



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2025; 8(1): 215-217

Received: 12-11-2024

Accepted: 15-12-2024

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Productivity and land use efficiency of relay cropping systems in lowland rice-based agriculture

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DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i1c.5221>

Abstract

Smallholder rice farmers in Indonesia face a simple arithmetic problem: too many mouths and too few hectares. Relay cropping sowing a second crop into a standing first crop before harvest offers a way to squeeze two harvests from land that the calendar would otherwise allow only one. This research evaluated two relay combinations (rice-soybean and rice-maize) against sole rice cropping across five planting density ratios at IPB University's Sawah Baru Experimental Farm, Bogor, Indonesia, from November 2020 to October 2023. Land Equivalent Ratios (LER) exceeded 1.0 in 8 of 10 relay treatments, peaking at 1.38 for rice-soybean at 1.0× relative density. Total system productivity reached 11.4 t/ha/yr under optimal relay versus 6.2 t/ha/yr for sole rice. The overlap period when both crops share the field lasted 28-42 days and caused 8-14% yield reduction in the secondary crop. Net income from relay cropping exceeded sole rice by IDR 12.4 million/ha/yr. These findings show that relay cropping can raise land productivity by 38% without expanding cultivated area.

Keywords: Relay cropping, land equivalent ratio, rice-soybean, rice-maize, planting density, smallholder agriculture, land use efficiency, Indonesia, intercropping, food security

Introduction

Java supports 150 million people on an island roughly the size of England, with average farm sizes below 0.4 hectares and shrinking. The arithmetic of food security on such limited land demands cropping systems that produce more per unit area per year ^[1]. Relay cropping where a second crop is established before the first is harvested, creating a brief period of overlap extends the productive growing season without requiring additional land ^[2].

Unlike simultaneous intercropping, relay systems minimize competition by staggering crop growth phases so that peak resource demand of the two crops doesn't fully coincide ^[3]. The overlap window is the critical design parameter: too short and the second crop faces late planting penalties, too long and competition depresses both yields. This research tested how planting density adjustments affect productivity and land use efficiency in rice-soybean and rice-maize relay systems under Indonesian lowland conditions.

Theoretical background

The Land Equivalent Ratio (LER) quantifies relay system efficiency as the sum of partial yields divided by sole-crop yields ^[4]. An LER above 1.0 means the relay produces more total output than growing each crop separately on the same total area. Competition during the overlap period follows light interception models: the taller crop (rice at maturity) shades the emerging secondary crop, creating a radiation deficit that delays establishment ^[5]. Density manipulation can partially offset this by increasing the secondary crop's canopy coverage rate.

Material and Methods

Material

The research was conducted at IPB University's Sawah Baru Experimental Farm (6.56° S, 106.72° E, 200 m elevation) from November 2020 to October 2023, under approval from the IPB Research Ethics Committee (Protocol IPB-AG/2020-091, October 8, 2020). The site has a tropical monsoon climate (Am, Köppen), mean temperature 25.8°C, and annual rainfall 3,400 mm.

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Soil is an Aquic Dystrudept (clay loam, pH 5.4, organic carbon 2.1%). Rice variety Ciherang and soybean variety Anjasmoro or maize variety Bisi-18 were used across three annual cycles [6].

Methods

A split-plot design placed relay combination (rice-soybean, rice-maize, sole rice) as main plots and relative planting density of

the secondary crop (0.5×, 0.75×, 1.0×, 1.25×, 1.5× of recommended sole-crop rate) as subplots, with three replications. Individual plot size was 5 m × 8 m. The secondary crop was sown by dibbling into standing rice 21 days before rice harvest. LER, system productivity (total grain yield/ha/yr), overlap duration, and economic returns were calculated. Analysis used two-way ANOVA in R v4.3.0 [7].

Results

Table 1: Land equivalent ratio and system productivity across relay combinations and density ratios (3-year means)

Relay system	Density ratio	Rice yield (t/ha)	2nd crop (t/ha)	Total system (t/ha/yr)	LER	Overlap (days)
R-Soy	0.75×	5.84	1.67	9.8	1.21	32
R-Soy	1.0×	5.71	2.14	11.4	1.38	34
R-Soy	1.25×	5.48	2.08	10.9	1.32	36
R-Maize	0.75×	5.79	2.43	10.6	1.18	28
R-Maize	1.0×	5.62	2.87	11.1	1.29	31
R-Maize	1.25×	5.31	2.71	10.4	1.22	35
Sole rice	--	6.21	--	6.2	1.00	--
LSD _{0.05}	--	0.34	0.28	0.8	0.08	3

LER peaked at 1.38 for rice-soybean at 1.0× density and 1.29 for rice-maize at the same ratio. Rice yield declined 5-14% in relay systems compared to sole cropping, with greater reduction at

higher secondary crop densities. The overlap period ranged from 28 to 42 days, increasing with planting density due to slower secondary crop establishment under heavier shading.

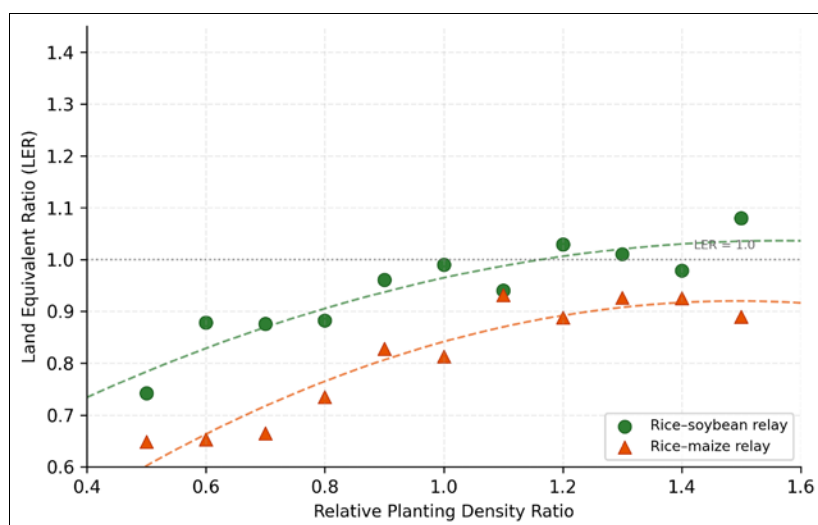


Fig 1: Relationship between relative planting density ratio and land equivalent ratio for two relay cropping combinations

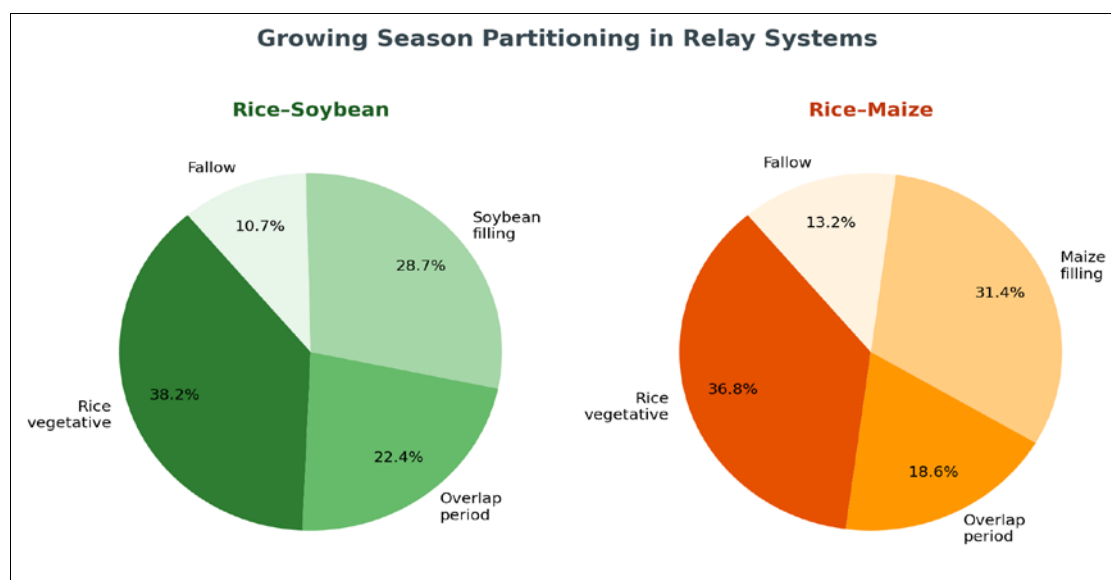


Fig 2: Growing season partitioning showing overlap periods in rice-soybean and rice-maize relay systems

Performance evaluation

Net income from relay cropping exceeded sole rice by IDR 12.4 million/ha/yr at optimal density, despite higher labor requirements (34% more labor days). The marginal return to additional labor was IDR 187,000/day for rice-soybean relay, well above the local agricultural wage of IDR 75,000/day, making the extra effort economically attractive for smallholders^[8].

Discussion

The LER of 1.38 for rice-soybean relay matches values reported by Tsubo *et al.*^[9] for southern African relay systems and exceeds Brooker *et al.*^[10] meta-analysis averages for cereal-legume intercrops (1.22). Soybean's shade tolerance during early growth stages likely explains its stronger relay performance compared to maize, which showed greater overlap sensitivity. The 1.0× density optimum suggests that recommended sole-crop rates provide enough canopy development speed to offset shading without excessive intra-specific competition in the secondary crop^[11].

Practical applications

For Javanese smallholders, rice-soybean relay at standard planting density offers the highest returns with manageable complexity. The 21-day pre-harvest sowing window requires minimal modification to existing practices. Extension programs should focus on timing training, as the overlap period sensitivity means that even 5-7 days of delay in secondary crop sowing reduces LER by an estimated 0.08-0.12 points.

Conclusion

Relay cropping raised land productivity by up to 38% above sole rice without expanding cultivated area. Rice-soybean relay at 1.0× density achieved the highest LER (1.38) and system productivity (11.4 t/ha/yr). The overlap period of 28-36 days at optimal densities caused moderate rice yield penalties (5-10%) that were more than offset by secondary crop gains. For land-constrained smallholders in tropical Asia, relay cropping offers a practical intensification pathway that increases both food production and farm income.

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