



Assessing the Role of Agroforestry in Enhancing Biodiversity Conservation and Climate Change Adaptation in Santchou Subdivision, West Region of Cameroon

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Abstract: Agroforestry is widely recognised as multifunctional strategy for biodiversity conservation and climate change adaptation in tropical agricultural landscapes. This study assessed the contribution of agroforestry practices to on-farm biodiversity conservation and climate change adaptation among smallholder farming households in Santchou Subdivision, west region of Cameroon. A cross-sectional mixed-method research design was employed, combining a semi-structured household questionnaire administered to 155 farming households, direct farm observation on 35 farms, 5 focus group discussions, and 5 key informant interviews. Quantitative data were analysed using descriptive statistics and chi-square tests ($\alpha=0.05$), while qualitative data were analysed thematically using Braun and Clarke's (2006) six-phase framework. The results revealed that agroforestry farms actively support on-farm biodiversity through multilayered vegetation (90.3%), widespread bird activity (92.2%), insect activity (87.1%), and natural regeneration on 60.0% of observed farms. Tree density was the strongest predictor of biodiversity outcomes and climate resilience including soil moisture retention ($p<0.001$), crop failure reduction ($p=0.002$), and yield stability ($p=0.023$). Tree species diversity independently predicted soil moisture conservation ($p=0.011$). Both null hypothesis were rejected for 4 of 5 associations tested. Iroko (*Milicia excelsa*) was present on 24.5% of farms and decline due to seedling unavailability. Farm structural quality outperformed farming experience as a predictor of outcomes across both biodiversity and climate dimensions. It is recommended that extension services and policy makers prioritise increasing tree density, diversify indigenous species, and formally integrate agroforestry into climate adaptation policies for smallholder farming landscapes across the western highlands of Cameroon and similar tropical highland farming systems in sub-Saharan Africa.

Keywords: Agroforestry; Biodiversity conservation; climate change adaptation; Tree density.

INTRODUCTION

Global agricultural landscapes face concurrent pressure from biodiversity loss, climate change, and land degradation, placing rural livelihoods in tropical regions at heightened risk (FAO, 2022; IPCC, 2021). In sub-Saharan Africa, where smallholder rain-fed agriculture underpins food security for most rural populations, the interaction between climate variability and ecological degradation is particularly acute (Mbow *et al.*, 2020;

Awazi *et al.*, 2025). Agroforestry, the deliberate integration of trees with crops within the same land management unit, has emerged as a widely promoted multifunctional strategies for simultaneously addressing biodiversity conservation, climate adaptation, and rural livelihoods (Nair, 2019; Jose, 2019; Schroth *et al.*, 2011).

The biodiversity conservation potential of agroforestry has been extensively documented. Agroforestry systems that maintain a structural complexity have been shown to harbor greater bird, insect and wildlife diversity compared to monoculture farms, largely due to their multilayered canopies and diverse habitat niches (Harvey and Gonzalez, 2007; perfecto *et al.*, 2019). Canopy structural complexity, rather than tree species richness, was identified by Clough *et al.* (2011) as the key determinant of functional insect diversity in Indonesian cacao agroforestry systems, while Bhagwat *et al.* (2008) showed that species diversification beyond six tree species generates disproportionate biodiversity gain through functional trait complementarity. Tree density has consistently emerged as the most immediate structural predictor of on-farm biodiversity outcomes. However, most biodiversity research in Cameroon has concentrated on the southern cocoa belt (Sonwa *et al.*, 2017) or the northwestern highlands (Awazi *et al.*, 2020), leaving the western highlands context comparatively underexplored.

Trees contribute to climate resilience through several simultaneous mechanisms: their canopies absorb rainfall energy before it reaches the soil, their roots open preferential flow pathways that enhance infiltration, and their fallen leaves form an insulating layer that reduce surface evaporation and runoff velocity (Verhot *et al.*, 2007; Mbow *et al.*, 2020). Quandt *et al.* (2023) demonstrated that tree species diversity contributes to water conservation independently through root architecture complementarity, whereby different species access different soil depths to collectively improve hydraulic capacity across the soil profile. Despite this global evidence base, limited locally grounded research has examined the specific structural farm characteristics that most strongly predict climate resilience outcomes among smallholder farmers in the western highlands of Cameroon.

Santchou subdivision is an agriculturally active landscape in the western highlands of Cameroon. Agricultural intensification across subdivision has contributed to declining tree cover, habitat fragmentation, and increased erosion risk (Nguemhe *et al.*, 2020; Tchawa and Abossolo, 2018). Forje *et al.* (2022) identified the need to upscale agroforestry for biodiversity conservation in the Santchou landscape but did not provide farm-level quantitative evidence on which structural characteristics drive biodiversity and climate outcomes across the subdivision. Kimengsi *et al.* (2022) examined institutional dynamics in Santchou landscape but did not assess ecological or climate adaptation outcomes of agroforestry at the household level. No empirical study has yet examined the statistical associations between specific agroforestry structural characteristics and on-farm biodiversity indicators or climate resilience outcomes at the farm level across Santchou subdivision.

This study address this gap by providing locally grounded mixed-methods evidence from across Santchou subdivision on: (i) the biodiversity conservation outcomes associated with smallholder agroforestry practices; and (ii) then climate adaptation outcomes associated with those

practices, and which specific farm structural characteristics most strongly predict both sets of outcomes. The study test two null hypotheses: agroforestry practices are not associated with on-farm biodiversity indicators; and agroforestry practices are not associated with climate resilience indicators.

MATERIALS AND METHODS

Study area

The study was conducted across Santchou subdivision, Menoua Division, West region of Cameroon (5°20'–5°40'N; 9°30'–10°15'E), covering approximate 335 km² with a population density of 137 person/ km² (DDADER/Menoua, 2025). Annual rainfall ranges between 1,800–2,500 mm and average temperatures between 18–25°C (Tchawa and Abossolo, 2018). Volcanic soils increase but face increasing erosion from steep slopes and agricultural intensification. The subdivision contains the Santchou wildlife sanctuary, and agroforestry farms across the subdivision support active wildlife populations including birds, insects and other fauna, reflecting the ecological richness of this landscape (Forje *et al.*, 2022; kimengsi *et al.*, 20220). Agroforestry system practiced across the subdivision includes cocoa and coffee agroforests, homegardens, mixed fruit-tree systems, boundary planting, and scattered trees (Ngong *et al.*, 20250). The location of study area and the distribution of sampled villages are shown in figure 1.

Research design and sampling

A cross-sectional mixed methods research design was employed, integrating quantitative data from household surveys and farm observations with qualitative data from focus group discussion (FGD) key informants interviews (KII). The target population comprised 20,580 agroforestry farming households in Santchou Subdivision, estimated from divisional delegation of agriculture and rural development (DDADER)/Menoua (2025) data and the adoption rate reported by Ngong *et al.* (2025). The sample of 155 households was determined using Yamane's (1967) formula at 95% confidence level and 8% margin of error. Seven villages were purposively selected to ensure topographic representation across upland zone (mbouko, tawoum, mbing, meket) and lowland zones (mogot, mokot, fombap). Equal allocation of approximately 22 households per village was adopted through simple random sampling, since village level household count could not be precisely verified, ensuring balanced representation across ecological zones. A sub-sample of 35 (22.6% of surveyed households) was purposively selected for direct ecological observation, capturing variation in agroforestry system type, tree density, species diversity, and years of practice across all seven villages and both topographic zones. Three FGDs (6–10 participants each) and five KIIs were conducted with village leaders, agricultural extension agents, and experienced agroforestry farmers.

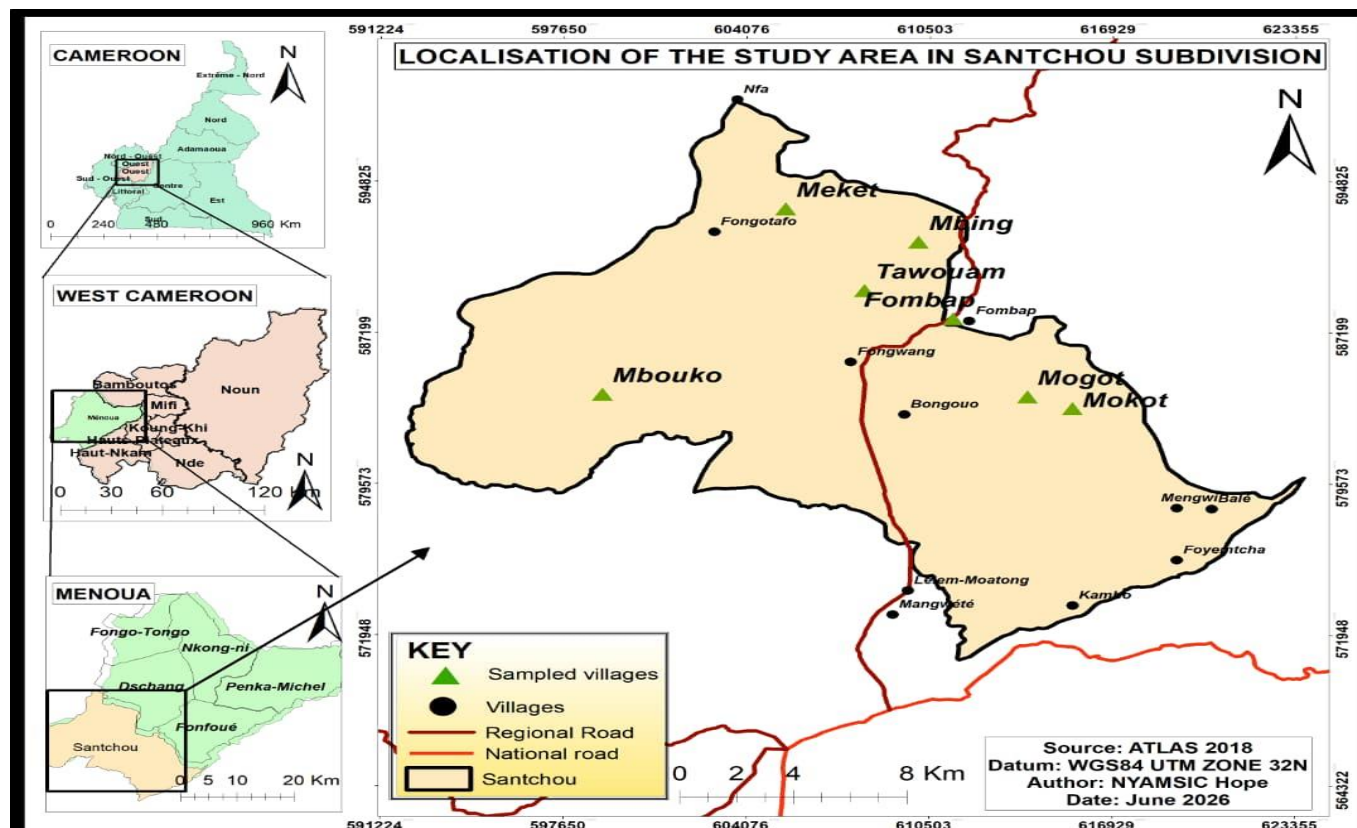


Figure 1. Map showing the location of Santchou Subdivision within Cameroon and the distribution of the seven sampled villages.

Data collection

A semi-structured household questionnaire collected quantitative biodiversity data (bird and insect observation frequency, vegetation layering, perceived biodiversity change, agreement that agroforestry improved biodiversity) and climate adaptation data (rainfall perception, soil moisture conservation, crop failure reduction, yield stability, availability of alternative tree products during crop failure). A structured farm observation checklist recorded tree species presence, tree density, vegetation structure, natural regeneration, wildlife signs and faunal activity on 35 farms. Biodiversity was characterised using species richness (number of tree species recorded per farm) and occurrence frequency (percentage of farms on which each biodiversity indicator was recorded). FGD and KII guides collected qualitative data on biodiversity observation, climate experiences, local perceptions, and farmer identified strategies.

Data analysis

Quantitative data were coded and analysed using SPSS Version 26.0. Descriptive statistics (frequency and percentages) characterised biodiversity and climate adaptation indicators. Chi-square tests were applied to test associations between agroforestry structural characteristics (tree density, tree species diversity, and years of

agroforestry practice) and five biodiversity indicators and five climate resilience indicators, with significance at $\alpha=0.05$ qualitative data were analysed using Braun and Clarke's (2006) six-phase thematic analysis framework, involving familiarisation with data, generating initial codes, searching for themes, reviewing and refining themes, defining and naming themes, and producing the final report. Triangulation across all four data sources employed throughout the analysis.

RESULT AND DISCUSSION

Agroforestry farm profile

Cocoa-based (91.6%) and coffee-based (87.7%) systems were most widely reported across the seven sampled villages, followed by mixed fruit-tree systems (67.7%) and homegardens (61.9%) (Figure 2). Direct farm observation confirmed the same dominant systems, through boundary planting was recorded on 31.4% ($n=11$) of observed farms compared to only 15.5% self-reported, suggesting farmers do not consistently recognise boundary tree arrangements as formal agroforestry systems. In terms of experience, 95.5% of farmers have practiced agroforestry for five or more years (Figure 3), confirming agroforestry is a well-established livelihood practice rather than a new intervention in the study area

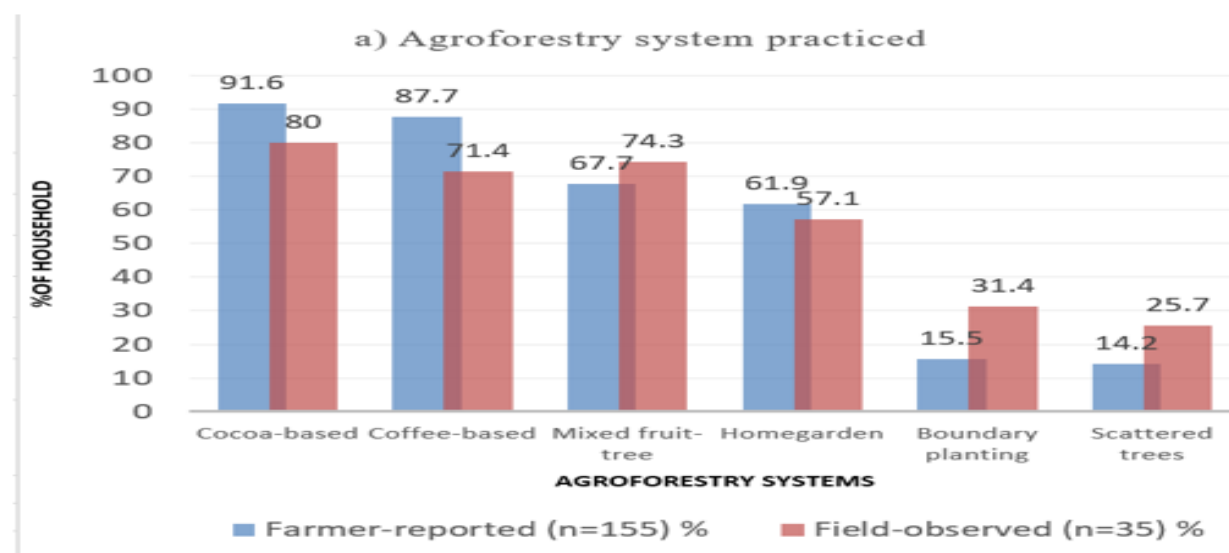


Figure 2. Agroforestry practiced across Santchou (farmer-reported versus field-observed)

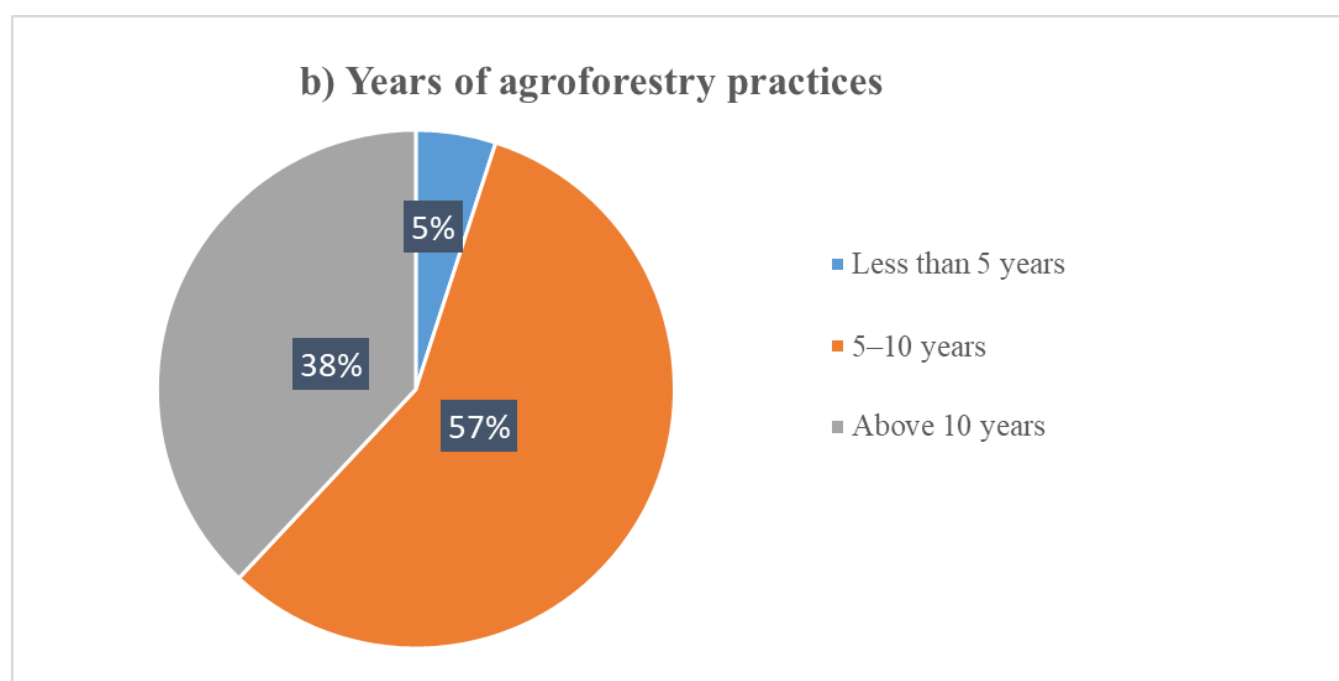


Figure 3. Distribution of years of agroforestry practice among surveyed farmers

Tree density was high across surveyed farms, with 95.5% of farms carrying 10 or more tree (Table 1). Direct farm observation recorded higher densities than self-reports, with 65.7% of observed farms having more than 30 trees, consistent with documented farmer tendencies to underestimate tree numbers on densely planted farm (Nair, 2019). Species richness was moderate across both data sources, with 3-5 species dominating both farmer reports

(61.3%) and field observations (65.7%). The consistent between self-reported and field-observed data across both tree density and species richness confirms the reliability of farmer surveyed responses as a data source for agroforestry structural characterisation in this context. Of surveyed farmers, 70.3% had no access to agricultural extension services, confirming severely limited institutional support for agroforestry improvement across the subdivision

Table 1. Tree density and species richness on agroforestry farms

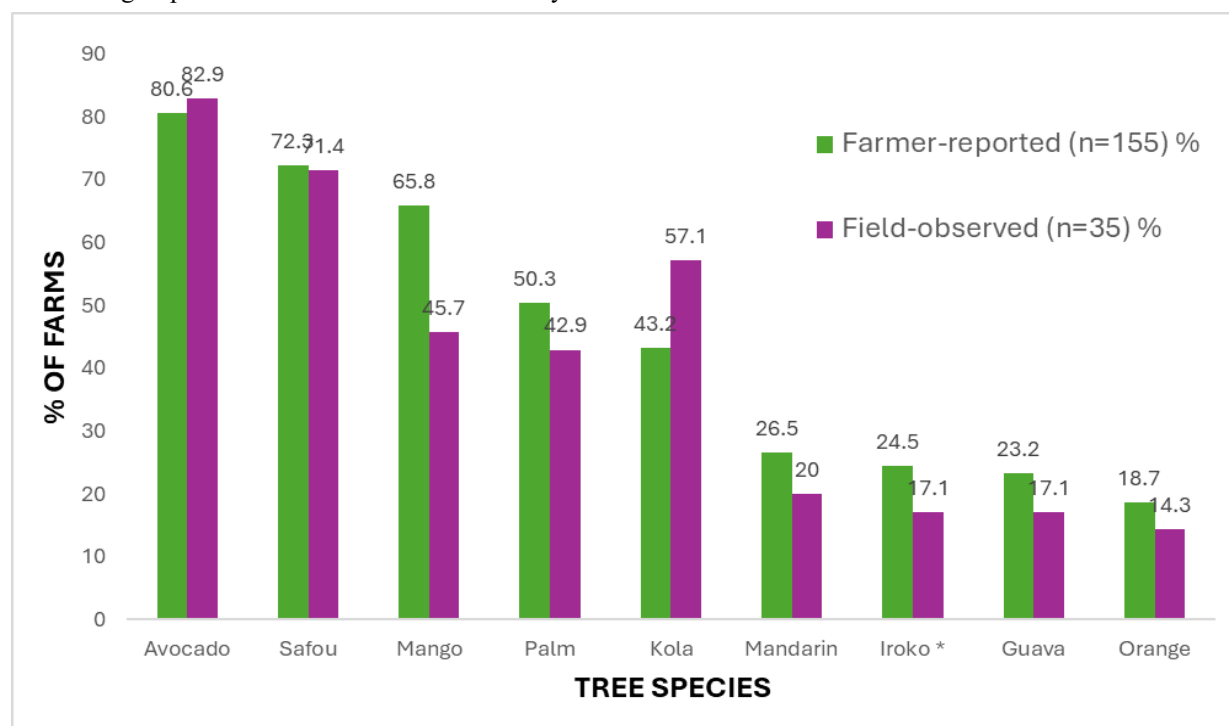
Parameter	Category	Farm reported(n=155) %	Field-observed (n=35) %
Tree density	<10 trees	4.5	8.6
	10-30 trees	43.2	25.7
	31-50 trees	36.1	28.6
	>50 trees	16.1	37.1
Species richness	1-2 species	5.8	14.3
	3-5 species	61.3	65.7
	6-10 species	28.4	17.1
	>10 species	4.5	2.9

Biodiversity conservation outcomes

Tree species composition

Nine tree species were identified across surveyed farms (Figure 4). Avocado (*Persea americana*) dominated at 80.6% of farms, followed by Safou (*Dacryodes edulis*, 72.3%) and mango (*Mangifera indica*, 65.8%). These commercially productive fruit species form the structural core of most farms across the subdivision. Iroko (*Milicia excelsa*) was the indigenous timber species identified. Present on 24.5% of surveyed farms and 17.1% of directly observed farms, the lowest proportion of all recorded species. FGD group 2 attributed this decline directly to

seedling unavailability: “disappearing of some trees like iroko due to lack of seedling.” Unlike the generally positive biodiversity trajectory across other indicators, iroko is declining specifically because seedling are unavailable for replanting, a supply chain failure rather than a motivational barrier. Degrande *et al.* (2013) confirmed that enrichment planting in highland Cameroon succeeds when seedling supply is maintained, while Bhagwat *et al.* (2008) showed that each indigenous species generates unique ecological contributions that commercially preferred fruit trees cannot replicate. Targeted community nursery support for iroko could therefore represent a high-impact, low-cost conservation intervention across the subdivision.

**Figure 4.** Tree species recorded on agroforestry farm across Santchou subdivision

Faunal activity and vegetation structure

Bird presence was reported by 92.2% of farmers and confirmed through direct field observation on 88.6% of observed farms. Species observed during field visits included weavers, doves, and bulbul. Among the 35 directly observed farms, bird activity was recorded as several on 34.3% (n=12) of farms and few on 54.3% (n=19), with only 11.4% (n=4) showing no bird presence (table2). Insect activity was reported by 87.1% of farmers

and confirmed on 82.9% of observed farms. Species observed during field visits included butterflies, ants, grasshopper, honey bees and white mosquitoes. Insect activity was recorded as few on 68.6% (n=24) of farms, many on 14.3% (n=5), and absent on 17.1% (n=6) of observed farms (table2). Wildlife signs including tracks, droppings, feathers, and direct sightings, were recorded on 88.6% of farms. Natural regeneration was recorded on 60.0% (n=6) of observed farms, indicating spontaneous tree establishment without deliberate planting. Multiple

vegetation layers were reported by 90.3% of respondent and confirmed through direct observation. A total of 78.7% of respondents reported that farm biodiversity had increased

since adopting agroforestry, and 96.8% agreed that agroforestry improved their farm biodiversity.

Table 2. Bird and insect activity recorded during direct farm observation

Indicator	Category	Frequency(n)	%
Birds observed	Several	12	34.3
	Few	19	54.3
	None	4	11.4
Total		35	100
Insect observed	None	6	17.1
	Few	24	68.6
	Many	5	14.3
Total		35	100

The closer agreement between farmer reported and researcher-observed faunal data confirms that farmer perceptions are reliable biodiversity indicators, consistent with Awazi *et al.* (2020), who demonstrated the reliability of farmer ecological perceptions in the western highlands of Cameroon. Natural regeneration on 60.0% of farms indicates that many farms have reached a structural

threshold at which secondary forest ecological functions emerge spontaneously (Perfecto *et al.*, 2019). Given that farms across Santchou subdivision support active wildlife populations and Santchou wildlife sanctuary, these farms may serve important ecological buffer zone functions at the landscape level (Forje *et al.*, 2022).

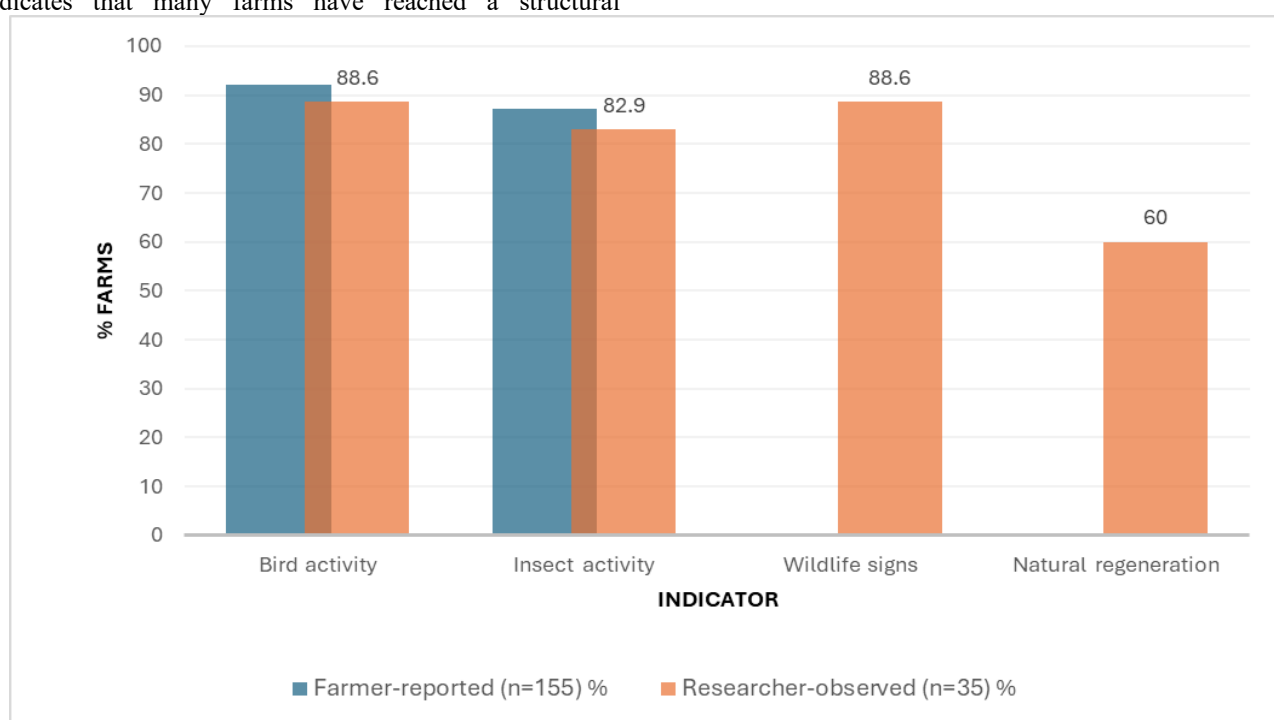


Figure 5. Faunal activity indicators across Santchou subdivision

Statistical association on biodiversity indicators

Chi-square analysis revealed significant associations between agroforestry structural characteristics and four of five biodiversity indicators tested (table3), leading to rejection of null hypothesis for 4 of 5 associations. Tree density was the strongest structural predictor, significantly associated with bird observation frequency ($\chi^2 = 14.016$, $df = 6$, $p = 0.030$), wildlife signs ($\chi^2 = 10.741$, $df = 3$, $p = 0.013$), and perceived biodiversity change ($\chi^2 = 18.547$, $df = 6$, $p = 0.005$). This consistent with Harvey and Gonzalez

(2007), who showed that bird diversity in shaded agroforestry systems track canopy density more closely than species composition, and with Clough *et al.* (2011), who confirmed that insect diversity is driven by canopy complexity independent of species count. Years of agroforestry practices was significantly associated with insect observation frequency ($\chi^2 = 17.597$, $df = 6$, $p = 0.007$), reflecting the time-dependent development of canopy maturity and microhabitat complexity documented by Mbow *et al.* (2014). Tree species diversity showed no

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significant association with perceived biodiversity change ($\chi^2 = 5.787$, $df = 6$, $p = 0.448$), which reflects the way farmers assess biodiversity primarily through visible wildlife rather than plant species counts, a perceptual pattern documented by Perfecto *et al.* (2019). Despite this,

Bhagwat *et al.* (2008) showed that crossing six or more species generates biodiversity benefits far exceeding the numerical gain, a threshold most farms approach but have not yet crossed.

Table3. Chi-square results on agroforestry structural characteristics and on-farm biodiversity indicators ($\alpha = 0.05$)

Independent variable	Dependent variable	X ²	df	p-value	Sig.
Tree density (HH)	Birds observed	14.016	6	0.030	*
Tree species diversity	Biodiversity change	5.787	6	0.448	ns
Years of practice	Insects observed	17.597	6	0.007	**
Tree density (obs.)	Wildlife signs	10.741	3	0.013	*
Tree density	Farm biodiversity	18.547	6	0.005	**

Significance: *** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ ns=not significant, Null hypothesis rejected for 4 of 5 associations.

Climate adaptation outcomes

Farmer perceptions on climate variability

A total of 94.2% of respondents reported noticing changes in rainfall patterns in recent years. All three FGD groups described both insufficient rainfall during dry periods and excessive rainfall causing crop damage, with additional reports of strong winds, flooding, and excessive heat. FGD group 1 stated “*lack of enough rainfall, and sometimes when it is too much it destroys our crops. Heavy wind also become a problem.*” Four of five KIIs confirmed rising temperatures as an additional challenge, and three reported increased pest and disease pressure associated with climate change. These perceptions are consistent with documented climate trends in Menoua division reported by Tchawa and Abossolo (2018) and with the broader IPCC (2021) assessment of increasing climate variability in sub-Saharan African highlands.

Perceived climate adaptation outcomes

Farmer agreement with agroforestry’s climate productive functions was consistently high across all five indicators measured (figure 6). Crop failure reduction attracted the highest agreement at 95.5%, followed by availability of alternative tree products during crop failure (94.2%), soil moisture conservation (92.0). all five KIIs identified soil moisture conservation and shade provision as the most important adaptive functions of trees on the farms. Key informant 3 stated: “*litter covers reduce runoff, tree roots hold the soil and prevent erosion.*” The 94.2% of farmers reporting alternative tree products as a safety net during crop failure confirms Nair’s (2019) multiple insurance function, where tree cover simultaneously protects crops through microclimate moderation, conserves soil moisture, and provides alternative income when primary crops fail.

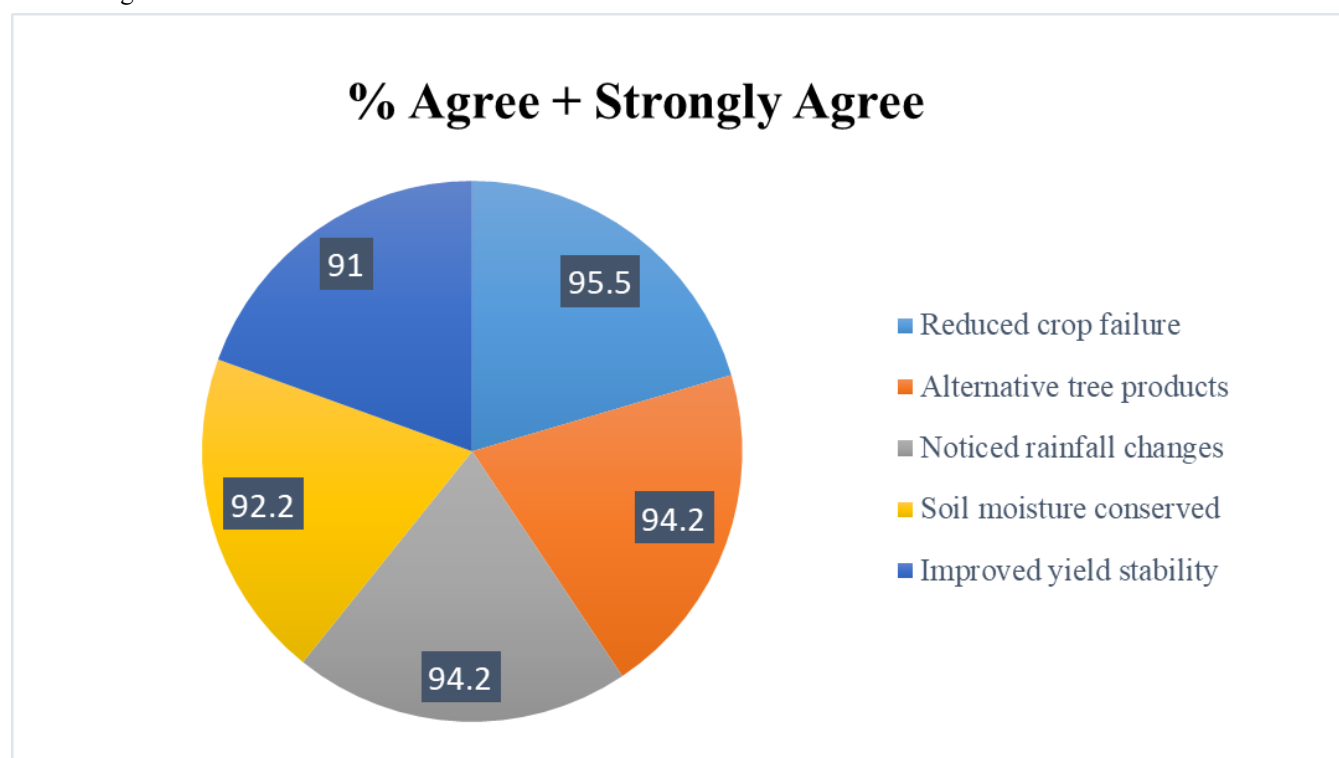


Figure 6. Farmer agreement with climate adaptation functions of agroforestry across Santchou

Erosion control strategies

All seven erosion control strategies reported by farmers across all sampled villages are tree-based or tree-assisted (figure 7). Tree-crop integration is most widely adopted (74.8%), followed by tree planting (48.4%), tree on slope (31.6%), and retaining trees (30.3). These strategies were developed and implemented independently by farmers, 70.3% of whom have no access to agricultural extension services. The exclusive reliance on tree-based erosion control, developed without formal guidance, demonstrates

locally evolved ecological knowledge that is scientifically validated. Verchot *et al.* (2007) documented exactly these mechanisms, canopy interception, root stabilisation, and litter cover as among the most effective farm-level erosion control measures in tropical highland systems. Form climate adaptation planning across Santchou subdivision should therefore build upon what farmers has already independently developed, rather than replacing locally evolved practices with externally designed alternatives (Sayer *et al.*, 2013).

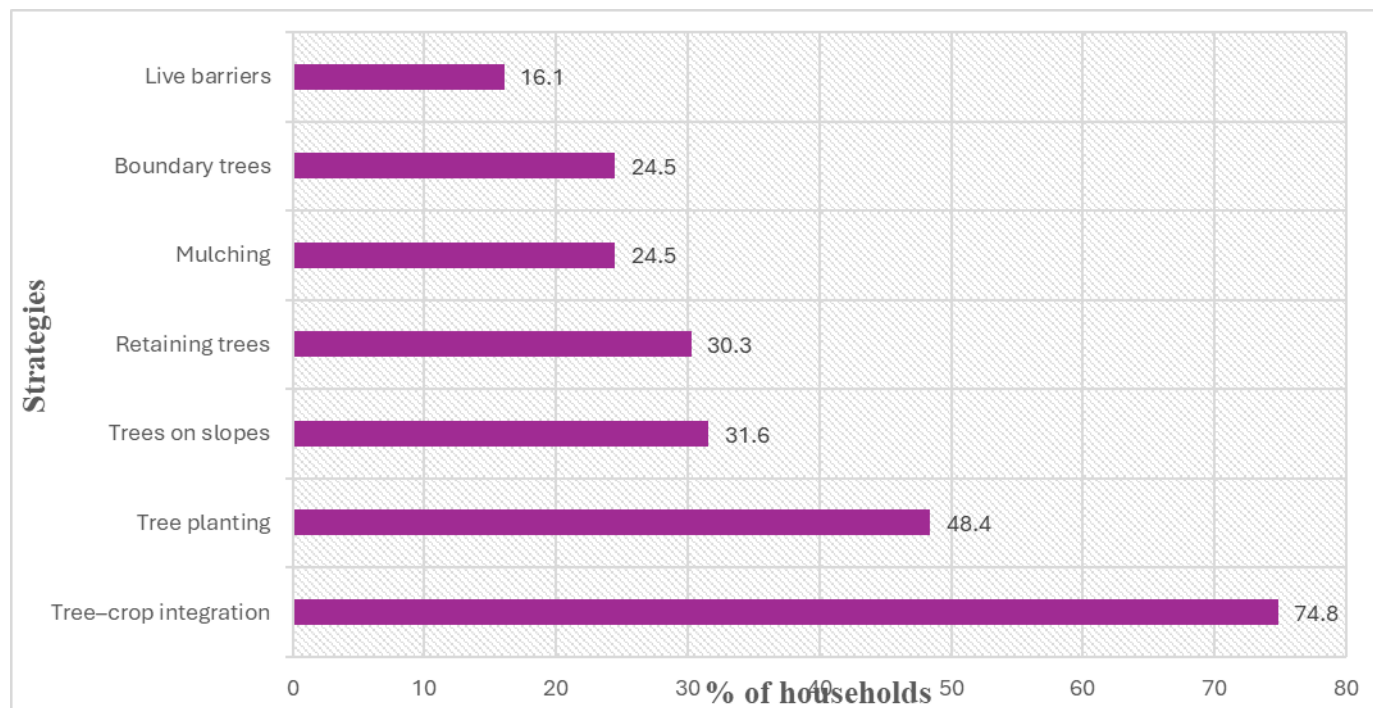


Figure 7. Erosion control strategies adopted by farmers in Santchou subdivision

Statistical association on climate resilience indicators

Chi-square analysis confirmed significant associations between agroforestry and structural characteristics and four of five climate indicators tested (table 4), leading to rejection of null hypothesis for 4 of 5 associations. Tree density showed the strongest individual association in the entire study, with soil moisture retention significant at the 0.1% level ($\chi^2 = 25.026$, $df = 6$, $p < 0.001$). Tree density was also significantly associated with crop failure reduction ($\chi^2 = 25.875$, $df = 9$, $p = 0.002$) and yield stability ($\chi^2 = 19.273$, $df = 9$, $p = 0.023$). These results reflect well-established biophysical mechanisms: Canopy interception reduces rainfall impact force; deep root systems create infiltration channels; an leaf litter insulates the soil surface (Verchot *et al.*, 2007), mechanisms especially critical on Santchou's steep slopes. Tree species diversity

independently predicted soil moisture conservation ($\chi^2 = 16.662$, $df = 6$, $p = 0.011$), supporting Quandt *et al.* (2023), who demonstrated that different species access different soil depths through root architecture complementarity, collectively creating a more complete hydraulic network. Years of practices showed no significant associations with yield stability ($\chi^2 = 11.721$, $df = 6$, $p = 0.069$), confirming that structural farm quality, not farming experience determines climate resilience. This contrast with Tebkew *et al.* (2024), who found experience was significant in northwestern Ethiopia, suggesting context-dependency. In Santchou subdivision, where 95.5% of farmers already have five or more years of experience but face structural limitations, climate adaptation programmes should prioritise farm structural improvement rather than adoption expansion.

Table 4. Chi-square results on agroforestry structural characteristics and climate resilience indicators ($\alpha = 0.05$)

Independent variable	Dependent variable	X ²	df	p-value	Sig.
Tree density	Soil moisture retention	25.026	6	<0.001	***
Years of practice	Yield stability	11.721	6	0.069	ns
Tree density	Reduced crop failure	25.875	9	0.002	**
Tree species diversity	Soil moisture	16.662	6	0.011	*
Tree density	Yield stability	19.273	9	0.023	*

Significance: *** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ ns=not significant, Null hypothesis rejected for 4 of 5 associations

Tree density as a shared driver of biodiversity and climate resilience

Perhaps the most striking findings across both objectives is that the same structural characteristic, tree density which is tree density predicts outcomes in both biodiversity and climate resilience simultaneously. The tree that provide canopy habitat for birds and insects are the same tree whose roots stabilize soil during heavy rainfall and whose litter conserves soil moisture during dry periods. As Mbow *et al.* (2020) noted, the birds and insects supported by these systems in turn sustain pollination, which feeds back into fruit production and farm income. This means that for Santchou's smallholder farmers, investing in farm structural quality serves multiple goals at once, there is no trade-off between making a farm more ecological active and making it more climate resilient.

CONCLUSION

This study fills an important evidence gap by providing the first farm level quantitative analysis of how agroforestry structural characteristics relate to biodiversity conservation and climate adaptation outcomes across Santchou subdivision. The results consistently show that tree density is the strongest predictor of ecological and resilience outcomes, stronger than years of farming experience confirming that what matters most is the quality and structure of the farm, not just whether agroforestry is practiced. The iroko decline stands out as specific and urgent concern; unlike the generally positive biodiversity trends, this indigenous timber species is disappearing from farms not because farmers want to remove it but because seedling are not available. Addressing this through community nurseries would be a simple, high-return conservation action. More broadly, agroforestry in Santchou already functions as a climate management tool farmers have independently developed tree-based erosion control and moisture conservation strategies without institutional support. Formal climate and landscape policies should build on this foundation rather than working around it. Future work across other highland subdivisions using ecological measurement tools and multi-season data collection would help determine whether these findings hold more broadly across the western highlands of Cameroon.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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