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MINI REVIEW

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Strategic crop diversification in Punjab and Haryana: Enhancing agroecological sustainability, food security, and nutritional outcomes

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ABSTRACT

Punjab and Haryana have long relied on the intensive wheat–rice cropping system that played a pivotal role in ensuring India's food security. However, this monoculture has contributed to ecological degradation, groundwater depletion, and stagnating farm incomes. This review critically explores the potential of strategic crop diversification as a sustainable solution. It synthesizes data from peer-reviewed literature, national databases, and government reports to examine the agroecological context, economic and nutritional implications, and structural barriers to diversification in both states. Empirical evidence demonstrates that integrating pulses, oilseeds, millets, and horticultural crops can enhance soil health, dietary diversity, and climate resilience. Key challenges such as policy bias, infrastructure limitations, and market failures are addressed, followed by strategic recommendations to operationalize diversification at scale. The review concludes that crop diversification is essential for transitioning to ecologically balanced, nutritionally secure, and economically viable agricultural systems in Punjab and Haryana.

KEY WORDS

Crop diversification; Sustainable agriculture; Agroecology; Food security; Climate resilience; Soil health

ARTICLE HISTORY

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Introduction

This review adopts a systematic literature synthesis approach, drawing from peer-reviewed journals (Google Scholar, Web of Science, Scopus), government reports (Ministry of Agriculture, CGWB, IMD), national databases (DAC&FW, ICAR), and policy documents spanning 2004–2022. Search terms included "crop diversification Punjab Haryana," "wheat-rice system," "agroecological sustainability," and "agricultural policy India." Inclusion criteria prioritized empirical studies, regional case studies, and quantitative assessments of diversification impacts on soil health, water resources, farm economics, and nutritional security.

Punjab and Haryana have historically been the epicenters of India's Green Revolution. The widespread adoption of high-yielding varieties (HYVs) of wheat (*Triticum aestivum*) and rice (*Oryza sativa*), coupled with assured government procurement under the Minimum Support Price (MSP) mechanism, extensive canal irrigation infrastructure, and subsidized inputs, transformed these states into India's primary food grain production hubs. This agricultural intensification system played a pivotal role in ensuring national food security during the 1970s and 1980s [1,2]. However, sustained cultivation of the wheat–rice cropping system over five decades has resulted in diminishing marginal returns and escalating ecological and socioeconomic costs. These adverse impacts include severe groundwater over-extraction (annual depletion rates of 0.5–1.0 m), soil organic carbon depletion, increased greenhouse gas (GHG) emissions (primarily methane and nitrous oxide), evolution of pest and disease resistance, and heightened vulnerability to climate variability and market fluctuations [3-5]. Crop diversification represents a strategic agroecological intervention involving the deliberate shift from cereal monocultures toward integrated cropping systems incorporating pulses (Fabaceae family), oilseeds (Brassicaceae and other families), millets (small-seeded grasses), fodder crops, and horticultural produce. This paradigm offers multifaceted benefits: enhanced agroecosystem resilience through improved soil health and biodiversity, economic risk mitigation via income diversification, nutritional enhancement through dietary diversity, and improved climate change adaptation capacity [6,7].

Beyond ecological concerns, policy distortions linked to groundwater–energy subsidies and cereal procurement have reinforced unsustainable cropping incentives in Punjab and Haryana [8,9]. Empirical evidence from Haryana further suggests that crop diversification improves farm income stability and reduces exposure to price volatility [10,11]. Market infrastructure and institutional arrangements also significantly influence diversification outcomes [12,13].

This review systematically evaluates crop diversification strategies in Punjab and Haryana through the analytical lens of agroecological sustainability, food and nutritional security, climate resilience, and policy-institutional frameworks. It synthesizes empirical evidence from peer-reviewed literature, government databases, and regional assessments to critically examine: (i) agroclimatic constraints and soil-water resource dynamics; (ii) temporal trends in cropping pattern evolution; (iii) quantifiable benefits of diversification on soil health, water conservation, farm profitability, and dietary outcomes; (iv) structural and institutional barriers impeding diversification; and (v) evidence-based policy recommendations for large-scale implementation. Additionally, this paper examines the potential of emerging precision agriculture technologies, including Artificial Intelligence (AI) and machine learning algorithms, in facilitating data-driven crop selection based on integrated soil-climate-market analytics, predictive modelling for pest and disease management, optimization of irrigation scheduling and nutrient application, and delivery of real-time mobile-based

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agricultural advisory systems.

By providing a policy-relevant roadmap, this review aims to facilitate the transition from monoculture to regenerative, nutrition-sensitive agriculture that can sustain Punjab and Haryana's agricultural productivity and ecological health in the long term.

Regional Agroecological Context

Soil resources

Parameter	Punjab (Avg.)	Haryana (Avg.)	Source
Soil Type	Alluvial	Alluvial/Arid	[14]
pH	7.3–8.5	7.5–9.0	[15]
Organic Carbon (%)	0.3–0.5	0.2–0.4	[16]
Available N (kg/ha)	220–280	180–240	[17]
Micronutrient Deficiency	Zn, Fe	Zn, B	[5]

Continuous monocropping has contributed to declining soil carbon stocks and nutrient-use inefficiencies in northwestern India [16,18]. Diversified rotations integrating pulses improve soil biological activity and long-term fertility restoration [19,20].

Water resources

Indicator	Punjab	Haryana (Avg.)	Source
Groundwater Table (m)	18.0 (falling)	15.0 (falling)	[21]
Districts Overexploited (%)	80%	60%	[21]
Annual Recharge (BCM)	17.0	10.5	[21]
Annual Draft (BCM)	30.5	18.2	[21]

Water-intensive cropping patterns, reinforced by institutional policy frameworks, have exacerbated aquifer stress in the region [8,22]. Diversification toward less water-demanding crops offers a viable pathway for groundwater stabilisation.

Climate risks

Climate Parameter	Trend (1980–2020)	Agricultural Impact	Source
Avg. Annual Temp. ↑	+0.7–1.0°C	Higher evapotranspiration	[23]
Rainfall Variability	±20% Monsoon swings	Sowing delays, droughts	[5,23]
Heat Wave Frequency ↑	+40%	Wheat yield losses	[24]

Crop diversification is increasingly recognized as a climate adaptation strategy capable of reducing yield variability under temperature and rainfall fluctuations.

Trends in Cropping Patterns

Punjab and Haryana's cropping patterns have been dominated by the intensive cultivation of wheat and rice for several decades, primarily due to government procurement policies, assured irrigation, and input subsidies. This system led to a sharp increase in food grain production during the Green Revolution. However, recent data indicate a slow but noticeable shift towards diversification, driven by concerns over resource depletion and market risks [25,26].

The continuous monoculture system has resulted in significant soil nutrient depletion over time. Figure 1 illustrates the comparative impact of sustained wheat-rice cultivation on soil nutrient dynamics, showing marked reductions in nitrogen, phosphorus, potassium levels, organic carbon content, and overall soil health parameters. This degradation necessitates the strategic shift toward diversified cropping systems that can restore soil fertility and ecological balance [27].

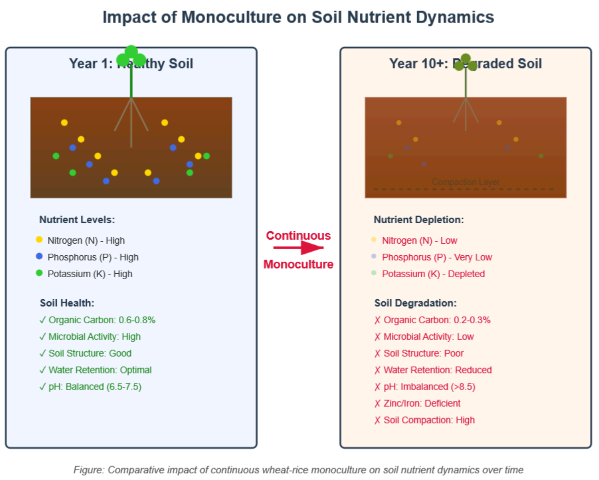

Figure 1. Comparative impact of continuous wheat-rice monoculture on soil nutrient dynamics.

In Punjab, wheat and rice together account for approximately 80–85% of the total cropped area, though the share of pulses, oilseeds, and horticultural crops is gradually increasing [17]. Haryana exhibits a similar trend, with wheat and rice occupying about 75–80% of the cultivated area, while diversification into maize, millets, and vegetables is expanding, especially in districts facing water stress [28].

Between 2010 and 2020, the area under pulses in Punjab grew by approximately 10%, and oilseeds by 8%, reflecting growing farmer interest and policy support. Millets, traditionally grown in arid regions of Haryana, have seen marginal growth due to renewed emphasis on climate-resilient crops [29]. However, the pace of diversification remains constrained by infrastructural and market challenges.

The gradual increase in horticultural crops, including fruits and vegetables, particularly in peri-urban areas, indicates a positive trend towards dietary diversification and higher-value agriculture. This trend is supported by improving cold chain infrastructure and consumer demand.

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Benefits of Crop Diversification

Agroecological benefits

Crop diversification enhances biodiversity and natural pest control mechanisms, reduces dependence on chemical inputs, and improves soil health through biological nitrogen fixation by pulses and organic matter addition from oilseeds and millets.

Conservation agriculture combined with diversified cropping systems enhances soil resilience and reduces input dependency [30]. Such approaches contribute to long-term agroecosystem sustainability under intensive production conditions.

Water use efficiency

Crop	Water Use (mm)	Water Use Efficiency (kg/ha-mm)	Source
Rice	1200–1500	0.30–0.40	[31]
Wheat	450–600	0.80–1.00	[32]
Maize	400–500	1.20–1.50	[7]
Chickpea	250–350	1.40–1.80	[31]
Pearl Millet	300–400	1.60–2.00	[24]

Economic and nutritional gains

Diversification into horticultural crops can generate 2–3 times higher economic returns compared to cereals [33]. Incorporating millets and pulses also significantly enhances dietary diversity, addressing nutritional security [7].

Barriers to Diversification

Several constraints hinder crop diversification in Punjab and Haryana. Policy frameworks exhibit bias by favoring wheat and rice through minimum support prices (MSP), discouraging farmers from adopting alternative crops [34]. Historical cereal-centric planning models and centralized agricultural policy structures have further reinforced path dependency in cropping patterns [35]. Inadequate infrastructure such as cold storage and decentralized procurement limits market access for diversified crops. Additionally, market risks related to price volatility, coupled with knowledge gaps and insufficient localized advisories, further deter diversification efforts.

Strategic Recommendations

Policy reforms

Expanding MSP to cover pulses and millets and providing incentives for cultivating water-efficient crops will encourage farmers to diversify.

Infrastructure development

Building decentralized procurement systems, enhancing cold storage capacity, and improving rural roads and mandi facilities will support diversified cropping.

Knowledge dissemination and extension

Customized diversification packages through Krishi Vigyan Kendras (KVKs) and training agricultural extension workers will bridge knowledge gaps.

Research and technology

Promoting drought- and heat-resilient crop varieties, alongside development of AI and ICT-based crop planning and advisory tools, will facilitate precision diversification and climate adaptability. Emerging digital agriculture platforms and AI-enabled advisory systems can further facilitate precision-based diversification decisions [36].

Policy reforms and initiatives: regional case studies

Several Indian states and national-level initiatives have pioneered reforms to promote crop diversification, offering valuable lessons for Punjab and Haryana. These case studies demonstrate the feasibility and effectiveness of diversification strategies when supported by appropriate policy frameworks, institutional mechanisms, and farmer engagement.

Andhra Pradesh: Zero Budget Natural Farming (ZBNF)

Andhra Pradesh launched ZBNF in 2018, covering over 600,000 farmers by 2022. This initiative promotes multi-cropping systems integrating pulses, millets, oilseeds, and vegetables using indigenous practices and biological inputs. The program has demonstrated 30-40% reduction in input costs, enhanced soil carbon levels, improved water retention capacity, and increased farm income by 20-25%. The state government provides extensive training, certification support, and market linkages for organic produce. This case highlights how institutional backing can facilitate large-scale adoption of diversified, sustainable farming practices.

Odisha: Millet Mission

Odisha's Millet Mission (2017) revitalized millet cultivation across 30 districts, benefiting over 70,000 tribal households. The mission provided seed distribution, value addition infrastructure, processing facilities, and market access through women's self-help groups. Millet cultivation area increased from 1.5 lakh hectares (2017) to 3.2 lakh hectares (2021), contributing to improved nutrition security and economic empowerment in rainfed regions. The initiative also integrated millets into school meals and public distribution systems, creating guaranteed demand. This model demonstrates how government procurement beyond rice and wheat can incentivize diversification while addressing nutritional deficiencies.

Karnataka: Rashtriya Krishi Vikas Yojana (RKVY) diversification program

Karnataka utilized RKVY funding to promote horticulture, spices, and floriculture diversification in previously paddy-dominant regions. Between 2015 and 2021, the state established 250+ farmer producer organizations (FPOs), modernized 180 cold storage facilities, and created 450 village-level collection centers. The program included subsidies for drip irrigation (up to 90%), integrated pest management training, and quality certification support. Horticultural production increased by 35%, with exports rising by 28%. Average farmer income in diversified districts increased by ₹45,000 annually compared to mono-crop areas. This case underscores the importance of comprehensive value chain infrastructure in successful diversification.

National Initiatives: Pradhan Mantri Krishi Sinchai Yojana (PMKSY) and National Food Security Mission (NFSM)

PMKSY (launched 2015) emphasizes micro-irrigation and water-use efficiency, critical enablers for diversification into less water-intensive crops. Under PMKSY, Punjab installed drip irrigation systems across 85,000 hectares and sprinkler

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systems on 120,000 hectares by 2022, primarily benefiting cotton, maize, and vegetable cultivation. NFSM-Pulses component expanded pulse cultivation area in Haryana by 18% (2018-2022), with targeted support for seed distribution, soil testing, and demonstration plots. These initiatives show how centrally-sponsored schemes, when adapted to local contexts, can accelerate diversification momentum. However, both programs require enhanced coordination with state procurement mechanisms to ensure market stability for diversified crops.

Lessons for Punjab and Haryana

These case studies reveal common success factors: political commitment, institutional capacity-building, farmer participation, value chain infrastructure, market linkages, and financial incentives. Punjab and Haryana can adapt these models by: (i) establishing dedicated crop diversification missions with district-level implementation units, (ii) expanding MSP coverage to pulses, oilseeds, and millets with procurement infrastructure, (iii) incentivizing FPO formation for diversified crops with startup capital and technical support, (iv) strengthening agricultural research systems to develop region-specific high-yielding varieties of alternative crops, and (v) leveraging digital technologies for precision agriculture, market information systems, and direct farmer-consumer linkages. The integration of these elements within a coherent policy framework offers a viable pathway for large-scale diversification in Punjab and Haryana.

Conclusion

Punjab and Haryana stand at a critical juncture. The wheat-rice system that once guaranteed national food security now threatens the sustainability of agriculture in these states. Strategic crop diversification offers a robust, evidence-based pathway to restore soil health, improve nutritional outcomes, and enhance farmers' economic resilience. Achieving this transformation demands coordinated reforms across procurement policy, infrastructure development, research innovation, and farmer support services. Crucially, crop diversification must move beyond rhetoric to become embedded in local and regional agricultural plans, leveraging ecological understanding and digital technologies. By embracing this holistic approach, Punjab and Haryana can lead India's transition toward sustainable, climate-resilient, and inclusive agriculture.

Disclosure Statement

No potential conflict of interest was reported by the author.

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