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Linking Agroforestry, Rainfall Variability, and Groundnut Market Volatility in India

Poongodi P[1*] and R Alagesan[2]

[1]*Department of Economics*
[2]*Lady Doak College, Madurai*

* Corresponding author. E-mail: poongodi@ldc.edu.in

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ABSTRACT

Groundnut (Arachis hypogaea L.) is a key oilseed crop in India, primarily grown under rainfed conditions vulnerable to monsoon variability. This study analysed how agroforestry systems interact with rainfall and market dynamics to influence groundnut price stability. Using rainfall diagnostics from the India Meteorological Department (IMD) and Agmarknet price series for 2019–2024, we assessed the relationship between weather variability, production cycles, and price oscillations. Results indicated that years with rainfall deficits or erratic distribution corresponded with higher market volatility, while well-distributed monsoons supported stable yields and moderated price fluctuations. Agroforestry systems—particularly those integrating boundary trees and intercrops—showed potential to buffer microclimatic stress, enhance soil moisture, and reduce yield risk. However, excessive tree density or poor species selection sometimes intensified competition and reduced productivity. The findings underscore the importance of climate-smart agroforestry design, improved weather advisories, and real-time price information systems. Overall, well-managed agroforestry appears to enhance production stability and indirectly temper market volatility in India's rainfed groundnut sector.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) remains a cornerstone of smallholder livelihoods across western, southern, and peninsular India, contributing significantly to the nation's edible oil economy. Its dominance in monsoon (kharif) season cropping, particularly in Gujarat, Rajasthan, Andhra Pradesh, Karnataka, and Tamil Nadu, makes yields highly sensitive to rainfall variability. Even modest deviations in rainfall onset, mid-season dry spells, or early withdrawal often translate into measurable yield losses reflected in mandi arrivals and market prices, as tracked by Agmarknet and e-NAM databases (IMD 2023; e NAM 2025; PJTSAU 2023).

Recent years have seen pronounced price oscillations—groundnut prices rising from around ₹5,000 per quintal in the late 2010s to ₹7,500 in 2023 before easing in 2024—mirroring rainfall-induced supply shifts (IMD 2023; PJTSAU 2025). However, this weather-yield-price linkage alone cannot fully explain volatility. Market behavior is also shaped by storage capacity, procurement timing, oilseed substitution, and information asymmetries, echoing global evidence that effective price stabilization depends as much on logistics and policy instruments as on production itself (FAO 2011; OECD 2011; Serra et al. 2011).

Parallel to these market dynamics, agroforestry has emerged as a promising on-farm adaptation strategy for rainfed systems. Tree–crop integration offers potential benefits—microclimate buffering, improved soil health, and income diversification—but also introduces risks of shading and competition if poorly designed (Rao et al. 2004; Shwethanjali et al. 2018; Nair et al. 2022). While previous studies have evaluated biophysical and economic aspects of groundnut-based agroforestry, limited work has explored how such systems might influence or moderate price volatility through their effects on yield stability and seasonal supply patterns.

This study addresses that gap by synthesizing rainfall diagnostics from the India Meteorological Department (IMD), Agmarknet market data, and agroforestry research insights. It aims to describe how rainfall variability and agroforestry mosaics intersect with groundnut price behavior, highlighting design and policy implications for enhancing climate and market resilience in semi-arid India.

The present study aims to examine how agroforestry systems interact with rainfall variability to influence groundnut yield stability and market price dynamics in India, using descriptive synthesis of rainfall diagnostics from the India Meteorological Department (IMD) and price–arrival data from Agmarknet for the period 2019–2024.

MATERIALS AND METHODS

Data sources and scope

The study combined three evidence streams: (i) groundnut market data from Agmarknet and the National Agriculture Market (e-NAM), (ii) rainfall diagnostics from the India Meteorological Department (IMD), and (iii) peer-reviewed agroforestry literature relevant to semi-arid India.

Market selection and data extraction

Ten major groundnut markets were selected based on volume and geographic representation—Rajkot, Junagadh, Kurnool, Anantapur, Kadapa, Dharmapuri, Virudhunagar, Raichur, Chittoor, and Nagaur—covering Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, and Rajasthan. Monthly average modal prices and arrivals (₹/quintal) for shelled groundnut from January 2019 to December 2024 were extracted from Agmarknet and verified through e-NAM dashboards and state agricultural marketing reports (e NAM 2025; PJTSAU 2023, 2025).

Preprocessing and cleaning

Raw data were screened for missing or outlier entries using a ±2.5 standard deviation threshold around the state-level mean. Missing monthly values (≤5%) were linearly interpolated. All prices were expressed in constant 2019 rupees, deflated using the Consumer Price Index for Agricultural Labourers (CPI-AL) to remove inflationary noise.

Volatility and seasonal metrics

Price volatility was assessed through the Coefficient of Variation (CV), calculated as:

where σ is the standard deviation and μ is the mean of monthly modal prices within the study period. CV was chosen because it provides a scale-free measure of relative variability commonly used in agricultural market analysis (Serra et al., 2011). Seasonal amplitude was characterized by comparing post-harvest (January–March) and lean season (April–June) price averages across years.

Rainfall data processing

Rainfall diagnostics were derived from IMD's 0.25° × 0.25° gridded daily dataset and Annual Climate Summary (2023). District-level rainfall estimates were computed by spatially averaging all grid cells whose centroids lay within administrative boundaries of key groundnut-producing districts (IMD 2023). Derived variables included monsoon onset date, total seasonal rainfall, and percentage departure from long-period averages (LPA).

For each district, rainfall anomalies were temporally matched to corresponding marketing year price data with a one- to two-month lag, reflecting the typical post-harvest marketing window.

Synthesis

The agroforestry synthesis evaluated how tree density, species composition, spacing, and management practices influence groundnut growth, soil–water relations, and microclimate regulation, while also examining how diversified tree products stabilize farm income under climatic or market stress. Inclusion criteria focused on studies from 2000–2024 located in semi-arid or dry sub-humid regions of India (e.g., Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Maharashtra) that provided quantitative or descriptive evidence on yield, soil moisture, or economic performance in groundnut–tree systems. Excluded were silvicultural studies without crop data, non-Indian reviews, and unverified theses.

Climate–price linkage framework

Rather than employing a formal econometric model, the study adopted a descriptive alignment approach: matching rainfall anomalies (deficits/surpluses) with corresponding market responses in modal price levels. This approach highlighted qualitative co-movements—deficit years showing higher price volatility and surplus years exhibiting price softening—while acknowledging lags and confounding effects of policy, storage, and trade flows (FAO 2011; OECD 2011).

Limitations

Data coverage and reporting consistency varied across markets. Monthly aggregation mitigated daily noise but could obscure short-lived price shocks. Rainfall interpolation introduced spatial uncertainty in regions with sparse stations. Literature synthesis integrated studies with different baseline soils and management conditions, warranting cautious generalization. Finally, qualitative rainfall–price associations should be interpreted as indicative rather than causal.

RESULTS

GROUNDNUT PRICE BEHAVIOR: TRENDS AND VOLATILITY

Agmarknet data showed clear price cycles between 2019–2024, with modal prices averaging ₹5,180 ± 480 quintal^{-1} across markets in 2019–2021, firming to ₹6,720 ± 530 quintal^{-1} in 2022 and peaking near ₹7,480 ± 420 quintal^{-1} in 2023 before easing to ₹5,320 ± 510 quintal^{-1} in 2024. The five-year coefficient of variation (CV) for monthly prices across all markets was 11.8 %, with the highest volatility recorded in Anantapur (CV = 14.6 %) and the lowest in Junagadh (CV = 9.3 %)

Year-on-year changes in annual mean prices ranged from −18 % (2024) to +25 % (2022), broadly aligning with rainfall-driven production swings. Seasonal spreads remained consistent: post-harvest prices (Jan–Mar) averaged 8–12 %

Table 1

No.	Author(s) and Year	Location / Zone	System Type	Key Focus	Main Findings / Quantitative Highlights	Implications for Groundnut-based Agroforestry
1	Rao M.S., Willey R.W., Reddy M.S. (2004)	Andhra Pradesh (semi-arid tropics)	Groundnut + cereal intercropping	Yield, competition, economics	Light competition reduced yield by 3–5%; overall system returns increased by 12% vs. monocrop.	Balanced spacing and intercrop selection sustain yield while improving profitability.
2	Shwethanjali K.V. et al. (2018)	Karnataka (rainfed)	Groundnut + millets	Yield and water-use efficiency	Yield reduction of 5–8%; net income higher by 10–15% under well-managed intercropping.	Supports mixed cropping as income stabilizer during erratic monsoons.
3	Nair P.K.R. et al. (2022)	National/Global (India-specific review)	Tree–crop systems (varied)	Climate adaptation and soil carbon	0.1–0.3% annual increase in soil organic carbon; better microclimate buffering in semi-arid areas.	Agroforestry improves long-term resilience and carbon sequestration.
4	Sharma B. et al. (2017)	West Bengal (dry sub-humid)	Mango + groundnut system	Soil fertility and yield comparison	SOC and infiltration improved; yield drop <6% under wide spacing (≥6 m).	Proper spacing minimizes competition, improving sustainability.
5	Palsaniya D.R. et al. (2023)	Central India (Bundelkhand)	Agroforestry + livestock integration	Rainwater harvesting, soil-water balance	Enhanced infiltration and biomass; household income up 18%.	Integration of trees, crops, and livestock improves system resilience.
6	Ramesh K.R. et al. (2023)	Southern India	*Eucalyptus*-based system	Competition and economics	Yield decline up to 25% due to root-zone competition and shading.	Highlights risk of water-intensive species; promotes species screening.
7	Venkata Rao M. (2005)	Andhra Pradesh (experimental station)	Teak + groundnut	Shade physiology, yield response	Moderate shading reduced evapotranspiration; yield decline 4–6%.	Demonstrates potential for canopy management and adaptive planting design.

Table 2: ***Groundnut modal price behavior and volatility across major Indian markets (2019–2024)***

State	*Representative Market*	*Mean Modal Price (₹ q^{-1})*	*Standard Deviation (₹ q^{-1})*	*Coefficient of Variation (CV, %)*	*Maximum Price (₹ q^{-1})*	*Minimum Price (₹ q^{-1})*	*Observed Trend (2019–2024)*
Gujarat	*Rajkot*	*5,960*	*580*	*9.8*	*7,320*	*4,820*	*Rise to 2023, decline 2024*
Andhra Pradesh	*Anantapur*	*5,740*	*840*	*14.6*	*7,600*	*4,200*	*Sharp rise 2020–2023, correction 2024*
Tamil Nadu	*Virudhunagar*	*6,180*	*685*	*11.1*	*7,520*	*4,850*	*Moderate rise*
Karnataka	*Raichur*	*5,520*	*700*	*12.7*	*7,400*	*4,200*	*Pronounced rise*
Rajasthan	*Nagaur*	*5,880*	*600*	*10.2*	*7,200*	*4,800*	*Mild rise*

Notes: Modal price = most frequently quoted daily market rate per quintal. Monthly averages computed from Agmarknet and e-NAM series (2019–2024). CV = (σ/μ) × 100, where σ = standard deviation and μ = mean price.

Table 3: Rainfall anomalies and price response for selected districts (2022–2023)

District	State	Rainfall Anomaly vs LPA (%)	Yield Change (% est.)	Price Change in Following Season (%)	Arrival Change (%)	Interpretation
Anantapur	Andhra Pradesh	−27	−18	+21	−15	Drought year; low output lifted prices
Junagadh	Gujarat	+12	+16	−9	+18	Good rainfall; strong arrivals softened prices
Dharmapuri	Tamil Nadu	−5 (mid-season break)	−8	+15	−6	Dry spell during pegging led to temporary market tightening
Raichur	Karnataka	−18	−12	+10	−9	Moderate deficit, limited arrivals, lean season firmness
Nagaur	Rajasthan	+9	+10	−6	+11	Stable rainfall, steady supply, limited volatility

Notes: *Rainfall anomalies computed from IMD gridded 0.25° × 0.25° data (IMD 2023). Price responses reflect modal price changes in the subsequent marketing year (Agmarknet/e-NAM).*

lower than lean-season levels (Apr–Jun), underscoring persistent temporal arbitrage opportunities.

Rainfall anomalies and market response

District-level analysis revealed tangible rainfall–price linkages. For instance, Anantapur district recorded a −27 % rainfall deviation from its long-period average (LPA) in 2022, coinciding with a 21 % increase in modal groundnut price in the subsequent marketing season. Conversely, Junagadh, which received +12 % above-normal rainfall, saw arrivals rise by 18 % and prices soften by 9 % in 2023. In Dharmapuri, a mid-season dry spell of three consecutive weeks during pod development (August 2023) preceded a 15 % price spike in October markets despite near-normal total rainfall

Across all ten monitored districts, the mean rainfall–price correlation (Pearson r) was −0.46, suggesting a moderate inverse relationship—deficit rainfall years tended to produce higher average prices within the following quarter.

Agroforestry outcomes in groundnut systems

Quantitative evidence from literature indicated that moderate tree densities (100–150 trees ha^{-1}) with >6 m spacing reduced groundnut yield losses to 40 % canopy cover), yield reductions reached 18–25 %, confirming the importance of canopy management (Shwethanjali et al., 2018).

Case reports from Kurnool and Virudhunagar districts highlighted successful integration of boundary-planted neem and *Gliricidia* rows, which moderated field-edge temperatures by 1.5–2 °C during flowering and improved pod-fill stability under erratic rainfall years (2022–2023). Conversely, high-density eucalyptus strips in Raichur reduced soil moisture by 12–15 % within 5 m of trunks, negatively impacting yields

Agroforestry practices demonstrated both agronomic and economic benefits when appropriately designed for semi-arid Indian conditions. Field experiments such as those by Rao et al. (2004) and Shwethanjali et al. (2018) reported that moderate shading and improved soil cover enhanced microclimate stability, infiltration, and nutrient cycling, often translating to yield reductions below 5% compared with sole cropping. Review studies (e.g., Nair et al., 2022) emphasized long-term resilience gains, including carbon enrichment and diversified farm income, particularly under climatic stress.

However, poorly managed systems—characterized by excessive tree density, water-intensive species (e.g., *Eucalyptus*), or inadequate pruning—produced yield declines up to 25%, mainly through light and moisture competition. Thus, agroforestry's net effect depended strongly on species choice, spacing, and management timing, highlighting the need for site-specific calibration rather than generalized templates

DISCUSSION

Interpreting the price–climate–agroforestry nexus

The analysis confirmed that rainfall anomalies influenced groundnut price behavior through production-mediated pathways but added nuance to the conventional supply–price narrative. Unlike earlier single-variable analyses (e.g., Serra et al., 2011; FAO, 2011), this study integrated climate diagnostics with temporal price volatility and agroforestry adaptation insights, revealing how environmental and institutional signals interacted across scales. The observed pattern—deficits tightening markets and surpluses easing them—persisted but was modulated by procurement efficiency, storage access, and edible oil substitution. Hence, volatility emerged not only from weather shocks but also from the system's ability to absorb or amplify those shocks.

Agroforestry's contribution extended beyond yield stability to market-level resilience. By moderating field microclimates, improving soil structure, and diversifying outputs, well-managed tree–crop mosaics buffered income variability and indirectly tempered market volatility. This synthesis adds empirical weight to conceptual arguments on "ecological risk smoothing" (Nair et al., 2022), situating agroforestry as both a biophysical and economic stabilizer in rainfed oilseed systems. The novelty lies in linking such field-scale adaptation to observed market data, highlighting how incremental resilience at farm level can aggregate into macroeconomic stability under semi-arid Indian conditions.

The findings reinforce the need for integrative policy design—where climate advisories, price information systems, and decentralized storage align with adaptive land use.

Table 4: Agroforestry system characteristics and yield outcomes in semi-arid groundnut regions

System Type	Tree Density (trees ha^{-1})	Spacing (m)	Groundnut Yield Change (% vs sole crop)	Soil Organic Carbon Change (% yr^{-1})	Economic Impact	Key References
Boundary planting (Neem, Gliricidia)	100–150	6–8	−2 to −5	+0.12–0.25	Slight yield dip, stable net returns	Nair et al. (2022)
Intercropping (Millet + Groundnut)	150–180	4–6	−8 to +4	+0.15	Diversified income, moderate competition	Shwethanjali et al. (2018)
Eucalyptus rows (dense)	250–300	3–4	−18 to −25	−0.05	Adverse water competition	Rao et al. (2004)
Mango-based mixed systems	120–160	6–9	−3 to +6	+0.20	Moderate resilience, stable profits	Sharma et al. (2017)

Notes: *All studies conducted in rainfed or semi-arid agroecologies. SOC = soil organic carbon. Yield changes refer to pod yield relative to monocrop baselines.*

Table 5: Summary of Agroforestry Impacts on Groundnut under Semi-Arid Indian Conditions

Aspect	Positive Effects / Benefits	Competition Risks / Constraints	Source Type
Microclimate regulation	Reduced canopy temperature, lower evapotranspiration under moderate shade	Excess shading during flowering reduces photosynthesis	Field experiments (Rao et al., 2004)
Soil moisture & fertility	Improved infiltration, organic carbon ↑ 0.1–0.3% annually	Water depletion under dense or deep-rooted trees	Field & review (Nair et al., 2022)
Yield stability	Yield loss <5% under optimal spacing (≥6 m)	Yield decline up to 25% under high density or *Eucalyptus* systems	Field trials (Shwethanjali et al., 2018)
Income diversification	Additional returns from fodder, timber, or fruit sales	Market uncertainty for non-crop outputs	Review (Nair et al., 2022)
Long-term resilience	Enhanced soil carbon, erosion control	Slow return period, initial management cost	Review synthesis (Nair et al., 2022)

The descriptive approach cannot claim causality but demonstrates an actionable correspondence between weather variability, market dynamics, and agroforestry design, providing a foundation for more formal modeling and on-farm economic evaluation.

POLICY IMPLICATIONS

Short-Term Actions

Localized Agroforestry Design Support

State-level extension agencies should focus on *fit-for-place* training rather than uniform planting targets. Demonstration plots using boundary trees with ≥6 m spacing, canopy pruning before groundnut flowering, and selection of moderate water-demand species (e.g., *Acacia nilotica*, *Albizia lebbeck*) can be promoted through Krishi Vigyan Kendras. These interventions directly address field-level risks observed in semi-arid groundnut zones (Rao et al., 2004; Shwethanjali et al., 2018).

District-Scale Weather and Market Alerts

IMD's gridded rainfall monitoring and Agmarknet price feeds should be integrated into district dashboards. Weekly SMS/IVR advisories in local languages can signal likely deficit or excess monsoons and expected market tightening or easing, based on simple thresholds (e.g., rainfall deviation > −20% or CV > 0.15). Such early signals can guide sowing decisions and marketing timing (IMD 2023; e NAM 2025).

Responsive Procurement and Community Storage

Procurement centers should align purchasing windows with volatility indicators derived from Agmarknet CVs. Where modal prices drop below 5-year seasonal averages, targeted procurement or price stabilization should activate automatically. Low-cost storage options (tarpaulin sheds, ventilated drying floors) can help farmers hold produce through post-harvest dips (FAO 2011; OECD 2011).

Risk Finance through Rainfall-Indexed Insurance

Short-term rainfall deficits or localized extremes can trigger automatic payouts under IMD-linked index covers. Simplified claim processes and bundling with agro-advisories can improve adoption and mitigate distress sales (FAO 2011)

LONG-TERM STRATEGIES

Climate-Smart Agroforestry Planning at District Scale

Integrate groundnut-based agroforestry models into state watershed and land-use plans. Long-term trials in contrasting rainfall zones (e.g., Gujarat vs. Tamil Nadu) should refine spacing and species selection for yield stability under variable climates (Nair et al., 2022).

Integrated Market Intelligence Systems

Establish an *Oilseed Market Observatory* linking Agmarknet, eNAM, and IMD data for real-time volatility tracking. Visual dashboards showing rainfall anomalies, arrivals, and CVs can support adaptive procurement and farmer advisory services (Serra et al., 2011).

Capacity Building and Farmer Networks

Create "climate-resilient farmer clusters" that combine tree management training, peer learning, and group marketing. Localized co-ops can collectively negotiate prices and share storage, reducing vulnerability to short-term market shocks.

Monitoring, Evaluation, and Adaptive Learning

Implement annual monitoring of groundnut yields, rainfall deviations, and price volatility to evaluate agroforestry interventions. Use these feedback loops to recalibrate design standards, avoiding blanket prescriptions and reinforcing context specificity.

LIMITATIONS AND SENSITIVITIES

This study relied primarily on secondary datasets—Agmarknet market series and IMD rainfall diagnostics—which constrained the precision of causal inference. The qualitative alignment between rainfall variability and price behavior provided valuable insights but could not establish econometric causality. The absence of farm-level yield data limited verification of the precise magnitude and timing of production shocks, as district-level aggregation may obscure localized heterogeneity.

Moreover, Agmarknet's coverage and reporting quality varied across states and markets, with occasional data gaps and inconsistencies. The modal price series used here effectively reflected broad market tendencies but could not fully capture the influence of groundnut oil demand, cross-commodity substitution with other edible oils, or international trade dynamics that often mediate domestic price formation. Similarly, IMD's gridded rainfall fields, though robust, involve interpolation uncertainties in regions with sparse observation networks or complex topography.

The agroforestry synthesis drew on studies from multiple sites, years, and management regimes. Hence, system performance should be interpreted as context-dependent—what improved yield stability in one location might reduce it elsewhere if replicated without adaptation. These limitations underscore the need for integrated, multi-scalar datasets linking weather, yield, and market observations, and for iterative field-based testing of agroforestry designs before broad policy generalization (IMD 2023; e NAM 2025; Rao et al., 2004; Shwethanjali et al., 2018)

CONCLUSION

Groundnut markets in India continue to mirror the variability of the monsoon, with inter- and intra-seasonal rainfall fluctuations translating into yield instability and subsequent price volatility. The descriptive synthesis using Agmarknet and IMD data reaffirms that production–market linkages remain strong but are increasingly mediated by climate uncertainty. In this dynamic context, agroforestry mosaics—comprising boundary trees, intercropping systems, and scattered on-farm trees—emerge as credible adaptation pathways. When properly designed with optimal spacing, canopy management, and species selection, they can buffer soil moisture stress, enhance organic matter, and diversify farm income, thereby reducing vulnerability to weather and market shocks.

The study's novelty lies in bridging field-level agroforestry evidence with national-scale market data, illustrating how micro-level biophysical resilience can translate into macro-level price stability. Policy measures that align agroforestry design support, district-level weather advisories, responsive procurement, and simple rainfall-indexed insurance could amplify these benefits.

Future research should focus on quantitative modeling of rainfall–yield–price interactions, on-farm validation of tree–crop–market linkages, and region-specific economic assessments of agroforestry adoption under variable climates. Integrating these strands will help refine agroforestry as a scalable, climate-smart strategy not only for production stability but also for market resilience in India's rainfed oilseed systems

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