Rainfed Agriculture in the Eastern Ghats of Andhra Pradesh: Climate Risks, Soil and Water Management, Crop Diversification and Livelihood Pathways – Review

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Abstract— *Rainfed agriculture is the dominant production environment for a large proportion of India's smallholder agriculture and remains particularly important in the Eastern Ghats, where farming systems are exposed to variable rainfall, short or shifting growing windows, soil erosion, low soil fertility, limited irrigation and weak access to markets and production services. This review synthesizes the material supplied by the authors on rainfed agriculture in the Eastern Ghats with evidence from Indian agricultural and ecological literature, with emphasis on climate-resilient soil and water management, crop and cropping-system diversification, integrated nutrient management, contingency planning, farming-system approaches and institutional support. The review places the Eastern Ghats of Andhra Pradesh, especially the tribal and rainfed production landscapes of Alluri Sitarama Raju District, within the wider national rainfed-agriculture context. Published evidence shows that rainwater harvesting and supplemental irrigation can substantially improve the productivity and economic performance of rainfed systems; conservation agriculture, land configuration, residue or biomass mulching and integrated nutrient management can improve soil moisture availability and resource-use efficiency; and diversification through millets, pulses, oilseeds, livestock and agroforestry can reduce climatic and income risk. District-level rainfall information also illustrates the importance of inter-annual variability: the NABARD district profile reports normal annual rainfall of 1,202.02 mm and actual annual rainfall of 1,256, 1,117 and 1,057 mm in 2019–20, 2020–21 and 2021–22, respectively. The review argues that the most appropriate pathway for the Eastern Ghats is not a single technology but a location-specific package integrating soil-water conservation, rainwater harvesting, climate-informed crop planning, improved varieties, balanced nutrition, diversified farming systems, mechanization access, farmer institutions, extension and market linkages. Priority research should combine long-term weather and soil datasets with participatory on-farm trials to quantify yield stability, water productivity, profitability, soil-carbon change and livelihood resilience.*

Keywords— Eastern Ghats; rainfed agriculture; climate resilience; soil and water conservation; rainwater harvesting; crop diversification; soil health; tribal agriculture; Andhra Pradesh; sustainable intensification.

I. INTRODUCTION

Rainfed agriculture is not a residual form of irrigated agriculture; it is a distinct production system in which the timing, amount and distribution of rainfall determine the feasible crop calendar, yield potential and risk profile. National assessments have consistently shown that a large share of India's cultivated area remains dependent on rainfall and that rainfed systems contribute substantially to food grains, pulses, oilseeds, coarse cereals and livestock feed. ICAR-CRIDA reports that, even after realization of irrigation potential, a substantial proportion of India's net sown area will remain rainfed, while the productivity of rainfed agriculture has increased but continues to show large yield gaps among regions and between research and farmers' fields (ICAR-CRIDA, 2026; Rao et al., 2016).

The Eastern Ghats present a particularly heterogeneous rainfed environment. The landscape includes hills, plateaus, valleys and sloping uplands, with strong spatial variation in rainfall, elevation, soil depth, slope and access to irrigation. In the tribal-dominated highlands of Andhra Pradesh, farming is closely linked to household food security, livestock, forest resources and local markets. Consequently, crop failure has consequences beyond yield: it affects food availability, cash income, employment, fodder supply and migration decisions. The authors' original bulletin emphasizes the same interconnected constraints—water scarcity, land degradation, drought, poor infrastructure, weak technology dissemination, poverty and market limitations—as central barriers to sustainable dryland development.

The scientific basis for climate-resilient rainfed agriculture has strengthened substantially. Indian research has demonstrated the importance of in-situ moisture conservation, runoff harvesting, supplemental irrigation, soil organic matter management, drought-tolerant crops and varieties, intercropping, contingency crop planning and diversified farming systems (Chary et al., 2020; Jinger et al., 2018; Rao et al., 2016; Srinivasa Rao & Gopinath, 2016). Water harvesting is especially important because rainfall deficits are often accompanied by periods of intense runoff. Sharma et al. (2010) estimated that 114 billion m^3 of surplus rainfall could potentially be harvested from 28.5 million ha of suitable rainfed area in India, and concluded that a single supplemental irrigation could produce large gains in rainfed production under improved management.

This review therefore reframes the authors' earlier bulletin as a contemporary, evidence-based review suitable for the Journal of Agriculture and Ecology Research International. The objective is to synthesize the major constraints and opportunities in rainfed agriculture of the Eastern Ghats of Andhra Pradesh and to propose a practical framework that integrates natural-resource management, crop production, climate-risk management, livelihood diversification and institutional support.

Novelty and Contribution of this Review: While numerous reviews on rainfed agriculture in India exist (e.g., Rao et al., 2016; Srinivasa Rao & Gopinath, 2016; Chary et al., 2020), most address either specific technologies or broad national contexts. This review makes three specific contributions. First, it focuses explicitly on the Eastern Ghats of Andhra Pradesh—a heterogeneous, tribal-dominated, and comparatively under-documented rainfed region—and integrates district-level rainfall variability data to contextualize the analysis. Second, it synthesizes evidence across five integrated themes (climate risk, soil-water-nutrient management, crop diversification, farming-system resilience, and institutional pathways) within a single framework, rather than treating these as separate domains. Third, it provides a structured research agenda with priority questions and measurable indicators tailored to the Eastern Ghats, together with an integrated climate-resilient management framework that can guide both research and extension. By distinguishing between demonstrated treatment effects and proposed management pathways, the review aims to support evidence-based decision-making under uncertainty.

II. SCOPE AND REVIEW METHOD

This article is a narrative review and does not present a new field experiment or a new statistical survey. The supplied manuscript, titled "Rainfed Agriculture in Eastern Ghats," was used as the baseline source for the original structure, local constraints and proposed research priorities. The review was expanded using published and authoritative sources identified through searches of ICAR journal repositories, Indian scientific journals, peer-reviewed literature and official institutional documents.

Search strategy: Literature was identified through targeted searches of Google Scholar, Scopus, Web of Science, ICAR journal repositories (Indian Farming, Indian Journal of Agronomy, Journal of Agricultural Engineering India), and official institutional sources (ICAR-CRIDA, NABARD, ICAR-IIRR) using combinations of the following terms: "rainfed agriculture," "dryland agriculture," "Eastern Ghats," "soil and water conservation," "rainwater harvesting," "supplemental irrigation," "contingency planning," "crop diversification," "integrated nutrient management," "conservation agriculture," "climate resilience," and "tribal agriculture Andhra Pradesh." The search was restricted primarily to English-language sources published between 2000 and 2026, with priority given to Indian evidence on rainfed agriculture, soil and water conservation, drought management, Eastern Ghats production systems and climate resilience.

Inclusion and exclusion criteria: Sources were included if they addressed rainfed/dryland agriculture, soil and water management, crop diversification, farming systems, or institutional dimensions relevant to Indian or comparable semi-arid contexts. Sources were excluded if they focused exclusively on irrigated systems or were not available in English. Grey literature was included only where it was issued by recognized institutions (e.g., NABARD district profiles, ICAR bulletins).

Synthesis approach: The synthesis focused on five themes: (i) climatic and biophysical risk; (ii) soil, water and nutrient management; (iii) crop and cropping-system diversification; (iv) farming-system and livelihood resilience; and (v) institutional, technological and policy pathways. Quantitative values are retained only when traceable to a cited source. Where a recommendation is a synthesis or inference rather than a direct experimental result, it is presented as a proposed management pathway rather than as a demonstrated treatment effect. The review also draws selectively on international literature from comparable rainfed regions (e.g., sub-Saharan Africa, Australia) to contextualize findings, although the primary evidence base is Indian.

III. RAINFED AGRICULTURE IN THE EASTERN GHATS OF ANDHRA PRADESH

3.1 Agro-ecological and socio-economic setting

The Eastern Ghats of Andhra Pradesh are characterized by complex topography, spatially variable rainfall, red and red-loamy soils in many uplands, and substantial areas under rainfed cropping. The Alluri Sitarama Raju District profile describes the district as containing warm-humid lowlands and cooler hill environments, with red loamy and sandy-loamy soils and a normal annual rainfall of about 1,202 mm. The district profile also illustrates inter-annual rainfall variability: 1,256 mm in 2019–20, 1,117 mm in 2020–21 and 1,057 mm in 2021–22 (NABARD, 2023). These values correspond approximately to +4.5%, −7.1% and −12.1% deviations from the reported normal, respectively.

TABLE 1
DISTRICT-LEVEL RAINFALL VARIABILITY, ALLURI SITARAMA RAJU DISTRICT

Indicator	Value	Interpretation
Normal annual rainfall	1,202.02 mm	District planning baseline
Actual rainfall, 2019–20	1,256 mm	≈ +4.5% from normal
Actual rainfall, 2020–21	1,117 mm	≈ −7.1% from normal
Actual rainfall, 2021–22	1,057 mm	≈ −12.1% from normal
Soil description in district profile	Red loamy and sandy loamy	Important for infiltration, erosion and nutrient management

Note. District rainfall values are from the NABARD Alluri Sitarama Raju District profile; percentage deviations are calculated from the reported normal.

Rainfall totals alone, however, are insufficient indicators of agricultural water availability. The effective rainfall available to a crop depends on rainfall intensity, distribution across crop-development stages, soil infiltration, runoff, evaporation, root-zone storage and the occurrence of dry spells. Thus, a season with near-normal rainfall can still produce drought-like stress if rainfall is concentrated in a few high-intensity events or if a prolonged dry spell occurs during flowering or grain filling.

3.2 Inherent features of rainfed agriculture

The authors' original review identified four inherent characteristics of dryland agriculture: diversity, fragility of the ecosystem, resilience and adaptability of farming communities, and the need for complementary investment in infrastructure and institutions. These characteristics remain useful for the Eastern Ghats. Diversity means that technology packages must be matched to rainfall regime, slope, soil depth, crop, farm size and market access. Fragility means that productivity gains cannot be separated from erosion control, soil organic matter and water conservation. Farmer resilience means that technologies must reduce risk rather than simply maximize yield under favorable seasons. Complementary investment means that improved seed or fertilizer has limited value when farmers cannot obtain timely machinery, credit, extension or remunerative markets.

IV. MAJOR CONSTRAINTS TO RAINFED AGRICULTURE

4.1 Climatic constraints

The dominant climatic risks are delayed onset of monsoon, early withdrawal, long dry spells, high-intensity rainfall, drought during sensitive crop stages, unseasonal rainfall and heat stress. Indian research on climate-resilient rainfed farming emphasizes that drought should be considered not only in terms of total seasonal rainfall but also according to its timing, duration and recurrence (Rao et al., 2016; Srinivasa Rao & Gopinath, 2016). Increased temperature can shorten crop duration, increase evaporative demand and accelerate phenological development, thereby reducing the time available for biomass accumulation and grain filling.

4.2 Soil and land constraints

Sloping land, surface crusting, compaction, low organic matter, poor aggregate stability, low available water capacity and erosion can reduce the fraction of rainfall stored in the root zone. Runoff is particularly important in the Eastern Ghats because intense rainfall on sloping fields can remove soil and nutrients while leaving crops exposed to water stress soon afterward.

Long-term national evidence shows that soil organic carbon is a major determinant of soil quality and productivity in rainfed systems. Srinivasarao et al. (2014) reported that long-term additions of fertilizer and organic amendments improved soil organic carbon stocks and that increases in root-zone soil carbon were associated with higher crop yields.

4.3 Nutrient-management constraints

Rainfed soils can experience multiple nutrient limitations because nutrient availability is strongly affected by soil moisture, pH, organic matter, erosion and the limited purchasing capacity of farmers. Under drought, nutrient uptake may decline even when soil nutrient concentration is adequate because root activity and nutrient diffusion are restricted. Consequently, balanced fertilization should be combined with organic matter management, residue recycling, legumes and soil-test-based nutrient application rather than relying on a single nutrient input.

4.4 Socio-economic and institutional constraints

Small holdings, limited access to credit, inadequate storage, weak market infrastructure, high input prices and limited access to farm machinery can magnify climatic risk. Timeliness is especially important in rainfed farming: delayed sowing can shorten the effective growing period and expose crops to terminal drought. Rao et al. (2016) highlighted access to machinery and custom-hiring arrangements as important adaptation measures because timely sowing and harvesting can reduce the consequences of weather variability.

V. CLIMATE RISK MANAGEMENT AND CONTINGENCY PLANNING

A climate-resilient rainfed production system should operate on three time scales: seasonal preparedness, within-season response and post-season recovery. Seasonal preparedness includes selection of suitable crops and varieties, seed availability, soil and water conservation before the monsoon, farm-pond maintenance and weather advisories. Within-season response includes sowing-date adjustment, re-sowing, thinning or gap filling, weed management, foliar nutrient application where scientifically justified, protective irrigation and crop substitution after a severe rainfall deficit. Post-season recovery includes residue management, livestock support, seed restoration and planning for the following crop.

TABLE 2
WEATHER SITUATIONS, PRODUCTION RISKS AND PRIORITY RESPONSES (PROPOSED MANAGEMENT PATHWAYS)

Weather situation	Likely production risk	Priority response
Delayed monsoon onset	Late sowing and shortened crop duration	Use short-duration varieties; staggered sowing; contingency crops
Long early-season dry spell	Poor establishment and plant mortality	Seed priming where appropriate; moisture-conserving seedbed; gap filling/re-sowing
Mid-season drought	Reduced canopy growth and reproductive failure	Interculture to break capillaries; mulch; life-saving irrigation; crop-specific drought measures
Heavy rainfall/high-intensity events	Runoff, erosion, nutrient loss and waterlogging	Contour/graded land treatment; vegetative barriers; drainage; farm ponds
Terminal drought	Poor grain filling and low harvest index	Early-maturing crops; prioritize protective irrigation; harvest at physiological maturity

Note: Responses are compiled and synthesized from the Indian rainfed agriculture literature (Rao et al., 2016; Srinivasa Rao & Gopinath, 2016; Chary et al., 2020; Jinger et al., 2018) and are presented as proposed pathways rather than as uniform recommendations.

VI. SOIL AND WATER CONSERVATION

6.1 In-situ moisture conservation

In-situ conservation aims to increase infiltration and reduce runoff and evaporation while retaining rainfall in the crop root zone. Depending on slope and soil, suitable practices include contour cultivation, ridges and furrows, broad-bed-and-furrow systems, compartmental bunding, tied ridges, conservation furrows, residue or biomass mulching and appropriate tillage. Jinger et al. (2018) emphasized land configuration as a key component of moisture conservation in rainfed agriculture. Chary et al. (2020) similarly concluded that location-specific soil and water management is a prerequisite for climate-resilient rainfed farming.

The choice of land configuration should not be standardized across the Eastern Ghats. Steeper slopes require stronger runoff and erosion-control measures; shallow soils require careful water retention without causing prolonged saturation; deep soils with moderate slopes may benefit from contour-aligned cultivation and surface storage. The design should therefore be based on slope, soil depth, infiltration rate, rainfall intensity and crop requirement.

6.2 Ex-situ water harvesting and supplemental irrigation

Farm ponds, small reservoirs, check dams, percolation structures and appropriately designed watershed interventions can convert a portion of otherwise lost runoff into a strategic source of supplemental irrigation. National analysis by Sharma et al. (2010) demonstrated the large potential of harvested runoff for supplemental irrigation. Evidence from the North-Eastern Ghats of Odisha is particularly relevant to the Eastern Ghats: Behera et al. (2024) reported that runoff harvesting from a 0.5-ha catchment provided usable stored water for life-saving and protective irrigation, and the treatment receiving additional protective irrigation recorded the highest crop-equivalent yield and crop-water productivity in the tested vegetable system.

For smallholder systems, the objective should be strategic rather than complete irrigation. A limited volume of stored water applied at a critical crop stage can have greater marginal value than spreading a small amount across the whole season. Priority stages differ among crops, but flowering, pod or grain initiation and early reproductive development are often sensitive. Farm ponds should also be managed to minimize evaporation and seepage losses, and their location should be integrated with field drainage and watershed planning.

VII. SOIL HEALTH AND INTEGRATED NUTRIENT MANAGEMENT

Improving soil organic matter is a long-term drought-proofing strategy because organic matter supports aggregation, infiltration, water retention and nutrient cycling. Srinivasarao et al. (2014) documented strong relationships between soil organic carbon and productivity across rainfed production systems in India. The implication for the Eastern Ghats is that soil-health interventions should be designed as part of the production system rather than as isolated fertilizer recommendations.

Practical components include soil-test-based fertilizer application; balanced nitrogen, phosphorus, potassium and micronutrient management; farmyard manure or compost where available; green manuring; inclusion of legumes; residue retention or incorporation where feasible; and reduced erosion. Because biomass is often scarce in smallholder systems and livestock compete for residues, residue management must be designed around the whole farm rather than assuming that all residues can be returned to the soil. Water and nutrient management are strongly coupled. Adequate soil moisture improves nutrient diffusion and root activity, while balanced nutrition can improve canopy development and water-use efficiency. Therefore, soil-water conservation and integrated nutrient management should be implemented together, especially on degraded uplands.

VIII. CROP AND CROPPING-SYSTEM DIVERSIFICATION

Crop diversification is one of the most practical ways to reduce climate and market risk in rainfed agriculture. The choice of crop should consider rainfall probability, soil depth, growing-season length, household food needs, fodder demand, market access and labor availability. Millets, pulses, oilseeds, maize, sorghum, vegetables and tuber crops can be combined according to local conditions. Legume inclusion is particularly important because it diversifies food production and can contribute to soil fertility.

Intercropping can improve resource capture and reduce the probability of complete crop failure when rainfall is uncertain. Evidence from the Eastern Ghats of Odisha is instructive. Jakhar et al. (2015) reported that finger millet–groundnut strip cropping in a 6:4 row ratio produced higher finger-millet-equivalent yield than sole finger millet, improved production efficiency and reduced runoff and soil loss relative to sole finger millet. Such findings support the principle of designing diversified systems that combine food, fodder, income and soil-conservation functions.

Crop diversification should also be connected to market diversification. A crop that performs well agronomically but lacks a reliable market may not improve livelihood resilience. Producer organizations, local aggregation, value addition and institutional procurement can therefore increase the economic value of diversified rainfed systems.

IX. CONSERVATION AGRICULTURE AND AGROECOLOGICAL APPROACHES

Conservation agriculture can contribute to rainfed resilience through reduced soil disturbance, residue retention, crop diversification and improved soil cover, but the practices must be adapted to local labor, residue availability, weed pressure and machinery access. Research in rainfed uplands of India found that reduced tillage combined with maize–cowpea intercropping and residue retention improved system productivity, net benefits and soil-quality indicators relative to farmers' practice (Pradhan et al., 2018). In the Eastern Ghats, conservation agriculture should be interpreted broadly as resource-conserving production rather than as a rigid package. On sloping land, erosion control and ground cover may be the first priorities. On compacted soils, strategic tillage may be necessary before reduced tillage becomes effective. In mixed crop-livestock systems, residue allocation should balance soil cover with fodder requirements.

X. INTEGRATED FARMING SYSTEMS AND LIVELIHOOD DIVERSIFICATION

Farm-level resilience is stronger when income and food sources are diversified. Crop–livestock integration can provide manure, fodder, milk, meat or eggs and cash flow at different times of the year. Backyard poultry, small ruminants, beekeeping, agroforestry and locally suitable horticulture can complement annual crops. The original authors' action plan appropriately included livestock, fodder use of crop residues and alternative land-use systems.

Agroforestry is particularly relevant to erosion-prone slopes because trees and perennial vegetation can reduce runoff, provide biomass and diversify income. However, species selection must consider competition for water, local ecological suitability, tenure arrangements and market demand. Agroforestry should therefore be planned at landscape scale rather than by simply adding trees to every field.

XI. WEATHER INFORMATION, MECHANIZATION AND EXTENSION

Weather information is valuable only when it is converted into an actionable farm decision. Village-level advisories should therefore translate rainfall forecasts and observed soil moisture into recommendations on sowing, interculture, fertilizer timing, pest surveillance, harvest and contingency crops. The authors' original action plan proposed systematic collection of weather data from research and meteorological stations and farmer awareness on weather-based decision making. This remains a strong research and extension priority.

Mechanization can reduce climate risk by improving timeliness. Custom-hiring centers can make seed drills, planters, weeders, threshers and harvesting equipment accessible to smallholders who cannot purchase machinery individually. The value of mechanization is especially high when the sowing window is narrow or when a delayed operation coincides with a forecast rainfall event.

XII. WATERSHED-BASED PLANNING FOR THE EASTERN GHATS

Field-level soil conservation is more effective when linked to watershed-scale planning. Upper-slope runoff controls, drainage-line treatment, farm ponds, vegetative barriers and downstream water-use planning should be treated as a connected hydrological system. Research from the Eastern Ghats has shown that a substantial fraction of rainfall can move through surface and base-flow pathways that may leave the local system without appropriate management (Panda, 2011).

Community-based watershed management is therefore essential where individual farms are too small to address runoff pathways independently. Collective maintenance of drainage structures, common lands, grazing resources and water-harvesting assets can reduce the risk that one farm's conservation measure simply transfers runoff to another farm.

XIII. INSTITUTIONAL AND POLICY PATHWAYS

Technology alone will not transform rainfed agriculture unless institutions reduce the transaction costs of adoption. Priority interventions include timely seed supply, soil testing, weather advisories, access to machinery, affordable credit, crop insurance, farmer producer organizations, storage and aggregation, and market linkages. ICAR-CRIDA emphasizes that rainfed farmers face simultaneous weather, credit and market risks; therefore, resilience policy should address these risks together rather than treating them as separate programmes.

Extension systems should prioritize location-specific packages rather than long lists of disconnected recommendations. For example, an Eastern Ghats upland package might combine contour-aligned land preparation, a short-duration or drought-tolerant crop, seed treatment, soil-test-based nutrients, interculture for moisture conservation, a farm pond or community water structure where feasible, and a contingency crop plan. The package can then be evaluated using yield stability, water productivity, net returns, labor demand and soil-health indicators.

XIV. PRIORITY RESEARCH AGENDA FOR THE EASTERN GHATS

TABLE 3
PRIORITY RESEARCH AGENDA FOR RAINFED AGRICULTURE IN THE EASTERN GHATS

Research theme	Priority question	Suggested indicator
Weather variability	How do onset, dry spells and extreme rainfall affect major crops?	Rainfall indices; crop phenology; yield loss
Soil and water	Which land configurations maximize infiltration and reduce erosion on different slopes?	Runoff; soil loss; soil moisture; yield
Water harvesting	What pond/catchment size and irrigation schedule provide the highest return?	Stored water; water productivity; B:C ratio
Soil health	Which combinations of organic and mineral inputs build SOC without reducing profitability?	SOC; available nutrients; yield; partial factor productivity
Crop diversification	Which intercrops stabilize income under variable rainfall?	Equivalent yield; income variance; LER
Climate advisories	Which advisory triggers produce measurable farm decisions?	Adoption; timeliness; yield stability
Livelihood systems	Which crop–livestock–tree combinations improve annual income and resilience?	Net income; employment; biomass balance
Climate projections	How will projected changes in rainfall and temperature affect rainfed production?	Downscaled climate scenarios; crop-model simulations; adaptation options

Long-term experiments and on-farm participatory trials should be prioritized because rainfed technologies can have different performance under favorable and drought seasons. Sustainability should be evaluated over multiple years rather than from a single high-rainfall season. The research framework should also capture trade-offs, such as crop-residue use for livestock versus soil cover, or tree biomass benefits versus competition for soil water. Climate projection analysis should be integrated into the research agenda to anticipate future risks and identify adaptation options.

XV. INTEGRATED CLIMATE-RESILIENT MANAGEMENT FRAMEWORK

TABLE 4
INTEGRATED CLIMATE-RESILIENT MANAGEMENT FRAMEWORK FOR EASTERN GHATS RAINFED AGRICULTURE

Component	Core practices	Expected contribution
Water	Farm ponds, runoff harvesting, contour measures, supplemental irrigation	Reduce crop failure and increase water productivity
Soil	Mulching, residue/biomass management, erosion control, organic matter addition	Improve infiltration, water retention and soil fertility
Crops	Drought-tolerant/short-duration varieties, millets, pulses, oilseeds, intercropping	Reduce climatic and production risk
Nutrients	Soil-test-based balanced fertilization and integrated nutrient management	Improve nutrient-use efficiency and yield stability
Climate services	Weather advisories and contingency plans	Improve timeliness of decisions
Livelihoods	Livestock, poultry, agroforestry, horticulture and value addition	Diversify income and food sources
Institutions	FPOs, custom hiring, credit, insurance, extension and markets	Reduce adoption and transaction barriers

XVI. DISCUSSION

The evidence reviewed here indicates that the central problem of Eastern Ghats rainfed agriculture is not simply insufficient rainfall. Rather, it is the mismatch between rainfall supply and crop demand caused by poor temporal distribution, rapid runoff, low soil-water storage, soil degradation and limited capacity to respond to weather variability. This explains why interventions that retain water in the root zone or provide a small amount of supplemental irrigation can generate disproportionately large benefits.

The evidence also supports a shift from yield maximization toward risk-adjusted productivity. A management practice that produces the highest yield in a favorable year may not be the best option if it has high input costs and fails during drought. Conversely, a diversified system with slightly lower maximum yield but substantially lower yield variance can provide greater annual livelihood security. Crop diversification, intercropping, soil organic matter management and strategic supplemental irrigation are therefore complementary rather than competing strategies.

The Eastern Ghats also require an ecological interpretation of agricultural intensification. Intensification should occur through better use of rainfall, nutrients, labor and biodiversity rather than through indiscriminate increases in external inputs. This is consistent with the concept of sustainable intensification developed for rainfed and fragile ecosystems: productivity gains must be accompanied by protection of soil, water and ecosystem services.

Trade-offs and conditions for success: Several trade-offs must be acknowledged. First, crop residues are a critical resource for both soil cover and livestock fodder in mixed crop–livestock systems; residue retention for conservation agriculture may compete with fodder needs, and the optimal allocation depends on herd size, feed availability, and the value of soil-cover benefits relative to livestock productivity. Second, conservation agriculture may fail to improve yields where weed pressure is high, residue availability is low, or machinery access is limited; in such cases, strategic tillage or partial adoption may be more appropriate than rigid adherence to CA principles. Third, agroforestry can improve soil and diversify income, but tree–crop competition for water and nutrients may reduce crop yields on shallow or water-limited soils, especially where species selection is inappropriate or where tenure arrangements discourage long-term investment. Fourth, supplemental irrigation from farm ponds provides the greatest marginal benefit when applied at critical crop stages, but pond performance depends on catchment characteristics, seepage control, and maintenance; poorly designed or maintained ponds may yield little usable water. Fifth, soil organic matter restoration is a long-term investment, and measurable improvements in soil carbon and water-holding capacity may take several years; short-term evaluations may underestimate benefits or overestimate costs. Recognizing these trade-offs and conditions is essential for designing locally appropriate packages rather than uniform recommendations.

International context: While this review draws primarily on Indian evidence, the challenges and pathways described here resonate with international experience in comparable rainfed regions. In sub-Saharan Africa, integrated soil fertility management (ISFM) combines organic and mineral inputs with improved germplasm, and has been shown to improve yields and soil health when adapted to local conditions—though adoption constraints related to input access, labor, and markets remain significant (Vanlauwe et al., 2010). In the semi-arid tropics of Australia and the Sahel, conservation agriculture and water harvesting have produced variable results depending on rainfall regime, soil type, and residue availability. The sustainable intensification and climate-smart agriculture frameworks developed internationally emphasize the need to integrate productivity, adaptation, and mitigation objectives—an approach that aligns with the integrated framework proposed here for the Eastern Ghats.

Finally, the review highlights the importance of scale. Farm-level practices cannot fully solve watershed-level runoff, common-land degradation, market access or machinery constraints. A resilient Eastern Ghats strategy therefore needs coordination among farmers, research stations, Krishi Vigyan Kendras, agricultural and horticultural departments, watershed agencies, financial institutions and markets. Such coordination should be supported by measurable indicators and periodic evaluation.

XVII. CONCLUSIONS

Rainfed agriculture in the Eastern Ghats of Andhra Pradesh is a high-risk but high-potential production system. The major constraints—rainfall variability, drought and dry spells, runoff and erosion, low soil fertility, limited irrigation, small holdings, weak market access and inadequate institutional support—interact to suppress productivity and increase livelihood vulnerability. Published evidence demonstrates that substantial gains are possible through integrated management of rainfall, soil, nutrients and cropping systems.

For the Eastern Ghats, the most appropriate strategy is a location-specific climate-resilient package based on: (1) in-situ soil and moisture conservation; (2) decentralized rainwater harvesting and strategic supplemental irrigation; (3) soil-test-based integrated nutrient management and organic-matter restoration; (4) diversified and climate-suitable crops and intercropping; (5) contingency planning based on weather information; (6) integrated crop–livestock–tree systems; and (7) stronger access to machinery, credit, insurance, extension and markets. Future research should quantify the long-term effects of these packages on yield stability, water productivity, soil carbon, profitability and livelihood resilience under the specific agro-ecological conditions of the Eastern Ghats.

Limitations of the Review: This is a narrative review based on published literature and publicly available institutional information; it does not present new experimental data. The evidence base is weighted toward Indian sources, with limited engagement with international literature from comparable rainfed regions. A formal systematic search strategy was not employed, and the possibility of publication or selection bias cannot be excluded. The recommendations presented here are syntheses and inferences from the reviewed literature rather than demonstrated treatment effects, and their applicability to specific farms, soils, and seasons will require local validation. Climate change projections for the Eastern Ghats were not analyzed in this review; future work should incorporate downscaled projections to anticipate future risks. Despite these limitations, the review provides a structured synthesis that can guide research, extension, and policy in the region.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this study.

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