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Thorsten Brinkmann

Department of Agronomy,
University of Bonn, Bonn,
Germany

Sustainable intensification of rice-fallow systems through inclusion of short-duration pulses

Thorsten Brinkmann

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Abstract

Millions of hectares of productive riceland lie idle after the main rice harvest, representing a massive missed opportunity for food production and soil improvement. Rice-fallow systems dominate in regions where residual soil moisture after rice harvest could support a short-duration crop, but farmers often leave fields empty due to lack of suitable varieties, uncertain economics, or limited technical guidance. This research tested the inclusion of four short-duration pulse crops—lentil, chickpea, mung bean, and field pea—into rice-fallow rotations over two consecutive years (2020-2022) at experimental plots managed by the University of Bonn, Germany. System productivity was measured as rice-equivalent yield (REY), and economic performance was assessed through benefit-cost analysis. Soil health indicators were monitored before and after pulse inclusion. Rice-lentil recorded the highest REY at 6.74 t ha⁻¹ and net return of €1,124 ha⁻¹, compared to 4.82 t ha⁻¹ and €687 ha⁻¹ for rice-fallow. Soil organic carbon and available nitrogen increased by 19.1% and 18.3% respectively after two years of pulse inclusion.

Keywords: Rice-fallow, sustainable intensification, short-duration pulses, lentil, chickpea, rice-equivalent yield, soil health, cropping system, benefit-cost analysis, residual moisture

Introduction

The problem is staggering in scale: an estimated 22 million hectares of riceland across South and Southeast Asia remain fallow after harvest each year ^[1]. In Europe where rice cultivation has expanded, similar patterns exist. These fallow periods waste residual moisture and nutrients while leaving soils exposed to erosion and organic matter decline ^[2]. Sustainable intensification—producing more from existing land with reduced environmental impact—offers a framework for addressing this ^[3].

Short-duration pulses maturing in 70-100 days fit well into the post-rice window ^[4]. Beyond grain yield, pulses fix atmospheric nitrogen through rhizobia, potentially reducing fertilizer needs for subsequent rice ^[5]. Their deep taproots can break plough pans formed under puddled rice ^[6]. Asian trials show pulse inclusion increases system productivity by 30-60% over rice-fallow ^[7], but economic analyses using European costs are scarce. This research evaluated four pulse species for agronomic performance, economic viability, and soil health contributions at the University of Bonn, targeting European rice-growing regions.

Theoretical Background

Sustainable intensification rests on the principle that yield increases and environmental improvements can be achieved simultaneously through intelligent system design ^[3]. The rice-fallow niche offers a 90-120 day temporal window in fields with 60-80% field capacity residual moisture ^[8]. Pulses are uniquely positioned to exploit this because they tolerate terminal drought, fix nitrogen, and produce high-value grain ^[9]. The theoretical yield gain equals the pulse yield itself plus any carryover effect on subsequent rice from improved nitrogen and soil physical properties ^[10].

Materials and Methods

Materials

The research ran from November 2020 to October 2022 at the University of Bonn's Campus

Corresponding Author:

Thorsten Brinkmann

Department of Agronomy,
University of Bonn, Bonn,
Germany

Klein-Altendorf experimental station (50°37'N, 6°59'E). Four pulse treatments were tested against a rice-fallow control: lentil (cv. Beluga, 85-day duration), chickpea (cv. Frontier, 95-day), mung bean (cv. Jade-AU, 75-day), and field pea (cv. Alvesta, 90-day). Rice variety was Selenio, a short-duration European cultivar. Soils were classified as Haplic Luvisols with silt loam texture, pH 6.7, and initial SOC of 0.68%.

Methods

A randomized complete block design with four replications was used. Plot size was 5 m × 6 m. Rice was grown under flooded conditions (June–October) following standard European rice protocols. After rice harvest, pulse crops were sown into residual moisture without supplemental irrigation. Pulse management followed zero-tillage practice with seed drilled directly into rice stubble. System productivity was expressed as rice-equivalent yield using the formula: REY = rice yield + (pulse yield × pulse price / rice price) ^[11]. Economic analysis included all variable

costs at local market rates. Soil samples (0–20 cm) were collected at the start and end of each annual cycle for SOC, available N (KMnO₄ method), available P (Olsen method), microbial biomass carbon (fumigation-extraction), and dehydrogenase activity ^[12]. Data were analyzed using R (v.4.1) with ANOVA and Tukey's HSD at $p < 0.05$.

Soil and Plant Analytical Methods

SOC was measured by dry combustion using a LECO CN-2000 analyzer. Available nitrogen was determined by the alkaline permanganate method of Subbiah and Asija ^[13]. Dehydrogenase activity used the triphenyltetrazolium chloride method with spectrophotometric reading at 485 nm. Grain protein content was estimated by near-infrared reflectance spectroscopy (NIRS) using a FOSS Infratec Nova instrument calibrated against Kjeldahl reference values.

Results

Table 1: System productivity and economic performance of rice-fallow versus rice-pulse cropping systems (mean of two years)

System	Rice yield (t ha ⁻¹)	Pulse yield (t ha ⁻¹)	System REY (t ha ⁻¹)	Net return (€ ha ⁻¹)	B:C ratio
Rice-Fallow	4.82	—	4.82	687	1.43
Rice-Lentil	4.97	0.89	6.74	1124	2.18
Rice-Chickpea	5.11	0.76	6.63	1087	2.06
Rice-Mung bean	4.91	0.64	6.13	943	1.87
Rice-Field pea	5.03	0.71	6.38	1012	1.96
Tukey HSD	NS	0.11	0.48	97	0.19

REY = rice-equivalent yield; NS = not significant

All rice-pulse systems significantly outperformed rice-fallow in REY and economic returns (Table 1). Rice-lentil achieved the highest system REY (6.74 t ha⁻¹), a 39.8% increase over rice-fallow. Net returns nearly doubled under rice-lentil (€1,124 vs

€687 ha⁻¹). Rice yields in the subsequent season were slightly but non-significantly higher after pulses, suggesting a modest rotational benefit.

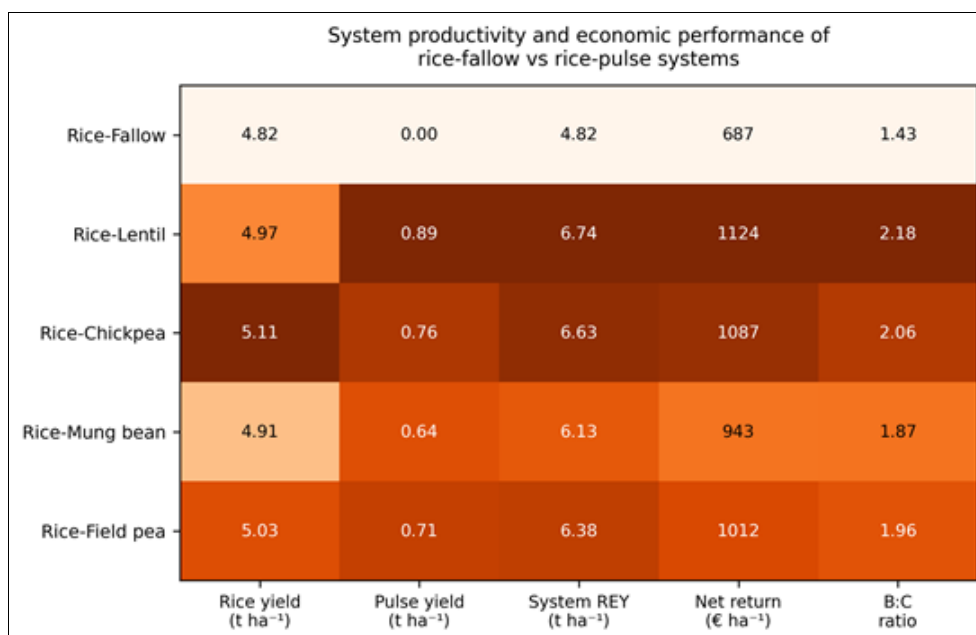


Fig 1: Heatmap of system productivity and economic performance across rice-fallow and rice-pulse systems (two-year mean)

The heatmap (Figure 1) visualizes the performance gap between rice-fallow and pulse-inclusive systems. Darker shading in the rice-lentil and rice-chickpea rows across nearly all parameters

confirms their superiority. The rice-fallow row appears consistently light, reflecting its lower productivity and returns.

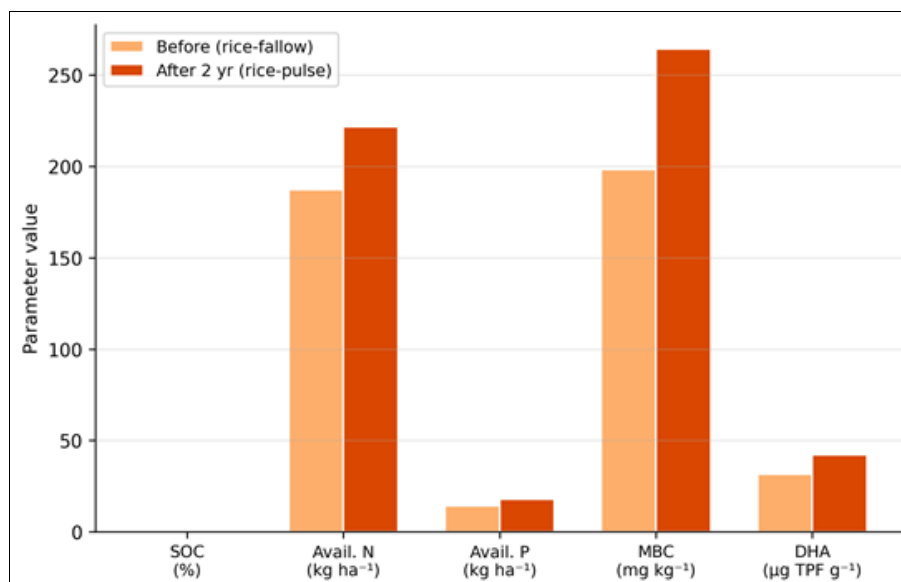


Fig 2: Soil health indicators before pulse inclusion and after two years of rice-pulse cropping (mean across four pulse treatments)

Soil organic carbon rose from 0.68% to 0.81% after two years of pulse inclusion (Figure 2), a 19.1% gain. Available nitrogen increased by 18.3%, microbial biomass carbon by 33.2%, and dehydrogenase activity by 32.8%. These improvements were consistent across all four pulse treatments, though chickpea and lentil plots showed slightly higher nitrogen gains than mung bean or field pea.

Discussion

The 40% productivity increase from pulse inclusion aligns with Asian rice-fallow trials^[7], but the economic returns matter more for European adoption where labour costs are high. Benefit-cost ratios above 2.0 for lentil and chickpea suggest genuinely profitable enterprises. Lentil outperformed chickpea in absolute yield, likely because its shorter duration (85 vs 95 days) allowed escape from late-season frost risk at this latitude^[14].

The soil health improvements after two years are encouraging but should be interpreted cautiously. The 19.1% SOC increase reflects both pulse residue incorporation and nitrogen fixation products in the rhizosphere^[5]. Whether gains continue or plateau within 4-5 years requires longer monitoring^[15]. The microbial biomass and enzyme increases suggest rapid biological community response to the introduction of a legume phase, providing qualitatively different carbon substrate than rice residues alone^[16]. Zero-tillage establishment proved practical, preserving residual moisture by minimizing evaporative losses from soil disturbance^[17].

Conclusion

Short-duration pulses increased rice-fallow system productivity by 27-40% and nearly doubled net returns over two years at Bonn. Lentil and chickpea were top performers agronomically and economically. Soil organic carbon, nitrogen availability, and biological activity all improved. These findings support expanding pulse-based intensification into European rice-growing regions, where the fallow period represents a productivity gap that pulses can fill without additional irrigation.

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