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Smallholder eucalyptus growers' perception on the causes and symptoms of soil degradation in Central Vietnam

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Abstract

This study examines smallholder perceptions of soil degradation in eucalyptus plantations in Central Vietnam, a context where rapid expansion raises long-term sustainability concerns. Drawing on semi-structured interviews and focus group discussions with 60 smallholder growers, we find near-universal awareness of soil decline: 93.3% of respondents reported degradation and 87.5% rated degradation severity as moderate or severe. Farmers identified monoculture forestry as the principal anthropogenic driver (87.5%), together with management practices such as clear-cutting, residue burning, short rotation cycles, and removal of harvest residues. Reported manifestations of degradation included reduced forest productivity (100% of respondents), soil compaction and loss of friability, decreased surface organic matter, rapid soil drying, and increased erosion. While natural factors were acknowledged, respondents attributed soil decline primarily to human management—indicating it can be reversed through improved silvicultural practices. Crucially, the findings reveal how smallholder decision-making is shaped by experiential knowledge gaps and underscore the need to integrate local knowledge with scientific evidence to co-design targeted strategies for restoring soil health and securing sustainable livelihoods.

Keywords: Soil degradation, Eucalyptus plantations, Farmers' perceptions, Central Vietnam, Sustainable forest management

1 Introduction

Eucalyptus species are widely utilized across Vietnam and other tropical regions due to their rapid growth and high economic value. However, the large-scale transition to monoculture eucalyptus plantations has raised growing concerns about long-term impacts on soil health and biodiversity. Soil degradation in eucalyptus plantations has attracted considerable attention. Eucalyptus plantations consume large amounts of water and nutrients, leading to soil-fertility depletion when poorly managed (Forrester, 2013). After several rotations, soils typically exhibit reduced organic matter, lower pH, increased acidity, nutrient imbalances, declining concentrations of N, P, K and micronutrients, and impaired soil enzyme activity (Dai et al., 2023; Tang et al., 2023; Xu et al., 2020; Zhang et al., 2015). These changes diminish forest productivity and impair natural regeneration and biodiversity.

The drivers of degradation in eucalyptus plantations are both biological and managerial. Rapid tree growth requires intensive nutrient uptake, while fertilisation often fails to replace exported nutrients. Deep and extensive root systems exploit water and nutrients from deeper horizons, and aromatic compounds in eucalyptus litter can alter soil pH, nutrient availability, and microbial activity, slowing organic matter accumulation (Christina et al., 2017; Knight, 1999; S. M. El-Darier, 2002; Zhiqun et al., 2017). Silvicultural practices such as post-harvest burning, excessive tillage, short rotations, and whole-tree harvesting without residue retention further reduce organic-matter inputs and disrupt nutrient cycling.

In Central Vietnam, smallholder farmers are the principal actors in establishing and managing eucalyptus plantations, and their perceptions of soil degradation strongly influence land use decisions. Accurate understanding can support the adoption of practices that maintain soil quality, whereas limited or incomplete knowledge may perpetuate unsustainable

management. Evidence from Thanh Hoa Province indicates that although farmers recognise some signs of declining soil quality, they often lack insight into underlying causes and effective technical responses (Mai Thi Linh, 2025). Characterising smallholder perceptions can therefore reveal gaps between scientific knowledge and field practices and expose knowledge-practice gaps and guide targeted capacity-building for more sustainable plantation forestry.

Against this background, this study investigates local communities' perceptions of the causes and manifestations of soil degradation in eucalyptus plantations in Central Vietnam. It analyses the level of understanding of degradation drivers, the field indicators observed by growers, and socio-economic factors shaping these perceptions. The results provide a basis for proposing soil restoration and sustainable plantation management measures and for designing strategies to strengthen community awareness, with the overarching goal of enhancing forestry sector performance, protecting the environment, and securing long-term livelihoods in the region.

2 Materials & Methods

2.1 Study area

The study was conducted at four sites across Central Vietnam, extending from Nghe An to Binh Thuan provinces, and representing a wide range of site conditions. Elevations ranged from 13 m to 174 m above sea level, with substantial variation among sites. Slope gradients were likewise heterogeneous, from gentle (0.3°) to relatively steep (27.5°). Mean annual precipitation also varied markedly, with the lowest values at Dien Chau (1,353–1,381 mm year^{-1}) and the highest at Quang Trach (2,506–2,668 mm year^{-1}), while Van Canh and Ham Thuan Nam recorded intermediate levels (1,418–1,616 mm year^{-1}). Soil types were diverse, including red–yellow soils, basaltic red soils, and degraded grey soils, reflecting variation in parent material and physicochemical properties (Table 1).

Most sites experience a tropical monsoon climate, but with distinct geographical differentiation. Dien Chau has a pronounced rainy season, Quang Trach is strongly influenced by intense rainfall and typhoons because of its location in the typhoon-prone region, and Van Canh is characterised by prolonged dry seasons. Notably, Ham Thuan Nam lies in a semi-arid region with extended dry periods, creating the most severe climatic conditions among the study sites. This diversity allows a comprehensive assessment of ecological factors influencing soil degradation in eucalyptus plantations under contrasting environmental conditions in Central Vietnam.

The population of Central Vietnam relies primarily on agriculture and forestry for their livelihoods. Eucalyptus smallholders across the four sites share some common characteristics while differing in local socio-economic context. Plantation growers are predominantly working-age household heads, mainly between 31 and 60 years old, with limited formal education, as most have only completed lower-secondary level, and they rely primarily on practical experience accumulated over years of cultivation. Farming experience is substantial: most growers have cultivated eucalyptus for more than a decade, with the largest group reporting 11–21 years of practice, reflecting the crop's long-standing role in local livelihood strategies. Farm holdings are characteristically small-scale; nearly half of growers manage plots of less than 0.5 ha under state-allocated land-use rights certificates, and only a minority cultivates areas exceeding 1 ha. Eucalyptus income supplements other agricultural activities and, in many households, constitutes a primary source of seasonal cash income. Despite near-universal participation in agricultural–forestry extension programmes, knowledge gaps in soil fertility management remain evident. This combination of contrasting site conditions, fragmented small-scale tenure, limited formal education, and strong livelihood dependence on eucalyptus creates a distinctive socio-ecological context that shapes how landowners perceive, respond to, and are constrained in addressing soil degradation, making the four sites collectively well-suited to investigating the interplay between ecological processes and smallholder decision-making.

Table 1: Study site characteristics

No.	Study Site	Mean elevation (m)	Slope (°)	Mean annual rainfall (mm/year)	Dominant soil type	Climatic characteristics
1	Dien Chau (Nghe An Province)	34 – 146	0.5 – 26.1	1,353 – 1,381	Ferralic soil (red-yellow)	Tropical monsoon climate with distinct rainy season
2	Quang Trach (Quảng Bình Province)	13 – 127	0.7 – 25.7	2,506 – 2,668	Ferralic soil (red-yellow)	Tropical monsoon climate with heavy rainfall and frequent storms
3	Van Canh (Binh Đinh Province)	28 – 126	2 – 27.5	1,418 – 1,434	Ferralic soil (red-yellow)	Tropical monsoon climate with a prolonged dry season
4	Ham Thuan Nam (Binh Thuan Province)	47– 174	0.3 – 19	1,434 – 1,616	Degraded grey soil, sandy loam	Semi-arid climate with a long dry season

2.2 Methods

2.2.1 Primary data collection

Semi-structured interviews, using an interview guide on perceived land degradation, its causes, and observable indicators, together with focus group discussions (Orchard, Stringer, & Manyatsi, 2017; Tesfaye Samuel Saguye, 2018) were employed to assess local communities' perceptions of the drivers and manifestations of soil degradation in eucalyptus plantations. The use of these complementary methods was intended to enhance reliability and representativeness, and to provide a comprehensive account of on-the-ground conditions in the study areas.

Semi-structured interviews were conducted to collect in-depth information from individuals directly involved in eucalyptus plantation activities at the study sites in Central Vietnam. This approach allowed interviewers to adapt questions to specific respondents, while enabling interviewees to share their experiences, perspectives, and assessments in a natural and detailed manner. In each study district, collaboration with forest management agencies (including the Sub-Department of Forest Protection, District Forest Protection Stations, and local forestry companies) facilitated the selection of interview sites. The selection criteria ensured that forestry production practices were well represented, including both households applying sustainable land management measures and those not implementing such measures. The socio-demographic profile of the 60 respondents is presented separately below (Table 2). Participants were purposively selected to ensure representation of diverse farming practices, land scales, and levels of experience with eucalyptus cultivation. The survey sample was predominantly male, accounting for 80.0% of the respondents, while females represented only 20.0%. Most respondents were middle-aged, with the largest proportion falling within the 41–50 age group (38.3%), followed by those aged 31–40 (28.3%) and 51–60 (25.0%). This indicates that eucalyptus cultivation is mainly undertaken by experienced, working-age farmers. Regarding education, the majority of respondents had attained lower secondary education (70.0%), while only a small proportion had completed university (10.0%) or postgraduate education (5.0%). This suggests that formal education levels among eucalyptus growers remain relatively modest. In terms of farming experience, most respondents had considerable experience in eucalyptus cultivation, with 68.3% reporting 11–21 years of experience and 18.3% having more than 21 years. This reflects a well-established practice of eucalyptus plantation management in the study area. With respect to land scale, nearly half of the respondents (48.3%) managed small cultivation areas of less than 0.5 ha, indicating that eucalyptus production is largely small-scale. Only 18.3% of respondents cultivated areas larger than 1 ha. Notably, all respondents (100%) reported having participated in agricultural–forestry extension training, highlighting the strong coverage of extension services in the study region (Table 2). These training programmes, delivered by district-level forestry extension agencies, covered topics such as sustainable plantation management, timber harvesting practices, post-harvest site rehabilitation, and technical training on the planting and tending of fast-growing plantation tree species. The universal participation rate (100%) indicates broad exposure of eucalyptus growers to formal knowledge on land management, which constitutes an important contextual factor when interpreting their perceptions of soil degradation.

The survey questions focused on collecting respondents' perceptions of land degradation within the study area. Specifically, participants were asked whether they believed the land was degraded (yes/no). If the answer was "yes," they were further requested to assess the level of degradation (mild, moderate, or severe). In addition, the questionnaire explored respondents' opinions on the causes of land degradation and the observable signs or indicators of degradation they have noticed in practice.

Table 2. Socio-demographic characteristics of the respondents (n=60)

No.	Variable	Category	Frequency	Percentage (%)
1	Gender	Male	48	80.0
		Female	12	20.0
2	Age (years)	20-30	3	5.0
		31-40	17	28.3
		41-50	23	38.3
		51-60	15	25.0
		>60	2	3.3
3	Education level	No formal education	0	0.0
		Primary education	9	15.0
		Secondary education	42	70.0
		University degree	6	10.0
		Postgraduate degree	3	5.0
4	Experience in eucalyptus cultivation (years)	1-10	8	13.3
		11-21	41	68.3

		22-32	11	18.3
		33-43	0	0.0
		> 43	0	0.0
5	Eucalyptus cultivation area (ha)	< 0.5	29	48.3
		0.5 - 1	17	28.3
		> 1	11	18.3
6	Participated in agricultural - forestry extension training	Yes	60	100.0
		No		0.0

Group discussion: In addition to individual interviews, several on-site focus group discussions were held with forest growing households. The aim was to obtain multidimensional perspectives from local communities, thereby clarifying issues raised in individual interviews concerning soil degradation in eucalyptus plantations, its impacts, and the strategies employed to manage it. The focus groups provided access to diverse and multifaceted viewpoints and captured the practical realities of soil degradation and management in the study areas. Participants for the focus group discussions were selected through purposive sampling, with the aim of ensuring diversity in terms of farming experience, cultivation area, age, and gender. Priority was given to individuals who had demonstrated direct knowledge of local land conditions, including both those who had applied sustainable land management practices and those who had not. Each focus group session comprised between six and ten participants and lasted approximately 60 to 90 minutes. Sessions were facilitated using a structured discussion guide that covered the same core thematic areas as the individual interviews: the perceived causes, indicators, and severity of soil degradation, as well as locally practised management and mitigation strategies. Discussions were recorded with participants' informed consent and subsequently transcribed for analysis. The principal outcomes of the focus group discussions included identification of consensus views on the most critical drivers of soil degradation under eucalyptus cultivation, recognition of locally observable soil quality indicators, and shared assessments of the adequacy and effectiveness of existing management interventions. These outcomes were used to cross-check, validate, and enrich the findings derived from the semi-structured interviews.

2.2.2 Data analysis

The reported causes of degradation were grouped into natural and anthropogenic categories: natural causes included weather conditions and topography, whereas anthropogenic causes comprised silvicultural practices such as planting methods, slash treatment, site preparation, rotation length, and harvesting practices. Soil degradation severity was classified into three levels—mild, moderate, and severe—following the Ministry of Natural Resources and Environment (2024). The perceived severity of soil degradation was synthesised according to the number of causal factors identified, and the reported manifestations of degraded soil were expressed as percentages within each severity class. Descriptive statistics, including frequency counts and percentage distributions, were computed for all key variables to characterise respondents' perceptions across the full sample. Relationships between socio-demographic characteristics of the respondents (such as age group, years of farming experience, and cultivation area) and their perceptions of degradation severity and causal factors were also analysed. Reliability of the qualitative data was enhanced through methodological triangulation: convergent themes emerging from both the semi-structured interviews and the focus group discussions were identified and reported, while divergent responses were noted and examined in relation to site-specific or individual contextual factors. Field notes recorded during data collection were used to contextualise and supplement the quantitative summaries. All data management and descriptive analysis were performed using Microsoft Excel 2016.

3 Results

3.1 Perceived soil degradation and its severity in eucalyptus plantations

Survey results indicate that local communities in Central Vietnam widely perceive soil degradation in eucalyptus plantations as a highly concerning issue. Overall, 93.3% of respondents perceived that their plantation soils had degraded, and none considered their soils to be in a satisfactory condition, while only 6.7% (4 respondents) expressed uncertainty about the presence or extent of degradation. These findings indicate that local communities broadly report a perceived decline in plantation soil condition, signalling widespread farmer concern about soil degradation that warrants further investigation and management attention. Most interviewees (56 of 60) perceived that soil degradation had occurred, and the majority (81.6%) characterised the degree of degradation as moderate or severe (Table 3). Specifically, 38.3% of respondents classified degradation as moderate and 43.3% as severe, compared with only 11.7% who perceived it as mild and 6.7% who were uncertain. Respondents were asked to assess degradation severity based on their own direct observations of changes in soil appearance and plantation productivity. Mild degradation was generally described by respondents as slight, early-stage deterioration with limited impact on yield; moderate degradation as clearly noticeable decline affecting plantation performance; and severe degradation as pronounced, widespread deterioration with substantially reduced yields across successive rotations. Together, these findings highlight widespread farmer-perceived soil degradation in eucalyptus

plantation landscapes, with potentially serious consequences for forest productivity and long-term land use sustainability in the region.

Table 3. Summary of interview results on the degree of soil degradation in eucalyptus plantation forests

No.	Degree of degradation	Percentage of respondents (%)
1	Uncertainty	6.7
2	Mild degradation	11.7
3	Moderate degradation	38.3
4	Severe degradation	43.3
Total		100

3.2 Causes of soil degradation in eucalyptus plantations

Survey responses indicate that farmers primarily attribute soil degradation in eucalyptus plantations suggest that farmers primarily attribute perceived degradation to human management practices rather than to natural conditions (Table 4). It is important to note that these reflect farmer-perceived causes based on field observations and practical experience, and should not be interpreted as empirically verified causal relationships. Among natural factors perceived by respondents, 62.5% identified extreme precipitation events as a contributing factor, while steep slopes and dissected terrain were mentioned far less frequently (19.6% and 12.5%, respectively).Anthropogenic causes, however, dominated farmers' explanations. Monoculture plantations were cited by 87.5% of respondents, greatly exceeding other management-related drivers such as clear-cutting (32.1%), vegetation management through clear-cutting and burning (25.0%), short rotation cycles (16.1%), removal of branches and residues after harvesting (10.7%), mechanical soil preparation (8.9%), and timber-extraction road construction (5.4%).

Table 4. Summary of interview results on the causes of soil degradation in eucalyptus plantation forests

No.	**Causes of soil degradation**	**Percentage of Respondents (%)**
Natural factors		
1.	Extreme precipitation events (heavy rainfall, irregular floods, storms, short-duration intense rain)	62.5
2.	Steep slopes	19.6
3.	Dissected terrain	12.5
Anthropogenic factors		
1.	Monoculture plantations	87.5
2.	Clear-cutting	32.1
3.	Vegetation management by clear-cutting and burning	25.0
4.	Short rotation cycles	16.1
5.	Removal of branches and residues after harvesting	10.7
6.	Mechanical soil preparation	8.9
7.	Timber-extraction road construction	5.4

These findings indicate that farmers view soil degradation as the outcome of interacting natural and human pressures, but with plantation management—especially monoculture forestry—playing the decisive role. This perception is critical because it suggests that much of the degradation could be mitigated through improved silvicultural practices and landscape management, rather than being seen as an inevitable consequence of uncontrollable natural processes.

3.4 Manifestations of soil degradation in eucalyptus plantations

Survey results show that, in addition to the universal perception of declining productivity, farmers consistently reported multiple visible symptoms of soil degradation in eucalyptus plantations (Table 5). Forest productivity decline compared with the previous rotation was cited by all respondents (100%), while soil compaction, loss of porosity, and reduced fertility were reported by 89.3% of farmers as perceived signs of soil deterioration, suggesting widespread farmer concern about the physical condition and fertility of their plantation soils. High proportions of respondents also perceived reduced organic matter on the soil surface (85.7%) and increased exposure of the ground surface with gravel and stones (78.6%), both of which point to depletion of protective litter cover and topsoil loss. Rapid soil drying after rainfall (73.2%) and the presence of rills and gullies (64.3%) further highlight impaired water infiltration and active erosion processes on these sites.

Table 5. Summary of perceived manifestations of soil degradation in eucalyptus plantations

No.	Indicators of degraded soil	Percentage (%)
1.	Forest productivity decreases compared to the previous rotation	100.0
2.	Soil becomes compacted, less porous, and infertile	89.3
3.	Reduced organic matter on the soil surface	85.7
4.	Ground surface exposed with gravel and stones	78.6
5.	Soil dries quickly after rainfall	73.2
6.	Soil erosion forming rills and gullies	64.3
7.	Sparse understory vegetation	62.5

Among biological indicators, 62.5% of respondents reported sparse understory vegetation, which they perceived as a sign of deteriorating soil conditions and competitive pressure from eucalyptus stands on ground-layer plant growth. Taken together, these farmer-reported indicators present a consistent picture of perceived soil degradation across physical, biological, and productivity dimensions of their plantation sites.

4 Discussion

4.1 Underlying drivers of soil degradation

Eucalyptus is a widely planted species in Vietnam and many other tropical countries because of its rapid growth and high economic value. However, the large-scale expansion of monoculture eucalyptus plantations in Vietnam has raised concerns about long-term impacts on soil health and biodiversity (Buu Nguyen, 2024). Multiple studies have clarified the mechanisms through which eucalyptus plantations contribute to soil degradation, including reductions in humus and total nitrogen (Nguyen Tien Linh et al., 2024) and decreased microbial activity compared with natural ecosystems (Gama-Rodrigues et al., 2008). Allelopathic compounds released via rainfall and litter decomposition can accumulate as phenolic acids, suppressing understory vegetation and woody plants and disrupting nutrient cycling, particularly of nitrogen and phosphorus (Ullah et al., 2023).

Eucalyptus plantations can further exacerbate degradation through competition for water and nutrients and changes to soil structure. Eucalypts planted near rice paddies have been shown to compete for water and light and to release compounds that inhibit crop growth (Islam et al., 2025). Their vigorous, deep root systems efficiently exploit groundwater, causing groundwater decline and soil desiccation during dry seasons. When plantations are maintained over multiple rotations without soil amelioration measures, these cumulative effects intensify, leading to productivity decline and increased demand for fertiliser inputs, thereby creating an economic and environmental vicious cycle.

The relatively high level of perceived degradation reported by respondents may be associated with several contextual factors, though the present study did not test these relationships directly. First, the number of plantation rotations may be associated with the perceived degree of degradation; in areas with two to four or more eucalyptus rotations, observable indicators such as yield decline, changes in soil appearance, reduced tilth, and visible erosion may become more apparent to farmers over time. Second, initial site conditions are likely relevant: sites that were already in poor condition before plantation establishment may deteriorate more noticeably under successive rotations. Third, the long-term cultivation experience of local farmers may support their capacity to recognise changes in plantation soil condition across planting cycles. Variation in perceived severity is closely linked to the same biophysical processes. Successive eucalyptus cultivation significantly increases bulk density and negatively affects soil physicochemical properties and enzyme activity (Jiang et al., 2024), while also reducing soil microorganisms and increasing microbial stress (Chen et al., 2013). These effects are cumulative, so longer cultivation periods and more rotations yield more severe and difficult to reverse impacts, particularly on nutrient-poor, acidic, or previously degraded soils.

An important issue is whether local perceptions accurately reflect actual degradation severity. Numerous studies have demonstrated strong agreement between farmers' perceptions and scientific indicators of soil quality. Falcão et al. (2024) showed that farmers' views on soil health are crucial for assessing degradation and mitigation effectiveness, in line with international soil policy frameworks. Izadi and Aghamir (2024) demonstrated that integrating formal and indigenous knowledge through ensemble learning approaches improves soil quality assessment. Nevertheless, perceptions are shaped by subjective factors such as experience, education, and age; some farmers may overestimate severity after sharp yield declines, whereas others may underestimate it if they lack long-term observation or reference sites.

The strong consensus that degradation is occurring (93.3% of respondents) and that it is moderate or severe for most sites (87.5%) indicates that soil degradation is both widespread and serious in Central Vietnam's eucalyptus plantations. This situation threatens the sustainability of production forest ecosystems. Yet, as shown in South Africa, awareness alone rarely leads to widespread adoption of restoration practices because financial constraints, limited technical support, and

weak institutional backing remain major barriers (Ebhuoma et al., 2022). Comprehensive policy, technical, and financial support is therefore required to translate awareness into effective soil improvement actions.

4.2 Management practices, manifestations, and implications

Survey results show that monoculture planting is perceived as the dominant driver of soil degradation (87.5%), consistent with international evidence on the impacts of monoculture plantation systems. Studies from Indonesia indicate that fast-growing monocultures reduce soil water content, diminish nutrient supply capacity, and suppress understory vegetation, leading to biodiversity loss, increased erosion, and declining soil quality (Widyati et al., 2022). Eucalyptus monocultures create uniform, low diversity stands that disrupt nutrient cycling, and recent work has shown that successive monoculture rotations alter rhizosphere bacterial networks, reducing productivity and degrading soil under intensive cultivation (Wang et al., 2024). Similar patterns have been observed in Kerala, India, where soils under monocultures are less healthy and less productive than those under natural forests, with markedly lower soil carbon stocks (Arathi Menon, 2021).

Respondents also highlighted several specific management practices that contribute to degradation. Vegetation management by clear cutting and burning (25.0%) is a notable example. Studies in hybrid eucalyptus plantations show that burning residues destroys soil structure, reduces fertility, and emits large amounts of CO_2 (Zhang et al., 2022), whereas retaining residues along contour lines improves soil fertility and stabilises microbial communities (Wang et al., 2024). Clear cutting (32.1%) and short rotation cycles (16.1%) are closely linked to economic pressures, but they cause abrupt loss of cover, increase erosion, and shorten recovery periods. Longer rotations have been shown to enhance soil organic carbon and microbial recovery, thereby improving sustainability (Xu et al., 2020; Zhou et al., 2017). Less frequently mentioned causes—residue removal, mechanised soil preparation, and timber extraction roads—still contribute significantly through organic matter loss, compaction, and localised erosion (Carneiro, Fabião, & Madeira, 2014).

The farmer-reported manifestations in this study are broadly consistent with measured soil property changes documented in the scientific literature on eucalyptus plantations, lending credibility to the perceptions recorded. Specifically, farmers' high recognition of soil compaction and loss of porosity corresponds with empirical findings of increased bulk density and reduced macroporosity under successive eucalyptus rotations; reported rapid drying after rainfall aligns with scientific evidence of lower water infiltration rates; perceived gully erosion and exposure of gravel and stones are consistent with measured increases in soil surface loss; and observations of reduced surface organic matter and sparse understory vegetation parallel documented declines in soil organic carbon and soil biota. Empirical studies confirm that eucalyptus plantations commonly exhibit higher bulk density, lower infiltration capacity, greater soil loss, and reduced soil biological activity compared with natural or mixed-species forests (Banfield et al., 2018; Silva et al., 2016; Zou, 1993). Together, these symptoms form a reinforcing degradation cycle in which loss of vegetation and organic matter leads to compaction and poor water retention, which in turn reduces productivity and encourages more intensive harvesting and shorter rotations.

The depth and consistency of local knowledge about these processes have important implications. Farmers' ability to identify multiple, interacting degradation indicators demonstrates a strong basis for participatory soil management and restoration programmes. Integrating indigenous knowledge with scientific evidence can support zoning of interventions according to degradation severity and help prioritise measures such as organic matter management, erosion control, mixed-species planting, and reduced-impact harvesting.

Addressing soil degradation in Central Vietnam's eucalyptus plantations therefore requires an integrated, multi-level management strategy. Key priorities include transitioning from monocultures to mixed-species stands, retaining residues and avoiding burning, extending rotations, limiting heavy machinery, maintaining understory or cover crops, and introducing allelopathy tolerant species. These technical measures must be embedded within supportive policy frameworks and financial incentives to enable adoption by smallholders. When coupled with participatory, bottom-up governance that values local ecological knowledge, such strategies can improve soil health, sustain eucalyptus productivity, and enhance rural livelihoods.

5 Conclusion

This study demonstrates that farmers in Central Vietnam's eucalyptus plantations widely perceive soil degradation as both widespread and severe, raising significant concerns about the long-term sustainability of these production forest ecosystems. These farmer-reported perceptions are broadly corroborated by independent empirical evidence: measured increases in bulk density, reductions in soil organic carbon, higher erosion rates, and diminished soil biota under eucalyptus monocultures all align with what farmers reported observing in this study. Respondents identified anthropogenic factors—particularly monoculture planting systems and short rotation cycles—as the primary perceived drivers of degradation, while acknowledging natural pressures such as steep slopes and heavy rainfall as contributing but secondary factors.

Addressing these issues requires an integrated, multi-level management strategy. Key technical priorities include transitioning from monocultures to mixed-species stands, retaining harvest residues and avoiding burning, extending rotation cycles to support soil and microbial recovery, and adopting reduced-impact harvesting practices that limit compaction and erosion. While local awareness of degradation is high, financial and institutional barriers often prevent the adoption of restoration practices. Therefore, these technical measures must be supported by policy frameworks and financial incentives that empower smallholders to prioritise soil health. The depth and breadth of local knowledge documented in this study underscore its value as an integral component of evidence-based soil management. Integrating farmer-reported perceptions with scientific monitoring can strengthen zoning of interventions, improve targeting of restoration measures, and support participatory governance that is both ecologically sound and locally legitimate.

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Conflict of interest
The authors declare no conflict of interest.

Authors' contribution
DTT: Project administration, Funding acquisition, Conceptualization, Methodology, Writing - Original draft preparation, Formal analysis. **DTBN**: Conceptualization, Supervision, Validation, Writing - Reviewing and Editing. **PMQ**: Data curation, Formal analysis, Investigation. **LTH**: Data curation; Methodology, Investigation.

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