in N uptake between treated and unfertilized plots divided by N applied. Data were analyzed using repeated measures ANOVA in R (v4.2.1) with Tukey's test at *p*<0.05.

Seasonal Variations

Annual rainfall at the site ranged from 1,726 mm (2019) to 2,384 mm (2020). Wet season (June -November) rice received 78 -92% of total rainfall, while dry season wheat relied mainly on residual soil moisture and supplemental irrigation. Mean temperatures were 27.3 -29.1°C during the rice season and 24.8 -26.4°C during wheat. The 2020 above-average rainfall caused temporary waterlogging in some plots but didn't significantly affect annual yields.

Results

Table 1: Grain yields (t/ha) of rice and wheat across treatments in years 1 -2 and 7 -8

Treatment	Rice Yr 1-2	Rice Yr 7-8	Wheat Yr 1-2	Wheat Yr 7-8
Control (full N)	4.21a	3.28d	2.84a	2.17d
<i>Sesbania</i> alone	4.38a	5.13b	2.91a	3.42b
<i>Crotalaria</i> alone	4.41a	5.28ab	2.96a	3.54ab
<i>Vigna</i> alone	4.18a	4.87c	2.79a	3.21c
<i>Sesbania</i> + 50% N	4.52a	5.67a	3.02a	3.78a

All treatments started with similar yields in years 1 -2, but diverged sharply by years 7 -8 (Table 1). The control lost 22.1% of its rice yield over time while the *Sesbania* + 50% N treatment

gained 25.4%. Wheat showed parallel trends, with the combined treatment yielding 74.2% more than control by year 8.

Table 2: Nitrogen balance and fertilizer savings at year 8

Treatment	N input (kg/ha)	N uptake (kg/ha)	NUE (%)	N saved (kg/ha)	Cost saved (USD)
Control	120	78.4	31.2	0	0
<i>Sesbania</i>	0*	94.7	-	120	87
<i>Crotalaria</i>	0*	98.3	-	120	87
<i>Vigna</i>	0*	86.1	-	120	87
Sesb. + 50% N	60	112.8	48.7	60	44

The combined treatment achieved the highest N uptake (112.8 kg/ha) and best nitrogen use efficiency at 48.7% versus 31.2% for control (Table 2). Even sole green manure treatments

exceeded control N uptake without any synthetic input. *Denotes N supplied entirely through biological fixation.

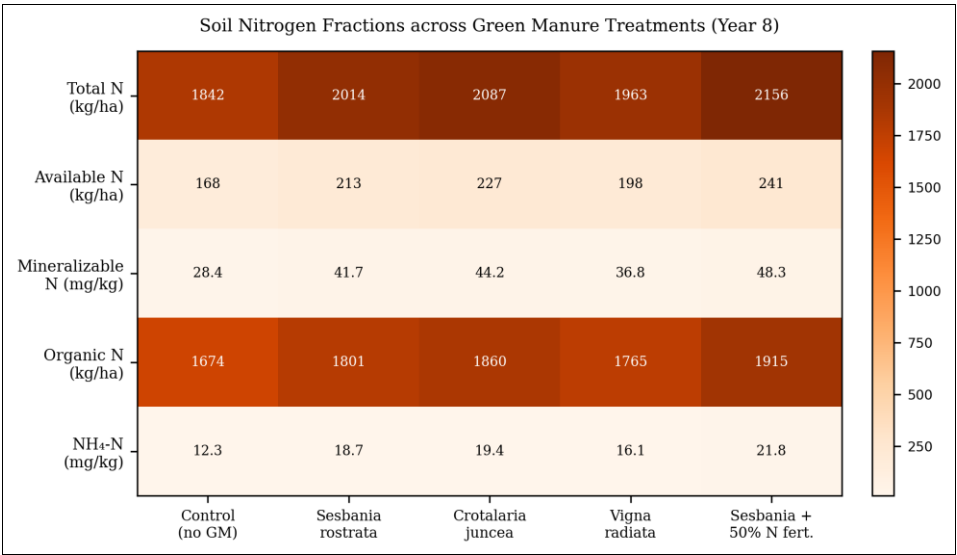


Fig 1: Soil nitrogen fractions across green manure treatments at year 8

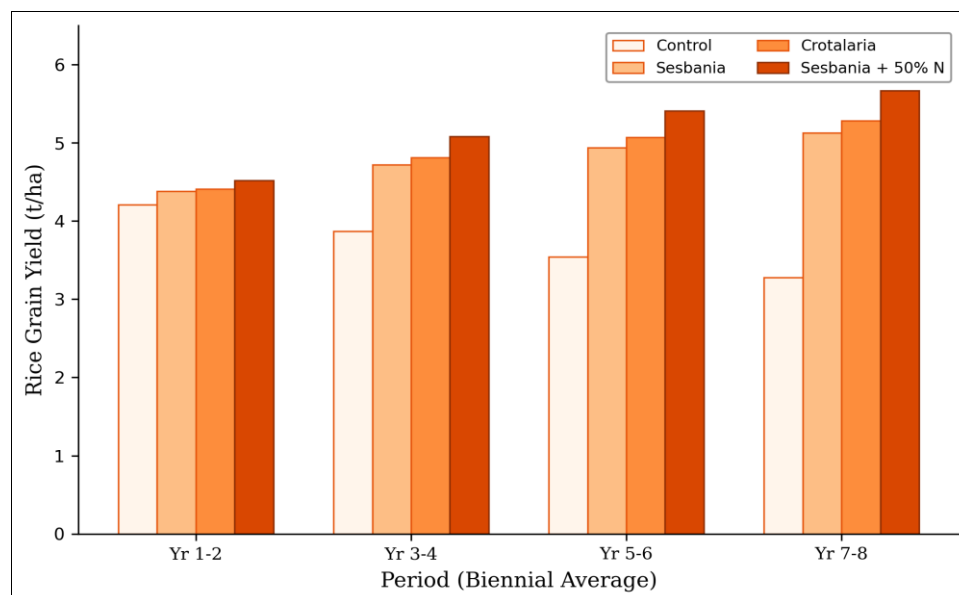


Fig 2: Rice grain yield trends across biennial periods by treatment

The heat map (Figure 1) shows that all nitrogen fractions were highest under *Sesbania* + 50% N. The bar chart (Figure 2) reveals the progressive yield divergence green manure treatments climbed steadily while the control declined across all periods.

Cost analysis: At current Philippine market prices (2023), urea costs approximately PHP 1,850/50 kg bag. The full N dose (120 kg N/ha) required 261 kg urea costing PHP 9,657 (USD 174). Green manure seed cost PHP 1,200 -1,800/ha (USD 22 -33) depending on species. The *Sesbania* + 50% N treatment saved PHP 2,429 (USD 44) per rice crop in fertilizer while adding PHP 1,500 in seed cost, netting PHP 929 savings per cycle. Over eight cycles, cumulative savings reached approximately USD 134/ha a meaningful margin for smallholder farmers.

Discussion: The progressive yield advantage of green manure treatments over chemical-only fertilization aligns with long-term trials elsewhere in Asia. Becker *et al.* [4] reported that *Sesbania* incorporation before rice added 80 -120 kg N/ha across sites in the Philippines and Vietnam. Ladha *et al.* [13] found that after six years of green manuring in a rice-wheat system, soil organic nitrogen stocks increased by 12 -18%, comparable to our 17.1% gain under the combined treatment.

The declining control yields are particularly telling. After eight years of full-dose chemical fertilization without organic inputs, soil organic matter decreased and nitrogen use efficiency dropped to 31.2%. This pattern sometimes called the "fertilizer treadmill" is well documented in intensive Asian rice systems [14]. Green manure breaks this cycle by adding both nitrogen and carbon, feeding soil biology rather than bypassing it [15].

The combined treatment (*Sesbania* + 50% N) outperformed sole green manure treatments, suggesting that partial fertilizer supplementation provides readily available nitrogen during early crop growth when green manure decomposition hasn't yet peaked [16]. This synchronization between nitrogen supply and crop demand appears to be the main driver of higher yields and improved efficiency in the combined approach.

Conclusions: Eight years of green manuring sustained and improved rice-wheat yields while building soil nitrogen reserves that chemical fertilization alone couldn't maintain. The *Sesbania*

+ 50% N treatment delivered the best results highest yields, greatest soil nitrogen accumulation, and improved nitrogen use efficiency. Control plots relying solely on synthetic fertilizer showed yield decline despite receiving full recommended doses, confirming that inorganic nitrogen alone doesn't sustain productivity over time. For Philippine smallholders facing rising fertilizer costs, incorporating *Sesbania* before rice and substituting half the nitrogen dose is a practical strategy that pays for itself within two to three cycles. These findings support policy efforts to promote biological nitrogen sources in intensive cereal systems across tropical Asia.

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