



Productivity, profitability and trade-offs in organic farming-based agricultural systems: Global trends and role in shaping new agri-food systems

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ABSTRACT

Organic farming is emerging as an alternative sustainable agri-food system globally both in developed and developing nations. In India, organic farming offers a promising alternative to conventional farming and may contribute significantly to mitigate climate change by improving soil health, fostering biodiversity, and enhancing carbon sequestration. Lower yields, higher production costs and market access barriers, particularly for smallholder farmers are significant challenges for scaling up of organic farming practices on small farmers' fields. However, growing opportunities for premium market prices for organic products, reduced input costs over time and improved soil resilience need to be addressed. This paper examines global and national trends, highlighting India's position as a major player in the organic food ecosystem with a growing area, organic food products market and organic production technologies. It also delves into the productivity and profitability of organic farming systems, acknowledging the trade-offs between environmental benefits and economic costs. The trade-off is evidenced in terms of long-term ecological advantages such as improved soil structure, nutrient cycling and reduced pesticide residues, thus ensuring healthier food system and sustainable farming practices. Government policies, institutional support and market incentives are crucial in accelerating the adoption of organic practices. For scaling up of organic farming, the role of policy recommendations is also vital and significant to contribute to food security and environmental sustainability. The key to achieving improvements in organic farming is adopting diversification into several different crops for direct human consumption and services for the community. Profitability in the market and promoting demand for products that would improve the sustainability of farm and beyond will increase the food security of the global food system at the farm-level, ultimately leading to greater sustainability and resilience in agri-food systems.

Keywords: Agri-food systems, Global trends, Organic farming, Productivity, Profitability, Sustainability, Trade-offs

Organic farming has gained increasing global attention as a viable alternative to conventional agricultural practices, particularly in addressing sustainability challenges. In the wake of the Green Revolution, conventional farming practices have been associated with several environmental and health-related issues, including soil degradation, loss of biodiversity, water pollution and the overuse of synthetic fertilizers and pesticides. In response to these challenges, organic farming emerged as a holistic system aimed at promoting the health of soils, ecosystems, and people. It emphasizes natural cycles and biodiversity while eliminating the use of synthetic inputs. Organic farming is now practiced in over 188 countries worldwide, covering a total area of 96 million hectares. India, accounting for 43.8% of the world's organic farmers, has emerged as a key player in the

global organic movement, despite occupying only around 5% of the total global organic farming area (Kumar *et al.* 2024a). The shift toward organic farming is particularly important in shaping sustainable agri-food systems that are resilient to climate change and can meet growing food demands without harming natural ecosystems (Ravisankar *et al.* 2021). This transition is fuelled by increasing consumer demand for healthier, pesticide-free food and the recognition of the role organic farming plays in enhancing ecosystem services (Ansari *et al.* 2024a, Singh *et al.* 2024). Studies showed that organic farming can improve soil health, sequester carbon and support biodiversity conservation, making it a critical part of global efforts to mitigate climate change (Macik *et al.* 2020). Organic farming, as an alternative food system, redesigns conventional practices using agro-ecological principles. It establishes an ecological infrastructure that supports soil fertility, nutrient cycling, water storage, pest and disease regulation, pollination, and other essential ecosystem services through diversification from plot to landscape scale (Altieri 2002,

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Ansari *et al.* 2024a). The cost of setting up this ecological infrastructure—such as living fences, crop rotation, and insect habitats—tends to be high in the first 3-5 years. However, once rotations and vegetative designs like cover crops, polycultures, and field borders start providing these services, key ecological processes such as nutrient cycling and pest regulation are activated. As a result, the need for external inputs decreases, and maintenance costs drop as the farm's biodiversity drives these ecological functions (Nicholls *et al.* 2016). Despite these benefits, the transition to organic farming poses certain challenges, particularly in terms of productivity, profitability, and trade-offs. While organic farming systems often command premium market prices for their products, they may experience lower yields, especially in the initial years of conversion from conventional systems. Additionally, higher labour costs and challenges associated with organic certification further complicate the adoption of organic practices, particularly for smallholder farmers. It is a daunting task to strike a balance between the production of safe, healthy, quality and environmentally sustainable food on the one hand and sufficient quantity of 400 million tonnes of food on the other for the projected 1.66 billion population of India by 2050 (Das *et al.* 2023, Sharma *et al.* 2023). Therefore, it is essential to critically examine the economic viability, productivity outcomes, and environmental trade-offs of organic farming to determine its role in shaping future agri-food systems.

In India, organic farming presents a viable solution to address critical agricultural challenges such as declining soil health, over-reliance on chemical inputs, and vulnerability to climate change. The shift to organic agriculture promotes long-term sustainability by enhancing soil fertility, improving water retention, and fostering biodiversity. Despite its benefits, the adoption of organic practices remains slow due to concerns about lower initial yields and higher labour requirements compared to conventional methods. Organic farming often requires substantial manual labour for tasks such as weeding, compost preparation, and pest control, which can raise costs for farmers transitioning from conventional practices. However, several studies and long-term experiments indicate that once organic systems are well-established, they can achieve competitive yields, particularly in rainfed and marginal areas where chemical inputs often provide diminishing returns. Organic farms reduce reliance on expensive synthetic fertilizers and pesticides, thereby lowering input costs. Moreover, farmers can command higher prices for certified organic products in both domestic and international markets, contributing to improved profitability. Organic farming also supports climate resilience by enhancing soil carbon sequestration and reducing greenhouse gas emissions. Government support, along with well-designed certification processes, awareness campaigns, and value-chain integration, could further promote organic farming, making it a realistic and sustainable solution for India's future agricultural landscape.

The scope of this review extends to both global and regional trends in organic farming, with a particular focus on

the Indian context. India, despite having the largest number of organic farmers globally, faces significant challenges in scaling up organic agriculture due to the country's dependence on conventional farming practices that prioritize high yields and low production costs. By addressing the interests of all stakeholders scientists, policymakers, and practitioners, this review aims to accelerate the adoption of organic farming as a viable and sustainable solution for reshaping global agri-food systems to meet future food security and environmental challenges. The relevance of this review lies in its potential to contribute to the broader global effort to create resilient, sustainable, and equitable food systems that can meet the demands of a growing global population. As the world faces increasing pressure to reduce its environmental footprint and combat climate change, organic farming offers a pathway to achieving both food security and environmental sustainability.

Global and National trends in organic farming

In 2022, global sales of organic food and beverages surpassed 122 billion euros (Willer 2022). Compared to 2021, the area under organic agriculture grew by 25.6%, now representing around 1.6% of the world's total agricultural land. Liechtenstein (40.2%), Samoa (29.1%), and Austria (26.5%) are the countries with the highest percentage of organic farming in relation to their total cultivated areas (Willer 2023). Oceania leads with the largest area of organic agricultural land, covering 36 Mha, which accounts for 47% of the global total. Europe follows with 17.8 Mha (23%), Latin America with 9.9 Mha (13%), Asia with 6.5 Mha (8.5%), Northern America with 3.5 Mha (4.6%), and Africa with 2.7 Mha (3.5%) (Willer 2023) (Fig. 1). The global organic farming market is projected to reach \$365.84 billion by 2029, growing at a Compound Annual Growth Rate (CAGR) of 12.3%. This growth is driven by concerns over climate change, shifting consumer preferences, and improvements in supply chain and distribution. Key trends include advancements in research, technology, organic livestock products, urban farming, and sustainable packaging (The Business Research Company 2023).

In India, the total area under organic farming, including organic and in-conversion land, stands at 4.47 Mha, excluding the 2.85 Mha designated for wild harvest collection (APEDA 2023–24). Organic farming in India yielded 3.55 million metric tonnes from both organic and in-conversion areas, along with 0.024 million metric tonnes from wild collection (APEDA 2023–24). The export value of organic products reached 494.8 million USD in 2023–24. Seven states dominate organic production in India, with Maharashtra (32.7%), Madhya Pradesh (25.4%), Rajasthan (11.3%), Gujarat (6.8%), Karnataka (5.6%), Uttar Pradesh (4.5%), and Odisha (4.5%) collectively contributing 91% of the total organic products. The top seven states account for 85.7% of India's organic farming area (both organic and in-conversion), with Madhya Pradesh (25.7%), Maharashtra (22.4%), Gujarat (15.2%), Rajasthan (13.0%), Odisha (4.0%), Uttarakhand (2.3%), Sikkim (1.7%), and Uttar

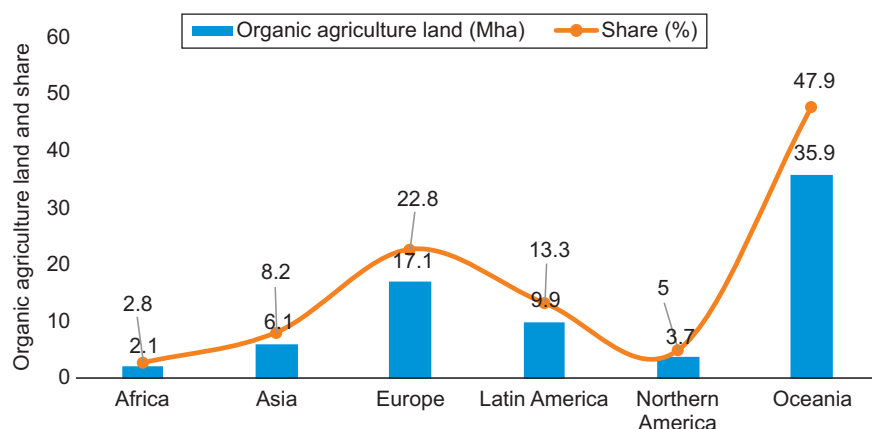


Fig. 1 World organic agricultural land (including in-conversion areas) and regions' shares of the global organic agricultural land 2020 (Source: Willer *et al.* 2022, FiBL survey 2022).

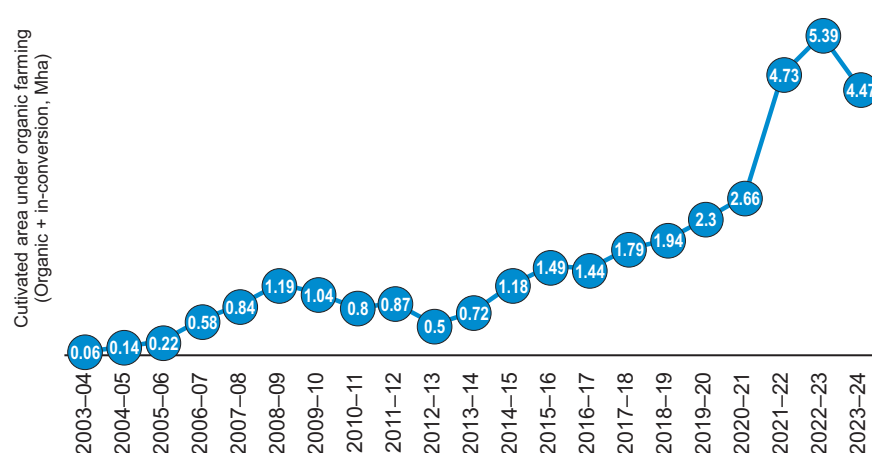


Fig. 2 National trends of organic farming.

Pradesh (1.5%) leading the way. Fig. 1 illustrates the National trends in the area under organic farming (including both organic and in-conversion land) from 2003–04 onward. This indicates that after the year 2019–20, there has been a rapid increase in the area under organic farming in India from 2.33 Mha reaching to highest area of 5.39 Mha in 2022–23 (Fig. 2).

Agroecology and organic farming

Agroecology is a cornerstone of organic farming, applying ecological principles to enhance the sustainability and resilience of agricultural systems. It emphasizes the integration of natural ecosystems with agricultural landscapes, promoting biodiversity, soil health, and ecosystem services while minimizing the reliance on external inputs (Rosset and Altieri 2017). Agroecological principles, viz. diversity, synergy, efficiency, resilience, and recycling are implemented through practices like crop rotation, intercropping, and composting, improving nutrient cycling and pest management, and increasing long-term productivity (Nicholls and Altieri 2018). The suitability of agroecological practices is heavily dependent on spatial and locational diversity. Initiatives like the Mission Organic Value Chain Development for North-Eastern Region

(MOVCD-NER) have been pivotal in supporting the organic transition in this area by promoting organic value chains, ensuring market access, and providing financial assistance to farmers. These efforts have allowed farmers in this region to adopt agroecological practices tailored to their unique environments, such as contour farming on hilly terrains and agroforestry systems that integrate trees with crops to enhance soil fertility and biodiversity. Agroforestry plays a significant role in regions like north-east India, where integrating trees into farming systems helps to maintain soil health, improve microclimates, and sequester carbon (Ansari *et al.* 2022, Bishaw *et al.* 2022). Moreover, agroecological practices such as rainwater harvesting and the use of indigenous crops ensure that the farming systems are adapted to local climatic conditions, enhancing both sustainability and resilience. Agroecology also strengthens ecosystem services critical to organic farming, including soil fertility, water retention, and pest regulation. By promoting species and genetic diversity, particularly in niche areas like the north-east, agroecology enhances resilience to environmental

stressors, such as climate variability, and reduces the need for chemical inputs (Ponisio *et al.* 2015). In these diverse environments, agroecology supports long-term sustainability and food security by fostering ecosystems that provide essential services to agriculture.

Productivity and profitability in organic farming

On average, organic farming yields were 25% lower than those of conventional farming, with cereals exhibiting a 30% yield gap (Alvarez 2021). When factoring in the reduction in crop rotation intensity, the productivity gap was estimated to range between 29% and 44%, depending on the crops included (Alvarez 2021). These findings indicate that the productivity gap exceeds the yield gap between organic and conventional farming. Organic farming generally results in lower yields than conventional farming, mainly due to the absence of synthetic fertilizers and pesticides (Murphy *et al.* 2007, Aguilera *et al.* 2015). This yield gap varies depending on crop type, environmental conditions, and farming practices. On average, organic yields are 20–25% lower, though this difference can vary significantly (Tiware 2022). Long-term results from organic management showed that scientific Packages of Practices (PoPs) for organic crop production can maintain or exceed crop productivity

compared to chemical farming. Under the ICAR-All India Network Programme on Organic Farming (AI-NPOF), 51 location-specific PoPs have been developed for 12 states (Ravisankar *et al.* 2021). Panwar *et al.* 2022 reported the location and nutrient management variation on system productivity and profitability in rice-based cropping systems and found that under different nutrient management systems, integrated crop management yields the highest productivity (8,002.1 kg/ha), followed by inorganic (7,643.1 kg/ha) and organic crop management (7,499.4 kg/ha). Similarly, ICM provides the highest net returns (1,15,306₹/ha), followed by inorganic (93,122 ₹/ha) and organic management (94,323₹/ha).

Organic crop yields typically range from 66–95% of conventional yields (Seufert *et al.* 2012, Ponisio *et al.* 2015), with wheat yields in European organic agriculture averaging 30–70% of conventional yields (David *et al.* 2012). Studies showed that farmyard manure (FYM) application results in a 5–15% decrease in rice yield and 35–58% reduction in wheat yields (Ramesh *et al.* 2009). For sugarcane, FYM and vermicompost were found to be as effective as synthetic fertilizers (Singh *et al.* 2007). In maize, soybean, and wheat, organic practices involving green manuring and FYM application resulted in higher yields compared to chemical farming (Walia 2004). Vegetables, particularly tomatoes, show a positive response to organic sources such as FYM and poultry manure (Samawat *et al.* 2001). Productivity of organic wheat can be increased significantly by FIRB method, with 75% RDN through FYM as a basal + 25% RDN during the 1st irrigation + *Jeevamrut* @ 500 litre ha during sowing and the 1st irrigation + spraying of *Panchagavya* @ 5% during the booting stage (Sharma *et al.* 2024).

Green manuring in organic farming resulted in 33.9% higher crop productivity and greater net returns in north-western India (Nima *et al.* 2020). However, small-scale farmers face challenges in adopting organic farming, including low yield, certification issues, and market barriers (Crowder and Reganold 2015). Organic farming is most profitable in dry, water-scarce, and least-developed regions (Te Pas and Rees 2014). Ansari *et al.* (2023) evaluated six cropping systems in organic farming and found that maize-sweet corn-vegetable pea/broad bean systems increased productivity by 158%, efficiency by 157%, and protein yield by 101% over conventional (maize-pea) system. It also improved net margin (171.5%), benefit-cost ratio (44%), and dietary energy returns (16.6%) compared to the maize-vegetable pea system, while enhancing nutritional security (Ca, Mg, Fe, Mn, Zn, Cu).

Trade-offs in organic farming

Organic farming offers environmental benefits like improved soil health and reduced pesticide use, contributing to ecosystem sustainability (Das *et al.* 2021). However, these benefits come with economic trade-offs, including lower yields (typically 20–25% less than conventional farming) and higher production costs due to the reliance on organic inputs and labour-intensive practices, potentially

reducing profitability for farmers (Panwar *et al.* 2022). Organic farming improves soil fertility, nutrient cycling, and microbial activity by using organic inputs such as FYM, compost, vermicompost, and green manuring (Panwar *et al.* 2022). These practices enhance nutrient availability, including nitrogen, phosphorus, and potassium, while reducing nutrient leaching (Diepeningen *et al.* 2006, Sudhakaran *et al.* 2013). *Sesbania* green manuring increases nutrient content (Ansari *et al.* 2022a), and microbial activity boosts phosphorus availability (Bhat *et al.* 2017). Organic inputs like vermicompost provide sustained nutrient release, improving soil structure and fertility (Singh *et al.* 2024). Excessive use of manures can lead to nutrient buildup, necessitating better nitrogen use efficiency (Choudhury *et al.* 2021). Long-term data from the All India Network Programme on Organic Farming showed that organic practices significantly enhance Soil Organic Carbon (SOC) stock (Panwar *et al.* 2022). Green manuring added >9.58 Mg C/ha/annum, while organic manure added 8.21 Mg C/ha/annum (Ansari *et al.* 2022b). Organic farming increased SOC by 0.66% versus 0.38% in conventional farming (Sahu *et al.* 2024), with higher nutrient availability (N, P and K). Long-term organic farming increases soil enzyme activity, promoting nutrient cycling and organic matter decomposition. Practices like composting, manure, and green manuring foster microbial growth, boosting enzyme levels. It also improves soil aggregate stability by adding organic matter, enhancing microbial diversity, and promoting soil binding agents like polysaccharides. This reduces erosion, improves water infiltration, and strengthens soil resilience (Zhao *et al.* 2017, Kumar *et al.* 2024b). The highest organic carbon (0.68%), bacterial (29.11×10^7 cfu/g), fungal (4.77×10^4 cfu/g), actinomycetes populations (5.67×10^4 cfu/g), acid phosphatase (44.1 µg/g/h), urease (45.3 µg/g/h) and dehydrogenase (23.3 µg triphenylformazan [TPF]/g/h) activity in soil were found in the conservation organic system in comparison to conservation chemical crop management approaches in soybean-wheat system of production. Also, the Soil Quality Index (SQI) significantly varied from the lowest score (0.30) at 45–60 cm layer of soil in the package of practices to the highest score (0.92) at 0–15 cm layer of soil with regards to the conservation organic system. This indicates the better opportunities of tradeoff capacity under organic production system than chemical production system (Meena *et al.* 2024).

Natural positive farming practices such as mulching, intercropping, and reduced tillage enhance soil health by improving organic carbon (SOC) content and microbial activity. Mulching contributes to a 7–35% increase in SOC at a 0–20 cm depth, enhancing water infiltration, reducing erosion, and boosting microbial activity. Mulching also increases soil dehydrogenase activity by 26.5% and fluorescein diacetate hydrolysis by 34.5%, significantly improving soil organic matter (SOM). These practices collectively lead to better nutrient cycling, increased soil fertility, and improved crop yields. Mulching also significantly contributed to the yield improvement which

ranged from 11–25.7% (Ravisankar *et al.* 2024). Organic farming involves both social and ecological trade-offs. Socially, it tends to increase labour intensity due to practices like manual weeding and composting, which can be challenging for smallholder farmers. However, it often enhances community involvement and health by reducing pesticide exposure. Ecologically, organic farming promotes biodiversity conservation by encouraging diverse cropping systems and reducing chemical use, but it may result in yield reductions (25% lower on average) compared to conventional systems. Despite lower yields, organic systems can improve soil health, enhance water retention, and sequester more carbon, fostering long-term sustainability. Scaling organic agriculture presents challenges in balancing profitability with sustainability. Organic farming tends to have lower yields compared to conventional farming due to restrictions on synthetic fertilizers and pesticides. While organic practices promote environmental sustainability through improved soil health, reduced pesticide use, and enhanced biodiversity, the intensification of organic systems to meet market demand often risks soil degradation and reduced biodiversity (Ashoka *et al.* 2023). Trade-offs include maintaining soil fertility through organic inputs like compost and manure while avoiding over-reliance on these inputs to prevent nutrient imbalances or environmental harm. Profitability may be constrained by higher labour costs and certification expenses, making it challenging for small-scale farmers.

Paradigm shift and transition towards organic based agri-food systems

Food systems are currently broken, as they fail to achieve desirable outcomes, such as eliminating malnourishment, while also minimizing environmental impacts (FAO 2020). Organic farming, known for addressing environmental, social, and economic challenges, is increasingly recognized as a viable model globally and in India. It conserves resources and promotes sustainability by emphasizing biodiversity, minimal soil disturbance, crop rotation, and biological pest control. While developed nations focus on organic farming for environmental and dietary health, developing countries, including India, view it through the lenses of economic feasibility and trade-offs. Although organic farming's higher productivity does not guarantee long-term sustainability, its emphasis on "naturalness" is crucial for ecological benefits. Environmental considerations drive the global carbon market and create opportunities for India to commercialize healthy, eco-friendly products. However, shifting all farmers to organic farming remains unrealistic given the country's population size and the need to ensure high yield food production, especially for cereals. Yet, integrating traditional diversified farming systems could enable organic farming at a regional level, especially in areas suited for export-driven organic produce.

Indian food systems vary widely in environmental footprints and vary with pattern of diets and regions. Globally the land footprints of Indian food systems are

lower than the United States of America diets and higher than the Chinese diets. Studies report that there is higher environmental footprint in the north Indian states of Punjab, Haryana, and Western Uttar Pradesh. The emission of greenhouse gases (GHG) is 1.30–2.19 kg CO₂eq/ Consumer Unit (CU)/day, the land footprint is 3.89–6.04 m²/CU/day and the water footprint is 2.02–3.16 m³/CU/day (Athare *et al.* 2022). A multi-faceted approach of organic farming system to addressing malnutrition, dietary changes, and sustainable food production may help make Indian food systems more sustainable. Households across the food systems spend around half of their income on food. Generally, the share of food expenditure decreases with an increase in income.

Given how Indian agri-food production and consumption system has localised challenges such as unviable smallholding of farms, low literacy rates, unsustainable farming practices, price fluctuations, lack of market access, and a digital divide that hampers technology acceptance, the organic farming-based food system transition will help to identify demand-supply and provide a plan for requisite action.

The domains of transformation that need to be addressed are, strengthening knowledge on agroecology; working with markets; enhancing cooperation; and ensuring policy coherence to create a conducive policy context for agroecology. These four domains address both agroecological practices (levels 1, 2 and 3 of Gliessman 2015) and the wider food system changes (levels 4 and 5).

Organic systems also empower smallholder farmers, contributing to greater equity in rural communities by creating market access and fairer income opportunities. The emphasis on locally adapted practices fosters a more decentralized and inclusive food system that is less vulnerable to global market fluctuations. Policy, institutional support, and market incentives are pivotal in promoting organic farming as a key component of future agri-food systems. Governments can incentivize organic practices through subsidies, grants, and research investments that support organic inputs, certification, and transition programs for farmers. Establishing strong organic certification systems and ensuring fair market access are also critical to promoting consumer confidence and demand. Supporting institutions such as extension services and cooperative networks can further enhance farmer capacity and knowledge sharing. Policy initiatives aimed at Sustainable Development Goals (SDGs) can align organic farming with larger social, environmental, and economic objectives, ensuring that organic agriculture becomes a cornerstone of global food systems.

Opportunities and challenges in organic farming systems

The dilemma of protecting ecosystems on one side and sustainably feeding the global population on another side has been discussed at various forums and are increasing attention in recent years. Sustainability of one earth and one future need both environmentally friendly production' towards 'food system sustainability', which includes both production

and consumption side improvements, as research has shown that reducing the pressures from production alone will not be enough to reach environmental targets. But substantial consumption changes, especially fewer animal products, and reductions in waste are needed simultaneously (Roos *et al.* 2021). Organic farming faces several global challenges, the most significant being yield gaps compared to conventional farming. Organic systems often rely on natural inputs, such as organic manure and compost, which may not provide nutrients as efficiently as synthetic fertilizers, resulting in lower crop yields. These yield gaps are particularly evident in high-demand crops and regions with poor soil quality. Another key challenge is market access; organic produce often comes with higher production costs, which can make it difficult for small-scale farmers to compete in global markets. Certification processes, which are both time-consuming and costly, further hinder access to organic markets, especially for farmers in developing countries. Additionally, policy constraints such as inadequate support for transitioning to organic practices and limited access to government subsidies or grants restrict organic farming's growth potential in many regions.

Despite these challenges, there are numerous opportunities for growth in organic farming. Technological innovations, such as precision agriculture tools, can improve the efficiency of organic systems by better managing nutrient cycles and pest control. Agroecology, which combines ecological principles with agricultural practices, can enhance resilience and productivity in organic systems by promoting biodiversity and soil health. Improved supply chains, such as direct farmer-to-consumer marketing and digital platforms, offer better market access for organic producers, allowing them to bypass intermediaries and receive fairer prices. Furthermore, increasing consumer demand for organic products presents significant opportunities to scale up organic farming and improve profitability. Life-Cycle Assessment (LCA) studies that compared organic and conventional farming methods showed mixed results, depending on impact category (climate change, eco-toxicity) and crop studied (de Backer *et al.* 2009, Tricase *et al.* 2018). LCA studies do not yet cover all impact categories relevant for comparing organic and conventional farming such as level of flora and faunal diversity, animal welfare and farm as well as community level strategic and financial indicators in a food system (Schader *et al.* 2014).

Innovations and technological advances in organic farming

Organic farming has undergone substantial advancements with the integration of modern technologies, enhancing both efficiency and productivity while maintaining the principles of sustainability. These innovations have reshaped traditional organic practices, enabling farmers to optimize resource use, reduce input costs, and improve yields. Technological tools, including digital platforms, remote sensing, and automated systems, have significantly contributed to the improved management of organic farms (FAO 2022). GPS-guided machinery and drones are now widely employed

to monitor crop health, soil conditions, and water needs in real time, enabling precise interventions. Furthermore, satellite imagery and data analytics facilitate the tracking of soil fertility and pest dynamics, supporting more targeted applications of inputs and minimizing wastage (Willer *et al.* 2023).

Precision agriculture tools, such as soil sensors and IoT devices, are instrumental in providing real-time data on soil moisture and nutrient levels. This enables precise irrigation and fertilization strategies, reducing water use and ensuring that organic inputs such as compost and green manures are applied effectively. These technologies help optimize nutrient availability while minimizing the risks of over- or under-application (Dhakal *et al.* 2023). Innovations in biofertilizers and biopesticides, including nitrogen-fixing bacteria and neem-based products, further enhance the sustainability of organic farming by promoting soil health and offering environmentally safe pest control alternatives, reducing reliance on chemical inputs (Choudhary *et al.* 2021). In India, technological innovations have proven particularly impactful.

Organic farming and climate goals

Organic farming has emerged as a key contributor to achieving global climate goals, particularly in alignment with the United Nations Sustainable Development Goals (SDGs) and national climate commitments like Nationally Determined Contributions (NDCs) under the Paris Agreement. By promoting sustainable farming methods, organic agriculture reduces greenhouse gas (GHG) emissions, enhances carbon sequestration and builds resilience against climate change impacts. Furthermore, the integration of organic farming into climate-resilient agricultural policies, supported by various initiatives launched by the Government of India, provides a model for achieving global climate objectives.

Organic farming aligns with several SDGs, particularly SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). By reducing dependency on chemical inputs, organic farming enhances soil health, promotes biodiversity, and improves food security (SDG 2). The Paramparagat Krishi Vikas Yojana (PKVY) and Namami Gange Programme initiated by the Government of India, aims to support organic farming by promoting cluster-based organic cultivation and sustainable practices that improve soil fertility and ecosystem services. Under this scheme, farmers are encouraged to adopt organic farming techniques that align with responsible consumption and production patterns (SDG 12), reducing the use of synthetic fertilizers and pesticides that contribute to soil degradation and water pollution (Mbow *et al.* 2019, Ansari *et al.* 2024a, Ansari *et al.* 2024b). Moreover, organic farming contributes to climate action (SDG 13) by mitigating the impacts of climate change. The National Mission for Sustainable Agriculture (NMSA), a key initiative under India's National Action Plan on Climate Change (NAPCC), emphasizes the adoption of climate-resilient agricultural

practices, including organic farming. This mission aims to reduce agriculture's carbon footprint by encouraging organic practices that sequester carbon in soils, reduce methane emissions from paddy fields, and minimize the use of energy-intensive inputs. Organic farms have higher soil organic carbon levels than conventional farms, contributing to carbon sequestration and climate mitigation (Lorenz and Lal 2016).

India's Nationally Determined Contributions (NDCs) under the Paris Agreement highlight the importance of sustainable agricultural practices in meeting its climate goals. Organic farming is recognized as a critical component of these contributions due to its potential to reduce GHG emissions and enhance carbon sinks. India has committed to reducing its GHG emissions intensity. Organic farming supports this goal by minimizing the use of synthetic nitrogen fertilizers, which are a major source of nitrous oxide emissions, a potent GHG. The MOVCD-NER is a significant initiative aimed at promoting organic farming in the north-eastern states, which have traditionally practiced low-input agriculture. This mission supports farmers in transitioning to certified organic farming, linking them with national and international markets, and providing financial assistance to create an organic value chain. The MOVCD-NER contributes to India's NDC by promoting organic farming practices that enhance soil health, reduce emissions, and sequester carbon in a region highly vulnerable to climate change. Organic farming's contribution to NDCs also extends to the preservation of biodiversity, which is crucial for maintaining resilient ecosystems. By fostering practices such as crop rotation, intercropping, and agroforestry, organic farming supports the diversity of species and genetic resources that enhance ecosystem resilience to climate impacts. The National Programme on Organic Farming (NPOF), provides capacity building and training for organic farmers, encouraging the adoption of climate-smart agriculture (Khanal 2009). Through such initiatives, India can meet its climate commitments by scaling up organic farming as a low-emission, high-resilience agricultural system. The Soil Health Card Scheme (SHC), launched by the Government of India, further supports organic farming by providing farmers with soil health assessments and recommendations for sustainable nutrient management. By promoting balanced use of organic amendments, the scheme helps farmers enhance soil fertility while reducing their reliance on chemical fertilizers, which contribute to GHG emissions.

Advancing organic farming: Innovation, sustainability and growth

The increasing recognition of organic farming's potential to contribute to sustainable agriculture, environmental health, and food security presents significant opportunities and challenges. Moving forward, a comprehensive approach is needed to enhance the productivity and profitability of organic farming, while addressing trade-offs that may arise during its adoption. Organic farming should embrace innovative,

regionally tailored technologies to boost productivity without compromising ecological sustainability. It involves developing location-specific solutions suited to diverse climatic conditions, for example, integration of traditional knowledge with modern science should be prioritized in regions like the north-east of India and niche areas where indigenous practices can improve yield and resilience. Technologies such as precision agriculture, biofertilizers, and organic nutrient management will help bridge yield gaps while maintaining soil health and biodiversity. Small and marginal farmers are critical to the success of organic farming, where resource-poor farmers benefit from low-input systems. Policymakers and institutions should provide financial incentives, training programmes, and market linkages for these farmers. Government initiatives like PKVY, MOVCD-NER etc. should evolve to offer more comprehensive support, improving certification and market access for organic farmers. Integrated Organic Farming Systems (IOFS) are proven to enhance productivity and profitability while reducing dependency on external inputs. These systems integrate crops, livestock, agroforestry, and fisheries, creating synergies that generate much of the input required within the farm itself. Scaling up IOFS models will contribute significantly to household income, food security, and climate resilience. To mitigate initial productivity trade-offs, investments in soil health, organic inputs, and pest management are essential. Research and extension services should focus on developing organic input packages that meet the nutrient demands of various cropping systems, especially in areas with low organic matter. Organic crop diversification, along with the use of cover crops and green manures, will also help reduce productivity losses during the transition to organic systems. One major trade-off in organic farming is the high cost of certification and market access. Governments and NGOs should streamline the certification process to reduce financial burdens on smallholder farmers. Participatory Guarantee Systems (PGS) and simplified certification processes can help make organic farming more accessible and profitable.

Organic farming plays a crucial role in enhancing ecosystem services, such as biodiversity, soil carbon sequestration, and water conservation, making it a key climate mitigation strategy. Incorporating organic farming into national climate action plans and offering carbon credits for climate-smart practices will incentivize broader adoption. Continued research and development are necessary to address challenges in pest and disease management, weed control, and nutrient supplementation in organic systems. Long-term experiments across ecological zones will provide critical data to refine organic practices. Collaboration between government and academic institutions is essential for building research networks that focus on region-specific challenges. Integrating organic farming into broader agricultural policies is key to scalability. Policies promoting climate-resilient agriculture should include organic farming, emphasizing its role in climate adaptation and sustainable food production. Public-private partnerships can help to

develop value chains for organic products, ensuring long-term profitability for farmers. Organic horticulture also holds potential due to high market demand. Promoting organic cultivation of fruits, vegetables, and spices, especially in the north-eastern region, will diversify income sources and unlock post-harvest processing opportunities for farmers.

Conclusion

Organic farming is gaining importance at global level as well as in India due to its universal capacity to deal with the global environmental, social and economic problems associated with equity, equality and distributive justice. Scientific evidences are emerging that organic farming promotes resource conservation and sustainability drivers in the food system as more and more research and case studies are being undertaken in system perspective over space and time in many countries. Priorities in developed and developing regarding upscaling and adoption of organic farming differs from sustainable healthy diets to environmental concerns and issue of intensity of awareness in consumers about present status of adverse effects of modern agriculture vis to vis health issues. Further at national level, policies, economics and scale of trade off management are the main driving force. Higher productivity in organic farming is not the guarantee of sustainability but value to naturalness is more important. Environmental concerns are need of the hour and opportunities regarding advantage of global carbon market and commercialization of niche healthy and safe diets need to be developed in India. Risk and opportunities need synergies which is context specific and cannot be a conventional practice for all farmers. Research should focus on optimizing yield potential, nitrogen use efficiency and pest management in organic systems. Policies should prioritize subsidies for organic inputs, incentives for organic adoption, and research and development for region-specific practices. Training programmes and awareness campaigns are essential for farmer transition. Organic farming has the potential to transform agri-food systems by improving soil health, food quality, and sustainability. With the right policy support, research and farmer engagement, organic agriculture can significantly contribute to global food security and environmental conservation.

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