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

## ****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**: Nutrient cycling, water-use efficiency, climate resilience, abiotic stress, biotic stress, sustainable agriculture, weed management

## ****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; 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. 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 risk in term of not available the facilities when farmers are ready to sale their produce 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. 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. The main aim of this review is to study the accommodation of different crops under changing climate and stress environment for sustainable agriculture and nutritional security.

## ****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 for present and next crops.

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

Organic manure supply all kind of nutrients i,e, major and minor nutrients under different 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. 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 for higher plant growth (Behera et al., 2007). Organic matter supplies in less quantity but supply almost all the nutrients, minerals, vitamins and microbes.

## ****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. Water resource availability is the key factor for selecting crop diversification (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.

### ****3.3. Rainfed Agriculture****

Rainfed farming practice relies entirely on rainfall for water, without any supplementary irrigation from other sources such as rivers, canals, or groundwater. 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.

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

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

Abiotic stress indicates the negative impact of non-living environmental factors on crop plants, which significantly limits agricultural productivity. These stresses include drought, salinity, extreme temperature, waterlogging, heavy metals, UV radiation, and nutrient deficiencies. Biotic stress caused by living organisms such as pests or pathogens, abiotic stresses are more pervasive and often occur simultaneously, making crop management more complex. The drought and high temperature are the most widespread, especially in arid and semi-arid regions, leading to severe yield losses. Salinity is another growing concern, in irrigated areas where poor water management causes soil degradation. Crops respond to abiotic stress at morphological, physiological, biochemical, and molecular levels—manifesting in stunted growth, wilting, chlorosis, reduced photosynthesis, and impaired reproductive development. Advances in plant breeding, genetic engineering, and biotechnology are helping develop stress-tolerant crop varieties. Climate change continues to exacerbate these stress conditions, a deeper understanding of plant stress physiology and adaptive mechanisms is essential for building climate-resilient agricultural systems and ensuring food security. 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.

**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). 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.

### ****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. 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 (*Oryza sativa* L.) (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.

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. 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*), 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**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Agroecological Region** | **Dominant Traditional Crops** | **Diversification Trend** | **Key Benefits** | **References** |
| Indo-Gangetic Plains- UP, Bihar, WB | Rice-Wheat | Pulses, maize, vegetables | Reduced water use, enhanced NUE | Sengupta and Hedayetullah, 2018;  |
| Eastern India- WB, Bihar, Orissa, Jharkhand | Paddy, Maize | Oilseeds, vegetables | Water saving, soil health improvement | Hedayetullah et al., 2024 |
| Western Dry Regions- Rajasthan, Punjab, Haryana | Pearl millet, cotton, Sorghum | Mustard, cluster bean | Drought resilience, soil fertility | Hussain et. al., 2024 |
| Southern India- TN, Kerala, Karnataka | Paddy, sugarcane | Pulses, horticultural crops | Climate adaptability | Hedayetullah and Singh, 2014 |
| North-Eastern India-Assam, Arunachal Pradesh, Tripura, Mizoram, Manipur | 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:

1. **National Food Security Mission (NFSM)** – for pulses and coarse cereals is a flagship initiative launched by the Government of India in 2007–08 to enhance the production of food grains in a sustainable manner and ensure food security for the growing population. Initially focused on increasing the production of rice, wheat, and pulses, the mission was later expanded to include coarse cereals, commercial crops, and nutritional components like oilseeds. It is a holistic approach by promoting improved technologies, quality seeds, soil health management, integrated nutrient and pest management, efficient water-use practices, and farmer training programs. The mission emphasizes productivity enhancement in districts with high potential yet low yield, especially in rainfed and resource-poor areas. It encourages the participation of Krishi Vigyan Kendras (KVKs), State Agriculture Universities (SAUs), and ICAR institutions to ensure effective technology transfer. One of the core objectives is to bridge yield gaps by addressing region-specific constraints and promoting climate-resilient agriculture.
2. **Paramparagat Krishi Vikas Yojana (PKVY)** – organic farming an initiative launched by the Government of India in 2015 under the National Mission on Sustainable Agriculture (NMSA) to promote organic farming through a cluster-based approach and participatory guarantee system (PGS) certification. It encourages farmers to adopt traditional and ecological farming practices that are free from chemical inputs and focus on enhancing soil health, biodiversity, and ecosystem sustainability. It focuses on groups of farmers are organized into clusters (usually of 20 hectares), provided with financial assistance for organic inputs like biofertilizers, compost, neem cake, and training for capacity building. One of the key features of the scheme is the promotion of indigenous techniques such as Jeevamrit, Beejamrit, and use of cow dung and urine for plant nutrition and protection. It is certified through the PGS-India system, which is a cost-effective certification mechanism ensuring credibility in organic markets. It also supports value addition, packaging, and marketing of organic produce through linkages with e-platforms and retail chains. By integrating traditional knowledge with modern organic practices, PKVY aims to improve farmers' incomes, reduce dependency on costly chemical inputs, and ensure long-term sustainability of Indian agricultur
3. **National Mission on Sustainable Agriculture (NMSA)** – climate-resilient agriculture is one of the eight missions under India’s National Action Plan on Climate Change (NAPCC), launched to make agriculture more resilient to climate change and ensure long-term sustainability of agricultural production. Start since 2014-15, NMSA focuses on promoting climate-smart agricultural practices that enhance soil health, water-use efficiency, and ecosystem stability. It comes with traditional knowledge with modern scientific innovations to support sustainable and resource-efficient farming. It is a range of interventions including soil health management, rainfed area development, agroforestry, and efficient water management through technologies like micro-irrigation and precision farming. It focuses the importance of conserving natural resources, improving organic matter in soil, and promoting integrated farming systems. NMSA also supports programs like Paramparagat Krishi Vikas Yojana (PKVY) and Sub-Mission on Agroforestry (SMAF) as sub-components. A region-specific adaptive strategies and capacity building of farmers, the mission aims to enhance productivity, stabilize farm incomes, and reduce the vulnerability of agriculture to climate-related risk.
4. **PMKSY** – water-efficient irrigation technologies launched in 2015, is a flagship irrigation scheme of the Government of India aimed at enhancing agricultural productivity by ensuring better access to irrigation and promoting water-use efficiency. The overarching goal of the scheme is encapsulated in the slogan **"Har Khet Ko Pani"** and **"More Crop Per Drop,".**

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

## ****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. By shifting from monoculture practices to a more varied cropping system that includes pulses, oilseeds, millets, fodder, and horticultural crops, farmers can improve soil fertility, optimize water use, and break the cycles of pests and diseases. Diversification enhances ecological balance and resource-use efficiency while reducing the vulnerability of crops to climatic fluctuations such as droughts, floods, and extreme temperatures. It contributes to nutritional security by providing a diverse food basket rich in essential nutrients. In rainfed and stress-prone regions, adopting crop diversification not only stabilizes yields but also improves the resilience of farming systems and the livelihoods of small and marginal farmers. Implementation of policy support, access to markets, availability of quality seeds, and extension services, crop diversification can play a transformative role in Indian agriculture promoting environmental sustainability, economic viability, and food and nutritional security in the face of climate change and resource constraints.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

## ****References****

Basu, B.; Kundu, M.; Hedayetullah, M.; Kundu, C.K.; Bandyopadhyay, P.; Bhattachariya, K. and Sarkar. S. (2014). Mitigation of arsenic in rice through deficit irrigation in field and use of filtered water in kitchen. *International Journal of Environmental Science and Technology*. DOI 10.1007/s13762-014-0568-1.

Behera, U. K., Sharma, A. R., & Pandey, H. N. (2007). Sustaining productivity of wheat–soybean cropping system through integrated nutrient management practices on the Vertisols of central India. Plant and Soil, 297(1), 185–199.

Bulbul Ahmed and Md. Hedayetullah (2018). Canary grass (Harding grass), Pp. 47-54. In: Forages of the World, Minor Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Dolai, A.K., Hedayetullah, M. and Ghosh, P. (2019). Eco-safe management of *Parthenium hysterophorus* L. in inceptisol. *LAP Lambert Academic Publishing*. ISBN: 978-620-0-28051-0

Dolai, A.K.; Hedayetullah, M.; Giri, U. and Ghosh, R.K. (2013). Herbicide Management of Parthenium (*Parthenium hysterophorus* L.) in non Crops Land and its Impact on Soil Micro-flora. *Madras Agric. J.* 100(1-3): 747-750.

Ghosh, P. K., Ramesh, P., Bandyopadhyay, K. K., & Hati, K. M. (2009). Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems. Indian Journal of Agricultural Sciences, 79(6), 431–435.

Giri, U.; Hedayetullah, M.; Saha, A.; Nanda, M.K. and Bandyopadhyay, P. (2014). Productivity and nutrient uptake of summer groundnut (*Arachis hypogaea* L.) towards different levels of irrigation and sulphur. *Journal of Crop and Weed,* 10(2):248-251.

Hedayetullah M, Arnob R C, Mainak G, Kali K H, Chaitanyo Prasad Nath, Raghunath Sadhukhan and Parveen Zaman. (2018). Paira Chickpea under Rice Fallow in Lowland Ecosystem of West Bengal, India. *Agri Res & Tech: Open Access J.* 13(1): 555870. DOI: 10.19080/ARTOAJ.2018.13.555870.

Hedayetullah, M. and Narendra Kumar (2023). Bio-efficacy of different POE herbicides for broad spectrum weeds management in chickpea (*Cicer arietinum* L.). *J. of. Food Legume*. 36(1): 43-46, 2023 DOI: 10.59797/jfl.v36.i1.128.

Hedayetullah, M. and R. Sadhukhan. (2018). Production technology of relay chickpea under rice fallow for sustainable agriculture. *J. of Agroecology and natural resource management*. 5(2): 122-124.

Hedayetullah, M. and Kundu, C.K. 2013. Arsenic in fodder crops approaches for mitigation in food web. *LAP Lambert Academic Publishing*. ISBN-13: 978-3-65926280-7.

Hedayetullah, M. and Zaman, P. (2018). Johnson grass (Aleppo Grass), Pp. 81-92. In: Forages of the World, Major Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Hedayetullah, M. and Zaman, P. 2018a. Forages of the World, Major Forage Crops. CRC press, Taylor and Francis Group, Inc., New Jersey, USA. ISBN: 13:978-1-77188-684-0.

Hedayetullah, M. and Zaman, P. 2018b. Forages of the World, Minor Forage Crops. CRC press, Inc., Taylor and Francis Group, New Jersey, USA. 13:978-1-77188-685-7.

Hedayetullah, M. and Zaman, P.; S.K. Yadav; M.A. Nayyar and M.W. Siddiqui. 2014a. Climate Change and Indian Agriculture. In: *Climate Change and Horticulture: Impact, Adaptation, and Mitigation* (Eds. Choudhary, M.L.; Patel, V.B.; Siddiqui, M.W. and Verma, R.B.) Apple Academic Press, Inc., New Jersey, USA. (ISBN 9781771880701)

Hedayetullah, M. Javed Akhtar, Champak Kumar Kundu, Bhaskar Rajbanshi and Kanu Murmu. (2023). Efficacy of selective and non-selective herbicide for broad-spectrum weed management in potato (*Solanum tuberosum* L.). *The Pharma Innovation Journal*; 12(7): 2741-2746.

Hedayetullah, M., and Barik, A. K. (2012). Influence of Cutting and Fertilizer Management on Growth and Yield of Fodder Oats (*Avena sativa* L.). *Madras Agric. J.* 90 (10-12): 711-714 (NAAS rating 4.0).

Hedayetullah, M.; Kundu, C.K.; Basu. B. and Sarkar. S. (2011). Effect of sources of irrigation water on growth and arsenic content in different fodder crops. *Journal of crop and weed science*. 7(2): 244-246.

Hedayetullah, M.; U. Giri, D. Saha, A. Saha and D. Sen. (2016). Varietal Performance of Transplanted Rapeseed and Mustard in Hilly Tract of Tripura. *Int. J. of Agron. & Crop. Sci.* 1(1):1-5.

Hedayetullah, M.; Zaman, P. and Singh, V. (2014). Medicinal and Aromatic Plants are in danger due to Climate Change. *Popular Kheti*. 2(3):208-213.

Hedayetullah, Md., C.K. Kundu, N.M. Devi, S. Das, and D. Tamang. (2025). “Deficit Irrigation and Source of Water: Possible Mitigation Option of Arsenic Load in Fodder Maize and Cowpea in Lower Gangetic Plain Zone of West Bengal, India”. International Journal of Environment and Climate Change 15 (4):477-87. https://doi.org/10.9734/ijecc/2025/v15i44825.

Hussain, Syed. Shujat., Ajaz.A. Ganie, Waseem A. Dar, Towseef.A. Wani, M. Hedayetullah, Jahangeer.A. Baba, Gowhar. N. Parrey, Javeed.A. Mugloo, and Rukhsar.A Dar. (2024). “The Role of Digital Soil Mapping in Soil Survey and Agricultural Planning”. *International Journal of Plant & Soil Science* 36 (9):438-49. https://doi.org/10.9734/ijpss/2024/v36i94993.

Jat, M. L., Singh, R. G., & Gerard, B. (2014). Conservation agriculture for sustainable intensification in South Asia. Nature Climate Change, 4(8), 1–7.

Joshi, P. K., Birthal, P. S., & Asok, A. (2004). Agricultural diversification in South Asia: Patterns, determinants and policy implications. Economic and Political Weekly, 39(24), 2457–2467.

Kajal Sengupta and Md. Hedayetullah (2018). Urad bean (Black gram), Pp. 155-168. In: Forages of the World, Minor Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Kerr, R. B., Snapp, S., Chirwa, M., Shumba, L., & Msachi, R. (2012). Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. Experimental Agriculture, 48(3), 438–453.

Kundu, C.K, R. Mondal, A. Kundu, S. Goswami and M. Hedayetullah. (2020). Studies on bio-efficacy and phytotoxicity of different formulation of 2, 4-D amine 50% SL in maize. Journal of Pharmacognosy and Phytochemistry 2020; 9(5): 559-562 (NAAS-5.2).

Kundu, C.K., M.K. Datta, U. Biswas , N.M. Devi, S. Das, M. Hedayetullah , L. Nayak and R. Pattnaik. 2023. Effect of Pretilachlor 50% EC on Weed Control of Transplanted Rice under Alluvial Soil of West Bengal, India. *International Journal of Environment and Climate Change*.13(12): 198-204.DOI: 10.9734/IJECC/2023/v13i123676.

Kundu, C.K.; Hedayetullah, M.; Bandopadhyay, P.; Gunry, S.K. and Basu, B. (2011). Studies on the effect of different phosphorus levels on green forage yield of fodder cowpea (*Vigna unguiculata* L. Walp) varieties. *Journal of Interacademicia*. 15(3): 410-414

Kundu, C.K.; Hedayetullah, M.; Bera, P.S.; Biswas, T. and Chatterjee, S. (2015). Effect of nitrogen levels on different varieties of fodder teosinte (*Euchlaena maxicana* l. schrod) in new alluvial zone of West Bengal. *Forage Res*., 40(4):243-246

M. Hedayetullah and C. K. Kundu. (2021). Arsenic in food web: an alert for public health. *Biological forum*, 13. (3) 621-624.

M. Hedayetullah, Kundu, C.K., Akhtar, J., Hussain, S.S., Das, S., Datta, M.K. and Devi, N.M. (2024). Actual Evapotranspiration, Water Expense Efficiency and Grain Yield of Chickpea under Varying Irrigation Regimes. *Legume Research*. doi: 10.18805/LR-5378.

M. Hedayetullah. (2023). Yield Advantages of New Technologies of Chickpea in Rice-Fallow of Indo-Gangetic Plains Zone of West Bengal. *Irish Interdisciplinary Journal of Science & Research*. 7 (3):17-21. *DOI:* [*https://doi.org/10.46759/IIJSR.2023.7302*](https://doi.org/10.46759/IIJSR.2023.7302)*.*

M. Rahaman, K. Murmu, J. Khandakar, S. K. Bordolui and M. Hedayetullah. (2022). Crop productivity and soil health in relation to the microbial population as influenced by different organic biostimulants in summer rice cultivation. *Oryza* 59(2): 194-204.

M., Hedayetullah, Kundu, C.K., Rajbanshi, B., Tamang, D, Mondal, S, Akhtar, J, Mondal, B, Das, S, Devi, N.M., and Hossain, S.S. 2024. “Reduction of Arsenic Load in Winter Fodder Crops As Influenced by Shallow Tube Well and Pond Water Irrigation”. *International Journal of Environment and Climate Change* 14 (8):314-20. <https://doi.org/10.9734/ijecc/2024/v14i84352>.

Meenambigai C., A. Samanta, S. Samanta. and M. Hedayetullah. 2023. Field screening of chickpea genotypes against gram pod borer *Helicoverpa armigera* (Hübner) in new alluvial zone. *J. ent. Res.,* 47. (Suppl.): 896-900. (NAAS rating 5.63).

Mohammed Abdel Fattah and Md. Hedayetullah (2018). Gajar (Carrot), Pp. 215-224. In: Forages of the World, Minor Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Mukherjee, A. and Hedayetullah, M (2018). Sudan grass (Sudan sorghum), Pp. 129-140. In: Forages of the World, Major Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Mukherjee, D and Hedayetullah, M. (2018). Nonconventional legumes forage crops, Pp. 287-308. In: Forages of the World, Minor Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Nair, P. K. R. (2011). Agroforestry systems and environmental quality: introduction. Journal of Environmental Quality, 40(3), 784–790.

S. Seth, M. Ghosh, R. Nath, M. Hedayetullah, M.K. Nanda. 2020. Phenology, thermal indices and yield of chickpea (Cicer arietirunn L.) varieties under different sowing dates in New Alluvial Zone of West Bengal. Journal of Food Legumes 33(2): 127-132.

Sadhukhan, R. Hedayetullah, M. and Zaman, P. (2018). Grass Pea (Indian vetch), Pp. 77-90. In: Forages of the World, Minor Forage Crops (Eds. Md. Hedayetullah and Parveen Zaman), CRC press, Taylor and Francis Group, Inc., New Jersey, USA (ISBN: 13:978-1-77188-684-0).

Singh, A.P, S. Majumdar, G. V. Kumar, W. Emam, Y. Tashkandy, M. Hedayetullah, H. L. Singh, P. K. Singh, S. Ray, F. Homa, A. Matuka and R. Sadhukhan. 2025. Evaluation of chickpea (*Cicer arietinum* l.) genotypes for geneticvariability and mechanization potential under gangetic plains. *J. Anim. Plant Sci*., 35 (1). <https://doi.org/10.36899/JAPS.2025.1.0017>.

Singh, V.; Hedayetullah, M.;Zaman. P.and Meher, J. (2014). Postharvest Technology of Fruits and Vegetables: An Overview. *Journal of Post Harvest and Technology*. 02(02):124-135.

U. Biswas, C. K. Kundu, A. Kundu, S. Mondal, T. Biswas and M. Hedayetullah. (2016). Evaluation of bio-efficacy of 2, 4-D Ethyl Ester 38 per cent EC for weed control in wheat. *Journal of Crop and Weed*. 12(3):138-141.

V, Singh, M. Hedayetullah, Jagamohan Meher, Soumya Ranjan Sahoo, M.K. Panda. (2014b). Effect of slice thickness on recovery of ginger oil from dry ginger. *Environment & Ecology*. 33(3A): 926-929.

Zaman, A. and Hedayetullah, M. 2020. Agricultural Heritage. *New India Publishing Agency.* New Delhi, India. ISBN: 978-93-89412-52-9.

Zaman, A. and Hedayetullah, M. 2022. Water Resource Development and management. CRC press, Taylor and Francis Group, Inc., Florida, USA. ISBN: 9781774630099.

Zaman, A. Hedayetullah, M.. and Parveen Zaman (2018) Watershed management for agricultural sustainability. pp. 305-311. In: A. Zaman and S. Maitra (Editors). Cutting Edge Technology for Agricultural Sustainability. New India Publishing Agency, New Delhi. ISBN: 978-93-87973-28-2.

Zaman, A.; Zaman, P.; Hedayetullah, M. and Talukder, M.L. (2016b). Water resource development and management research for Agricultural sustainability in eastern India. *Global J. Biol. Res.* 1(1): 1-4.