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Comparative analysis of natural and inorganic farming systems in India: Implications for crop diversity, sustainability, and productivity

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Abstract

Indian agriculture has witnessed a paradigm shift from traditional, low-input systems to high-input inorganic farming following the Green Revolution. While this transition ensured food security and enhanced productivity, it has also led to adverse consequences such as soil degradation, declining biodiversity, environmental pollution, and increased production costs. In recent years, natural farming has emerged as a sustainable alternative that emphasizes ecological balance, reduced dependence on external inputs, and improved soil health. This review critically examines natural and inorganic farming systems in India with a focus on their impacts on crop diversity, sustainability, and productivity. The analysis reveals that inorganic farming is effective in achieving short-term yield gains but often leads to long-term ecological and economic challenges. Conversely, natural farming promotes biodiversity, soil regeneration, and resilience but faces issues related to yield variability, knowledge dissemination, and scalability. The review highlights the need for a hybrid approach that integrates the ecological principles of natural farming with the technological advancements of modern agriculture to ensure sustainable agricultural development in India.

Keywords: Natural farming, inorganic farming, crop diversity, sustainability, productivity, agroecology, India

1. Introduction

Agriculture remains the backbone of the Indian economy, contributing significantly to employment and livelihoods (Giri and Hedayetullah, 2020) ^[10]. Nearly 50% of India's population is dependent on agriculture for sustenance. The transformation of Indian agriculture began with the Green Revolution in the 1960s, which introduced high-yielding varieties (HYVs), chemical fertilizers, pesticides, and irrigation infrastructure. India's agriculture, historically diverse (Zaman and Hedayetullah, 2020) ^[97], 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) ^[46]. This shift enabled India to overcome food shortages and become self-sufficient in food grain production (Zaman and Hedayetullah, 2026) ^[108, 28]. Temperature, humidity, draught, soil salinity, soil acidity, and other elements have been found to have an important influence on seed germination, vigor, viability, and ultimately seed yield (Patra, 2022) ^[69]. The germination, vigor, viability, and productivity of several crops are greatly enhanced by seed invigoration treatments (Mandal *et al.*, 2011a, 2011b; Patra. S, 2016a, 2016c, 2017a & 2017b; Patra, S., & Burman, D., 2017; Patra, S., 2021, 2025d; Patra *et al.*, 2012, 2013, 2026a) ^[74, 82, 80, 68, 66, 65, 57]. In seed invigoration, Seed priming is greatly successful in breaking dormancy, preventing deterioration, and boosting tolerance to biotic and abiotic stressors by triggering metabolic pathways (Garai, U., & Patra, S., 2024) ^[9]. The success of sustainable agriculture depends on high-quality seeds, particularly those with high vigor and viability (Patra, S., 2025a) ^[74]. Crop varieties become unhealthy and lose their unique characteristics when they are mismanaged (Zaman and Hedayetullah, 2026a) ^[108, 28]. Diseases spread by seeds, genetic

drift, outcrossing, volunteer plants, mutation, and environmental stressors are the primary drivers of harmful toxins and degradation. This degradation can be avoided by managing seeds carefully during seed multiplication (Patra, S., 2023a, 2025b) [74, 70]. According to Patra, S. (2023c) [70], traditional rice varieties are also protected by following the requisite seed multiplication technique. The importance of macro and micronutrients in producing high-quality seed was discussed by Patra (2023b) [70], who also emphasized their role in crop productivity, seed filling, and vigor. These findings are particularly significant in the ancient alluvial soils of West Bengal, where nutritional imbalance and declining seed quality typically limit yield. Patra (2016b, 2025d) [74] showed varietal differences in rice performance under Burdwan's historic alluvial soils, emphasizing the importance of site-specific crop management. However, Patra *et al.* (2026b) [82] recently found that processing steps including grinding and storage also substantially impact nutrient availability (Zaman and Hedayetullah, 2025h) [29, 100]. The report emphasizes the need for integrated solutions that mix ecological farming with effective processing to ensure food security and safety. Patra *et al.* (2025) [74] emphasized the importance of traditional seed systems and paddy production for sustainability and livelihoods. In addition to sustainable farming, balanced nutrient management strategies can increase the yield and quality of aromatic rice while maintaining long-term soil sustainability (Hedayetullah *et al.*, 2026) [28], and the preservation of traditional (local) paddy

varieties for genetic diversity in sustainable agriculture, Murmu and Patra (2022) [64] have reported on safeguarding human culture in relation to knowledge, belief, morality, art, habits, abilities, etc (Zaman and Hedayetullah, 2026b) [108]. However, the long-term consequences of inorganic or chemical-based farming have raised serious concerns. Continuous use of synthetic fertilisers and pesticides has led to soil degradation, loss of soil organic matter, groundwater contamination, and reduction in biodiversity (Zaman and Hedayetullah, 2020a) [97]. Moreover, monocropping practices have replaced traditional diversified cropping systems, making agriculture more vulnerable to climatic and biological stresses. In response to these challenges, alternative farming systems such as natural farming have gained attention. Natural farming emphasizes the use of locally available inputs, ecological processes, and minimal disturbance to natural systems. It promotes crop diversity, soil health, and sustainability (Hedayetullah, 2023) [14]. Given the contrasting characteristics of these two systems, a comprehensive comparative analysis is essential to understand their implications for crop diversity, sustainability, and productivity in India (Zaman and Hedayetullah, 2026c) [108]. The main objective of this study is to integrate the ecological principles of natural farming or organic farming under crop diversity with the technological advancements of modern agriculture to ensure sustainable agricultural development in India.

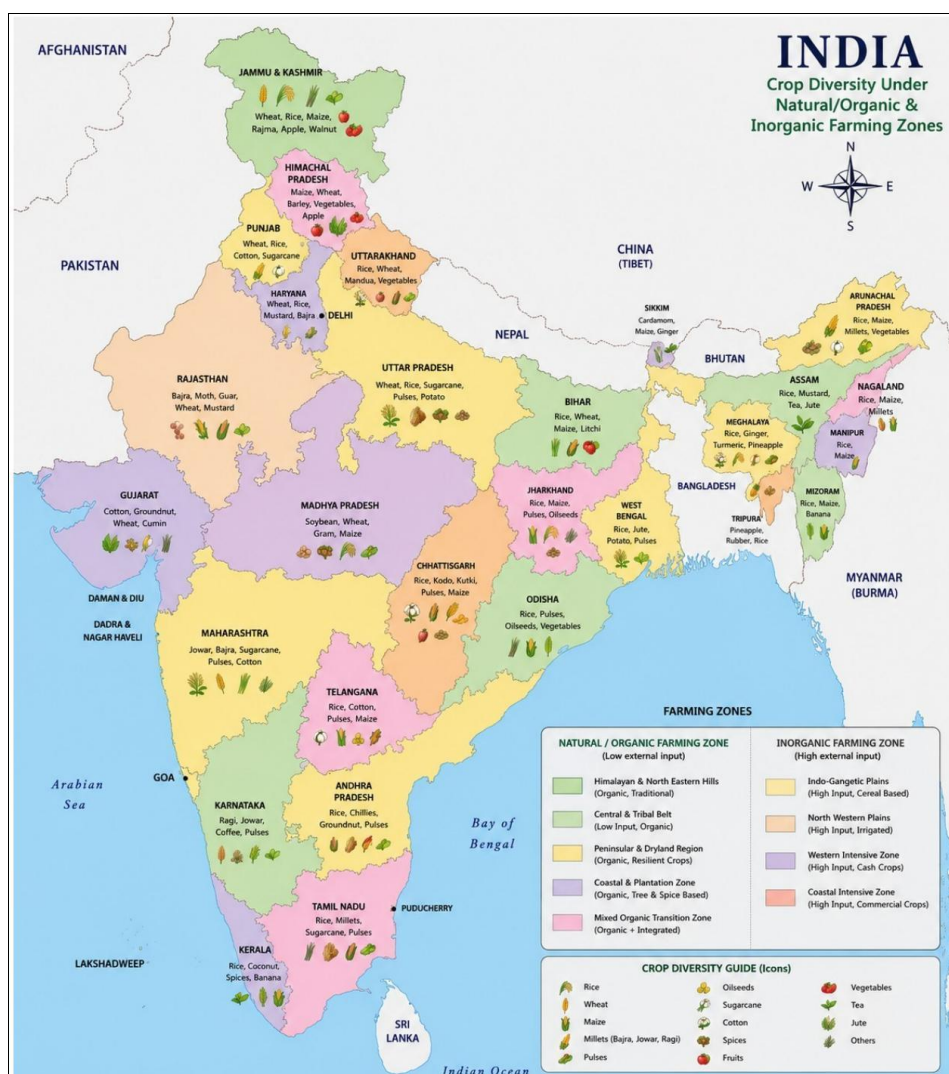


Fig 1: Crop diversity under natural/organic and Inorganic farming zone

2. Concept and Principles of Farming Systems

2.1 Natural Farming

Natural farming is not merely a technique but a philosophy that perceives humanity as an integral part of nature rather than separate from it. Often referred to as "the Fukuoka Method," "the natural way of farming," or "do-nothing farming," it emphasizes a holistic approach to agriculture (Zaman and Hedayetullah, 2026d) ^[108, 28]. The term "do-nothing farming" does not imply a lack of effort but rather emphasizes the avoidance of manufactured inputs and equipment. Natural farming is an agroecological approach that emphasizes harmony with nature and the use of biological processes to sustain agricultural production (Zaman and Hedayetullah, 2025g) ^[29, 100]. It avoids the use of synthetic fertilizers, pesticides, and herbicides, relying instead on organic inputs such as farmyard manure, compost, and bio-formulations like Jeevamrutha and Beejamrutha. These inputs enhance soil microbial activity and improve nutrient availability (Zaman and Hedayetullah, 2025f) ^[100]. In addition, natural farming promotes practices such as mulching, intercropping, crop rotation, and minimal soil disturbance, which collectively contribute to improved soil health and ecological balance. By encouraging crop diversity and reducing input costs, natural farming is particularly beneficial for small and marginal farmers (Zaman and Hedayetullah, 2026e) ^[108]. The system aims to create a self-sustaining agricultural ecosystem that is resilient to environmental stresses and economically viable (Hedayetullah *et al.*, 2014) ^[32]. The main aim of natural farming is to increase the yield of farmers by optimizing production potential and by avoiding the use of chemical (Fertilizers, herbicides and pesticides) to provide abundant high quality healthy food at the best price. The important step in natural farming is conservation of crop diversity, no tillage, water shed management, crop diversification, integrated nutrient management, integrated weed management and integrated pest management (Zaman and Hedayetullah, 2025e) ^[100].

2.2 Inorganic Farming

Inorganic farming, also referred to as conventional or chemical farming, is characterized by the intensive use of synthetic fertilizers, pesticides, and herbicides to maximize crop yields. This system relies on high-yielding varieties and advanced irrigation techniques to achieve high productivity levels. While inorganic farming has been instrumental in increasing food production, it often prioritizes yield over environmental sustainability (Giri *et al.*, 2023) ^[12]. The widespread adoption of monocropping and intensive input use has led to several ecological concerns, including soil degradation, water pollution, and loss of biodiversity. Despite these challenges, inorganic farming continues to dominate Indian agriculture due to its ability to provide immediate and high returns in terms of crop yield (Zaman and Hedayetullah, 2025d) ^[29, 100, 74].

3. Crop Diversity under Natural and Inorganic Farming

3.1 Importance of Crop Diversity

Crop diversity (Fig. 1) is a fundamental component of sustainable agriculture, as it enhances ecosystem stability, improves soil health, and reduces the risk of crop failure due to pests, diseases, or climatic variability (Hedayetullah and Sadhukhan, 2018) ^[15, 88]. Singh *et al.*, 2025 also focuses on genetic diversity in different pulses for special characters of yield and harvesting of pulses crop. Traditional farming systems in India were inherently diverse, incorporating multiple crops within a single farming system (Roy *et al.*, 2025) ^[87, 91].

3.2 Crop Diversity in Natural Farming

Natural farming inherently promotes crop diversity through practices such as intercropping, mixed cropping, and crop rotation. Farmers often cultivate a combination of cereals, pulses, oilseeds, and vegetables, which helps in maintaining ecological balance and improving soil fertility. The inclusion of leguminous crops enhances nitrogen fixation, thereby reducing the need for external nutrient inputs (Sengupta and Hedayetullah, 2018) ^[15, 89]. Moreover, natural farming encourages the use of indigenous crop varieties that are better adapted to local environmental conditions and more resilient to biotic and abiotic stresses. This diversification not only improves farm resilience but also contributes to nutritional security by providing a variety of food products. Major pulse crops include chickpea (Meenambigai *et al.*, 2023) ^[60], 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) ^[54] enhancing soil fertility through biological nitrogen fixation (Kundu *et al.*, 2023) ^[51]. 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) ^[6, 18].

3.3 Crop Diversity in Inorganic Farming

In contrast, inorganic farming systems tend to favor monocropping, particularly of highyielding varieties of major crops such as rice and wheat. This practice leads to a reduction in genetic diversity and increases the vulnerability of crops to pests, diseases, and environmental fluctuations (Hedayetullah *et al.*, 2025) ^[29]. The dominance of monoculture systems also results in imbalanced nutrient extraction from the soil, further contributing to soil degradation (Zaman and Hedayetullah, 2026e) ^[108, 28].

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 (Hedayetullah *et al.*, 2018a) ^[15]. These crops are categorized as major and minor based on area, production, and regional importance. Major cereal crops include rice (Rahaman *et al.*, 2022; Hedayetullah, 2022) ^[13, 86], wheat (*Triticum aestivum*), maize (*Zea mays*) (Kundu *et al.*, 2020) ^[55], 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 (Hedayetullah *et al.*, 2014a) ^[46]. Minor cereals such as millets (finger millet, foxtail millet, barnyard millet) are gaining attention under nutri-cerealbased diversified systems, especially in rainfed and tribal areas due to their drought tolerance and nutritional value (Hedayetullah and Giri, 2021) ^[19].

Major oilseed crops include mustard (*Brassica juncea*) (Hedayetullah *et al.*, 2016), groundnut (*Arachis hypogaea*) (Giri *et al.*, 2014) ^[11], and soybean (*Glycine max*) are low water requiring crops. These are integrated into systems like soybean–wheat, groundnut–sorghum, and rice–mustard (Zaman and Hedayetullah, 2018) ^[15]. 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

(Zaman and Hedayetullah, 2025c; Zaman and Hedayetullah, 2018b) ^[29, 95, 15, 100]. Such diversification also enhances resilience to climatic variability and contributes to sustainable agricultural intensification in India (Hedayetullah *et al.*, 2014b) ^[32]. 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) ^[88]. Based on agro-climatic conditions and cropping systems, fodder crops can be broadly categorized into major and minor species (Hedayetullah, 2022) ^[13]. These are integrated into different farming systems, such as croplivestock or agroforestry systems, to ensure year-round forage availability including ginger crops (Mukherjee and Hedayetullah, 2018a; Singh *et al.*, 2024b) ^[33, 62].

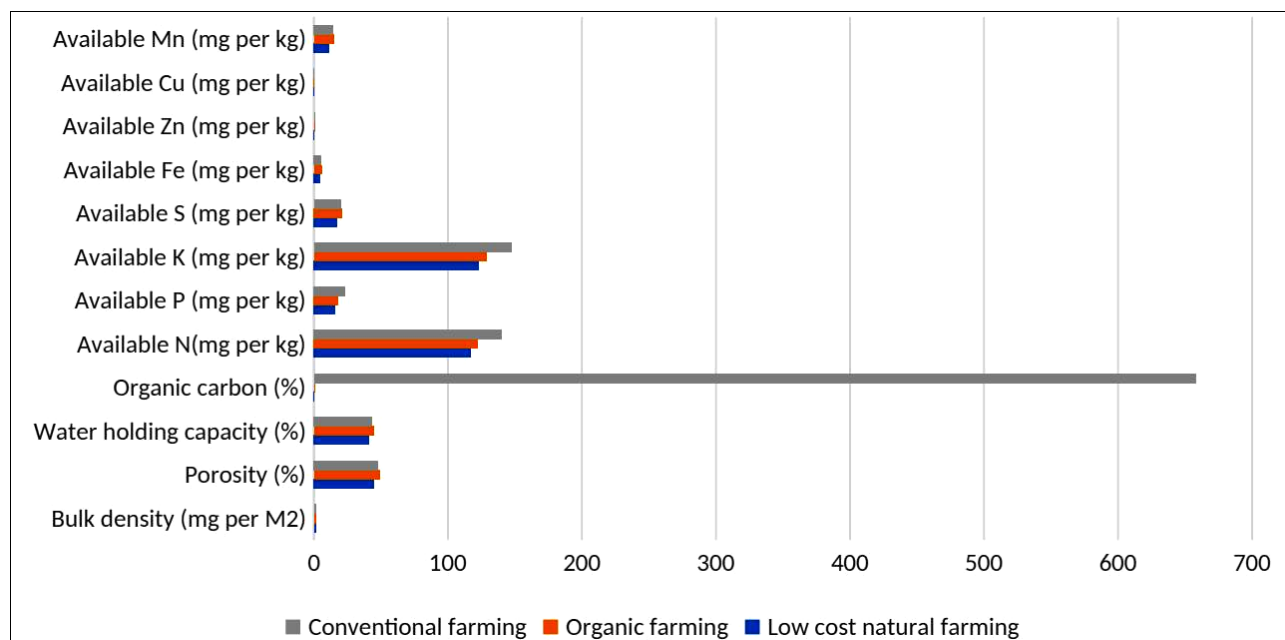
Major fodder crops include sorghum (*Sorghum bicolor*), maize (*Zea mays*), berseem (*Trifolium alexandrinum*) (Barik and Hedayetullah, 2018) ^[15, 2], oat (*Avena sativa*) (Hedayetullah and Barik, 2012) ^[17], napier-bajra hybrid (*Pennisetum glaucum* × *P. purpureum*), and guar (*Cyamopsis tetragonoloba*). These are grown extensively due to high biomass yield and nutritional value in fenugreek (Zaman *et al.*, 2018c) ^[95, 15]. 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) ^[8] include senji (*Melilotus spp.*), Rhodes grass (Hedayetullah and Banerjee, 2018) ^[15], lablab (*Lablab purpureus*), canary grass (Ahmed and Hedayetullah, 2018) ^[1], sunhemp (*Crotalaria juncea*), Deenanath grass (Hedayetullah and Bandopadhyay, 2018) ^[15], stylo (*Stylosanthes spp.*), and silage maize varieties (Hedayetullah and Zaman, 2018; Kundu *et al.*, 2011, Kundu *et al.*, 2012) ^[34, 52]. These are often grown on marginal lands, bunds, or as intercrops in orchards and agroforestry systems. Lablab, senji, setaria, pangola and stylo are especially valuable in semi-arid zones due to drought resilience (Hedayetullah *et al.*, 2018b; Hedayetullah *et al.*, 2018c; Hedayetullah *et al.*, 2018d). In integrated cropping systems, fodder crops are rotated or intercropped with cereals (*e.g.*, berseem in wheat-rice systems), or grown as border crops (Johnson and doob grass) 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, 2018; Hedayetullah *et al.*, 2018) ^[62]. 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 (Hedayetullah and Zaman, 2018c; Zaman and Hedayetullah, 2019) ^[18].

4. Soil Health and Sustainability

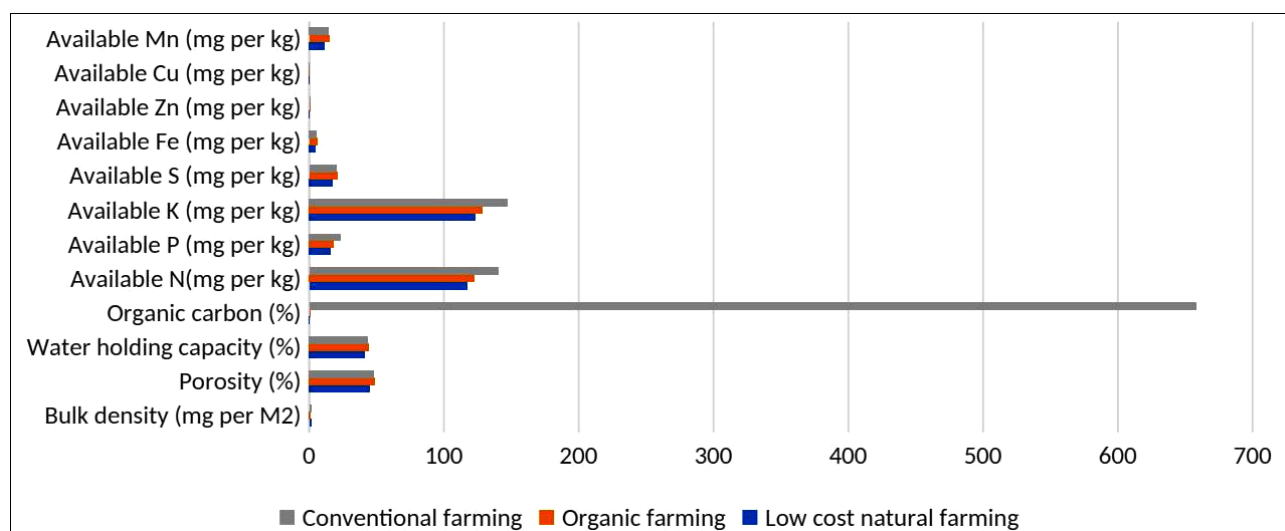
4.1 Comparative study on Soil Health among Natural Farming, Inorganic Farming and Conventional Farming

Natural farming significantly improves soil health by increasing soil organic carbon content and enhancing microbial activity. The application of organic inputs and mulching practices helps in improving soil structure, water retention capacity, and nutrient availability. Over time, these improvements lead to a more resilient and productive soil system. Conversely, inorganic farming frequently results in a deterioration of soil health because of the overuse of chemical pesticides and fertilizers (Zaman and Hedayetullah, 2025b) ^[29, 100, 74]. These inputs have the potential to create soil compaction, lower organic matter content, and disturb soil microbial populations (Zaman *et al.*, 2026b) ^[108]. Consequently, the soil's long-term fertility and productivity are negatively impacted. Together, Figures 2 and 3 show how low-cost natural farming, organic farming, and conventional farming affect the chemical and physical characteristics of soil during the Rabi and Kharif seasons. When compared to conventional farming methods, the comparative research shows that farming systems based on natural and organic approaches have a favorable impact on soil health indices. Under low-cost natural and organic farming systems, improvements in soil organic carbon, nutrient availability, water-holding capacity, microbial activity, and soil structure were more noticeable (Zaman and Hedayetullah, 2025a) ^[100]. By adding organic residues and lowering reliance on synthetic agrochemicals, these methods improved soil fertility and encouraged sustainable nutrient cycling. Conventional farming, on the other hand, demonstrated comparatively less increase in a number of soil quality metrics because of intense cultivation techniques and ongoing chemical fertilizer use, which may have a negative impact on long-term soil sustainability (Zaman and Hedayetullah, 2026f) ^[28]. Additionally, seasonal change between the Rabi and Kharif seasons was noted, indicating the impact of agricultural practices and climate on soil properties (Zaman *et al.*, 2026a) ^[108, 82]. In comparison to conventional farming systems, the results generally indicate that low-cost natural farming and organic farming are environmentally viable substitutes that support longterm agricultural sustainability, enhance soil biological activity, and preserve soil productivity (Hussain *et al.*, 2024) ^[48].



Source: Korat, et al., 2023 ^[49]

Fig 2: Physical and chemical properties of soil under low cost natural farming, organic farming and conventional farming (Rabi)



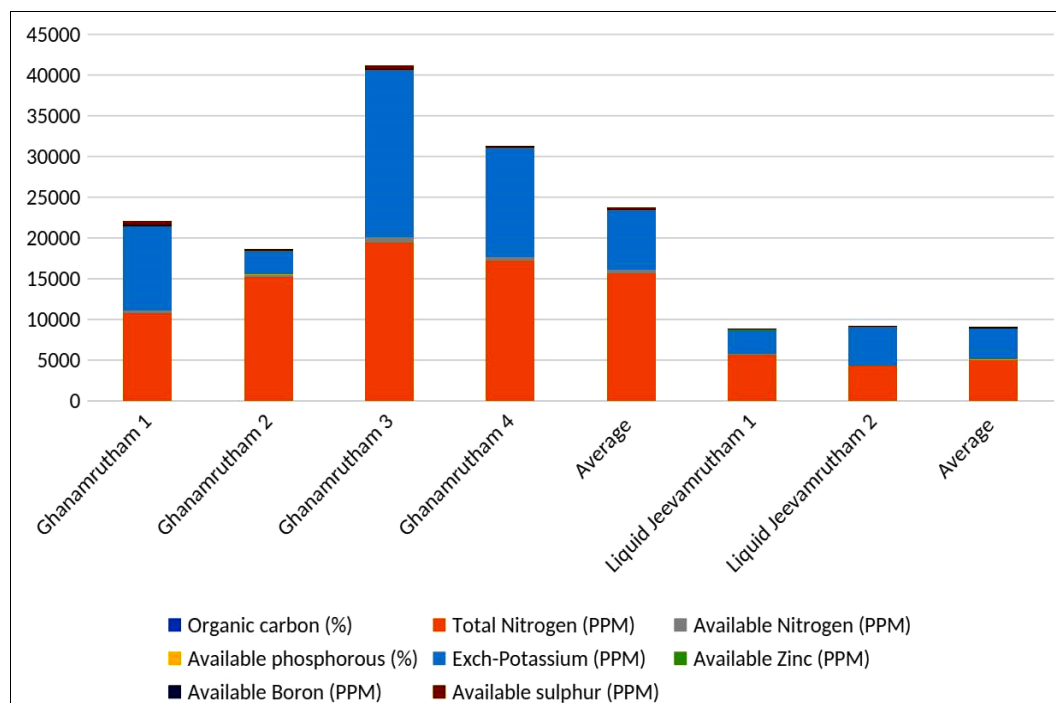
Source: Korat, et al., 2023 ^[49]

Fig 3: Physical and chemical properties of soil under low cost natural farming, organic farming and conventional farming (Kharif)

4.2 Efficacy of various farming techniques and natural agricultural inputs on soil fertility, crop growth, yield, and paddy yield attributes

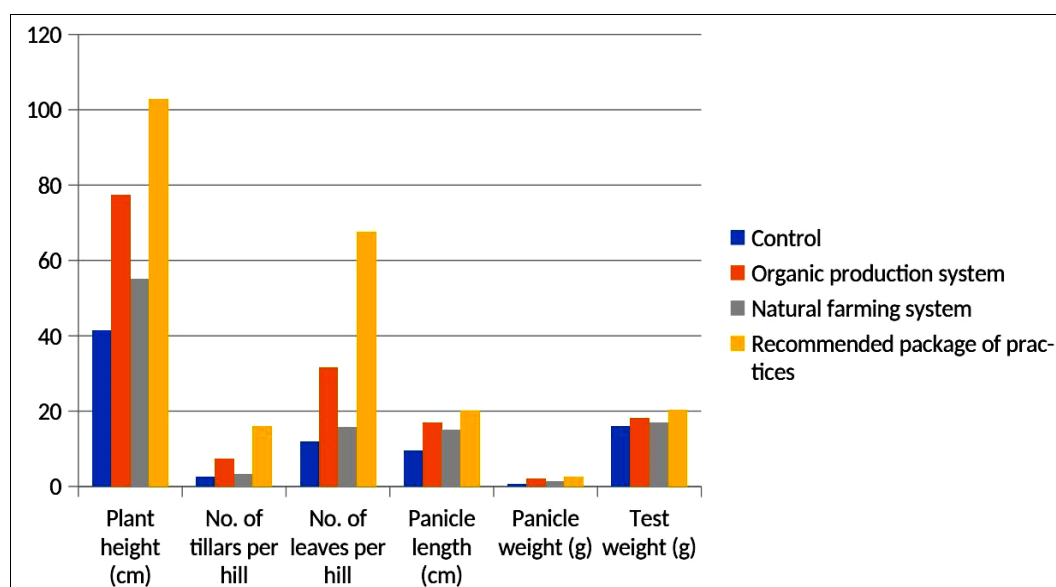
The significance of natural farming inputs like Ghanamrutham and Jeevamrutham in enhancing soil fertility, crop development, and productivity in paddy agriculture is shown together in Figures 4 and 5. The rich chemical makeup and nutrient status of these native bio-formulations are shown in Figure 4, suggesting their potential to improve soil microbial activity, nutrient availability, and organic matter content (Zaman and Hedayetullah, 20125) ^[17]. Under natural agricultural methods, the presence of vital nutrients and advantageous microbes in Ghanamrutham and Jeevamrutham enhances soil biological health and promotes sustainable nutrient cycling. The beneficial effects of various farming techniques on paddy growth, yield, and yield qualities are further demonstrated in Figure 6. When compared to the control treatment, natural farming methods that included mulching, Ghanajeevamrutha, Jeevamrutha application,

and Beejamrutha seed treatment showed a significant improvement in crop production (Zaman et al., 2026) ^[108]. Through improved soil fertility management and moisture conservation, these techniques improved plant growth, tillering, panicle development, and grain output. Because organic mulches and farmyard manure are used, organic farming also demonstrated positive impacts on crop productivity and sustainability (Zaman and Hedayetullah, 2018a) ^[95, 15]. Natural farming delivered satisfactory yield performance with less reliance on external inputs and less environmental effect, even though the suggested package of methods reported higher productivity in some cases due to intense chemical fertilizer and herbicide application. Overall, the numbers highlight how natural farming methods, bolstered by locally produced organic formulations, can preserve crop yields, enhance soil health, and advance environmentally sustainable agriculture while lowering dependency on artificial agrochemicals (Hedayetullah et al., 2014) ^[32].



Source: Shyam, Dixit, & Nune, 2019

Fig 4: Chemical properties of Ghanamrutham and Jeevamrutham



Sources: Malakannavar *et al.*, 2024.

Fig 5: Growth, Yield and yield attributes as influenced by different farming practices in paddy

Note: Treatment details : Control (Only sowing of seeds), Organic production (FYM applied based on N equivalent (100 kg N ha⁻¹) +mulching with paddy straw (4 t ha⁻¹) + weeding at 30 DAS.), Natural farming (1000 kg ha⁻¹ of Ghanajeevamrutha) + Beejamruthaseed treatment + Jeevamrutha at intervals of 15 days (500 liters ha⁻¹) + mulching with 4 t ha⁻¹ of paddy straw at 30 DAS, Recommended package of practices (FYM application (10 t ha⁻¹) +N: P₂O₅ : K₂O (100:50:50 kg ha⁻¹) recommended dose of nitrogen applied as 50% N and 100% P as basal, Remaining 50% N was applied at tillering& panicle initiation stage at equal splits, potassium was applied as 50% basal + 50% tillering and Spraying of preemergence herbicide (bensulfuron methyl 0.6% +pretilachlor 6% GR @ 10 kg /ha) at 2-3 DAS and postemergence herbicide (bispyribac sodium 10% SC@ 200 mL / ha) at 30 DAS and one hand weeding

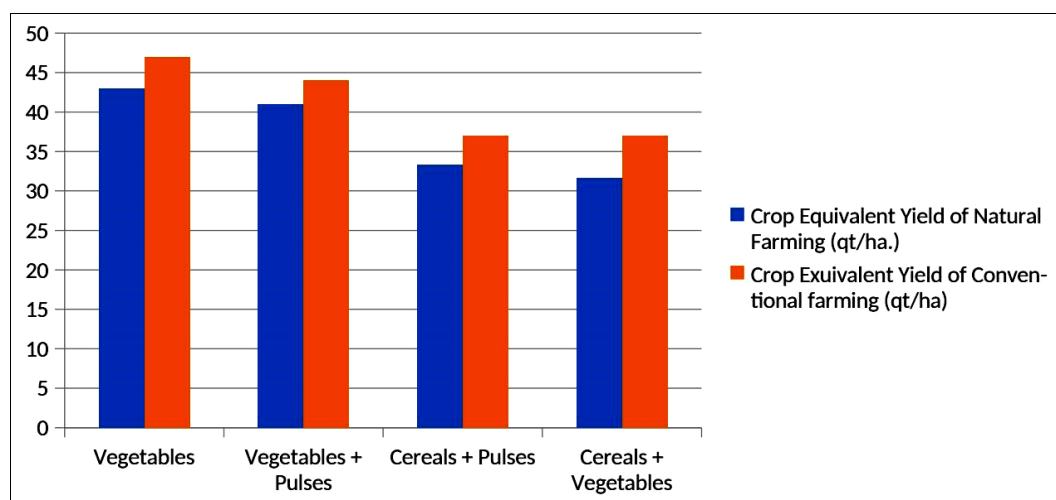
Comparative Study on Crop Equivalent Yield and Cost of Cultivation among Natural Farming, Inorganic Farming and Conventional Farming

At first, natural farming systems may be less productive than artificial farming, especially in the transition period. However, yields tend to stabilize and, in certain circumstances, may even equal those of traditional systems when soil health recovers and ecological balance is restored. Additionally, farmers frequently get larger net returns as a result of lower input costs. High yields,

particularly in the near term, are a hallmark of inorganic farming (Hedayetullah *et al.*, 2018) ^[15]. However, over time, soil deterioration and nutrient imbalances may result in diminishing results from ongoing chemical input use. Moreover, overall profitability may be lowered by rising input costs. Together, Figures 6 and 7 show how Natural Farming and Conventional Farming systems compare in terms of crop equivalent yield (CEY) and cultivation costs for various crop combinations. The findings show how the two farming methods' economic input needs and productivity are related.

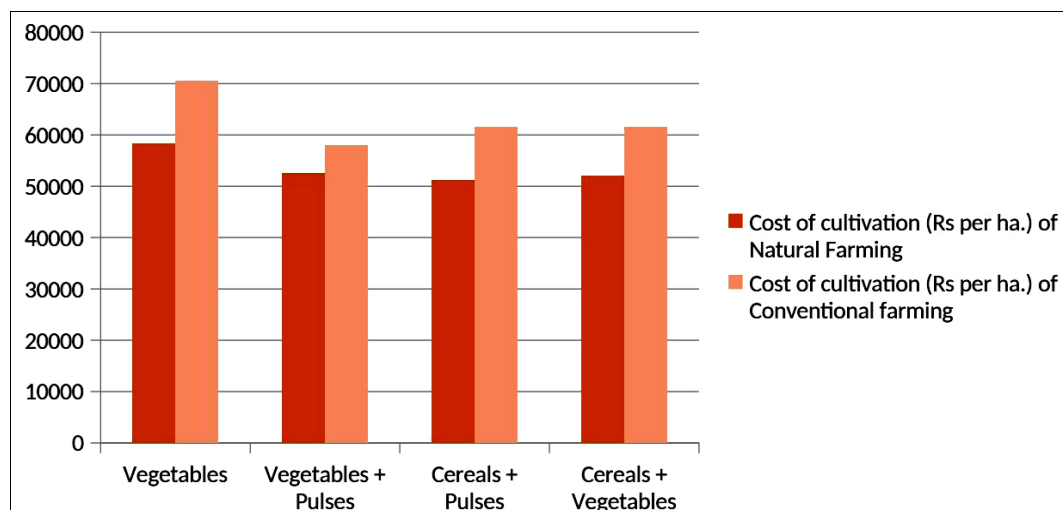
When compared to conventional farming methods, Figure 3 shows that a variety of crop combinations under natural farming were able to maintain competitive crop equivalent yields. Under natural farming, the use of mixed and varied cropping patterns promoted sustainable crop productivity, increased soil fertility, and improved resource usage efficiency in preference with pulses (Seth *et al.*, 2020) ^[90]. Natural farming demonstrated promise productivity with less reliance on external inputs, even though some crop combinations under conventional farming may have achieved somewhat greater yields due to the intense use of chemical fertilizers and agrochemicals. The cost of cultivation was significantly lower under Natural Farming systems than under Conventional Farming systems, as shown in Figure 4. Lower production costs in natural farming were a result of spending less on synthetic fertilizers, pesticides, and other chemical inputs. Conversely, due to its reliance on outside

agricultural supplies and intensive management techniques, conventional farming necessitated a greater financial commitment. Overall, the combined results of Figures 3 and 4 indicate that by lowering cultivation expenses while preserving acceptable crop output, Natural Farming provides a more economically feasible and sustainable farming method. Through low-input and ecologically friendly farming methods, the system not only promotes long-term soil health and ecological balance but also increases farmers' resilience and profitability. By reducing reliance on outside supplies, natural farming lowers production costs and eventually boosts profitability. Additionally, it offers chances for premium pricing on natural or organic goods. Even while inorganic farming can produce large yields, it requires expensive inputs and frequently causes financial strain for farmers, especially when subsidies aren't available.



Source: Pradesh, 2020 ^[85].

Fig 6: Crop equivalent yield (CEY) of various crop combinations under Natural Farming and Conventional Farming systems



Source: Pradesh, 2020 ^[85].

Fig 7: Cost of cultivation of various crop combinations under Natural Farming and Conventional Farming systems

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 (Hedayetullah *et al.*, 2012; Zaman *et al.*, 2018) ^[95, 15, 17]. For instance, replacing paddy with maize or pulses in eastern India has led to significant water savings while maintaining or

improving productivity under rice fallow (Zaman *et al.*, 2014a; Hedayetullah *et al.*, 2018e; Zaman *et al.*, 2014b) ^[32]. Water resource availability is the key factor for selecting crop diversification (Zaman *et al.*, 2016a; Zaman *et al.*, 2016b, Zaman and Hedayetullah, 2022) ^[13]. 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) ^[21, 54]. 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) ^[21]. Crop diversification presents a practical and sustainable strategy to mitigate arsenic uptake and accumulation in agricultural ecosystems (Basu *et al.*, 2015) ^[3]. 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 ((Zaman *et al.*, 2018) ^[95]). 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) ^[33]. Additionally, inclusion of deeprooted 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 (Zaman and Hedayetullah, 2022) ^[99]. Intercropping and agroforestrybased models incorporating arsenic-tolerant or non-accumulator species also help buffer arsenic exposure in vulnerable areas (Hedayetullah *et al.*, 2011; Hedayetullah *et al.*, 2025) ^[29, 34]. 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) ^[19]. Integrating this approach with awareness campaigns and policy support can strengthen India's efforts toward safe and sustainable farming in arsenicaffected regions (Zaman *et al.*, 2015).

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 (Hedayetullah and Kumar, 2023b; Dolai *et al.*, 2013) ^[7, 14, 21]. 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 (Dolai *et al.*, 2019) ^[6]. 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) ^[14]. 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 (Mudi *et al.*, 2026) ^[61]. Rotating crops with different growth patterns, canopy structures, and nutrient demands interferes with weed establishment and reproduction (Hedayetullah *et al.*, 2023) ^[14]. Some crops, like sorghum and sunflower, exhibit allelopathic properties that inhibit weed germination, providing a biological method of weed suppression (Hedayetullah *et al.*, 2025a) ^[29]. Intercropping systems create ground cover that shades the soil surface, minimizing light availability for weed seed germination

(Kundu *et al.*, 2020) ^[55]. Furthermore, incorporating legumes in rotation improves soil fertility and helps build resilient cropping systems (Hedayetullah, 2023) ^[14]. 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 (Kumar *et al.*, 2025; Biswas *et al.*, 2016) ^[4, 50]. 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 (Hedayetullah and Zaman, 2026) ^[108, 28].

Environmental and Ecological Impacts

Natural farming has a positive impact on the environment by reducing chemical pollution, enhancing biodiversity, and promoting carbon sequestration. It also improves water use efficiency and reduces greenhouse gas emissions (Zaman *et al.*, 2026c) ^[108]. In contrast, inorganic farming contributes to environmental degradation through the release of harmful chemicals herbicides, insecticides and fungicides into soil and water bodies, increased greenhouse gas emissions, and loss of biodiversity (Meenambigai, 2023) ^[60].

Climate Resilience

Natural farming systems are more resilient to climate variability due to their emphasis on biodiversity, soil health, and water conservation. These systems can better withstand droughts, floods, and temperature fluctuations. In contrast, inorganic farming systems are more vulnerable to climate stress due to their reliance on external inputs and monocropping practices.

Policy Support and Current Scenario in India

The Government of *India* has introduced several initiatives to promote sustainable agriculture, including natural farming. Programs such as BharatiyaPrakritik Krishi Paddhati and Paramparagat Krishi Vikas Yojana aim to reduce chemical input use and encourage ecofriendly farming practices. Despite these efforts, the adoption of natural farming remains limited due to various challenges.

Challenges and Constraints

Natural farming faces challenges such as lack of awareness, limited scientific validation, initial yield variability, and inadequate market infrastructure. Inorganic farming, on the other hand, is constrained by environmental degradation, high input costs, food losses due to different techniques, and health risks associated with chemical exposure (Singh *et al.*, 2014; Singh *et al.*, 2014a; Singh *et al.*, 2014b) ^[92].

Conclusion

In conclusion, there are benefits and drawbacks to both inorganic and natural farming methods. Although inorganic farming has been essential to maintaining food security, its long-term viability is in doubt. By encouraging crop diversity, soil health, and ecological balance, natural farming presents a viable option. However, overcoming current obstacles through research, policy backing, and capacity building is necessary for its widespread adoption. To guarantee resilient, productive, and sustainable agriculture in *India*, a well-rounded and integrated strategy is necessary. Achieving sustainable agriculture in *India* requires a hybrid strategy that incorporates the advantages of

both systems. To build a robust and sustainable agricultural system, policymakers, academics, and farmers must collaborate. Overall, the study concludes that crop diversification and natural farming offer an economically viable, socially advantageous, and environmentally sustainable route for future agricultural development, while guaranteeing the preservation of natural resources, improving farmers' livelihoods, and long-term agricultural sustainability.

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Conflict of Interest

Authors have declared that no conflict of interest.

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