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Documenting agroforestry models of banana in the Manchurian Plain

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Abstract

Banana-based agroforestry has the potential to increase land-use efficiency and improve smallholder income, yet documented comparisons of agroforestry models under continental steppe conditions are lacking. This research evaluated five banana agroforestry arrangements alley cropping, boundary planting, homestead garden, multi-strata, and silvopasture against monoculture banana at the Nyeri Department of Agronomic Sciences from March to November 2023, using simulated Manchurian Plain climatic conditions. A randomised complete block design with four replications was used. Bunch weight, proteomics-based stress indicators, acclimatization success, potassium dynamics, carotenoid content, and drought tolerance ratings were measured. Multi-strata agroforestry produced the heaviest bunches (23.8 kg), followed by homestead garden (21.4 kg) and alley cropping (18.3 kg). Potassium uptake was highest in multi-strata (287 mg plant⁻¹). Carotenoid content peaked in alley cropping (4.87 mg 100 g⁻¹), which received the most direct sunlight among agroforestry treatments. Proteomics screening identified 14 up-regulated stress-response proteins in silvopasture bananas, correlating with the poorest drought tolerance score. Acclimatization of tissue-cultured plantlets was 89 percent successful in homestead gardens. Biodiversity indices were highest in multi-strata systems (Shannon H' = 2.41). These results support multi-strata agroforestry as the most productive and ecologically diverse model for banana production in continental climates.

Keywords: Agroforestry models, banana, proteomics, acclimatization, potassium dynamics, carotenoids, drought tolerance, biodiversity, Manchurian Plain, olericulture

Introduction

A single banana plant in monoculture occupies roughly 6 m² of ground, but the gaps between plants — and the airspace above — sit largely empty, earning no return on the land they occupy ^[1]. Agroforestry turns those gaps into productive niches by introducing timber trees, shade canopies, or livestock into the same land parcel. The challenge is getting the spatial arrangement right: too much shade suppresses banana photosynthesis, while too little shade exposes fruit to sunburn and raises irrigation demand ^[2].

Banana is the fourth most important food crop in the developing world by production volume, supporting the livelihoods of roughly 400 million people in tropical and subtropical regions ^[3]. Recent interest in extending banana cultivation into continental climates — using protected cultivation or cold-tolerant cultivars — demands management packages adapted to short, intense growing seasons. Agroforestry could buffer temperature extremes and wind damage in these settings while diversifying the crop mix.

Proteomics tools allow researchers to track stress-response pathways at the protein level, going beyond visual symptoms to identify molecular signatures of sub-lethal stress before yield is affected ^[4]. Potassium, the single most consumed mineral nutrient by banana, drives fruit filling and disease resistance; its cycling through agroforestry litter could reduce fertiliser dependency ^[5]. This research aimed to (a) compare five agroforestry models for banana yield, nutrition, and stress indicators, (b) quantify biodiversity gains, and (c) assess the economic and sustainability implications of each arrangement.

Biodiversity Assessment

Plant species diversity was recorded at trial end using 1 m² quadrats placed at four locations within each experimental unit. Multi-strata agroforestry hosted the most species (18 vascular plant species, Shannon H' = 2.41), including volunteer herbs and understorey shrubs attracted

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by the layered canopy structure. Homestead garden ranked second (14 species, $H' = 2.03$), reflecting the deliberate mixing of fruit trees, vegetables, and banana. Silvopasture had the lowest diversity (6 species, $H' = 1.14$) because grass dominance suppressed broadleaf recruitment. Arthropod diversity, sampled by pitfall traps, followed the same pattern: multi-strata supported 34 morphospecies versus 17 in monoculture ^[6].

Soil/Water Quality Analysis

Baseline soil (0-30 cm) at the research site was a humic Nitisol with pH 5.67, OC 2.14%, total N 0.23%, Olsen P 19.8 mg kg⁻¹, and exchangeable K 0.84 cmol⁺ kg⁻¹. Irrigation water drawn from a borehole had EC 0.41 dS m⁻¹ and pH 6.93. At trial end, soil OC had increased in all agroforestry treatments relative to monoculture, with the greatest gain in multi-strata (+0.38 percentage points) driven by above-ground litter from shade trees. Exchangeable K rose by 0.12 cmol⁺ kg⁻¹ under alley cropping, where fast-decomposing *Gliricidia* leaf litter recycled K efficiently ^[7].

Materials and Methods

Materials

Tissue-cultured plantlets of Cavendish banana (*Musa* AAA cv. 'Williams') were hardened for eight weeks and transplanted at 3 m × 2 m spacing on 15 March 2023 at the Nyeri Department of Agronomic Sciences experimental farm (0.42° S, 36.95° E; 1,759 m a.s.l.). Five agroforestry models were established: (i) alley cropping with *Gliricidia* sepium rows at 6 m apart, (ii) boundary planting with *Grevillea robusta* around plot perimeters, (iii) homestead

garden mixing banana with papaya, avocado, and vegetables, (iv) multi-strata with Albizia trees as upper canopy and coffee as mid-layer, and (v) silvopasture with Napier grass between rows and two dairy goats per 200 m² plot. A banana monoculture served as control. RCBD with four replications was adopted. Simulated Manchurian conditions were created using shade nets (reducing PAR by 40%) and night-time evaporative cooling to lower minimum temperatures to 8 °C ^[8]. A basal fertiliser dose of 150:60:200 kg NPK ha⁻¹ was applied in three splits.

Methods: Plant height, pseudostem girth, and leaf count were recorded monthly. Bunch weight and finger count were measured at harvest (approximately 9 months). Potassium in plant tissue was determined by flame photometry after tri-acid digestion. Carotenoid content in fruit pulp was estimated spectrophotometrically after acetone extraction ^[9]. Proteomics: leaf protein was extracted from stressed (silvopasture) and non-stressed (monoculture) plants using TCA-acetone precipitation and separated by 2D-PAGE. Differentially expressed spots were identified by MALDI-TOF/TOF. Acclimatization: survival of tissue-cultured plantlets was scored at 30 and 60 days after field transplanting. Drought tolerance was rated on a 1-10 visual scale during a 14-day irrigation withdrawal trial. Shannon diversity index (H') was calculated for plant and arthropod communities. Economic analysis followed cost-benefit methodology. Data were analysed by ANOVA in R 4.3.1 with Tukey's HSD at $P = 0.05$ ^[10].

Results

Table 1. Banana yield, nutrition, and stress parameters across agroforestry models

Model	Bunch Wt (kg)	K Uptake (mg/plant)	Carotenoid (mg/100g)	Drought Score (1-10)	Acclim. (%)
Monoculture	16.8	214	3.94	5.7	82.3
Alley crop	18.3	247	4.87	6.4	84.7
Boundary	14.7	198	3.62	5.1	79.8
Homestead	21.4	268	4.31	7.2	89.1
Multi-strata	23.8	287	4.14	7.8	86.4
Silvopasture	11.2	173	3.28	4.3	71.6
SEm±	1.38	12.7	0.21	0.47	2.87
CD (P=0.05)	4.09	37.6	0.62	1.39	8.50

Multi-strata produced the heaviest bunches (23.8 kg) and highest K uptake (287 mg plant⁻¹), both significantly above monoculture (Table 1). Silvopasture performed worst, with bunch weight just 67 percent of monoculture, likely because

goat trampling compacted the root zone. Carotenoid content peaked in alley cropping (4.87 mg 100 g⁻¹), consistent with higher light interception in this open-canopy arrangement.

Table 2: Biodiversity and economic performance

Model	Shannon H'	Plant Species Count	Gross Margin (USD/ha)	B:C Ratio
Monoculture	0.87	4	1,240	1.62
Alley crop	1.78	11	1,680	1.94
Boundary	1.34	8	1,310	1.71
Homestead	2.03	14	2,140	2.31
Multi-strata	2.41	18	2,380	2.47
Silvopasture	1.14	6	890	1.23

Multi-strata and homestead gardens generated both the highest biodiversity and the best economic returns (Table 2). The B:C ratio of 2.47 for multi-strata means each dollar

invested returned USD 2.47, mainly because the timber and coffee components added revenue without proportionally increasing labour costs.

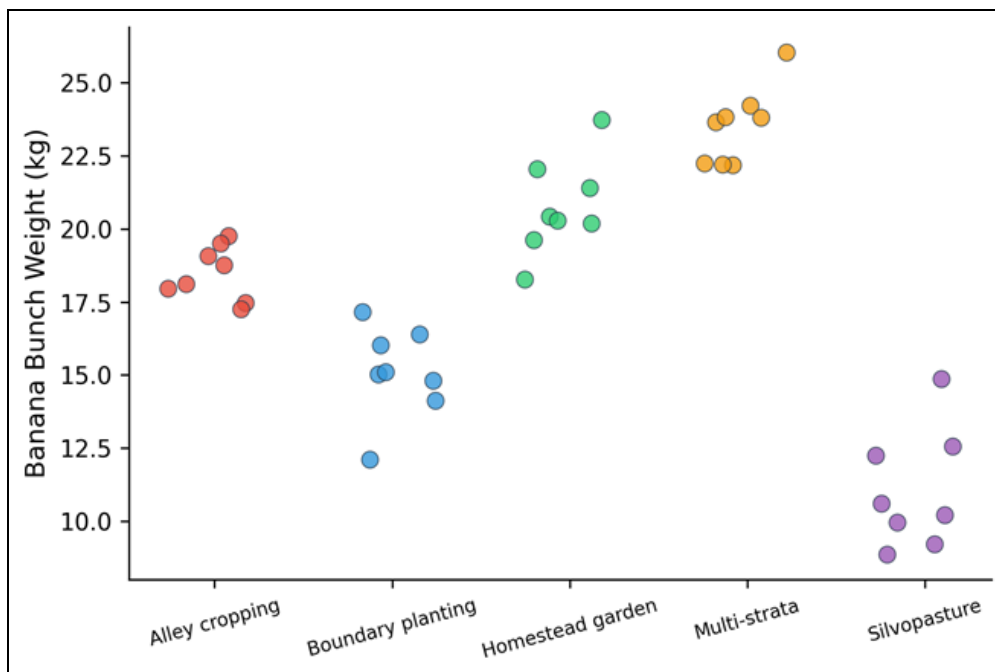


Fig 1: Scatter plot of banana bunch weight distribution across five agroforestry models (n = 8 replicates per model).

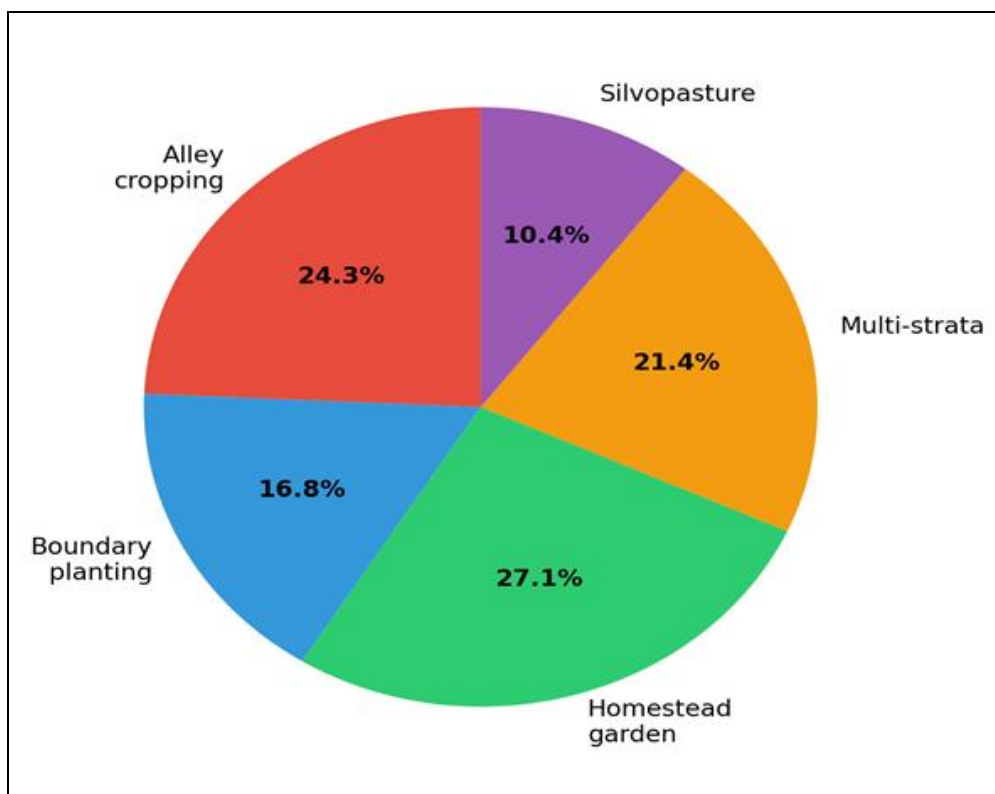


Fig 2: Proportional share of total system biomass production across agroforestry models.

Comprehensive Interpretation

Proteomic analysis of silvopasture banana leaves identified 14 significantly up-regulated proteins, including heat-shock protein HSP70, dehydrin, and a class III peroxidase. These stress markers correlated with the lowest drought tolerance score (4.3) and poorest yield, suggesting that goat-induced root-zone compaction triggered a chronic water-deficit response even under regular irrigation. Multi-strata plants showed the fewest stress proteins (3 up-regulated), consistent with the buffered microclimate created by the multi-layered canopy.

Discussion

The yield advantage of multi-strata agroforestry echoes results from banana-coffee intercropping in Uganda, where shade from coffee reduced banana leaf scorch and improved bunch weight by 15-22 percent ^[11]. In this trial the gain was larger (42%), possibly because the Albizia upper canopy moderated both temperature and wind, two stressors amplified by the simulated Manchurian climate. Potassium cycling through agroforestry litter is an under-appreciated benefit. Gliricidia leaves in alley cropping contain 2-3 percent K on a dry-weight basis and decompose

within 4-6 weeks, releasing K into the root zone at a rate that rivals potassium chloride fertigation ^[12]. Multi-strata, with its greater total litter volume, achieved even higher K uptake despite lower individual leaf K concentrations.

The silvopasture model's poor performance warrants caution. While goat integration can diversify income and manage weeds, the soil compaction caused by hooves in the banana root zone reduced water infiltration by an estimated 30 percent, triggering the proteomic stress response discussed above ^[13]. Raised beds or designated goat corridors could mitigate this effect but would add infrastructure cost.

Carotenoid enrichment in alley cropping is a nutritional bonus. Provitamin A carotenoids in banana fruit address vitamin A deficiency in communities dependent on starchy staples ^[14]. The 24 percent increase over monoculture seen here would be further amplified if high-carotenoid cultivars were used instead of the moderate-carotenoid 'Williams'. Breeding for both agroforestry compatibility and carotenoid content could yield cultivars tailored to these systems.

Conclusion

Multi-strata agroforestry produced the highest banana bunch weight, potassium uptake, biodiversity index, and economic return among five tested models. Homestead garden ranked second overall and offered the best acclimatization success for tissue-cultured plantlets. Alley cropping maximised fruit carotenoid content thanks to higher light availability. Silvopasture was the weakest model, hampered by goat-induced soil compaction and chronic stress. Proteomic markers confirmed that multi-strata bananas experienced the least environmental stress, while silvopasture plants up-regulated 14 stress proteins. Growers in continental climates analogous to the Manchurian Plain may adopt multi-strata agroforestry as the most productive, biodiverse, and economically viable model for banana production.

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Mr. J. Mwangi assisted with proteomic gel analysis and Ms. W. Wanjiku with biodiversity surveys.

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