SCIENCE FOR A FOOD-SECURE FUTURE

TECHNICAL REPORT

Agroecological Transition Pathways for India: Scaling from Homesteads to Multifunctional Landscapes

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CGIAR Multifunctional Landscapes Program

Multifunctional Landscapes is a CGIAR Science Program that aims to enhance the resilience, productivity, and sustainability of agricultural landscapes by integrating diverse land uses, ecosystem services, and livelihood strategies. The initiative supports evidence-based policies and innovations that balance food production with climate adaptation, biodiversity conservation, and social inclusion. By working with local communities, governments, and partners, it promotes landscape-level approaches to managing natural resources for long-term ecological and economic benefits. To learn more about the CGIAR Research Portfolio, please visit www.cgiar.org/cgiar-research-porfolio-2025-2030/

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Acronyms

AHM – Agroecological Homestead Model
AHP – Analytical Hierarchy Process
APCNF – Andhra Pradesh Community-managed Natural Farming
CGIAR – Consultative Group on International Agricultural Research
CGWB – Central Ground Water Board
DA&FW – Department of Agriculture and Farmers Welfare
FAO – Food and Agriculture Organization of the United Nations
FPC – Farmer Producer Company
FYM – Farmyard Manure
ICAR – Indian Council of Agricultural Research
IFPRI – International Food Policy Research Institute
IPCC – Intergovernmental Panel on Climate Change
ITPS – Intergovernmental Technical Panel on Soils
IWMI – International Water Management Institute
MFL – Multifunctional Landscapes
NARES – National Agricultural Research and Education System
NPP – Net Primary Productivity
NRLM – National Rural Livelihoods Mission
PMKSY – Pradhan Mantri Krishi Sinchayee Yojana
POSHAN Abhiyaan – Prime Minister's Overarching Scheme for Holistic Nutrition
PRI – Panchayati Raj Institution
PSB – Phosphorus-Solubilizing Bacteria
RCT – Randomized Controlled Trial
RySS – Rythu Sadhikara Samstha
SHG – Self-Help Group
UNCCD – United Nations Convention to Combat Desertification
VB-G RAM G Act – Viksit Bharat–Guarantee for Rozgar and Ajeevika Mission (Gramin) Act

Contents

1. Introduction

India's agrifood system is at an important turning point. For decades, the Green Revolution and the recent policy support ensured national food security through improved crop varieties, widespread fertiliser use, expansion of irrigation and natural resource conservation and management in rainfed regions. These investments enabled the country to move decisively from food scarcity to surplus (Pathak, 2025). As production intensified over time, new challenges related to soil health, water resources and input efficiency have also emerged.

Recent assessments indicate that more than 40% of India's land is degraded (FAO & ITPS, 2015; UNCCD, 2022; ICAR, 2010), groundwater levels are declining across several agrarian regions (CGWB, 2023), and fertiliser nutrient-use efficiency remains below 35% (FAO, 2019). Studies reporting pesticide residues in vegetables, fruits, and livestock products (Tripathy et al., 2025; Sivaperumal et al., 2022) further highlight the widening gap between current agricultural practices and human and environmental health. Together, these concerns have shifted the policy debate beyond productivity toward food quality, safety, and ecological impacts. Recognising these emerging concerns, several national programmes and missions have been launched to promote sustainable resource management, natural farming, and nutrition-sensitive agriculture.

At the same time, India is preparing for a future shaped by climate variability, resource constraints, and changing dietary preferences. Climate projections point to more frequent extreme events, erratic monsoons, and increasing vulnerability of rainfed regions (IPCC, 2022). In this context, agroecology, which integrates ecological principles, traditional knowledge, and locally adapted innovations, offers a practical pathway to strengthen resilience, nutrition, and rural livelihoods.

Policy momentum toward agroecological approaches is already visible. The National Mission on Natural Farming promotes natural-input farming at scale; National Rural Livekihood Mission (NRLM) strengthens women-led local food systems; Prime Minister's Overarching Scheme for Holistic Nutrition (POSHAN) Abhiyaan emphasises diversified diets; and Mission Live FOR ENVIRONMENT (LiFE) calls for more sustainable production and consumption patterns also include Integrated Watershed management Program (IWMP)- Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)-Watershed Development Component (WDC) Component, Viksit Bharat–Guarantee for Rozgar and Ajeevika Mission (Gramin) Act, 2025 (VB-G RAM G Act). Several states, including Andhra Pradesh, Gujarat, Kerala, Himachal Pradesh, Madhya Pradesh, and parts of Odisha, have initiated large pilots in natural or climate-resilient ecological farming. Together, these efforts create a favourable policy environment for a transition grounded in ecological stewardship and community participation.

A key policy challenge is that agroecology cannot follow one common model across regions. India's diversity of agroecological zones, socioeconomic conditions, and farming systems requires multiple entry points and differentiated transition pathways, each with distinct risk profiles and institutional requirements. In most cases, the starting point for transition is existing smallholder farming systems, including conventional or partially traditional rainfed and irrigated agriculture. Evidence emerging from CGIAR and partner initiatives highlights three complementary pathways:

i. agroecological homesteads as low-risk entry points that enable households to experiment with agroecological practices while strengthening nutrition and women's agency; and

ii. rainfed agroecological pathways as priority transition domains where soil restoration, climate resilience, and livelihood diversification can be achieved with relatively low production risk, and

iii. phased, efficiency-led transitions in intensive irrigated systems to reduce environmental footprints while safeguarding productivity.

This policy paper synthesises emerging evidence from IWMI, ICAR and partner institutions to present a coherent framework for agroecological transition in India. It discusses how homestead-level innovations, agroecological intensification in rainfed areas, and context-sensitive transitions in irrigated systems can together support the development of nature-positive, climate-resilient, and nutritionally secure multifunctional landscapes (MFL), in line with the CGIAR Multifunctional Landscapes science agenda.

India has already made important progress toward more sustainable and inclusive agrifood systems through several national missions and state-led initiatives. Building on these positive efforts, this paper offers practical insights on how agroecological transitions can be further strengthened and better aligned across diverse farming contexts.

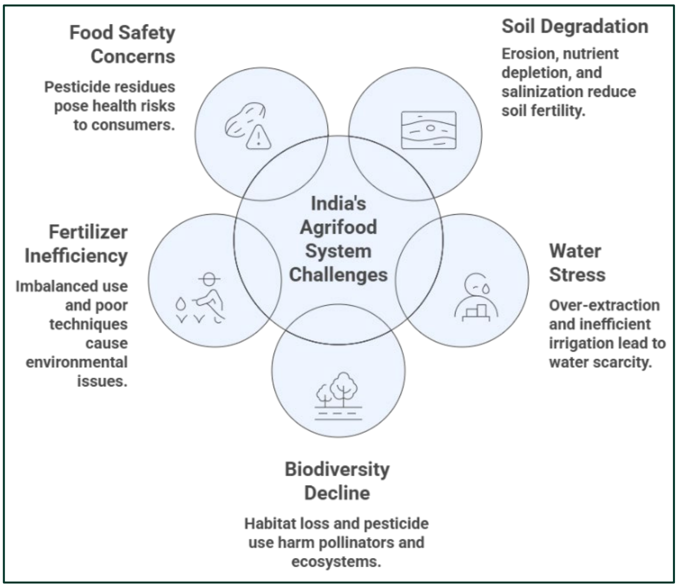

Figure 1. Broader aspect of agrifood system challenges in India

2. Agroecological Homestead Model – The Entry Point for Transition

Agroecological transition **on their main cultivated fields** is often seen by farmers as complex and risky, especially for small and marginal households with limited land, labour, and capital. In this context, homesteads offer a practical and low-risk entry point. Located close to the household, homesteads allow families to try agroecological practices on a small area, see results quickly, and build confidence before considering changes on larger farm plots. Homesteads sit at the interface of household needs, farming activities, and local ecosystems. Because of this position, they are well suited for introducing agroecological principles related to soil care, food diversity, and input reduction in ways that are socially acceptable and easy to manage.

2.1 Why Homesteads Are Suitable Entry Points

Homestead cultivation has a long tradition in India and was once a common feature of rural livelihoods. Until a few decades ago, most rural households produced vegetables, fruits, and small livestock products at home, mainly using organic inputs and recycled household resources. These systems contributed significantly to household food availability, dietary diversity, and nutrition, particularly for women and children. Over time, rapid urbanisation, migration, and changing lifestyles have reduced homestead cultivation. Many households now depend on markets for food that was earlier produced at home. This shift has weakened household food self-reliance and dietary diversity, with greater impacts on women, who play a key role in managing household nutrition.
Recent efforts to revive agroecological homesteads (Kumar et al., 2024a; Malaiappan et al., 2024a; Malaiappan et al., 2024b) aim to address these gaps by bringing food production back closer to households in ways that are affordable, culturally acceptable, and environmentally sound. Homesteads are typically managed by women, rely

mainly on family labour and local resources, and face lower production and market risks than field crops. This makes them suitable spaces for introducing diversified cropping, organic nutrient recycling, and natural pest management.

From a transition perspective, homesteads offer several advantages:

- Quick and visible benefits, such as access to fresh vegetables, fruits, eggs, and small livestock products for household consumption
- Low opportunity cost, as homestead plots are small and often under-used
- High social acceptance, particularly among women and youth
- Clear links between soil health, food quality, and family well-being, which support behavioural change
- Potential links to local and peri-urban markets, especially for safe and naturally grown produce

These features make homesteads effective learning spaces where agroecological practices can be tested, adapted, and socially accepted.

2.2 Core Design Principles of the Agroecological Homestead Model

The Agroecological Homestead Model (AHM) builds on traditional home gardens while incorporating current understanding of soil health, crop diversity, and efficient resource use (Kumar et al., 2024a). It follows a principle-based approach, allowing flexibility across agroecological and cultural contexts rather than prescribing a fixed package.

Key design elements include:

- Crop and functional diversity: Growing a mix of crops including root and tuber crops, leafy vegetables, shrubs, legumes, spices and climbers, and, where possible, small livestock and poultry. This improves use of space and light, supports regular harvesting, improves diet diversity, and reduces pest and disease pressure
- Soil regeneration and nutrient recycling: Regular use of compost, vermicompost, and bio-formulations prepared from household and farm residues helps improve soil organic matter, biological activity, and moisture retention.
- Efficient water use: Small-scale water storage including above ground transportable tank (Kumar et al., 2025), mulching, and targeted irrigation enable year-round or extended-season production, even in rainfed areas.
- Natural plant protection: Use of botanical extracts, fermented preparations, traps, mechanical measures and ecological regulation in place of synthetic pesticides.
- Local knowledge and seed systems: Preference for locally adapted varieties, supported by community-based seed exchange and nursery systems.

Importantly, the model emphasises learning-by-doing, supported by hands-on training, peer exchange, and collective problem-solving.

2.3 Outcomes and Early Transition Signals

Experience from homestead-based initiatives across tribal, rainfed, and peri-urban settings shows that the AHM can generate **early and visible outcomes**.

Case example: Mandla District, Madhya Pradesh

In Mandla district, 40 AHMs were co-designed and co-piloted across seven villages during 2023–2025 under the CGIAR Agroecology Initiative and Multifunctional Landscapes science programme. The designs followed a common core framework mentioned in the preceding section but allowed flexibility in crop choice and layout based on local conditions. With support from the Madhya Pradesh Rajiv Gandhi Watershed Mission, the initiative later expanded to about 100 homesteads at different stages of development.

To support learning at scale, IFPRI is currently providing training and starter inputs to a larger group of farmers as part of an ongoing Randomized Controlled Trial (RCT), aimed at generating systematic evidence (Gupta et al., 2025). Table 1 presents the key components and design features of the AHM as piloted in Mandla district and should not be interpreted as a fixed or standard package.

Table 1. The key components and design features of the co-piloted Agroecological Homestead Model in Mandla district, Madhya Pradesh. India.

Component	Description
Area required	350–450 square meters (typically 400 sq m)
Site preparation	10-15 raised beds per plot (width: ~1.2 m; length depending on land availability), bamboo trellises, green net cover
Water storage tanks (Jal Kund)	Above-ground portable tanks (Kumar et al., 2025) and/or below-ground storage pits
Compost pits	Vermicompost pit/ compost pits
Seed treatment	*Trichoderma*, phosphorus-solubilizing bacteria (PSB)
Nutrient management	Farmyard manure (FYM), vermicompost, *kanda khad* (cow dung slurry), *Shivansh khad*, *jeevamrit* (cow urine and cow dung–based fermented preparation)
Pest management	Plant-extract and fermentation-based formulations such as Brahmastra, Neemastra, Agnisatra, and Mahastra (butter milk based preparation)
Crop combinations	Tuber crops (ginger, taro, turmeric); leafy vegetables (red amaranthus, spinach, fenugreek); shrub vegetables (brinjal, tomato, chilli, okra); climbers (cowpea, bitter gourd, sponge gourd, cucumber, runner beans, cluster beans)
Livestock	Low-cost poultry shed and poultry management; indigenous cow and goats (where feasible)
Pollinators and honey production	Bee boxes; training on beehive management
Support mechanism	Nursery support: Farmer Producer Company (FPC) facilitation for produce aggregation; training on individual components and integrated AHM management; institutional support through Self-Help Groups (SHGs)

Key Outcomes of Agroecological Homestead Models (AHM): Based on early field observations from the Mandla pilots, Agroecological Homestead Models (AHMs) have shown multiple positive outcomes. These results are indicative and reflect short-term changes during the initial phase of implementation.

- Nutrition and dietary diversity: Households reported a substantial increase in food diversity (around 150%), with green vegetable consumption rising by about 70%. Estimated protein intake also improved (by up to ~10 g per person per day), mainly due to regular access to vegetables, pulses, eggs, and small livestock products.
- Income and economic resilience: Gross income generated from the AHM land parcel increased significantly (by approximately 2–20 times), with net income gains of up to ~2.4 times from the same area. These gains were supported by shorter harvest cycles, regular small incomes, and reduced household expenditure on purchased food.
- Soil and water health: Within one to two cropping seasons, visible improvements were observed in soil organic matter, earthworm activity, and microbial presence. Water productivity also improved markedly, in some cases nearly doubling (reaching up to ~9 kg tomato equivalent per m^3 of water), reflecting better soil condition and targeted water use.
- Women and youth engagement: Women's role and decision-making within households were strengthened, as they led planning, management, and marketing of AHM produce. In most cases, income generated from the homestead was managed and used by women, contributing to household-level empowerment. Youth participation increased through nursery management, bio-input preparation, and local marketing activities, generating around ~8 person-days of green employment per hectare.

These visible and measurable changes have helped build farmer confidence, reduced scepticism around agroecological practices, and encouraged peer learning. In several locations, this has led to spillover effects beyond pilot households, including interest in similar practices on nearby farm plots and at the community level.

Figure 2. (a) Women at the heart of Agroecological Homestead Model, Mandla district, Madhya Pradesh, India

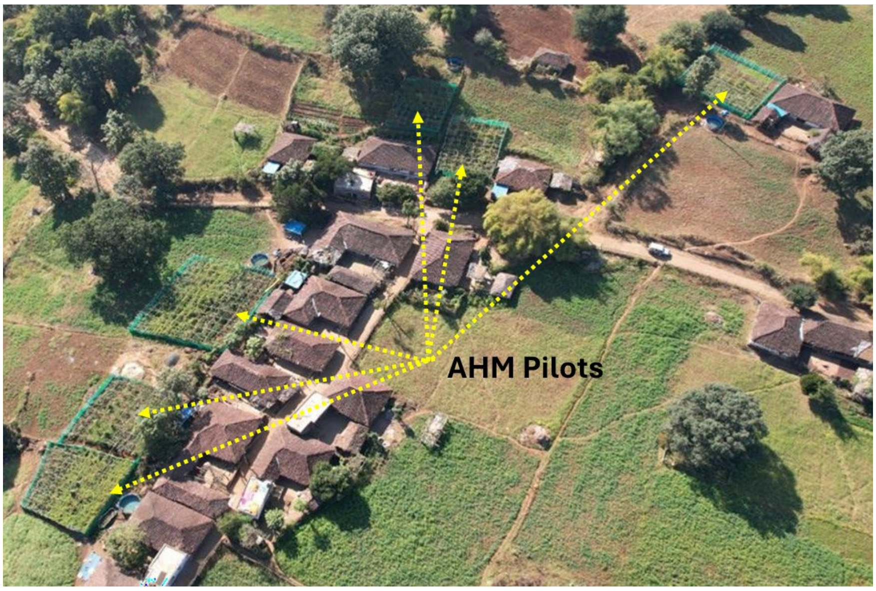

Figure 2. (b) Agroecological Homestead Model piloted in Mandla district, Madhya Pradesh, India

2.4 From Household Change to Wider Social Diffusion

Although AHMs are managed at the household level, their impacts often extend beyond individual families. As neighbouring households observe improvements in food availability, nutrition, income, and overall well-being, practices spread through informal learning; Women's Self-Help Groups, farmer collectives, and village institutions frequently support this process through training, seed exchange, and collective preparation of bio-inputs. Over time, clusters of agroecological homesteads can influence local food markets by supplying chemical-free produce. Composting and bio-input use often extend beyond homesteads to nearby fields, and perceptions around food quality, soil care, and chemical dependence begin to shift.

At the same time, uptake of AHMs is not without challenges. Initial adoption may be constrained by labour availability, especially for women, the need for sustained handholding and technical guidance, seasonal water limitations, and access to quality planting material and bio-inputs. Without institutional support, these constraints can limit replication beyond pilot households. It is therefore important to 8recognize limits. AHMs alone cannot deliver landscape-scale outcomes related to soil restoration, water regulation, or climate resilience. Their primary

contribution lies in improving nutrition, livelihoods, and behaviour, and in preparing households and communities for broader change.
The real value of the Agroecological Homestead Model lies in how effectively it builds confidence, skills, and institutional readiness, creating a foundation for gradual agroecological transition in rainfed and selected irrigated systems.

3. Rainfed Agroecological Pathways – Restoring Soils, Resilience, and Livelihoods

Rainfed regions constitute nearly 50% of India's net cultivated area and support a large proportion of small and marginal farmers. These landscapes are characterised by shallow and degraded soils, erratic rainfall, limited irrigation infrastructure, and high exposure to climate variability. While productivity levels are generally low, rainfed systems also offer the greatest opportunity for agroecological transformation, as chemical input dependence is relatively low and traditional ecological knowledge remains strong (Kumar et al., 2024b). Building on the confidence and skills developed through homestead-based interventions, rainfed agroecological pathways enable the next level of transition i.e. from household to farm-scale productivity, resilience, and landscape regeneration.

3.1 Why Rainfed Systems Are Central to Agroecological Transition

Rainfed agriculture is currently positioned at the intersection of multiple national priorities including productivity enhancement, potential pulse and oilseed bowl, climate adaptation, land restoration, poverty reduction, and nutritional security. Conventional intensification approaches since the era of the green revolution have delivered limited gains in these regions mainly due to water constraints, soil degradation, and rising input costs. This has also reduced farmers stress and migration to nearby cities. Agroecology, by contrast, focuses on regenerating ecological processes and reducing external inputs. Key reasons rainfed systems are ideal candidates for agroecological transition include poor soil organic matter and moisture retention, making them responsive to composting, mulching, and biological soil management; diverse cropping including millets, pulses, oilseeds, and mixed systems well-suited to diversification; lower baseline chemical use, reducing the risks associated with transition; and strong links between land degradation and livelihoods, meaning ecological gains translate quickly into social benefits (Kumar et al., 2024b).
These characteristics allow agroecological practices to deliver **both productivity stabilisation and resilience gains**, even under variable rainfall conditions.

3.2 Core Agroecological Practices in Rainfed Landscapes

Rainfed agroecological pathways combine field-level practices with community-scale resource management, guided by the broader set of agroecological principles and recognising that individual farms are embedded within shared landscapes.

Key elements include:

- Soil regeneration through organic matter management: Regular application of compost, crop residues, green manures, and biological inoculants improves soil biological activity, soil structure, infiltration, and nutrient cycling.
- Crop diversification and intercropping: Integration of cereals with pulses, oilseeds, and fodder crops spreads production risk, enhances biological nitrogen fixation, and improves dietary diversity.

- Pre-monsoon dry sowing, continuous crop cover, and residue mulching: Strategic pre-monsoon dry sowing, continuous crop cover through relay cropping or cover crops, and residue mulching are recognised practices for conserving soil moisture, moderating soil temperature, and improving soil structure. Residue cover and mulching not only reduce soil evaporation but also support higher soil organic matter and influence microbial community composition, which in turn enhances soil biological functions important for sustainable cropping systems (Singh & Chamroy, 2025; RySS, 2025).
- Micro-site enhancement and landform management: Practices such as Krishi Kund -a pit-based cultivation involving one-time subsurface application of organic manure for site improvement and perennial crop establishment (Kumar et al., 2024a; Malaiappan et al., 2024c), along with contour farming, vegetative barriers, field and contour bunds, planting basins, stone lines, and land-shaping interventions (broad-based terraces, alternate furrow–ridge systems, tied ridges), reduce runoff and erosion while improving soil moisture availability.
- Agroforestry and perennial integration: Trees and shrubs contribute biomass for food, fodder, fibre, and fuel, regulate microclimates, enhance long-term soil fertility, and strengthen climate resilience.
- Biological pest and disease regulation: Increased habitat and crop diversity supports natural enemies, helping to regulate pest populations and reduce reliance on chemical control.
- Livestock integration and integrated farming systems: Livestock has long been an integral component of rainfed farming systems, and its relevance has increased with the wider adoption of natural farming. Systematic integration through customised integrated farming system models is an important contributor to agroecological transition.
- Biodiversity corridors, commons, and bunds: Declining biodiversity in rainfed areas is a growing concern. Integrating biodiversity considerations into landscape regeneration through enhanced floral diversity that supports faunal populations, particularly pollinators, and through the use of field and contour bunds as biodiversity sites and corridors where feasible, can significantly strengthen landscape-level ecological connectivity and farm–landscape integration.
- Context-specific and selective adoption of natural farming practices: While full natural farming packages (DA&FW, 2025) may be feasible in limited contexts, policy support should prioritise selective and phased adoption of practices based on local agroecology, farmer capacity, and risk tolerance, rather than uniform or complete transition

These interventions are knowledge and often labour intensive rather than input-intensive, and they align well with local capacities when supported by appropriate extension services, peer learning, and collective action.

3.3 Water as the Binding Constraint and Opportunity

In rainfed systems, water availability is the primary limiting factor. Agroecological transition therefore places strong emphasis on rainwater harvesting, soil–water conservation, and landscape hydrology.

At both farm and community levels, key interventions include in-situ moisture conservation through mulching and continuous soil cover; small water-harvesting structures such as farm ponds, recharge pits, and contour trenches; and the restoration and rejuvenation of traditional tanks, water-harvesting structures, streams, and drainage lines. These measures are most effective when supported by collective planning of water use aligned with local crop calendars.

When combined with improvements in soil organic matter, such interventions may substantially enhance water productivity, enabling crops to better withstand dry spells and reducing the risk of crop failure. Over time, cumulative actions across farms contribute to groundwater recharge, reduced downstream sedimentation, and improved hydrological functioning, thereby strengthening resilience at landscape and watershed scales.

3.4 Livelihood Diversification and Risk Reduction

Rainfed agroecological transition is not only about stabilising yields; it is equally about reducing livelihood risk. Diversified systems generate multiple income streams—food grains, pulses, vegetables, fodder, tree products, and small livestock—spread across seasons. This diversification shortens income cycles, improves household cash flow, strengthens fodder availability, and enhances livestock productivity (FAO, 2019). Importantly, rainfed agroecological systems align well with public employment, watershed, and rural livelihood programmes, allowing convergence of investments in soil and water conservation with tangible livelihood outcomes.

Evidence from the Andhra Pradesh Community-managed Natural Farming (APCNF) programme and similar rainfed initiatives indicates that agroecological practices are more knowledge- and labour-intensive than conventional input-driven systems, requiring regular family engagement in activities such as bio-input preparation, mulching, disaggregated harvesting and field observation. In rainfed regions, where under-employment and seasonal labour availability are common, this labour demand can become a strength by improving management quality and reducing dependence on purchased inputs. Given the low productivity baseline in many rainfed systems, improvements in soil health, moisture retention, and crop diversity have often resulted in yield gains alongside cost reductions. These characteristics explain why national-scale prioritisation exercises identify rainfed regions as the lowest-risk and highest-potential entry points for agroecological transition.

3.5 Social and Institutional Dimensions of Scaling

Scaling rainfed agroecology requires collective action. Individual farms are embedded within shared landscapes, grazing commons, drainage lines, and aquascapes. Local institutions such as Panchayati Raj Institutions (PRI), watershed committees, women’s self-help groups, user groups, and Farmer Producer Organisations play a critical role in planning land and water interventions, coordinating input preparation and sharing, managing common resources, and linking farmers to markets and public schemes. Experience shows that when homestead-based learning is embedded within such institutions, communities are better prepared to adopt and sustain rainfed agroecological practices at scale.

3.6 Bridging Toward Landscape-Level Transformation

Rainfed agroecological pathways therefore act as a bridge between household-level change and broader landscape transformation. As soils recover, water retention improves, and diversified systems stabilise livelihoods, cumulative impacts become visible across watersheds and landscapes. To achieve full multifunctionality—linking food production with ecosystem services, biodiversity conservation, and climate mitigation—rainfed pathways must ultimately connect with transitions in irrigated systems and value chains. This sequencing and integration position rainfed regions not as marginal spaces, but as strategic leverage points for agroecological transformation.

4. Integrating Agroecological Practices in Intensive Irrigated Systems: Managing Risk and Environmental Stress

Intensive irrigated systems producing rice, wheat, sugarcane, cotton, and horticultural crops remain critical for India's food security and rural economy. These systems have benefited from long-term public investment in irrigation, fertilizers, energy, and procurement. Any significant reduction in yields in this region would have serious consequences. At the same time, there is growing evidence of declining soil health, groundwater depletion, nutrient imbalance, and increasing environmental and human health concerns linked to prolonged input-intensive farming including pesticide exposure and environmental contamination (Lal, 2020; IPCC, 2019; CGWB, 2023). Instead, the

Spatial Prioritization of Rainfed Agroecological Transition in India- Recent national-scale spatial analysis (Kumar et al., 2025b; Sikka et al., 2024) provides strong empirical support for prioritizing rainfed and low-productivity regions as strategic entry points for agroecological transition in India. A multicriteria-based agroecology priority mapping exercise, conducted under the CGIAR Agroecology Initiative, applied decision-support framework to identify regions where agroecological interventions can deliver the highest combined benefits for productivity improvement, resilience, and environmental sustainability The analysis integrated multiple biophysical, climatic, and agronomic indicators that are critical for agroecological performance, including net primary productivity (NPP), fertilizer consumption, rainfall patterns, aridity index, groundwater depth, land slope, heat stress indicators, length of growing period, and solar radiation. These spatial layers were harmonized and weighted using the Analytical Hierarchy Process (AHP), based on structured consultations with agricultural system actors and other stakeholders. The approach allowed prioritization to be grounded not only in environmental vulnerability but also in food security considerations and practical transition risks.

Rainfed, Low-Productivity Regions as the Primary Transition Zone- The priority map reflecting the perspectives of agricultural system actors' places high priority on rainfed, low-productivity regions, where agroecological transition is least likely to compromise national food security. Approximately 37.9 million hectares (nearly one-third of cultivated land) were classified as high priority, largely concentrated in western, central, and parts of peninsular India. These regions are characterized by low NPP, shallow and degraded soils, limited groundwater availability, high aridity, and limited dependence on chemical inputs.

From a transition perspective, these areas offer several advantages. First, yield penalties associated with reducing external inputs are minimal, while the scope for productivity improvement through soil regeneration, moisture conservation, and diversification is substantial. Second, agroecological practices in these landscapes directly address dominant constraints including soil degradation, rainfall variability, and livelihood vulnerability, thus making benefits both visible and rapid. Third, these regions coincide with high concentrations of small and marginal farmers, for whom agroecology can enhance resilience and income stability without increasing financial risk.

Balancing Food Security and Environmental Objectives- The spatial analysis also highlights an important policy insight: agroecological prioritization involves trade-offs. A parallel priority map, developed from the perspective of agroecological and environmental advocates, emphasizes high-input, high-yield regions experiencing severe environmental stress, particularly excessive fertilizer use, groundwater overexploitation, and declining factor productivity. While these irrigated zones are critical for food security, they are also environmentally vulnerable in the long term. Notably, only about 1.5% of agricultural land overlaps as high priority between the two perspectives, underscoring the need for differentiated, pathway-specific strategies rather than uniform prescriptions. The analysis therefore reinforces the logic of sequencing agroecological transition, beginning with rainfed, low-risk regions to build evidence, confidence, and institutional capacity before expanding to more intensive systems.

Implications for Rainfed Agroecological Pathways- The priority mapping provides a spatial rationale for the rainfed agroecological pathway discussed in this section. It demonstrates that rainfed landscapes are not merely vulnerable zones in need of support, but strategic leverage points where agroecology can simultaneously improve productivity, restore ecological functions, and strengthen livelihoods. By targeting these priority regions, public investments in soil and water conservation, diversification, and community institutions can yield high returns in terms of resilience and sustainability.

Equally important, the mapping framework is designed to be dynamic and adaptive. As awareness grows, technologies evolve, and food security safeguards improve, priority zones can be periodically revised to include additional regions, including selected intensive systems. In this sense, spatial prioritization is not a static classification, but a planning tool that supports phased and evidence-driven agroecological transition.

policy challenge is to reduce environmental stress and production risk while maintaining productivity, farmer incomes, and food security. This section therefore focuses on the gradual and risk-aware integration of selected agroecological practices that improve resource-use efficiency, enhance system resilience, and build farmer confidence within prevailing intensive irrigated production systems.

4.1 A Distinct Transition Logic for Irrigated Systems

Unlike rainfed regions, irrigated landscapes are characterised by high capital investment in infrastructure and machinery, strong policy signals linked to procurement and subsidies, and heavy dependence on synthetic inputs and energy. In this system, agroecology can be better approached as a system-optimisation strategy with emphasis on reducing excess input use, improving efficiency, strengthening soil biological processes, and closing nutrient loops, while safeguarding yield stability. This way of looking at agroecology is supported by experience from conservation agriculture, integrated nutrient management, and climate-smart intensification approaches in irrigated systems (Jat et al., 2020; Raj et al., 2023).

4.2 Entry Points for Gradual and Low-Risk Transition

Agroecological transition in irrigated systems can begin through small, low-risk adjustments rather than full system transformation. Evidence from irrigated regions shows that moderate reductions in fertiliser and pesticide use, when combined with better timing, placement, and biological supplementation, can often be achieved without yield loss (Jat et al., 2018; Lal, 2020). Precision nutrient management, fertigation, and improved irrigation scheduling can reduce losses, lower production costs, and improve water and nutrient use efficiency. Farmers are more likely to accept these measures are presented as ways to improve efficiency, rather than as complete replacement of chemical inputs.

Biological inputs such as composts, crop residues, biofertilizers, and microbial formulations can be used as supplements to improve soil condition and fertiliser efficiency over time. Evidence from integrated nutrient management and natural farming experiments shows that these approaches can stabilise or raise yields while improving soil organic carbon and reducing dependence on external inputs (Lal, 2020; RySS, 2025).

Gradual crop diversification within irrigated rotations, through inclusion of pulses, oilseeds, fodder crops, or vegetables can also reduce pressure on groundwater, improve soil structure, and lower pest and disease incidence, spreads risk and opens pathways for income diversification without disturbing core food-grain production.

4.3 Addressing the Water–Energy–Soil Nexus

Water management remains one of the most critical issues in irrigated agriculture. Groundwater over-extraction, inefficient irrigation practices, and energy-intensive pumping have created long-term ecological and economic stress.
Agroecological approaches in irrigated systems can help address this challenge by linking soil health improvement with better water and energy management. Practices that increase soil organic matter can improve water retention, reduce irrigation demand and enhance resilience to heat and dry spells (Lal, 2020; IPCC, 2019). Improved irrigation scheduling and micro-irrigation, where suitable, can further enhance water productivity.

The increasing spread of solar-based irrigation presents both opportunities and risks. When combined with clear norms for groundwater use and incentives for productive use of surplus energy, solar irrigation can support more sustainable water–energy management rather than accelerating over-extraction (Shah et al., 2018).

4.4 Circular Bioeconomy as a Transition Accelerator

One of the strongest agroecological entry points in irrigated systems lies in the circular bioeconomy. Crop residues, livestock waste, food-processing by-products, and biomass from field margins are often under-utilised or treated as waste. When managed through local or, community-level bioresource centres, these materials can be converted into compost, enriched organic amendments, animal feed, and bio-energy products. Such circular flows reduce dependence on external inputs, lower waste burdens, and create local enterprise opportunities particularly for women and youth. Experience from CGIAR-supported work on multifunctional landscapes, agroecology, and nature-positive initiatives in India shows that circular bioeconomy approaches can improve environmental outcomes, create additional income opportunities, and support social inclusion, without disturbing existing production systems (Somorin et al., 2025).

4.5 Managing Risk, Perception, and Farmer Confidence

Caution around agroecological transition in irrigated regions reflects both legitimate food security concerns at the policy and research level, as well as perception- and risk-related considerations at the individual farmer level, rather than limitations of technical feasibility alone. Farmers are understandably concerned about yield loss, market acceptance, and disruption of established practices. Published studies shows that even when technologies such as Happy Seeder are technically proven, adoption is mainly constrained by farmers perception and institutional barriers (Jat et al., 2020; Singh et al., 2021)

Building farmer confidence therefore requires locally grounded and evidence-based approaches. Demonstration plots within farmers' fields, transparent yield and cost comparisons, and advisory support from trusted institutions are more effective than broad messaging. Gradual scaling, rather than mandates, allows farmers to observe results and adapt practices at their own pace. Agroecology should be framed as a risk-management and efficiency-improving approach, not as an ideological shift.

4.6 Role of Policy and Institutions

Public policy strongly influences decision-making in irrigated systems. Fertiliser subsidies, power pricing, procurement norms, and extension messages shape farmer behaviour more than technical recommendations alone. Policy alignment should therefore focus on encouraging input efficiency, soil health improvement, and diversification, without abrupt withdrawal of existing support that could threaten food security or farmer incomes. Coordination among agriculture departments, irrigation agencies, extension systems, and farmer organisations is essential to ensure that agroecological practices are technically sound, economically viable, and locally adapted.

5. Scaling Agroecology: Practical Constraints and Policy Enablers

5.1 Entry Points and the Nature of Agroecological Transition

Agroecological transition in India cannot be uniform or simultaneous across regions and farming systems. Field experience shows that homesteads function as the most practical entry point, especially for small and marginal farmers. They allow farmers to experiment with agroecological practices at low risk, observe visible benefits related to food quality and costs, and gradually change perceptions about soil health and chemical inputs.

In rainfed areas, limited spillover from homesteads to main fields is often observed, particularly for compost and bio-input use. While this spillover is modest, it helps farmers test practices without making abrupt changes. Beyond these entry effects, agroecological performance varies widely depending on rainfall, soils, labour availability, crop type, and institutional support. Recognising this variability is essential to avoid unrealistic expectations and one-size-fits-all policy approaches.

5.2 Factors Shaping the Pace of Agroecology Adoption

Despite growing interest, agroecology has not scaled at the pace often expected. This is not due to a lack of farmer interest alone, but because adoption is shaped by multiple interlinked constraints related to knowledge, perception, labour, markets, policy design, and research support. These constraints are common across homesteads, rainfed systems, and irrigated agriculture, though their intensity varies by context. The key barriers and corresponding policy responses are summarised in Table 2. The table highlights why agroecology often underperforms in practice when promoted through partial adoption, short-term pilots, or biased comparisons, and how policy can address these issues in a realistic and enabling manner.

Table 2. Key Constraints in Agroecology Adoption and Corresponding Policy Responses

Key Constraint	Policy Response (Enabling)
Limited knowledge and weak capacity building on agroecological principles, especially links between soil health, food quality, and human health	Strengthen long-term capacity building through farmer field schools, demonstration clusters, and continuous learning platforms. Reorient extension from input delivery to knowledge support and field-based learning.
Partial adoption of selected practices (e.g. *beejamrit* or botanical sprays alone) leading to misleading performance comparisons	In homestead and rainfed regions, promote evaluation of agroecology as a set of complementary practices rather than isolated components, and clearly communicate the limits of partial adoption in performance assessment. In irrigated areas, support *phased, system-oriented integration* of functionally linked agroecological practices through gradual replacement of existing practices, while avoiding evaluation based on single components.
Perception gaps, especially in irrigated areas where agroecology is seen as risky or yield-reducing	Treat perception management as a policy issue. Support transparent field demonstrations, side-by-side comparisons, and locally trusted farmer champions instead of broad awareness campaigns.
Higher labour and management requirements, particularly during early adoption	Support labour-saving innovations and customisation of tools, including simple machinery and drone-based or mechanised application of bio-formulations. Encourage local service providers and custom hiring models.

Lack of reliable price premium for agroecological produce beyond niche markets	Avoid over-reliance on price premiums. Focus policy support on reducing input costs, improving input self-reliance, stabilising incomes during transition, and selective linkage with public procurement and nutrition programmes.
Incomplete cost comparisons that do not fully account for fertiliser, energy, and irrigation subsidies.	Improve cost accounting frameworks by explicitly recognising subsidies and externalities when comparing farming systems. Use full-cost or adjusted comparisons in policy analysis and programme evaluation.
Food security concerns persist despite current food-grain surplus, especially due to deficits in pulses and legumes and future population pressure.	Adopt phased and region-specific agroecological transitions specially in intensively cultivated areas that safeguard food security, while gradually aligning farming systems with future food and nutrition needs, including pulses and legumes.
Weak mainstreaming in the National Agricultural Research and Education System (NARES)	Integrate agroecology into mainstream research agendas, long-term trials, and extension curricula. Broaden performance metrics beyond yield to include soil health, water productivity, and livelihood outcomes.
Fragmented policy support and short-term pilots	Encourage convergence of existing programmes at village or cluster level rather than creating new schemes. Support longer implementation cycles to build credibility and learning.

5.3 Policy Enablers for a Realistic Scale-up

The policy challenge is not to promote agroecology as a complete replacement of existing farming systems on main cultivated fields, but to reduce transition risk, correct systemic distortions, and build farmer and institutional capacity over time. In rainfed regions, where prevailing farming practices are already relatively closer to agroecological principles, near-complete adoption of agroecological packages can be encouraged, supported by soil and water conservation, diversification, and community institutions.

In intensive irrigated areas, policy needs to explicitly recognise entry-based and phased transition pathways. Farmers should be enabled to begin with a limited set of high-return, low-risk agroecological practices and gradually expand adoption as confidence, skills, and evidence accumulate. Extension services play a critical role in guiding this process by supporting context-specific selection and sequencing of practices, rather than promoting uniform packages. In such systems, incremental and efficiency-led transitions are more appropriate than abrupt or radical shifts.

Perception management, particularly in irrigated regions where agroecology is often viewed as risky or yield-reducing, requires locally generated evidence, trusted demonstrations, and transparent comparisons, rather than generic messaging. Correcting cost-accounting biases is equally important. Fertiliser and energy subsidies, along with environmental and human health externalities, need to be explicitly acknowledged in policy evaluations to ensure fair comparison between agroecological and chemical-intensive systems. At the same time, expectations around price premiums should remain realistic, with greater emphasis placed on reducing input costs and stabilising farm incomes during transition periods.

Labour constraints, especially during early adoption, should be addressed through appropriate mechanisation and service-delivery models, including customised tools and drone-assisted or mechanised application of bio-formulations. Finally, agroecology needs to be mainstreamed within research and extension systems, supported by long-term trials, context-specific recommendations, and performance metrics that extend beyond yield to include soil health, water productivity, and livelihood outcomes.

5.4 Policy Way Forward

Agroecological transition in India is best understood as a gradual, learning-oriented process, rather than a one-time shift. Agroecological homesteads can serve as confidence-building and learning entry points, rainfed systems can adopt agroecological practices more comprehensively over time, and irrigated systems are more likely to respond through efficiency improvements and phased integration, rather than full conversion. Policies that recognise these differences across farming contexts, address real constraints faced by farmers, and support informed and voluntary decision-making are more likely to enable credible, scalable, and farmer-acceptable agroecological transitions.

India has already taken important steps toward promoting more sustainable and inclusive agrifood systems through multiple national missions, state-led initiatives, and community-based programmes. These efforts reflect strong policy intent and are broadly aligned with long-term goals of food security, resource conservation, and farmer welfare. Building on these foundations, this paper offers pathway-based insights to support better alignment and sequencing of agroecological transitions across diverse farming systems, without proposing new or parallel programmes.

Policy Recommendations: Enabling Agroecological Transition in India

- Adopt differentiated transition strategies, recognising that agroecological transition cannot follow a single uniform model across regions and farming systems.
- Institutionalise Agroecological Homestead Models (AHMs) as low-risk entry points, supporting behavioural change, nutrition improvement, and women's empowerment through convergence with NRLM, POSHAN Abhiyaan, watershed programmes, and village planning processes.
- Prioritise rainfed and low-productivity regions for agroecological scaling, where transition risks are lower and potential gains in soil restoration, resilience, and livelihoods are highest.
- Enable phased, efficiency-led integration of agroecological practices in irrigated systems, while avoiding abrupt withdrawal of fertiliser, irrigation, or procurement support that could threaten productivity and food security.
- Assess agroecology as a system-level transition over time, rather than through isolated adoption of individual practices, to avoid misleading performance comparisons.
- Treat perception and risk management as core policy functions, investing in demonstration clusters, transparent field comparisons, and trusted advisory support.
- Correct cost accounting and incentive structures by explicitly recognising fertiliser, energy, and irrigation subsidies, along with environmental and health externalities, and by focusing support on input cost reduction and income stability.
- Mainstream agroecology within research, extension, and planning systems, integrating it into NARES agendas, extension curricula, and performance metrics, and promoting convergence of existing schemes rather than creating new ones.

6. Conclusions and the Way Forward

India's main agrifood challenge today is not only to increase crop yields. It is also about improving nutrition, protecting soil and water, dealing with climate risks, and ensuring stable livelihoods for farmers. These goals need to be addressed together. Agroecology offers a practical way forward because it builds on natural processes, reduces heavy dependence on external inputs, and strengthens local institutions.

This paper discusses three agroecological transition pathways that respond to different farming conditions. Homesteads provide a low-risk starting point and quickly improve household nutrition and well-being. Rainfed systems offer the greatest opportunity to restore degraded soils, improve water use, and reduce livelihood risks. Intensive irrigated systems, which are important for national food security, need a gradual and careful transition focused on improving efficiency and reducing environmental damage. When these pathways are taken together and linked at the landscape level, they are more likely to generate wider and more durable change than isolated efforts.

Agroecological transition is not only a technical issue; it is equally shaped by coordination, governance, and institutional alignment. Success depends on better alignment of existing investments in agriculture, soil and water conservation, nutrition, livelihoods, and climate adaptation. Local institutions such as Panchayats, watershed committees, women's self-help groups, and farmer organisations play a key role in planning, implementation, learning and perception management. Instead of creating new schemes, policy efforts should focus on bringing existing programmes together and allowing solutions to be adapted to local conditions.

For policymakers, the main message is that agroecology should be used as a framework to improve how current programmes work, not as a separate or parallel initiative. Progress should be tracked not only through crop yields, but also through simple and meaningful outcomes such as soil health, water productivity, diet diversity, livelihood stability, and ecosystem condition.

The approach presented in this paper, linked to the CGIAR Agroecology and Multifunctional Landscapes agenda, provides a realistic and scalable pathway for India. It supports food security while helping farming systems become more resilient, inclusive, and environmentally sustainable in the face of climate change.

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