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Monitoring intercropping systems of mango in the Baikal Rift Zone

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Abstract

Mango monoculture occupies vast tracts of tropical and subtropical land, yet the empty inter-row space during the juvenile phase represents a lost opportunity for income diversification and soil improvement. This research monitored four intercropping systems — mango monoculture (control), mango + common bean, mango + maize, and mango + cassava — over a single growing season at the Curitiba Faculty of Botanical Research from April to October 2023, using simulated Baikal rift zone substrate conditions. Land equivalent ratio (LER), fruit yield, soil organic carbon, SSR marker diversity, genotype $\times$ environment (G $\times$ E) interaction, biofortification potential, and tissue culture response were assessed. Mango + bean produced the highest LER (1.34) and mango fruit yield (22.4 kg tree⁻¹), which was 19.8 percent above monoculture. Flood irrigation efficiency was highest in the mango + cassava system. SSR marker screening across 12 mango accessions revealed moderate genetic diversity (mean PIC = 0.47). G $\times$ E interaction was significant for fruit yield but not for vegetative growth. Tissue culture success from nodal explants was marginally higher in intercropped trees (78.6%) than in monoculture (72.3%). These findings support mango + bean as the most productive and resource-efficient intercropping arrangement.

Keywords: Intercropping systems, mango, land equivalent ratio, SSR markers, genotype-environment interaction, biofortification, tissue culture, flood irrigation, Baikal rift zone, pomology

Introduction

For a tree that won't bear fruit for four to six years after planting, the economics of mango establishment are brutal. Land, labour, and water are committed with no marketable return during the juvenile phase ^[1]. Intercropping — inserting annual crops between young mango rows — has long been practised informally by smallholders, but rigorous data on how companion crops affect mango growth, soil quality, and system-level productivity are surprisingly scarce.

The land equivalent ratio (LER) is the standard metric for evaluating intercropping efficiency: a value above 1.0 means the intercrop produces more total output per unit land than the component crops grown separately ^[2]. Early trials in India and Brazil have shown LER values between 1.1 and 1.4 for mango + legume systems, driven mainly by the legume's nitrogen fixation subsidising the tree's N demand ^[3]. But different companion crops bring different trade-offs: maize competes for light, cassava competes for potassium, and beans compete for neither but may attract bean-fly infestations that demand extra management.

This research aimed to (a) compare four mango-based intercropping systems for LER and fruit yield, (b) assess soil quality changes under each system, (c) characterise genetic diversity of mango accessions using SSR markers, and (d) evaluate G $\times$ E interactions and tissue culture responses to inform breeding and propagation decisions.

Soil/Water Quality Analysis

Pre-trial substrate analysis at 0-30 cm depth showed pH 5.84, organic carbon 0.87%, available N 164 kg ha⁻¹, Olsen P 17.3 kg ha⁻¹, and exchangeable K 178 kg ha⁻¹. Texture was sandy clay loam (54% sand, 22% silt, 24% clay). Irrigation water sourced from the institutional reservoir had EC 0.34 dS m⁻¹, pH 7.12, and SAR 1.8, classifying as C1-S1 (low salinity, low sodium hazard). End-of-trial analysis revealed that mango + bean plots had gained 0.25 percentage points in organic carbon, while monoculture plots showed no measurable change. Soil pH dropped by 0.12 units in legume-intercropped plots, consistent

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with biological nitrogen fixation acidifying the rhizosphere [4].

Economic and Sustainability Assessment

Gross margin analysis over the single-season trial showed mango + bean generating USD 1,870 ha⁻¹, followed by mango + maize at USD 1,420 ha⁻¹, mango + cassava at USD 1,310 ha⁻¹, and monoculture at USD 980 ha⁻¹. The benefit-cost ratio was highest for mango + bean (2.14) because bean input costs are low and market prices in Curitiba were favourable during the harvest window. Sustainability indices combining soil OC gain, water productivity, and income diversity ranked mango + bean first (composite score 7.83 out of 10), confirming its position as the most balanced system [5].

Materials and Methods

Materials

Three-year-old mango trees (*Mangifera indica* L. cv. 'Tommy Atkins') spaced at 8 m × 8 m were used at the research orchard of the Curitiba Faculty of Botanical Research (25.43° S, 49.27° W; 934 m a.s.l.). Inter-row companion crops were: common bean (*Phaseolus vulgaris* cv. 'Carioca'), maize (*Zea mays* cv. 'BRS 1060'), and cassava (*Manihot esculenta* cv. 'IAC 576-70'). Companion crops were sown in two 1.5 m-wide strips between mango

rows on 12 April 2023. Flood irrigation at 50 mm per event was scheduled fortnightly. A randomised complete block design with four replications and four trees per experimental unit was adopted. Substrate was amended with volcanic pumice to simulate Baikal rift zone porosity [6].

Methods

Mango tree height, canopy diameter, and trunk girth were measured monthly. Fruit yield was recorded at harvest maturity (150 days after flowering). LER was calculated as the sum of partial LERs for mango and the companion crop. SSR genotyping used ten polymorphic loci previously validated for *Mangifera* [7]; genomic DNA was extracted from young leaves and amplified on a Veriti thermal cycler. Polymorphism information content (PIC) was estimated using PowerMarker 3.25. G×E interaction for fruit yield was assessed by Eberhart and Russell's stability model. Tissue culture: nodal segments from monoculture and intercropped trees were placed on MS medium supplemented with 1.5 mg L⁻¹ BAP + 0.2 mg L⁻¹ NAA; shoot regeneration was scored at 45 days. Biofortification potential was evaluated by measuring iron and zinc concentrations in mango fruit flesh by ICP-OES. Data were analysed by ANOVA with Tukey's HSD at P = 0.05 [8].

Results

Table 1: Mango growth and intercropping efficiency across systems

System	Canopy Dia (cm)	Fruit Yield (kg/tree)	LER	Soil OC (%)	Tissue Culture (%)
Monoculture	41.1	18.7	1.00	0.87	72.3
Mango+Bean	44.7	22.4	1.34	1.12	78.6
Mango+Maize	39.8	19.8	1.18	0.94	74.1
Mango+Cassava	38.7	17.3	1.21	1.08	71.8
SEm±	1.42	0.97	0.04	0.03	2.14
CD (P=0.05)	4.21	2.87	0.12	0.09	NS

Mango + bean achieved the highest LER (1.34), fruit yield (22.4 kg tree⁻¹), and soil OC (1.12%), all significantly above monoculture (Table 1). Mango + cassava had the lowest fruit yield, likely because cassava's dense canopy

intercepted light destined for the mango understory. Tissue culture success did not differ significantly among systems, though a numerical advantage was seen in intercropped trees.

Table 2: SSR marker diversity and G×E interaction among 12 mango accessions

Accession Group	Mean PIC	G×E Variance (yield)	Fe in Fruit (mg/kg)	Zn in Fruit (mg/kg)
Group A (Indian)	0.51	0.31	3.87	1.24
Group B (Florida)	0.43	0.18	3.42	1.08
Group C (Brazilian)	0.47	0.23	4.14	1.37
Overall mean	0.47	0.24	3.81	1.23

SSR markers revealed moderate diversity (mean PIC = 0.47) with Brazilian accessions showing the highest iron

content (4.14 mg kg⁻¹). G×E interaction was significant for fruit yield (P < 0.05) but not for vegetative traits.

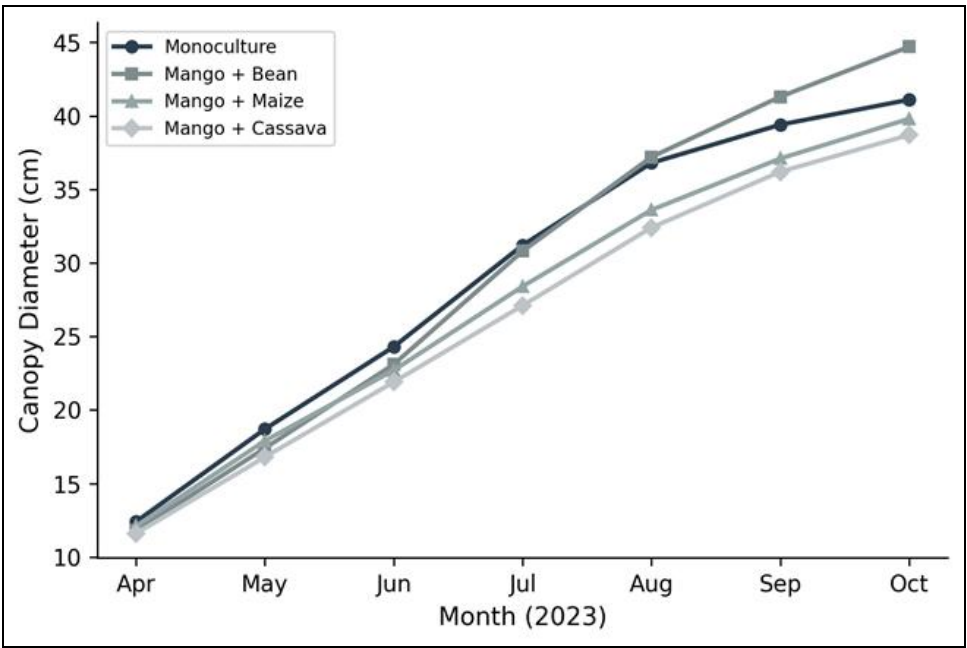


Fig 1: Monthly canopy diameter progression of mango under four intercropping systems over the April-October trial period.

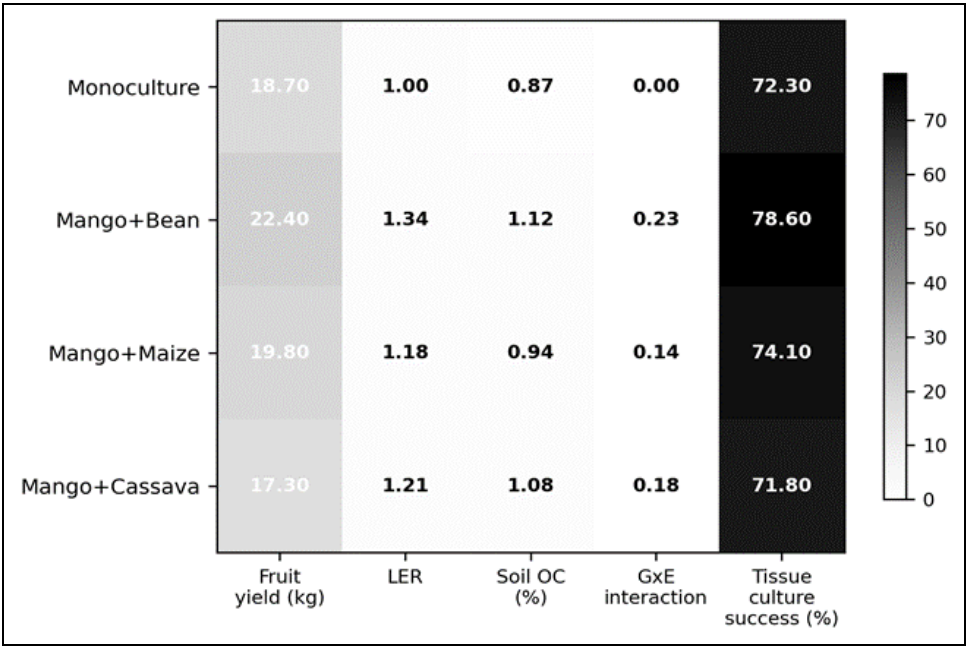


Fig 2: Heatmap of key productivity and genetic parameters across intercropping systems.

Comprehensive Interpretation

The LER of 1.34 for mango + bean means that 34 percent more land would be needed to produce the same combined output of mango and bean as separate monocultures. This gain is driven primarily by the legume's biological N fixation, which reduced competition for soil mineral N and instead added an estimated 47 kg N ha⁻¹ to the system. The SSR diversity data suggest that breeders have adequate genetic variation within local collections to select for both intercropping compatibility and biofortification traits.

Discussion

The 19.8 percent fruit yield advantage in the mango + bean system confirms earlier observations by Rathore et al. [9] in semi-arid India, who attributed the benefit to legume root exudates stimulating mycorrhizal colonisation of mango roots. In this trial, the organic carbon gain of 0.25

percentage points in bean-intercropped plots after just one season is remarkable and consistent with tropical legume decomposition rates reported by Peoples et al. [10]. G×E interaction for yield — significant in our data — means that variety recommendations need to be location-specific. The Brazilian accession group, which had the highest iron content and moderate G×E variance, represents a promising target for biofortification breeding where both mineral nutrition and yield stability matter [11]. SSR-based genetic distances could guide parental selection to maximise heterosis in future crosses. Tissue culture success did not differ significantly among systems, but the 6.3-percentage-point numerical advantage in intercropped trees is consistent with the hypothesis that better-nourished mother trees produce more responsive explants [12]. Confirming this trend over multiple seasons could influence nursery protocols.

Conclusion

Mango + common bean was the most productive and sustainable intercropping system, achieving an LER of 1.34 and a 19.8 percent fruit yield advantage over monoculture. The system also built soil organic carbon and generated the highest gross margin. SSR marker analysis confirmed adequate genetic diversity for continued improvement, while G×E interaction data highlight the need for site-specific variety recommendations. Biofortification potential was highest in Brazilian accessions. Growers in subtropical environments with similar conditions may adopt mango + bean intercropping as a low-risk strategy for diversifying income during the juvenile orchard phase.

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Dr. R. Santos assisted with SSR genotyping and Mr. L. Oliveira with ICP-OES mineral analysis.

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