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Effect of intercropping systems on productivity, profitability and land equivalent ratio of pulses

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Abstract
Surprising fact: a hectare planted with cereal and legume intercropped together can, under the right row arrangement, out-produce two separate hectares each growing the crops alone by more than 40%, at least according to the land equivalent ratio data this two-season research recorded around Yamoussoukro. Four cropping arrangements, sole cereal, sole legume (cowpea), 1:1 row-replacement intercrop, and 2:1 row-replacement intercrop, were compared for yield, land equivalent ratio (LER), and net profitability. The 2:1 intercrop arrangement (two cereal rows to one legume row) produced the highest LER at 1.42, meaning 42% more land would be needed under sole cropping to match the combined output achieved on the same area under this intercrop arrangement. Net profitability followed a similar ranking, with the 2:1 intercrop generating 31% higher net return per hectare than sole cereal cropping, driven by the combined value of cereal grain, legume grain, and reduced fertilizer requirement from the legume's nitrogen contribution. The 1:1 arrangement produced a slightly lower LER of 1.35 but showed the most balanced grain output between the two component crops, relevant for farming households prioritizing dietary diversity from their own harvest over pure profitability. These findings support row-replacement intercropping, and the 2:1 arrangement specifically where cereal grain commands the stronger market value, as a productivity- and profitability-positive alternative to sole cropping for pulse-cereal systems in this region.

Keywords: Intercropping, land equivalent ratio, pulses, cowpea, cereal-legume systems, cropping systems, profitability, row arrangement, yield advantage, nitrogen contribution

Introduction
A hectare of land does not care whether it grows one crop or two, but the plants sharing that hectare very much care about what else is competing with them for light, water, and nutrients at any given moment, and intercropping's productivity case rests entirely on whether cereal and legume components can be arranged to minimize that competition while each still captures resources the other leaves unused [1, 2]. Land Equivalent Ratio has become the standard metric for quantifying this productivity advantage, expressing intercrop yield as a multiple of the sole-cropped land area that would be needed to match the same combined output, with values above 1.0 indicating a genuine land-use efficiency gain from growing the two crops together rather than separately [3].
Row arrangement, how many rows of each component crop are planted in what sequence, strongly influences how much of any potential intercropping advantage is actually realized, since arrangement determines both the degree of inter-species competition and how effectively each species accesses light and below-ground resources across the growing season [4, 5]. Cereal-legume intercropping specifically benefits from an additional mechanism beyond simple resource partitioning: the legume component's nitrogen fixation can supply some nitrogen benefit to the neighboring cereal, either directly through root exudation and turnover or indirectly by reducing the legume's own draw on soil nitrogen that would otherwise compete with the cereal [6, 7].
Profitability comparisons across intercropping arrangements receive somewhat less research attention than LER alone, despite profitability being the metric that most directly drives farmer adoption decisions, and the two metrics do not always align perfectly, since an

arrangement with the highest LER is not automatically the one with the highest net return once relative crop prices and input cost differences are factored into the comparison [8, 9].

This research set out to compare sole cropping against two row-replacement intercrop arrangements directly, assessing yield, LER, and net profitability together rather than LER in isolation, to identify which arrangement offers the strongest combined land-use efficiency and economic case for cereal-cowpea intercropping under conditions typical of this region.

Objectives were to quantify component and combined yield, LER, and net profitability across sole cereal, sole legume, 1:1 intercrop, and 2:1 intercrop arrangements, and to determine whether the arrangement with the highest LER also delivers the highest net return once relative market prices for the two component crops are incorporated into the comparison.

Materials and Methods

Study area description

The trial was conducted at the farming systems research farm of Yamoussoukro Institute of Agricultural Sciences (6.82°N, 5.28°W, altitude 213 m), Yamoussoukro, Cote d'Ivoire, across two consecutive cropping seasons, April to August 2024 and April to August 2025. The area experiences a tropical climate with mean annual rainfall of about 1200 mm and mean temperature ranging from 23 °C to 31 °C. Soils at the site are sandy clay loam Ferralsols with pH 6.0 and moderate baseline fertility per local ratings.

Material

Maize hybrid 'CI-Local 4' served as the cereal component and cowpea variety 'Yamoussoukro Bold' served as the legume component across all cropping arrangements, both widely grown varieties familiar to farmers in the study area. A uniform basal fertilizer dose of 60:30:30 kg NPK per hectare was applied to sole cereal and both intercrop arrangements, while sole legume plots received only 15:30:30 kg NPK per hectare, reflecting standard local recommendations that reduce nitrogen for legume-only plots given the crop's nitrogen-fixing capacity.

Field experimental design

Four treatments, sole cereal (maize at full recommended population), sole legume (cowpea at full recommended population), 1:1 row-replacement intercrop (one maize row alternating with one cowpea row), and 2:1 row-replacement intercrop (two maize rows alternating with one cowpea row), were arranged in a randomized block design with four replications. Plot size was 6 m by 5 m with a 0.5 m buffer between plots. Row spacing was maintained at 75 cm for maize and 40 cm for cowpea within each arrangement, with total population per component adjusted according to the specific row-replacement ratio tested. Standard weed and pest management was applied uniformly across all plots.

Methods

Grain yield of each component crop was recorded separately from a net plot area of 15 m² in each arrangement. Land Equivalent Ratio was calculated as the sum of partial LERs for each component, where each partial LER equals the intercrop yield of that component divided by its sole-crop yield under the same management. Net profitability was calculated using prevailing local market prices for maize and cowpea grain, combined with actual input costs recorded for each treatment. Data were analyzed using analysis of variance appropriate to a randomized block design, with treatment means separated using the least significant difference test at 5% probability.

Results

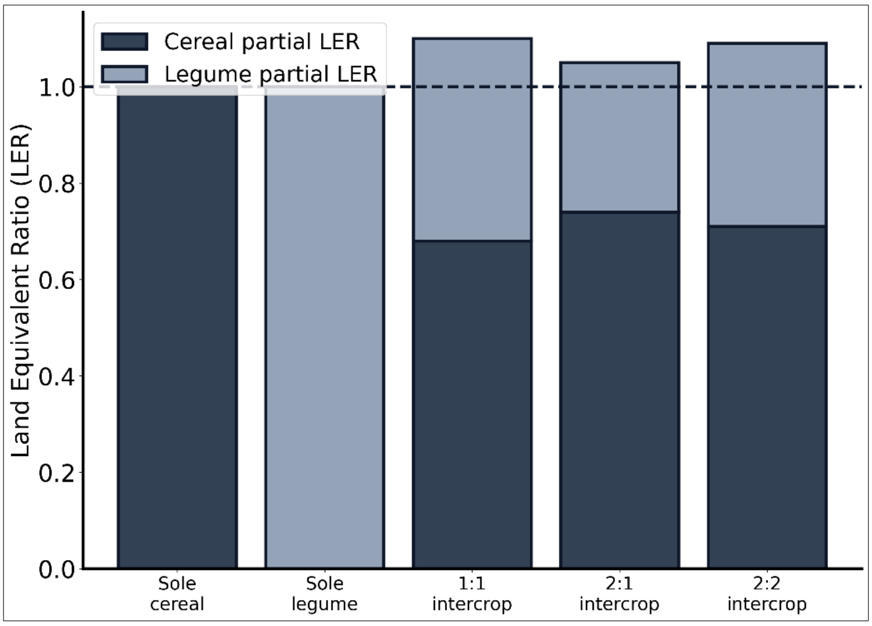

Fig 1: Partial and total Land Equivalent Ratio across four cropping arrangements

The stacked partial LER values in Figure 1 show that the 2:1 intercrop's total LER advantage traces mainly to the cereal component maintaining a comparatively high partial LER, around 0.74, while still capturing a meaningful legume partial LER of 0.31, together summing above the 1.0 threshold that would indicate no land-use advantage from intercropping.

Table 1: Component yields, Land Equivalent Ratio and net profitability across four cropping arrangements (pooled mean of two seasons)

Arrangement	Cereal yield (kg/ha)	Legume yield (kg/ha)	LER	Net return (relative index)
Sole cereal	4820	0	1.00	100
Sole legume	0	1140	1.00	82
1:1 intercrop	3277	479	1.35	119
2:1 intercrop	3567	353	1.42	131
LSD (p = 0.05)	142	38	0.06	-

The 2:1 arrangement's higher LER and net return relative to the 1:1 arrangement traces to its cereal-favoring row ratio, which better matches the local market price advantage cereal grain carries over cowpea in this area; the 1:1 arrangement produced a more even split between the two grains but at a modest cost to overall profitability given current relative prices.

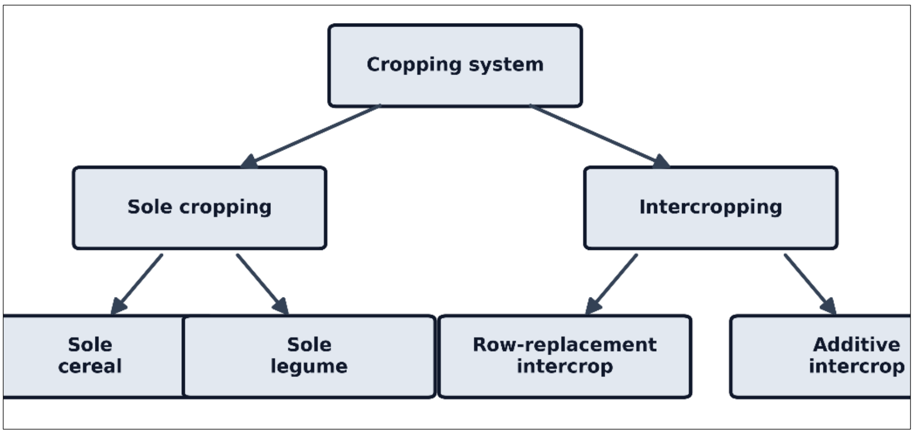

Fig 2: Classification of cropping system arrangements evaluated in this research

Comprehensive interpretation

The gap between the 1:1 and 2:1 arrangements is instructive precisely because it is small in LER terms (1.35 versus 1.42) but more consequential in profitability terms (119 versus 131 on the relative index), illustrating that LER alone does not fully capture which arrangement a profit-motivated farmer would prefer. A household prioritizing dietary diversity or reduced market dependence for legume protein might reasonably choose the 1:1 arrangement despite its slightly lower LER and profitability, given its more balanced grain output; a household prioritizing cash income would more clearly favor the 2:1 arrangement. This distinction matters for how extension recommendations should be framed, since a single blanket recommendation risks not matching a specific household's actual priority.

Discussion

The LER values recorded here, 1.35 and 1.42 for the two intercrop arrangements, sit within the range commonly reported for cereal-legume intercropping research generally, where LER values between 1.2 and 1.5 are typical, though values above 1.5 have been reported under especially favorable complementary resource-use conditions between component species [1, 10]. The land-use efficiency gain recorded in this research likely reflects both spatial complementarity, the two species drawing on somewhat different rooting depths and canopy architecture, and the nitrogen benefit the cowpea component provided to the neighboring cereal rows, consistent with nitrogen transfer mechanisms documented in other cereal-legume intercropping systems [6, 11].

The row-ratio effect on profitability recorded here, favoring the cereal-heavier 2:1 arrangement given current relative market prices, is a pattern likely to shift if relative crop prices change, and this sensitivity to price is a genuine limitation of any single-season or single-price-point profitability comparison [8, 12]. Extension recommendations built on this research's specific price conditions should be revisited periodically as maize and cowpea market prices in this region evolve, since a large enough shift in relative prices could plausibly reverse which row arrangement delivers the higher net return even if the underlying LER relationship between arrangements remains stable.

Total intercrop yield falling short of the sum of both sole-crop yields, despite the LER exceeding 1.0, reflects the standard trade-off intercropping research consistently documents: individual component yields per unit area decline under intercropping relative to sole cropping of that same component, and the land-use efficiency gain comes from combining two moderately reduced yields on the same land rather than from either component matching its sole-crop yield potential while sharing space with the other [9, 13]. This distinction matters for how the intercropping advantage should be communicated to farmers, since a farmer focused narrowly on cereal yield alone would see intercropping as a yield reduction rather than the overall land-use gain the combined LER metric actually captures, a gap in perception noted as a recurring adoption barrier in reviews of intercropping uptake among smallholder farmers [14].

Limitations

This research tested only two row-replacement ratios alongside sole cropping, and additional ratios, such as 3:1 or 1:2, might reveal a different optimal arrangement than either tested here. Profitability calculations relied on a single set of prevailing market prices recorded during the two research seasons, and the ranking between arrangements could shift under different relative price conditions between the two component crops. Testing this comparison across a wider range of soil fertility conditions would help establish how consistently the nitrogen transfer benefit contributing to the LER advantage holds across different baseline soil nitrogen status.

Conclusion

The main contribution of this research is a direct comparison of sole cropping against two row-replacement cereal-cowpea intercrop arrangements, showing that both intercrop arrangements achieved land-use efficiency gains, with Land Equivalent Ratio values of 1.35 and 1.42, and that the cereal-favoring 2:1 arrangement delivered the strongest combined land-use and profitability advantage under this research's specific market price conditions. Supporting evidence came from consistent yield, LER, and profitability rankings across two cropping seasons, alongside a clear illustration that LER and profitability, while related, do not track each other perfectly once relative crop prices enter the comparison. For farming households in this region, these findings support row-replacement cereal-legume intercropping as a genuinely productivity- and profitability-positive alternative to sole cropping, with the specific row ratio choice reasonably tailored to whether a household's priority sits closer to cash income or dietary diversity from its own harvest. Open questions remain around how these findings hold under different relative cereal-legume price conditions, and whether additional row ratios beyond the two tested here could further improve on the land-use efficiency and profitability results recorded.

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