International Journal of Nature Science (IJNS)

Regd.No. 114/2017

Estd:2024

https://doi.org/10.64906/IJNS.2026.03.03.1

Strategies for Agrarian Resilience in the Nilgiris District of Tamil Nadu:

Integrating Crop Diversification, Agricultural Insurance, Ecosystem Restoration and Traditional Ecological Knowledge

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Article History

Volume:3, Issue:3, 2026

Received: 17th July 2026

Accepted: 10th August 2026

Published: 15th August 2026

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The Nilgiris District of Tamil Nadu, a biodiversity hotspot in the Western Ghats, faces intensifying climate stressors including rising temperatures (approximately 0.5°C observed), erratic monsoons with rainfall deficits reaching 28–47% in recent seasons, frost, hail, and extreme events linked to El Niño/Super El Niño patterns. These threaten tea (the dominant crop), coffee, hill vegetables, and indigenous farming systems. This comprehensive review synthesizes peer-reviewed literature (primarily 2020–2026) and recent evidence on agrarian resilience strategies. Two complementary pathways receive focused attention: crop diversification and agricultural insurance. Evidence shows that farms diversifying into vegetables, floriculture, dairy and agroforestry alongside tea report 23–35% lower income volatility than monoculture tea farms, with risk-pooling across multiple enterprises proving more effective than crop diversification alone. However, diversification is constrained by limited market access, high capital requirements, and weak extension services, with Farmer Producer Organizations (FPOs) playing a critical role in overcoming these barriers. On insurance, the Pradhan Mantri Fasal Bima Yojana (PMFBY) shows markedly low penetration in the Nilgiris (less than 15% of surveyed farmers enrolled), largely because the scheme is designed around field crops rather than perennial tea and hill-specific horticulture. Weather Index-Based Insurance (WII) is identified as a promising alternative but is hindered by basis risk arising from the district's sharp topographic and microclimatic variation. Beyond these, the review integrates evidence on shade management and soil–water conservation for tea, ecosystem restoration of shola–grassland mosaics, traditional ecological knowledge (TEK) of Toda, Irula and other communities, organic/regenerative practices, agroforestry carbon sequestration (mean ~8.67 Mg C/ha/year), and institutional support mechanisms. Diversification and insurance function best as complements: diversification lowers the probability of total crop failure and reduces insurance costs, while insurance protects income during the transition period before diversification investments mature. Institutional intermediation through FPOs and cooperatives emerges as the strongest common enabler. The review identifies gaps in longitudinal data, hyper-local actuarial modelling, gender-disaggregated analysis, and market-linkage research, and calls for future studies to address these to strengthen resilience planning for hill agriculture.

Keywords: *Nilgiris; Crop Diversification; Agricultural Insurance; Climate Resilience; PMFBY; Weather Index-Based Insurance; Farmer Producer Organizations; Hill Agriculture; Traditional Ecological Knowledge; Shola–Grassland Restoration; Agroforestry; Tea*

Author's citation: P. Riaz Ahamed et al. Strategies for Agrarian Resilience in the Nilgiris District of Tamil Nadu. *Int.J.Nat.Sci*.Vol.3(3). 2026.Pp:1-10. https://doi.org/10.64906/IJNS.2026.03.03.1

1. Introduction and Context

The Nilgiris district with Ooty (Udhagamandalam) as its headquarters represents a unique agro-ecological zone in the Western Ghats of Tamil Nadu. Characterized by high-altitude hill agriculture (elevations roughly 900–2,600 m), dual monsoons, and a temperate climate, the district's economy is heavily dependent on tea cultivation, complemented by vegetable farming, floriculture, coffee, spices and dairy. Over 90–94% of land holdings are small or marginal, and more than 97% of cultivation is rainfed. This monoculture dependency, combined with increasing climate variability, has rendered small and marginal farmers highly vulnerable to agrarian distress.

Recent peer-reviewed scholarship has increasingly focused on complementary resilience pathways: crop diversification (to reduce ecological and economic risk), agricultural insurance (to buffer income volatility), ecosystem restoration, traditional ecological knowledge (TEK), shade management, soil and water conservation, and institutional innovations such as Farmer Producer Organizations (FPOs). This review synthesizes recent literature specific to the Nilgiris and contextualizes it within broader Tamil Nadu, Western Ghats and Indian hill-agriculture evidence, with particular attention to studies published between 2020 and 2026.

2. Climate Vulnerability and Agrarian Stress in the Nilgiris

2.1 Tea Sector Vulnerability

Research on climate impacts in the Nilgiris focuses predominantly on tea, the district's primary crop occupying the majority of net sown area (historically ~55,000–56,400 ha) and ranking first in Tamil Nadu production. Sathishkumar et al. (2021, 2022) documented significant links between rising temperatures, erratic rainfall and decreased tea yield. Thermal stress during vital growth periods adversely affects productivity. Subsequent work (Sathishkumar et al., 2023) assessed the resilience of small tea growers, revealing compounded vulnerabilities to climate shocks, market price fluctuations and limited credit access. Resilience requires comprehensive strategies beyond climate adaptation alone. Studies in 2024–2026 further reiterated the risks of monoculture, indicating that diversified tea gardens recover more effectively from climatic disturbances.

UPASI Tea Research Foundation analyses (Murugesan, 2026) highlight Super El Niño risks: average temperature rise of approximately 0.5°C, higher frequency of dry days, short-duration high-intensity rainfall, and expanded geographic reach of frost and hailstorm damage. Tea (Camellia sinensis) is exceptionally vulnerable to even slight environmental shifts in temperature, soil moisture, irradiance and humidity. Long-term data indicate that total annual rainfall volume has not plummeted dramatically, but temporal distribution has undergone major shifts.

2.2 Broader Western Ghats and District Context

Reddy et al. (2021) examined climate change adaptation strategies across the Western Ghats. Their comparative analysis of hill districts (including Tamil Nadu's Nilgiris and neighbouring Kerala's Wayanad) found that altitude-specific microclimates amplify climate risks, making localized adaptation strategies more effective than generic state-level prescriptions. This finding is critical for the Nilgiris, where elevation gradients create highly heterogeneous farming conditions. Recent observations (2025–2026) recorded Southwest monsoon deficits of 28–47% in parts of the district, with Ooty urban limits experiencing particularly severe shortfalls, threatening both tea and vegetable production and intensifying water scarcity.

Table 1. Observed Climate Trends and Stressors in the Nilgiris (Recent Decades to 2026)

Parameter	Observation	Implication
Temperature	~0.5°C rise; expanded frost/hail reach	Yield & quality loss
Rainfall pattern	More dry days; intense short events; 28–47% SW monsoon deficits	Drought & erosion risk
Extremes	El Niño / Super El Niño linkage	Bush stress, pest surge
Annual rainfall range	900–1,500+ mm (bimodal)	Temporal redistribution critical

Table 2. Approximate Area and Production of Major Crops in the Nilgiris

Crop	Area (ha)	Production (t)	Notes
Tea	55,000–56,400	549,000–750,000	1st in TN; dominant
Coffee	7,200–8,200	6,400–10,700	2nd in TN
Carrot	2,100–2,700	55,000–83,000	High-value vegetable
Potato	940–1,300	28,000–38,000	Erosion-sensitive
Cabbage / Beans / Beet	Variable	High yields on suitable land	EHI-constrained

3. Crop Diversification as a Resilience Strategy

3.1 Direct Evidence from the Nilgiris

Sathishkumar et al. (2023) provide the most targeted peer-reviewed evidence. Using a mixed-methods approach combining farm-level surveys with climatic data analysis across agro-climatic zones within the district, the authors documented the following key findings:

- **Diversification typologies:** Farmers in Ooty taluk have progressively shifted from pure tea monoculture to integrated systems incorporating vegetables (carrots, beans, cabbage), floriculture (gerbera, carnations), and fruit orchards (peaches, plums). Diversified farms exhibited 23–35% lower income volatility compared to monoculture tea farms over a five-year period.
- **Risk-pooling effects:** Diversification across enterprises (crop + dairy + agro-tourism) provided superior resilience than crop diversification alone, suggesting that integrated farming systems are more robust in hill ecosystems.
- **Barriers:** Market access limitations, high initial capital requirements for switching crops, and weak extension services were primary constraints. Farmers with access to Farmer Producer Organizations (FPOs) were significantly more likely to diversify successfully.

3.2 National and Hill-Agriculture Evidence

Kumar et al. (2022), using panel data across Indian agro-ecological zones, established that diversification indices (Simpson's Index of Diversity) were positively correlated with household-level agrarian resilience, measured as the inverse of income coefficient of variation. Birthal et al. (2021) found that diversification into high-value horticulture and livestock reduced household vulnerability to climate shocks by improving resource-use efficiency and stabilizing year-round cash flows — particularly relevant to Ooty, where the cool climate permits off-season vegetable production commanding premium prices. Sharma and Nain (2022) argued that hill districts require altitude-specific diversification models; for high-altitude zones (>2,000 m) they recommended shifting toward horticulture, floriculture and medicinal plants — precisely the trajectory documented by Sathish kumar et al. (2023).

Table 3. Diversification Pathways and Documented Resilience Benefits

Pathway	Examples	Resilience Benefit
Crop diversification	Vegetables, floriculture, fruit	23–35% lower income volatility
Enterprise diversification	Crop + dairy + agro-tourism	Superior risk-pooling
Millet & pulse expansion	Ragi, little millet, pulses (Gudalur)	Drought tolerance, nutrition
Medicinal & aromatic plants	Herbs suited to cool climate	Premium markets, low input
Agroforestry / multi-tier	Pepper, coffee under shade trees	Biodiversity, carbon, income

4. Agricultural Insurance Solutions

4.1 The PMFBY and Tamil Nadu Implementation

The Pradhan Mantri Fasal Bima Yojana (PMFBY), launched in 2016, is India's flagship crop insurance scheme. Kumar and Singh (2021) evaluated its effectiveness in Tamil Nadu and revealed significant spatial disparities: while Cauvery delta districts showed reasonable enrolment and claim settlement ratios, hill districts including the Nilgiris recorded among the lowest insurance penetration rates in the state. Less than 15% of surveyed Ooty farmers had enrolled in any crop insurance scheme (Sathishkumar et al., 2023), with tea growers particularly excluded due to the perennial crop status.

Key reasons for low penetration include:

- **Crop specificity:** PMFBY design is heavily oriented toward Kharif/Rabi field crops (paddy, millets, pulses), while Nilgiris agriculture is dominated by perennial tea and annual vegetables with different risk profiles.
- **Awareness deficits:** Lower literacy among small tea growers and language barriers in scheme communication.
- **Delayed claim settlements:** Administrative delays eroded trust in hill areas where banking infrastructure is sparse.

Raju and Chand (2021) provided a pan-Indian critique, noting that schemes have historically underperformed in non-notified crop areas and horticulture belts — both characteristics of the Nilgiris. They argued for crop-specific actuarial redesign rather than one-size-fits-all approaches.

4.2 Weather Index-Based Insurance (WII)

Given the limitations of indemnity-based insurance in hill agriculture, recent scholarship has examined Weather Index-Based Insurance (WII). Kumar et al. (2020) analyzed WII pilots across Indian states, finding that index-based products reduced moral hazard and transaction costs — critical advantages for remote hill districts where individual farm loss verification is expensive. However, basis risk (the mismatch between index triggers and actual farm losses) remains a significant challenge in heterogeneous topography. For the Nilgiris, where rainfall and temperature can vary dramatically across short distances due to orographic effects, designing appropriately localized weather indices remains technically demanding.

Singh et al. (2023) found that insured households recovered from climate shocks 1.5–2 years faster than uninsured counterparts, but this effect was concentrated in areas with high scheme awareness and efficient claim processing. For Nilgiris farmers, insurance effectiveness depends as much on institutional delivery mechanisms as on product design.

Table 4. Comparison of Insurance Approaches for Nilgiris Agriculture

Feature	PMFBY (Indemnity)	Weather Index Insurance
Design focus	Field crops (Kharif/Rabi)	Weather parameters
Suitability for tea	Low (perennial status)	Potentially high if localized
Transaction / verification cost	High in remote hills	Lower (index-based)
Key challenge	Low penetration (<15%)	Basis risk from topography
Enabling factor	FPO group products	Hyper-local actuarial models

5. Complementary Resilience Strategies

5.1 Shade Management, Soil and Water Conservation

For tea under Super El Niño conditions, recommended field-level interventions include strategic shade management using trees such as Gliricidia sepium to regulate microclimates, soil and water conservation engineering, customised crop care to build drought resistance, diversified planting material (avoiding large-scale monoclonal planting), pruning schedules aligned with wind/frost/drought vulnerability, strengthened pest surveillance (red spider mite, blister blight, grey blight), and protection of young tea via hardened nursery stock, shade, mulch and irrigation. The governing principle is to protect the bush before protecting the short-term crop.

A 2026 Scientific Reports study refined FAO land-evaluation criteria by introducing an Erosion Hazard Index (EHI) that jointly integrates slope gradient and active land-management conditions (especially terracing). Under the revised criteria, tea exhibited high and moderate suitability across 37.4% and 44.4% of a representative watershed, respectively. Potato, cole and root vegetables were more constrained by high EHI values.

Table 5. Land Suitability under Revised EHI Criteria (Illustrative Watershed)

Crop Group	Highly Suitable (%)	Moderately Suitable (%)	Key Constraint
Tea	37.4	44.4	Minimal
Potato / Cole / Root veg	6.9	8.2	EHI > 0.54–0.62
Fruit crops	—	12.6	Temp, acidity, texture

5.2 Ecosystem Restoration and Traditional Ecological Knowledge

Community-led restoration of shola–grassland mosaics is advancing through organisations such as Keystone Foundation and Edhkwehlynawd Botanical Refuge (EBR). More than 34,000–38,000 ha have been cleared of invasive species (lantana, Senna spectabilis, eucalyptus, wattle). Native nurseries (150+ species) and planting of tens of thousands of tussock grasses, shrubs and trees have facilitated wildlife return, including rising Nilgiri Tahr populations. Traditional Ecological Knowledge of the Todas (grassland preference, seasonal indicators, pioneering species) and Irulas (seed storage, weather prediction via biota, millet systems) offers low-cost, culturally congruent nature-based solutions. Integration of TEK with contemporary science is repeatedly advocated for climate resilience and carbon sequestration.

Table 6. Key Ecosystem Restoration Metrics and TEK Elements

Intervention / Knowledge	Scale / Content	Outcome / Application
Invasive removal	34,000–38,000+ ha	Native grassland recovery
Native planting / nurseries	25,000+ plants (2025); 150 species	Wildlife return (Tahr increase)
Toda TEK	Grassland preference, seasonal cues	Restoration planning
Irula TEK	Seed storage, biota weather cues	Contingency cropping

5.3 Organic, Regenerative and Carbon Practices

Organic and regenerative practices (vermicompost, jeevamrit, panchagavya, non-hybrid seeds, mulching) reduce input costs (reports of ~35% reduction in committed pockets) while improving soil health and drought resilience. Agroforestry systems in the Nilgiris demonstrate carbon sequestration rates ranging from 0.38–21.67 Mg C/ha/year (weighted mean ~8.67 Mg C/ha/year). Community-based and nested carbon-project models score highest for local feasibility, cost-effectiveness and alignment with smallholder conditions. Simplified MRV combining participatory monitoring with digital tools can lower transaction costs substantially.

Table 7. Selected Resilience Practices and Reported Benefits

Practice	Primary Benefit	Supporting Evidence
Shade trees (Gliricidia etc.)	Microclimate regulation	UPASI / Murugesan 2026
Terracing & contour	Reduced EHI / erosion	Scientific Reports 2026
Mulching / RWH	Moisture retention	KVK advisories
Organic inputs	~35% lower production cost	Local organic pockets
Agroforestry	Carbon + income diversity	Frontiers 2025 review

6. Integrated Resilience Framework

The most policy-relevant scholarship argues that diversification and insurance are complements, not substitutes. Sathishkumar et al. (2023) modelled this interaction: farmers who combined crop diversification with insurance participation achieved the highest resilience scores. Diversification reduces the probability of total crop failure (lowering insurance premiums and basis risk), while insurance provides income protection during transition periods when diversification investments have not yet matured.

Institutional intermediation through cooperatives, FPOs and self-help groups is the critical common enabler. Organised farmer groups demonstrated superior capacity to collectively negotiate diversification inputs, access group-based insurance products, and share market information for diversified produce. Kumar et al. (2023) corroborated that FPOs significantly enhance agricultural resilience by reducing transaction costs for both diversification and risk-management services.

Table 8. Complementary Roles of Diversification and Insurance

Function	Crop Diversification	Agricultural Insurance
Risk reduction	Lowers probability of total failure	Buffers residual income loss
Transition support	Builds long-term adaptive capacity	Protects income while investments mature
Cost implication	May raise short-term capital need	Premiums lower with diversification
Key enabler	FPOs / market linkages	FPOs / local actuarial design

Table 9. Institutional Actors and Enabling Roles

Actor / Scheme	Role in Resilience
FPOs & Cooperatives	Collective input access, group insurance, market linkages
KVK Nilgiris	Climate advisories, non-hybrid seeds, mulching, sprinkler promotion
Horticulture Department	Organic schemes, rainwater harvesting subsidies, vermicompost
Forest Dept / Project Nilgiri Tahr	Invasive clearance, grassland restoration, water security
TN Agriculture Budget (2026-27)	Millet mission, organic certification support, wildlife conflict measures

7. Research Gaps and Methodological Limitations

Despite growing scholarship, several gaps remain in the Nilgiris-specific peer-reviewed literature:

1. **Longitudinal deficit:** Most studies rely on cross-sectional or short-panel data. Long-term (10+ year) longitudinal studies tracking diversified versus non-diversified farms are absent.
2. **Actuarial specificity:** No peer-reviewed study has yet developed Nilgiris-specific actuarial models for weather index insurance. Topographic complexity demands hyper-local index design.
3. **Vegetable and floriculture focus:** While tea dominates the literature, peer-reviewed research on diversification into vegetables, floriculture and medicinal plants remains comparatively thin.
4. **Gender dimensions:** The resilience literature is notably silent on gendered dimensions of diversification and insurance access, despite women playing significant roles in tea plucking and vegetable cultivation.
5. **Market linkage analysis:** Diversification success depends on market access, yet peer-reviewed analysis of value chains for diversified produce from the Nilgiris is limited.

8. Conclusion and Recommendations

Climate vulnerability is acute and well-documented, particularly for tea monoculture systems. Crop diversification into vegetables, floriculture, fruit orchards, millets, pulses and integrated dairy demonstrably reduces income volatility (23–35%) and enhances adaptive capacity. Agricultural insurance penetration remains critically low (<15%), hampered by scheme designs ill-suited to perennial crops and hill topography; Weather Index-Based Insurance offers theoretical advantages but requires localized actuarial development to manage basis risk. Ecosystem restoration of shola–grassland mosaics, TEK integration, shade and conservation practices, and organic/regenerative approaches further strengthen system resilience. Institutional intermediation through FPOs and cooperatives is the most consistent enabler of both diversification and insurance uptake.

Priority recommendations:

1. Scale community native nurseries and invasive-species clearance guided by Toda and other TEK.
2. Mandate climate-adaptive extension content and appoint language-capable tribal extension coordinators in high-vulnerability blocks.
3. Redesign or complement PMFBY with topography-specific Weather Index products and group-based insurance via FPOs.
4. Expand micro-irrigation subsidies (gravity sprinklers preferred for hilly terrain), organic certification support, and millet/pulse missions.
5. Strengthen market linkages and value-chain infrastructure for diversified produce (e-NAM, inter-state linkages, organic premiums).
6. Develop simplified carbon aggregation and hybrid MRV systems so smallholders can capture co-benefits of agroforestry and restoration.

Future research should prioritise longitudinal designs, gender-disaggregated analysis, hyper-local actuarial modelling for WII, and rigorous evaluation of market linkages for diversified produce. These pathways can secure livelihoods, biodiversity and water services in this fragile highland agroecosystem.

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Additional supporting sources: TNAU contingency plans; NABARD Potential Linked Credit Plans for Nilgiris; AESA network analyses on El Niño resilience and pulse expansion (2026); Keystone Foundation and EBR restoration reports; Tamil Nadu Agriculture Budget references (2026); contemporary media syntheses of monsoon deficits and organic initiatives (The Hindu, Economic Times, Deccan Chronicle, 2025–2026).