# *Review Article*

# ****Crop Diversification for Nutrient, Water, and Stress Management in Indian Agriculture: A Review****

## ****Abstract****

Crop diversification, the practice of cultivating a variety of crops in space and time, is gaining prominence in Indian agriculture as a sustainable solution to emerging challenges such as nutrient depletion, water scarcity, and climate-induced stresses. This review synthesizes existing knowledge on how diversified cropping systems enhance nutrient cycling, improve water-use efficiency, and increase resilience to abiotic and biotic stresses. Drawing on empirical studies from across India's diverse agro-ecological regions, the review also explores regional trends, policy initiatives, and future strategies to promote diversification as a core principle of sustainable agriculture. India’s agriculture, though historically diverse, has witnessed significant structural shifts since the Green Revolution. While the intensified rice–wheat systems of the Indo-Gangetic Plains greatly enhanced food production, they have concurrently led to deteriorating soil health, excessive exploitation of water resources, and increased vulnerability to climatic variability. In this context, crop diversification shifting from input-intensive monocultures to ecologically-balanced, multiple cropping systems—has emerged as a sustainable strategy to address these interlinked challenges. By integrating pulses, oilseeds, millets, horticultural crops, and fodder species into existing cereal-based systems, crop diversification enhances nutrient cycling, improves soil organic matter, and boosts water productivity. Furthermore, diversified cropping patterns provide resilience against abiotic stresses such as drought, salinity, and heat, while reducing farmers’ exposure to market and climate risks. Incorporating crops with complementary nutrient and water demands also fosters more efficient use of land and inputs. As a cornerstone of ecological intensification, crop diversification contributes to higher system productivity with reduced environmental footprint. In a country where agriculture remains a primary livelihood source for more than half the population, region-specific and climate-smart diversification strategies are vital to ensuring long-term sustainability, food and nutritional security, and natural resource conservation. Thus, crop diversification is not only a means of enhancing productivity but also a multidimensional tool for managing nutrients, water, and agricultural stress in Indian farming systems.

**Keywords**: Crop diversification, nutrient cycling, water-use efficiency, climate resilience, abiotic stress, sustainable agriculture, India

## ****1. Introduction****

India’s agriculture, historically diverse (Zaman and Hedayetullah, 2020), has undergone significant changes following the Green Revolution. While the intensification of rice-wheat systems in the Indo-Gangetic Plains has improved food production, it has also led to declining soil health, excessive water use, and increased vulnerability to climate variability (Hedayetullah et al., 2014a; Sharma et al., 2016; Hedayetullah et al., 2014b). Crop diversification shifting from monocultures to multiple cropping systems is increasingly viewed as a sustainable strategy to restore agro-ecological balance, improve resource use efficiency, and reduce farming risks (Joshi et al., 2004). Crop diversification, the strategic inclusion of multiple crop species and varieties in agricultural systems, is increasingly recognized as a vital approach for enhancing the sustainability and resilience of Indian agriculture. In the face of challenges such as declining soil fertility, groundwater depletion, and climate-induced stress, diversification offers a pathway to optimize resource use, reduce environmental degradation, and stabilize farm income (Hedayetullah et al., 2012). Traditionally dominated by cereal monocultures like rice and wheat, Indian agriculture is gradually transitioning towards more diversified systems that incorporate pulses, oilseeds, millets, horticultural crops, and fodder species. This shift not only improves nutrient cycling and soil health through crop rotation and inclusion of legumes (Mukherjee and Hedayetullah, 2018) but also enhances water productivity by promoting crops with lower irrigation requirements. Moreover, diversified systems are better equipped to buffer the impacts of abiotic stresses such as drought, heat, and salinity, and they reduce the vulnerability of farmers to market and climate risks. By integrating crops with varying rooting depths, nutrient demands, and stress tolerances, farmers can create a more balanced and resilient agro-ecosystem. Crop diversification also supports the goals of ecological intensification by minimizing external inputs, improving biodiversity, and enhancing overall system productivity (Zaman and Hedayetullah, 2018b). In India, where agriculture supports over half the population, implementing region-specific diversification strategies can play a key role in addressing food and nutritional security while conserving natural resources. As such, crop diversification is not merely a production strategy but a comprehensive tool for sustainable nutrient, water, and stress management in Indian farming systems.

## ****2. Nutrient Management through Crop Diversification****

### ****2.1. Soil Fertility and Biological Nitrogen Fixation****

Crop diversification contributes significantly to nutrient cycling by improving soil fertility through the inclusion of legumes, green manures, and deep-rooted crops like sugarcane (Kundu et al., 2018). Legumes such as chickpea (Hedayetullah et al., 2018), pigeon pea, and green gram enrich soils with nitrogen via symbiotic nitrogen fixation (Ghosh et al., 2009; Singh et al., 2025). Additionally, crop rotations involving legumes enhance microbial activity, soil organic matter, and nutrient availability (Reddy et al., 2012).

### ****2.2. Organic Matter and Nutrient Recycling****

Intercropping and mixed cropping systems enhance nutrient recycling by capturing nutrients from different soil strata. Deep-rooted crops like safflower and cotton extract nutrients from sub-soil layers and contribute to nutrient redistribution when residues are incorporated (Ali et al., 2017). Green manure crops such as sunn hemp, Sesbania noxious weed like parthenium (Dolai et. al., 2019 and Dolai et al., 2013) also improve nutrient status and soil structure (Behera et al., 2007).

## ****3. Water Management in Diversified Cropping Systems****

### ****3.1. Improved Water Use Efficiency****

Crop diversification enhances water-use efficiency (WUE) by introducing less water-intensive crops and reducing the overall evapotranspiration of the system and also adoption of crop intensification under watershed development areas (Zaman et al., 2018). For instance, replacing paddy with maize or pulses in eastern India has led to significant water savings while maintaining or improving productivity (Zaman et al., 2014a; Zaman et al., 2014b; NAAS, 2013). Water resource availability is the key factor for selecting crop diversification (Zaman et al., 2016a; Zaman et al., 2016b, Zaman and Hedayetullah, 2022).

### ****3.2. Conservation Agriculture and Cropping Systems****

Diversified cropping systems under conservation agriculture (CA) practices improve water retention and infiltration. Mulch retention and minimum tillage practices associated with CA enhance soil moisture availability and reduce irrigation frequency (Jat et al., 2014). Cropping patterns such as rice-wheat-mung bean or maize-wheat-cowpea rotations have demonstrated improved WUE and better drought resilience (Zaman et al., 2016d; Singh et al., 2020).

### ****3.3. Examples from Rainfed Agriculture****

In rainfed ecosystems such as the Deccan Plateau, diversification with sorghum, millets, and pulses has proved effective in stabilizing yields and conserving moisture (Kerr et al., 2012). Traditional tribal cropping systems in Odisha and Chhattisgarh, where mixed cropping of cereals, legumes, and tubers is practiced, serve as models of water-efficient, diversified farming (Sahu et al., 2017).

## ****4. Stress Management through Diversified Systems****

### ****4.1 Abiotic Stress (Drought, Floods, Salinity and Heavy metals)****

Diversified systems buffer crops against climatic extremes. Millets and pulses are naturally drought-resilient and thrive in marginal soils. Short-duration crops help avoid terminal drought (Hedayetullah et. al., 2018) or floods, while salinity-tolerant crops like barley and mustard are gaining popularity in coastal and saline-prone areas (Arunachalam et al., 2006).

**4.2 Arsenic (Heavy metals) Mitigation through Crop Diversification**

Arsenic contamination in groundwater and soil, particularly in parts of eastern India such as West Bengal, Bihar, Uttar Pradesh, and Assam, poses a serious threat to agricultural sustainability, food safety, and human health (Hedayetullah and Kundu, 2013 and Zaman and Hedayetullah, 2018a). Prolonged cultivation of water-intensive crops like rice under flooded conditions exacerbates arsenic mobilization and accumulation in soil and plant systems, increasing the risk of arsenic entering the food chain (Hedayetullah et al., 2013). Crop diversification presents a practical and sustainable strategy to mitigate arsenic uptake and accumulation in agricultural ecosystems (Basu et. al., 2014). By shifting from continuous rice cultivation to diversified cropping systems that include less water-dependent crops—such as pulses, oilseeds, millets, and certain vegetables farmers can significantly reduce groundwater extraction and limit arsenic mobilization. Upland crops like maize, mustard, chickpea, and lentil, when grown in place of rice, help maintain aerobic soil conditions that discourage arsenic solubility and uptake by plants. Studies have shown that aerobic rice cultivation, crop rotation, and alternating flooded and non-flooded cropping systems reduce arsenic bioavailability in the root zone and consequently lower arsenic concentrations in edible plant parts (Hedayetullah et al., 2024). Additionally, inclusion of deep-rooted crops and legumes in rotations improves soil structure, enhances microbial activity, and increases organic matter, which can help immobilize arsenic through adsorption and transformation processes. Intercropping and agroforestry-based models incorporating arsenic-tolerant or non-accumulator species also help buffer arsenic exposure in vulnerable areas (Hedayetullah et al., 2025). In regions facing chronic arsenic contamination, promoting region-specific diversification models with emphasis on low-accumulating food crops and improved irrigation management can serve as a critical tool for protecting both agricultural productivity and public health. Thus, crop diversification not only contributes to improved resource efficiency and income resilience but also offers a low-cost, ecologically sound approach to mitigate arsenic risks in agriculture (Hedayetullah and Kundu, 2021). Integrating this approach with awareness campaigns and policy support can strengthen India's efforts toward safe and sustainable farming in arsenic-affected regions (Zaman et al., 2015).

### ****4.3 Biotic Stress (Pests and Diseases)****

Crop rotation and intercropping interrupt the life cycles of pests and pathogens. For instance, maize intercropped with cowpea significantly reduced stem borer incidence due to increased biodiversity and natural enemy populations (Bambara & Torto, 2008). Diversification also minimizes the risks of epidemic outbreaks common in monocultures.

### ****4.4 Climate Change Adaptation****

Diversified cropping systems are inherently more resilient to climate variability. Multi-crop systems spread risk and allow farmers to adapt to shifting rainfall and temperature regimes (Timsina et al., 2020). Agroforestry and integrated farming systems further add resilience by combining annual crops, perennials, and livestock components (Nair, 2011).

## ****5. Crop diversification**** under Different Cropping Systems

India's diverse agro-climatic zones support a wide range of cereal, pulse, and oilseed crops, which are cultivated under various cropping systems to optimize land use, enhance soil fertility, and improve farm income. These crops are categorized as major and minor based on area, production, and regional importance. Major cereal crops include rice (Rahaman et al., 2022), wheat (*Triticum aestivum*), maize (*Zea mays*) (Kundu et al., 2020), and sorghum (*Sorghum bicolor*). These are grown predominantly in mono-cropping or rotation systems like rice–wheat (Indo-Gangetic Plains), rice–maize, and sorghum–chickpea in semi-arid regions. Minor cereals such as millets (finger millet, foxtail millet, barnyard millet) are gaining attention under nutri-cereal-based diversified systems, especially in rainfed and tribal areas due to their drought tolerance and nutritional value. Major pulse crops include chickpea (Meenambigai et al., 2023), pigeon pea (*Cajanus cajan*), lentil (*Lens culinaris*), and green gram (*Vigna radiata*). These are crucial in cereal-based cropping systems, such as rice–chickpea, sorghum–pigeon pea, or maize–green gram, Sugarcane- rice (Kundu et al., 2018) enhancing soil fertility through biological nitrogen fixation (Kundu et al., 2023). Minor pulses like black gram, field pea, and horse gram are cultivated on marginal lands and intercropped with cereals or oilseeds in dryland systems (Hedayetullah and Dolai, 2019).

Major oilseed crops include mustard (*Brassica juncea*) (Hedayetullah et al., 2016), groundnut (*Arachis hypogaea*) (Giri et al., 2014), and soybean (*Glycine max*) are low water requiring crops. These are integrated into systems like soybean–wheat, groundnut–sorghum, and rice–mustard. Minor oilseeds such as safflower, linseed, and niger are grown in dryland regions, often as relay or intercrops. Integrating major and minor cereals, pulses, and oilseeds under diverse cropping systems improves productivity, ensures food and nutritional security, and maintains soil health. Such diversification also enhances resilience to climatic variability and contributes to sustainable agricultural intensification in India. Fodder crops play a crucial role in supporting India's livestock sector, which is integral to rural livelihoods and agricultural sustainability (Sadhukhan et al., 2018). Based on agro-climatic conditions and cropping systems, fodder crops can be broadly categorized into major and minor species (Hedayetullah, 2022). These are integrated into different farming systems, such as crop-livestock or agroforestry systems, to ensure year-round forage availability including ginger crops (Singh et al., 2024b)..

Major fodder crops include sorghum (Sorghum bicolor), maize (Zea mays), berseem (*Trifolium alexandrinum*) (Barik and Hedayetullah, 2018), oat (*Avena sativa*) (Hedayetullah and Barik, 2012), napier-bajra hybrid (*Pennisetum glaucum × P. purpureum*), and guar (*Cyamopsis tetragonoloba*). These are grown extensively due to high biomass yield and nutritional value. In kharif season, sorghum, maize, and cowpea are common, while berseem and oats dominate the rabi season in northern India. Napier grass and perennial species like Guinea grass are used in year-round cut-and-carry systems, especially in intensive dairy zones. Minor fodder crops (Fattah and Hedayetullah, 2018) include senji (*Melilotus spp*.), lablab (*Lablab purpureus*), sunhemp (*Crotalaria juncea*), stylo (*Stylosanthes spp*.), and silage maize varieties (Hedayetullah and Zaman, 2018; Kundu et al., 2011, Kundu et al., 2012). These are often grown on marginal lands, bunds, or as intercrops in orchards and agroforestry systems. Lablab and stylo are especially valuable in semi-arid zones due to drought resilience. In integrated cropping systems, fodder crops are rotated or intercropped with cereals (e.g., berseem in wheat-rice systems), or grown as border crops in horticulture-based systems (Hedayetullah and Zaman, 2018a; Hedayetullah and Zaman, 2018b). In mixed farming systems, dual-purpose cereals (like multi-cut sorghum or maize) provide both grain and fodder (Mukherjee and Hedayetullah et al., 2018). Fodder legumes intercropped with millets enhance forage quality and soil fertility (Ahmed and Hedayetullah, 2018). Strategically integrating major and minor fodder crops in cropping systems enhances feed availability, improves soil health, and supports livestock productivity, contributing to resilient and sustainable farming systems in India (Zaman and Hedayetullah, 2019).

**Table 1 : Regional Trends and Agroecological Suitability**

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| --- | --- | --- | --- | --- |
| **Agroecological Region** | **Dominant Traditional Crops** | **Diversification Trend** | **Key Benefits** | **References** |
| Indo-Gangetic Plains | Rice-Wheat | Pulses, maize, vegetables | Reduced water use, enhanced NUE | Giri et. Al., 2023; Hedayetullah et al., 2014; Sengupta and Hedayetullah, 2018;  |
| Eastern India | Paddy | Oilseeds, vegetables | Water saving, soil health improvement | Hedayetullah et al., 2024; Zaman et al., 2016c |
| Western Dry Regions | Pearl millet, cotton | Mustard, cluster bean | Drought resilience, soil fertility | Hussain et. al., 2024 |
| Southern India | Paddy, sugarcane | Pulses, horticultural crops | Climate adaptability | Hedayetullah and Singh, 2014 |
| North-Eastern India | Shifting cultivation | Agro-horticultural systems | Slope stability, resource efficiency | Singh et. al., 2014; Seth et. al., 2020 |

## ****6. Crop diversification and weed management****

Weed and crop diversification play a vital role in sustainable weed management by enhancing ecological balance, disrupting weed life cycles, and reducing reliance on chemical herbicides. Weed diversification, which refers to the variety of weed species present in an agroecosystem, allows farmers and researchers to understand weed behavior, adapt management strategies, and prevent the dominance of a single, hard-to-control species. Diverse weed flora can help in maintaining ecological interactions and preventing the emergence of herbicide-resistant biotypes due to repetitive control measures (Hedayetullah and Kumar, 2023).

On the other hand, crop diversification through practices such as crop rotation, intercropping, mixed cropping, and the use of cover crops serves as a powerful tool to suppress weed growth naturally. Rotating crops with different growth patterns, canopy structures, and nutrient demands interferes with weed establishment and reproduction (Hedayetullah et al., 2023). Some crops, like sorghum and sunflower, exhibit allelopathic properties that inhibit weed germination, providing a biological method of weed suppression. Intercropping systems create ground cover that shades the soil surface, minimizing light availability for weed seed germination. Furthermore, incorporating legumes in rotation improves soil fertility and helps build resilient cropping systems (Hedayetullah, 2023). By integrating weed and crop diversification, farmers can manage weeds more effectively without excessive dependence on herbicides, thus minimizing environmental pollution and production costs. These diversified systems promote biodiversity, improve soil health, and enhance resource-use efficiency, making them a cornerstone of integrated weed management (IWM) strategies (Biswas et al., 2016). Despite certain challenges such as increased management complexity and the need for knowledge about crop compatibility, weed and crop diversification offer long-term benefits for sustainable agricultural productivity and ecological stability.

## ****7. Policy and Institutional Support****

The Government of India has promoted diversification through multiple missions, including:

* **National Food Security Mission (NFSM)** – for pulses and coarse cereals
* **Paramparagat Krishi Vikas Yojana (PKVY)** – organic farming
* **National Mission on Sustainable Agriculture (NMSA)** – climate-resilient agriculture
* **PMKSY** – water-efficient irrigation technologies

However, challenges such as poor market access for non-cereal crops, MSP biases, and inadequate extension services remain barriers to widespread adoption (Planning Commission, 2014).

## ****8. Conclusion****

Crop diversification represents a multi-functional solution to many of the sustainability challenges facing Indian agriculture. Through enhanced nutrient cycling, improved water efficiency, and greater stress resilience, diversification not only stabilizes farm income but also restores agroecosystem balance. A convergence of research, policy, and farmer-led innovations is essential to mainstream crop diversification as a central pillar of India's agricultural development.

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