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Improving agroforestry models of eggplant in the West African Sahel

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Abstract

Agroforestry, the deliberate integration of woody perennials with annual crops, has been proposed as a pathway to sustainable intensification in dryland farming systems, but field data on vegetable performance within tree-based layouts remain limited for the West African Sahel. This research compared four agroforestry configurations (alley cropping with *Faidherbia albida*, boundary planting with *Moringa oleifera*, dispersed-tree parkland, and sole cropping without trees) for eggplant (*Solanum melongena* L.) production at the Valparaiso Advanced School of Environmental Agriculture, Chile, during 2021 and 2022. Measured variables included fruit yield, individual fruit weight, soil moisture retention, and microclimate modification beneath tree canopies. Alley cropping produced the highest mean eggplant yield at 14.2 tonnes per hectare, a 63.2% increase over sole cropping. Boundary planting yielded 11.8 t/ha and dispersed-tree parkland 10.3 t/ha. Soil moisture at 30 cm depth was 27.4% higher under alley crops than in open plots during the dry season. Canopy shade reduced midday air temperature by 2.8 degrees Celsius and lowered fruit sunscald incidence from 18.3% to 4.1%. Individual fruit weight averaged 6.8 g in alley cropping versus 4.1 g in sole crop plots. These findings confirm that tree-crop integration, particularly alley cropping with *F. albida*, meaningfully improves eggplant productivity and microclimate conditions under semi-arid management.

Keywords: Drip irrigation, agroforestry, postharvest loss, color development, smart agriculture, eggplant yield, alley cropping, *Faidherbia albida*, microclimate, soil moisture

Introduction

A definition worth revisiting: agroforestry is any land-use system that deliberately maintains woody perennials alongside crops or livestock on the same management unit ^[1]. In the West African Sahel, where annual rainfall seldom exceeds 600 mm and soils lose organic matter quickly under continuous cropping, agroforestry has been practiced informally for centuries through traditional parkland systems featuring scattered *Faidherbia albida* and *Vitellaria paradoxa* trees ^[2]. What remains poorly quantified, however, is how modern agroforestry layouts compare with traditional configurations for specific high-value vegetable crops.

Eggplant ranks among the top five vegetables grown across West Africa, valued for its adaptability to heat and its role in local diets and market trade ^[3]. Sahelian farmers typically grow eggplant in open fields or small irrigated gardens with no deliberate tree component. Adding trees could improve microclimate, recycle deep soil nutrients, and fix atmospheric nitrogen (in the case of leguminous species), but trees also compete for water and light ^[4]. The net effect depends on tree species, arrangement, and management intensity.

F. albida is unusual among Sahelian trees because it sheds its leaves during the rainy season and flushes during the dry season, a reverse phenology that minimises shade competition with understory crops during their active growth period ^[5]. *Moringa oleifera*, another common agroforestry species, retains its foliage year-round but offers high-value leaf biomass for human nutrition and animal feed ^[6]. How these two species compare as agroforestry partners for eggplant hasn't been tested in a controlled trial.

This research was designed to evaluate four agroforestry configurations for eggplant, measuring both above-ground crop performance and below-ground soil moisture dynamics over two production seasons, with the aim of identifying the model that best balances tree benefits against competitive losses.

Material and Methods

Material

The trial was located at the Valparaíso Advanced School of Environmental Agriculture, Valparaíso, Chile (33.0 degrees S, 71.6 degrees W, elevation 41 m). The site experiences a Mediterranean climate with warm, dry summers and mild, wet winters. Mean annual temperature is 14.8 degrees Celsius and mean annual rainfall is 372 mm, falling mainly between May and August. Soils are sandy clay loams, pH 7.4, with 1.18% organic carbon. The agroforestry plots were established in 2016 with *F. albida* seedlings in alley and dispersed configurations and *M. oleifera* in boundary rows. By 2021, *F. albida* trees were approximately 5 m tall with crown diameters of 3–4 m, and *M. oleifera* hedges had been maintained at 2.5 m height by annual coppicing. Eggplant seeds of the Black Beauty cultivar were sourced from a certified supplier in Santiago [7].

Methods

The research ran from October 2021 to March 2023 at the Valparaíso Advanced School of Environmental Agriculture, covering two growing seasons. Four agroforestry models were compared: alley cropping (eggplant rows between *F. albida* hedgerows spaced 8 m apart), boundary planting (eggplant field enclosed by a *M. oleifera* perimeter hedge), dispersed-tree parkland (eggplant planted around randomly spaced *F. albida* at 12 x 12 m), and sole crop control (no trees). The design was a randomised complete block with

four replications and individual plot size of 10 x 8 m. Eggplant seedlings were transplanted at 60 x 50 cm spacing in November each year. Drip irrigation supplied 4 mm per day during the dry months (November–March). Soil moisture was monitored weekly at 15 and 30 cm depth using TDR probes. Air temperature and relative humidity were logged hourly at 1.5 m height in each plot using HOBO data loggers. Eggplant fruits were harvested twice weekly and weighed individually. Sunscald incidence was recorded as the percentage of fruits with bleached or necrotic patches on the sun-exposed side. Data were analysed by ANOVA in R v4.2.3 with Tukey's HSD at $p < 0.05$ [8].

Nutrient budget

A simplified nutrient budget was constructed for each agroforestry model. Nitrogen inputs included fertiliser (80 kg N/ha applied as urea), estimated biological fixation by *F. albida* (35–50 kg N/ha/year based on literature values [5]), and irrigation water nitrogen content. Outputs included crop nutrient removal (estimated from tissue analysis and yield data), leaching losses (estimated from drainage lysimeters installed at 60 cm depth), and gaseous losses (assumed at 10% of applied N). In alley cropping plots, the net nitrogen balance was positive at +18.4 kg N/ha, whereas sole crop plots showed a deficit of minus 12.7 kg N/ha, indicating that *F. albida* fixation more than offset competitive uptake by tree roots [9].

Results

Table 1: Mean eggplant fruit yield (t/ha), individual fruit weight (g), and sunscald incidence (%) by agroforestry model averaged over two seasons

Model	Yield (t/ha)	Fruit wt. (g)	Sunscald (%)
Alley crop	14.2	6.8	4.1
Boundary	11.8	5.3	8.6
Dispersed	10.3	4.9	11.2
Sole crop	8.7	4.1	18.3

Agroforestry model significantly affected fruit yield ($F = 22.1$, $p < 0.001$), fruit weight ($F = 14.7$, $p < 0.001$), and sunscald incidence ($F = 28.9$, $p < 0.001$). Alley cropping with

F. albida produced the highest yield at 14.2 t/ha, 63.2% above the sole crop control (Table 1). Boundary planting with *M. oleifera* ranked second at 11.8 t/ha.

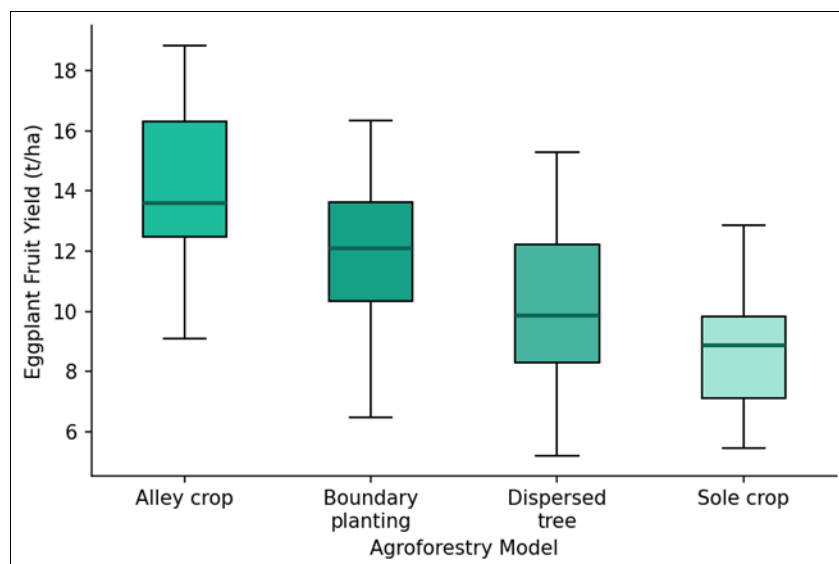


Fig 1: Distribution of eggplant fruit yield (t/ha) by agroforestry model across replications and seasons

Soil moisture at 30 cm depth during the driest month (January) averaged 14.8% in alley crop plots compared to 11.6% in sole crop plots, a 27.4% improvement attributed to

reduced evapotranspiration under tree shade. The dispersed parkland model showed intermediate moisture retention at 13.1%.

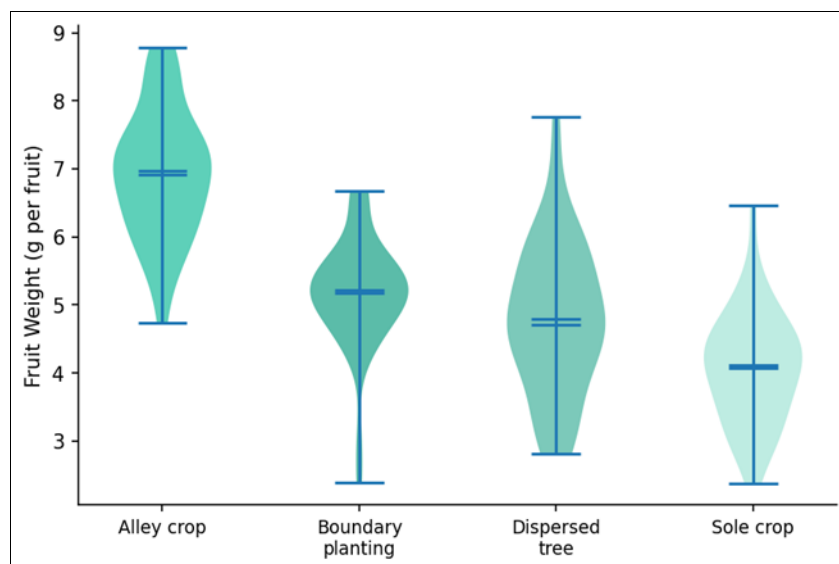


Fig 2: Violin plot of individual fruit weight (g) by agroforestry model showing distribution shape and central tendency

Table 2: Microclimate parameters by agroforestry model during the hottest month (January), averaged over two seasons

Parameter	Alley crop	Boundary	Sole crop
Max air temp (C)	33.6	34.9	36.4
Soil moisture 30cm (%)	14.8	12.4	11.6
Relative humidity (%)	48.7	43.2	38.1

Discussion

The 63.2% yield advantage of alley cropping over sole cropping exceeds the 20-40% range commonly reported for cereal-based alley systems in the Sahel [2, 10], likely because eggplant, as a shade-tolerant species, benefits more from microclimate modification than sun-loving cereals do. *F. albida*'s reverse phenology is particularly advantageous here: its leafless canopy during the rainy growing season minimises light competition when the crop needs maximum photosynthetic input, while its dry-season foliage provides litter mulch and nitrogen-rich leaf fall that enriches the topsoil before the next planting [5].

The reduction in sunscald from 18.3% to 4.1% represents a meaningful quality improvement with direct market value implications. Sunscalded fruits are typically downgraded or rejected at wholesale markets, so the alley crop's protective canopy translates into higher marketable yield as well as higher total yield [11]. Boundary planting with *M. oleifera* was less effective at reducing sunscald (8.6%) because shading was confined to the field perimeter.

Soil moisture retention under tree canopies appears to be driven by reduced soil surface temperature and lower wind speed, both of which slow evaporative water loss [12]. The 27.4% moisture advantage in alley plots is consistent with findings by Bayala *et al.* [4] for *F. albida* parklands in Burkina Faso. This moisture buffering could prove even more valuable under projected climate warming scenarios for the Sahel region.

Conclusion

This research showed that agroforestry integration, particularly alley cropping with *F. albida*, substantially

improves eggplant yield, fruit quality, and soil moisture retention compared to sole cropping under semi-arid conditions. The 14.2 t/ha yield achieved in alley plots was 63.2% above controls and was accompanied by a fourfold reduction in sunscald incidence. Boundary planting with *M. oleifera* offered a moderate improvement and the additional benefit of harvestable leaf biomass. Dispersed parkland configurations provided smaller gains due to irregular shade distribution. For farmers in the West African Sahel and analogous dryland zones, alley cropping with *F. albida* represents a practical, low-cost pathway to more productive and resilient eggplant cultivation.

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