Project Synthesis
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Organic cotton-based farming systems & their role in sustainable development

Long-term farming systems comparisons in the tropics (SysCom) India

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Executive Summary

This document presents evidence from over 16 years of research conducted within the SysCom India project of the Research Institute of Organic Agriculture FiBL. Organic cotton farming systems offer significant benefits across social, economic, and environmental dimensions, in comparison to conventional farming systems. Evidence from our work is used to suggest key policy measures and recommendations essential to support farmers in sustainably transitioning to organic production systems.

Social aspects

Organic systems improve food and nutrition security through increased dietary diversity, higher nutritional content in grains and by improving the purchasing power of farm labour. With reduced exposure to harmful pesticides, organic systems are safer for the health of farm workers. Organic farming also empowers marginalised communities, particularly women, by providing higher income and better networks, as women are key actors in these systems.

Economic impact

Our data demonstrates that organic yields can match conventional ones with good management, improved varieties, and enhanced soil fertility. While organic systems have lower input costs due to their reliance on local resources, the labour requirements and costs are often higher in these systems. Although, these can potentially be offset by including high-value crops in the organic systems.

Ecological impact

Organic cotton farming systems have higher soil organic carbon (SOC), higher biodiversity of earthworms and beneficial insects, and support higher local plant diversity.

Intrinsic factors, such as caring for their health and nature, motivated farmers towards adoption of organic practices, highlighting the long-term sustainability of these systems. Conventional profitability metrics often overlook crucial environmental and social externalities. True cost accounting is needed to provide a more comprehensive perspective.

Key recommendations

Policies and financial support systems tailored to sustainable agricultural transition are essential to harness the potential of organic agriculture and promote sustainable development and rural livelihoods.

Establish financial incentives and technical support programmes to strengthen Farmer Producer Organisations (FPOs) and Self-Help Groups (SHGs) within the organic agriculture sector, **emphasising collaborative resource sharing** and cost-effective practices to facilitate access to resources needed for mechanisation, certification and critical inputs.

Allocate government funding and resources to research and development initiatives focused on **breeding crop varieties specifically suited for organic farming practices**, including intercropping and mixtures, to improve the resilience, productivity and sustainability of the sector.

Implement policies that incentivise and **educate farmers on the benefits of integrating legumes into crop rotations**, emphasising improved soil fertility, nitrogen fixation and overall crop yield enhancement through sustainable agricultural practices.

Establish national and regional **marketplaces specifically for organic products**, with features that allow farmers to list their products, set prices, and connect directly with consumers.

Develop comprehensive livestock management and support programmes to enable farmers to **integrate livestock into their organic farming systems**, ensuring a consistent supply of organic manure for soil enrichment and closing local nutrient cycles.

Establish education and **training programmes tailored to women and youth** in rural areas, focusing on organic farming techniques, sustainable agricultural practices and entrepreneurship opportunities within the organic farming sector, to empower and engage these marginalised groups in sustainable livelihoods.

Implement policies that provide **financial incentives and premium pricing mechanisms to farmers engaged in organic crop production**, recognising the environmental and social benefits of organic farming practices, thereby encouraging wider adoption and sustainability of organic agriculture in India.

Introduction

What are the benefits of organic and agroecological approaches, particularly in the context of cotton farming systems? This document explores this question by synthesising results from over 16 years of research in the SysCom India trials, complemented with additional scientific sources. Particularly, it provides an overview of the potential and limitations of organic and agroecological practices for sustainable development and livelihoods. The SysCom India trials [1], consisting of the long-term experiments (LTE) and participatory farmer research trials (POR), was established in 2007 in Madhya Pradesh, India, by the Research Institute of Organic Agriculture FiBL. These trials are implemented by bioRe Association India and Remei India, under scientific guidance of FiBL. We evaluate organic cotton production in terms of (1) its relevance to food systems and social and health benefits, (2) its economic performance and limitations, and (3) its environmental implications. This research synthesis is structured accordingly, highlighting key implications:

Chapter 1: Social Impacts of Cotton Production and Relevance for Food Systems

- Highlights the role of crop diversity for household food security.
- Points out the health aspects of cotton production for local communities.
- Examines the role of farmer organisations and support systems in improving farmers' livelihoods.
- Proposes an integration of marginalised communities for long term sustainability of cotton production systems.

Chapter 2: Productivity and Economic Viability

- Highlights the differences in productivity of organic and conventional cotton.
- Proposes a "systems approach", integrating new crops to reduce the yield gap.
- Notes the economic attractiveness of organic farming, especially in India, due to lower input costs.

Chapter 3: Ecological Sustainability

- Addresses soil health, including fertility, nutrient availability, and biological activity.
- Emphasises the critical role of sustainable farming systems for ecosystem wellbeing and functionality.
- Explores elements such as functional biodiversity and ecosystem services supporting crop production.

[1] https://systems-comparison.fibl.org/project-sites/india.html

Box 1: SysCom India trials

The heart of the SysCom India trials is the Long-Term Experiment (LTE) established in 2007. Four different cotton production systems are being compared to each other in terms of agronomic and economic performance, soil fertility, biodiversity and other aspects. The systems in comparison are organic (ORG), biodynamic (BD), conventional (CONV) and conventional with genetically modified Bt-cotton (Bt-CONV). Cotton is grown in a two-year crop rotation with soybean, wheat, and since 2019, chickpea in the ORG and BD systems.

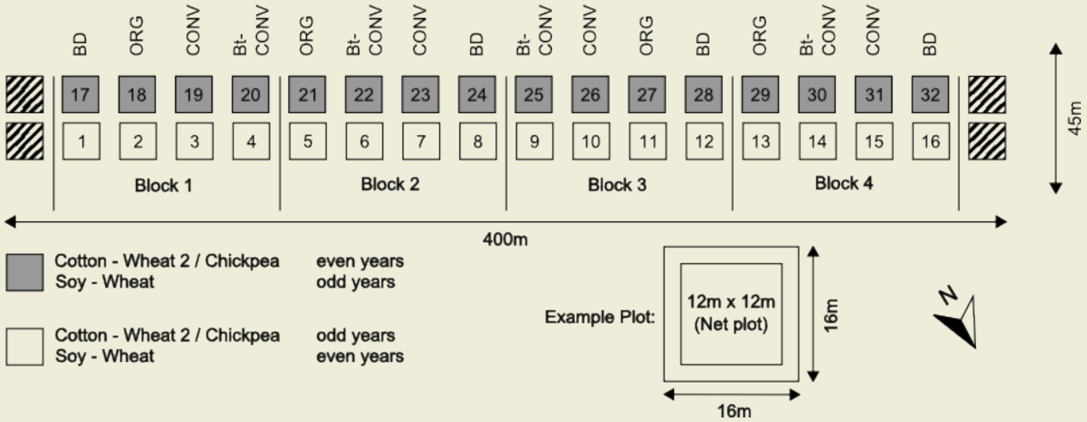

Figure 1: Plot layout of the LTE trial

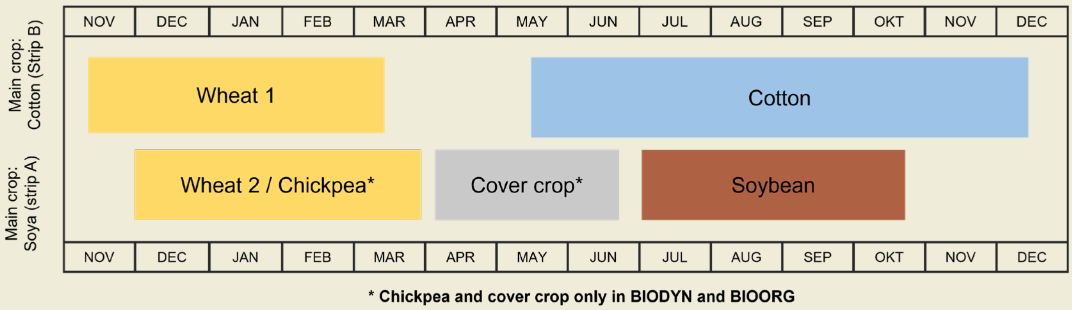

Figure 2: Crop rotation of the LTE trial. (adapted from: Lori et al., 2024; Singh et al., 2025)

Chapter 1: Social impacts of cotton farming and relevance for food systems

Promoting diversity for food security

Dietary diversity is essential to address malnutrition and its health consequences. Diverse agricultural systems that produce a varied mix of food crops and nutrients play a central role in achieving this (Altieri and Nicholls, 2012; Bezner Kerr et al., 2021; Herrero et al., 2017). Importantly, these diversified landscapes are major contributors to the global micronutrient and protein supply (Herrero et al., 2017).

SysCom India results and other scientific work show that organic cotton systems can improve food security by diversifying the farming systems and by improving the purchasing power of farmers. Promotion of diversified crop rotation is an integral approach within organic agriculture, and organic cotton farmers include food crops like wheat and pulses in their crop rotation. Specifically the integration of legumes into crop rotations has been shown to positively impact food production and food security (Marini et al., 2020; Zhao et al., 2022). Furthermore, a study by Habermann (2021) in the study region revealed that organic cotton farmers tend to have more livestock compared to their conventional counterparts. This not only ensures a steady supply of manure for fertilisation but also opens up opportunities for additional food sources like dairy products. Organic production can even increase the nutritional content of produced crops: we found zinc content to be 20% higher in organic wheat than in conventional systems (Helfenstein et al., 2016). And in a meta-analysis including 343 publications, Barański et al. (2014) found substantially higher antioxidant concentrations in organic crops compared to conventionally produced crops. Finally, stable market access for cash crops and premium prices provided by organic cotton production provides critical source of income for food purchase, specifically for smallholder farmers.

Pesticides and human health: A critical link

Synthetic agrochemicals, particularly pesticides, pose well-established short- and long-term risks to human health (Fuhrimann et al., 2022; IPES-Food, 2016; Mateo-Sagasta et al., 2017). Pesticide residues that accumulate in water and the food chain pose potential health risks to consumers, especially if they are regularly consumed or exposed to high levels (Mateo-Sagasta et al., 2017; Vigar et al., 2019). The situation is exacerbated for farmers by issues such as overuse of pesticides, inadequate regulation, and limited knowledge of how to handle hazardous chemicals during application (Mateo-Sagasta et al., 2017; Schreinemachers et al., 2020; Staudacher et al., 2020). Pesticide residues are often found at high levels in conventional foods, including those containing pesticides banned in Europe (Barański et al., 2014; Bhullar et al., 2021). Organic farming represents a safer option for producers and farm labour, reducing the risk of exposure to hazardous pesticides (Silva Pinto et al., 2020). Choosing organic food is a suitable strategy to minimise the intake of pesticide residues (Barański et al., 2014; Mie et al., 2017).

Farmer motivations support sustainability

A survey conducted in 2015 at the SysCom India study region revealed that organic and conventional farmers have different motivations for choosing a specific practice. Organic farmers were primarily driven by broader considerations such as human and environmental health and food safety, but also economic considerations including the price premium, while conventional farmers were more motivated by productivity and labour efficiency aspects, but also indicated lack of awareness of alternative practices (Kadzere et al., 2020; Riar et al., 2017). Other main concerns of organic farmers centred around closing nutrient cycles and reducing their dependence on external inputs (Riar et al., 2017). What stood out was their desire to have a positive impact on their natural environment and future generations, managing the land for the well-being of their children.

Given these motivations, support for organic and agroecological approaches can be a crucial step in strengthening the sustainability of farming systems. Such advocacy goes beyond external factors, tapping into farmers' intrinsic desire to protect the environment and secure a legacy for the next generation.

Access to knowledge – unlocking farmers' yield potential through training and farmer organisations

Organic farming systems and associated best practices often require a thorough understanding of complex ecological principles (Jacobi et al., 2015; Schader et al., 2021; Sinclair et al., 2019). While field trials show that improved practices lead to increased yields, these results are not consistently replicated in on-farm trials and specific case studies. The challenge lies in poor adoption of practices due to limited farmer knowledge and access to high quality organic inputs (Schader et al., 2021). However, when knowledge is accessible and appropriate training is provided, farmers can fulfil their potential as observers and experts of the agro-ecosystem in which they work, increasing productivity and resilience. Farmer group membership and effective capacity development programmes have been shown to have a positive impact on smallholder profitability (Schader et al., 2021; Ssebunya et al., 2019).

Farmer organisations, a cornerstone of sustainable agriculture, make a significant contribution. Group members benefit from shared training opportunities, enabling economies of scale, such as in transport, that are not available to individuals, and certification costs are reduced for individual members (Jacobi et al., 2017; Keller et al., 2024). In addition, these organisations improve access to critical inputs such as seeds (Krishnan et al., 2021; Setboonsarng et al., 2008).

In a case study at SysCom India, more than half of the organic farmers surveyed expressed concern about the lack of quality cotton varieties and low-quality seeds (Habermann, 2021). After identifying the urgent need for non-GM (not genetically modified) cotton seeds adapted to organic farming conditions, a large spin-off project of SysCom India – Seeding the Green Future – took it in their hands to advance organic cotton breeding. Using a participatory approach, the project successfully released the first two organic cotton varieties of India bred under organic conditions in 2022[2]. Remei India Ltd and bioRe Association, partners of the Syscom India project, also run their own non-GM seed breeding programme and are supplying their farmers with seeds of organic cotton varieties.

[2] https://www.fibl.org/en/info-centre/news/first-ever-release-of-organic-cotton-varieties-in-india

Box 2: Creating impact through participatory research

It is crucial to raise farmers' awareness of yield-enhancing technologies and practices, especially among smallholders who may not be fully informed about the potential benefits (Riar et al., 2017). Participatory innovation platforms serve as successful structures to accelerate adoption by building local capacity and developing locally adapted technologies (Andres et al., 2016).

With the principle of participatory research, a key approach used by SysCom India – "with the farmer, by the farmer, and for the farmer" – effective solutions can be found that tackle the challenges farmers meet in their fields.

In addition, integrating local knowledge is essential not only to increase the effectiveness of innovations, but also to promote **adoption through local ownership**. Building linkages, capacities and strengthening the collective knowledge base in agriculture are necessary steps to integrate traditional local knowledge into scientific innovations.

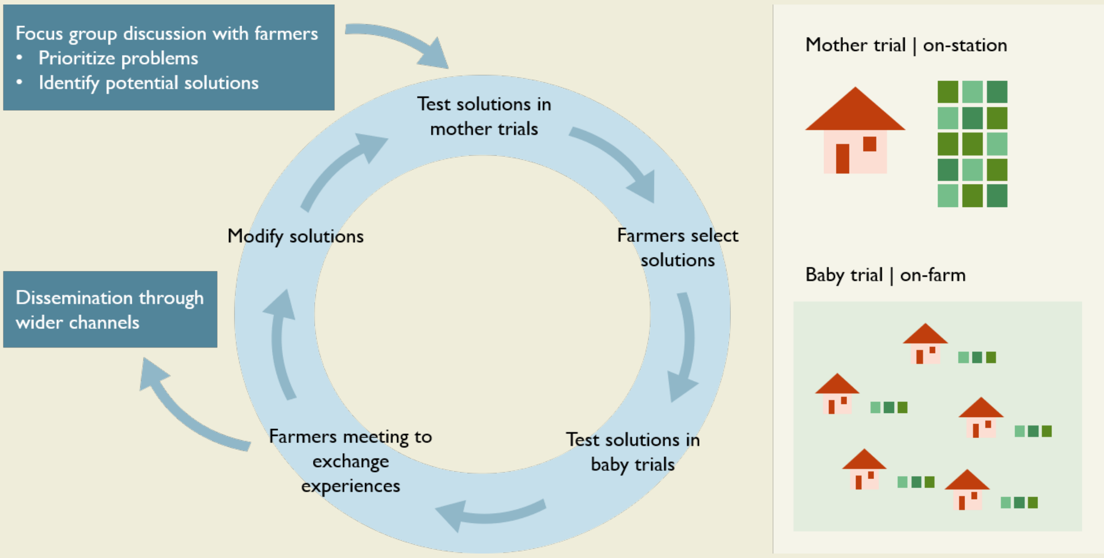

Figure 3: The participatory research cycle to co-create innovations that are fit to the local context

With the participatory research methodology applied, farmers' real-life challenges are prioritised, and potential solutions identified by a team of researchers and farmers. Simplified scientific trials are implemented on farmers' fields ("baby/on-farm trials") based upon their selection and preferences of what they see in the scientific "mother/on-station trials". Effectiveness and practicability are evaluated together so that either adaptations can be realised, or the most effective solutions can be further disseminated.

One very successful innovation developed through the participatory research cycle in SysCom India is the improved phosphorus availability in Vertisol soils using farmyard manure mixed with rock phosphate. The results were further scaled up through spin-off projects and discoveries, such as dissolving rock phosphate in buttermilk or lemon and applying it with compost during planting to help crops take up phosphorus from the soil (Cicek et al., 2020; Mwangi et al., 2020).

Supporting marginalised communities

Marginalised groups, particularly women in cotton production (Box 3: Women farmers count among the main actors in cotton production), face notable inequalities that affect their well-being (FAO, 2018; HLPE, 2020). Studies suggest that under certain socio-political conditions, organic agriculture can contribute to improved livelihoods, workers' rights, human safety, health, gender equality, fair trade practices, and support for marginalised and vulnerable people (Ssebunya et al., 2019). While these improvements vary according to local conditions, they play a critical role in addressing power imbalances. Ultimately, they allow farmers to have a greater say in the redistribution of income and resources, thereby supporting the resilience of rural communities. Similar effects were observed in a study conducted at SysCom India (Witharanage et al., 2024), which found the bargaining power of laborers to be higher in organic cotton production, which in turn provided them more income for necessities such as purchasing of food.

Box 3: Women farmers count among the main actors in cotton production

Women are key actors in the cycle of organic cotton production where many of the tasks are performed only by women. A recent study of SysCom India highlighted that despite of women's role, they do not receive adequate training or access to knowledge (Luther, 2025, 2024). These results are in line with other studies that also show that in comparison to men, women have fewer agricultural assets such as land and financial resources and, limited access to information and participation in community-based organisations (HLPE, 2020).

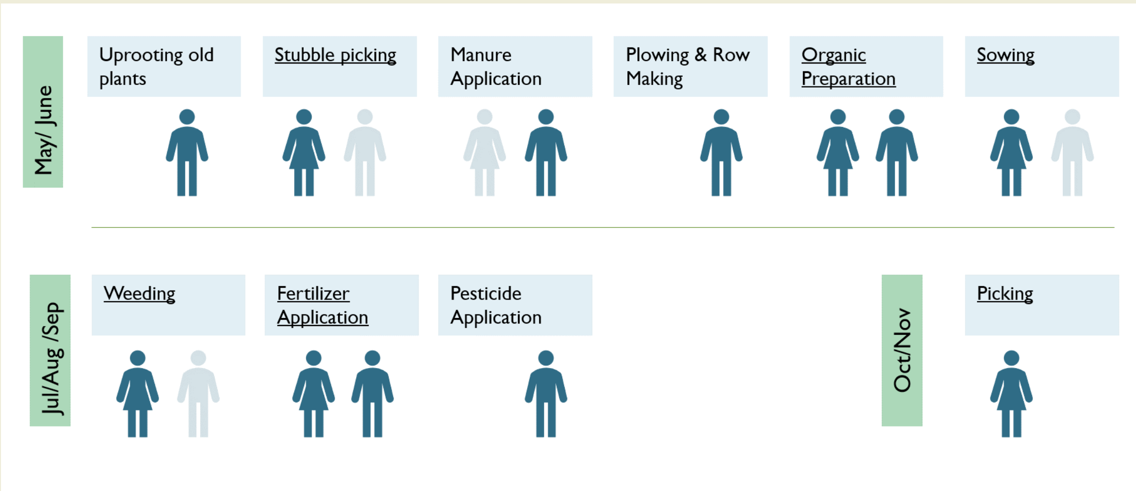

Figure 4: Depiction of different tasks in the cotton production cycle along the year and the role women and men take in them. Pale icons illustrate a minor role of the respective gender in that task. (adapted from Witharange et al. (2024))

Chapter 2: Productivity and economic viability of cotton farming

Cotton productivity

Results from the long-term experiment (LTE) of SysCom India show a cotton yield gap of 25% between organic and Bt-conventional systems (Figure 5, left), over 18 years. However, the more recent developments (years 2021 – 2024) illustrate that a more system-oriented approach and the implementation of best practices can help improving the productivity of organic systems and close the yield gap. A system-oriented approach in farming views a farm as a complex, interconnected system of elements. In organic farming, it focuses on productivity of the whole farm system in the long-term using best practices such as, crop rotations, crop diversity, improving soil fertility, instead of focusing on short-term income from a single cash crop (Bautze et al., 2024). The best practices that were introduced in recent years are the use of high yielding organic cotton varieties and improved soil management practices. Interestingly, when yields in farmers' fields were examined (Figure 5, right), greater variability was observed among organic and Bt-conventional farms and on average, yields in both systems were comparable (Habermann, 2021; Riar et al., 2018). These results suggest that effective farm management can lead to high yields, irrespective of the system being organic or conventional. Hence, it is crucial to not only integrate best practices within organic systems, but also to focus on successful adoption of these practices by the farmers.

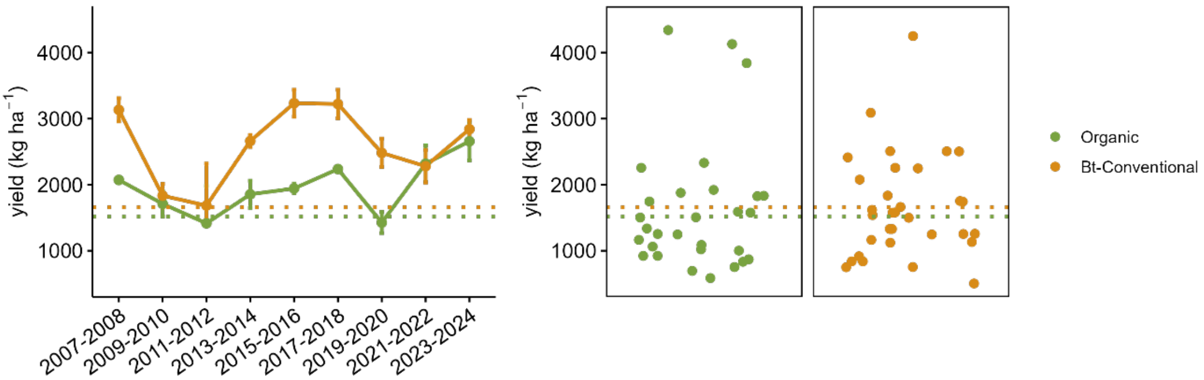

Figure 5: Left: Yields of organic and Bt-conventional cotton within the long-term experiment (LTE). Right: Yields of organic and Bt-conventional farmers in Nimar valley, based on two farmer surveys (adapted from Bhullar et al., (2021)). Dotted horizontal lines: average yield of organic (green) and conventional (orange) farmers surveyed.

Cost of inputs

Reduced input costs often make organic farming systems an attractive choice for smallholders with limited capital (Jouzi et al., 2017). Smallholder families, who often rely on family help rather than hired labour, can meet the increased labour requirements of organic practices with their available labour. The reduced dependence on external inputs, unlike conventional systems, also protects them from falling into cycles of debt.

Long-term experiment data of SysCom India demonstrates that organic farming has lower external input costs than conventional methods (Box 4: Production costs in cotton systems). This cost-effectiveness is mainly due to the use of local resources in organic systems, a departure from conventional practices that rely heavily on inputs purchased on the market. For example, organic cotton pest management practices encourage the use of locally available materials such as herbs, while fertilisation relies predominantly on the application of livestock manure and compost. This is interesting not only in terms of closing local nutrient cycles, but also for the long-term economic viability of a farming system.

Box 4: Production costs in cotton systems

In the long-term experiment, overall lower input costs were recorded for organic systems than for Bt-conventional systems, while overall labour costs were higher in organic systems (+10%). The input costs, notably for pest control (-28%) and fertiliser (-8%) were lower in organic systems. The cost for fertilisers for organic systems was calculated based on market prices for farmyard manure (FYM) and might not reflect farmers' reality appropriately as they often have lower cost or free of cost access to FYM. The organic systems incurred no input costs for weed control, as all weeding was done mechanically and is therefore reflected in the labour cost.

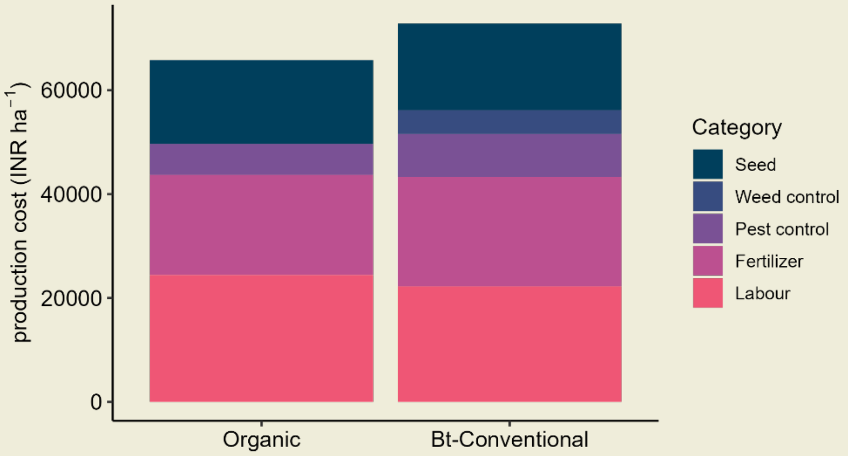

Figure 6: Average yearly production costs (INR per ha) in organic and Bt-conventional cotton-based rotation systems, based on long term experiment (LTE) data from 2007 to 2022.

Labour requirements in organic

SysCom India long-term trial data indicates that while cotton picking and weeding are the most laborious field activities across both organic and conventional systems, organic farming requires additional labour for the preparation and application of inputs for fertilisation (compost) and pest control. Technological innovation and mechanisation have the potential to reduce labour requirements, thereby increasing gross margins (Bhullar et al., 2021). Beyond the economic aspects, agricultural labour plays a crucial role in promoting rural stability, especially in areas with underemployment challenges (Crowder and Reganold, 2015). However, adapting to the changing availability of labour and adopting sustainable mechanisation requires support for farmers. Promoting fair wages will be critical to ensuring a reliable agricultural workforce for the future. Ultimately, for organic farmers to be able to pay fair wages to their labour, their income opportunities need to improve, for example via access to organic markets with premium prices for all of their organically grown produce in the crop rotation (Keller et al., 2024).

Improving systems economic viability

Crop diversification plays a key role in enhancing economic resilience by providing income sources beyond cash crops (Bhullar et al., 2021). While fair premiums significantly increase gross margins for some, challenges arise for certified producers that do not have access to organised markets offering premium prices for their diverse organic crops (Schader et al., 2021).

In our long-term experiment, the 10-15 % organic premium for cotton alone proved insufficient to offset the income gap from lower wheat and cotton yields, resulting in 11 % lower average annual gross margin in the organic systems compared to the Bt-conventional system (Riar et al., 2025). However, gross margins in the organic system surpassed the Bt system after introduction of chickpea into the organic crop rotation – a crop with attractive market prices 250 % above the prices for wheat (see also Figure 6). These results highlight the need for development of local or national organic markets to provide premium prices for multiple organic products. Farmers would further need to be supported in sourcing of organic seeds for the different crops and in training for effective management of diversification crops less familiar to them (Keller et al., 2024). Finally, it is essential to financially support farmers during the transition to organic farming, especially in the absence of an official premium in the early years, as yields tend to drop during the conversion phase (Crowder and Reganold, 2015). Organisations such as Remei India Ltd. (the implementing partner of SysCom India) address this by compensating farmers during the transition period through premium prices for the main cash crop (cotton) from the second year onwards.

It is crucial to recognise that conventional agronomic profitability metrics often overlook externalities. Given the environmental and social benefits associated with organic management systems, assessing true profitability through mechanisms such as true cost accounting could provide a more comprehensive perspective (HLPE, 2019).

Box 5: Optimising rotation and enhancing income through diversification

Cotton, a crop with high nutrient requirements, faces yield challenges when nutrient availability does not match during critical growth stages (Bhullar et al., 2021). Legumes, such as beans, peas and lentils, have a unique ability to fix nitrogen from the atmosphere, and can help reducing reliance on chemical fertilisers while ensuring comparable yields in both organic and conventional systems (Ponisio et al., 2015). Additionally, choosing the right rotation crop can also be economically interesting, as the example from the SysCom India LTE shows (Figure 7): Chickpea, a nitrogen fixing legume, was introduced to the organic systems replacing the second wheat crop. Thanks to higher market value, it has helped boost the profitability of the organic crop rotation since.

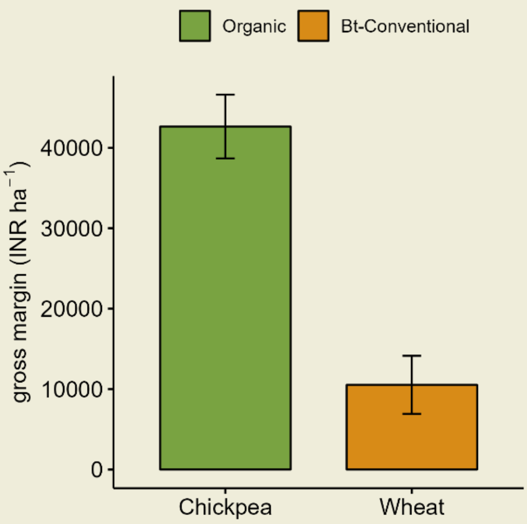

Figure 7: Average yearly gross margins of chickpea and wheat as rotational crops in cotton-based farming systems in the SysCom India long-term experiment, data from 2019 to 2022.

Chapter 3: Ecological Sustainability

Promoting healthy soil as the basis for agriculture

Box 6: Earthworm abundance

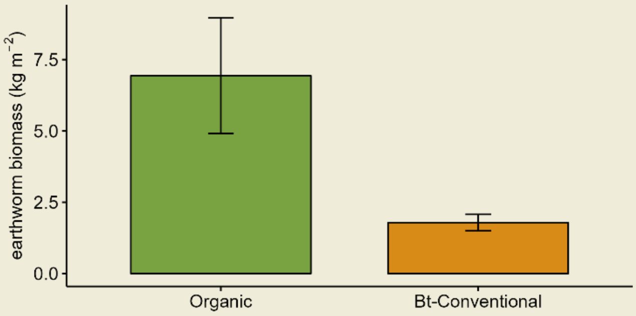

Figure 8: Earthworm biomass in kg per m² for organic and Bt-conventional production systems in SysCom India LTE. Adapted from Ledroit (2021).

Earthworm biomass was significantly higher in organic soils than in conventional soils. This indicates that organic management practices foster more active and biologically active soils, supporting improved soil fertility, structure and nutrient availability, essential factors for long-term productivity and resilience.

Declining global soil health poses a significant threat to future food production, with 20% of land classified as degraded (IPES-Food, 2016; UNCCD, 2022). The main drivers of this decline, linked to industrial agriculture, include adverse land-use changes such as deforestation, unsustainable agricultural practices, overuse of chemical fertilisers and soil erosion (IPES-Food, 2016). These processes deplete soil of essential nutrients and organic matter, with negative impacts on agricultural productivity and the environment.

A healthy and productive soil is the cornerstone of agricultural systems, providing an optimal environment for plant growth and supporting a healthy ecosystem. By balancing physical, chemical and biological properties, healthy soils play a key role in maintaining agricultural production, biodiversity and environmental well-being. They are also resilient to drought, erosion and nutrient imbalances, contributing to climate resilience. Diverse and active communities of species in healthy soils enhance nutrient cycling, organic matter decomposition and nutrient availability to plants. A study conducted in 2019 at the SysCom India long-term experiment confirmed enhanced soil quality in the organic system compared to the Bt-conventional system, including increased microbial activity and abundance associated with nutrient mineralisation (Lori et al., 2024). In contrast, soils in the Bt-conventional system were enriched with microorganisms with potential pathogenic traits (Lori et al., 2024). Monitoring soil biological activity, such as the diversity of microbial communities or earthworm biomass (Box 6: Earthworm abundance), is a valuable indicator of soil fertility and overall soil health.

Cultivating soil carbon for productivity and climate resilience

Increasing soil organic carbon content is vital for both farmers and the environment. It promotes healthier, more productive soils for farmers and helps to sequester carbon and mitigate global warming. Increasing soil organic carbon content improves soil fertility and nutrient availability for plants, and mitigates water stress by improving water uptake and retention, minimising run-off and evaporation (Jacobi et al., 2015).

Soil analyses of the SysCom India long-term experiment found organic systems to have accumulated 13 % more soil organic carbon compared to Bt-conventional systems after 8 years (Singh et al., 2025). Organic farming also had increased soil nitrogen content (+18 %) and favored different microbial communities (Lori et al., 2024; Singh et al., 2025). In contrast, Bt-conventional systems based on mineral fertilisers favored bacteria associated with ammonium oxidation, which may contribute to greenhouse gas emissions (Lori et al., 2024). The increased biological activity in organically managed soils supports the provisioning of nutrients to plants, reducing the need for external additions such as synthetic fertiliser (Bhat et al., 2017).

On-farm biodiversity

Productive and resilient agricultural systems depend on the integrity of ecosystems and biodiversity, which in turn provide multiple benefits to farmers and society. Biodiversity conservation plays a vital role in ensuring health, food and water security, pollination, a well-functioning food web, carbon sequestration and more. However, the expansion and industrialisation of agriculture in the 20th century has also contributed to global biodiversity loss (HLPE, 2020; IPES-Food, 2016; Norris, 2008). Recognising this, there are tangible opportunities to support biodiversity through the adoption of good agricultural practices - such as mulching, organic manure, crop diversity and integrated livestock management - and the avoidance of environmentally harmful inputs, such as synthetic pesticides. Farms that adopt such practices exhibit greater biodiversity, characterised by increased diversity and abundance of flora and fauna (Bandanaa et al., 2021; Bhullar et al., 2021; Kamau et al., 2022).

Sustainable practices transform pest management challenges

Effective pest management is a pressing issue in agriculture, having a significant impact on crop yields and posing a major challenge to farmers (Schader et al., 2021). The conventional reliance on pesticides is reaching its limits, exacerbated by expected changes in pest patterns due to climate change (IPCC, 2019) and the increasing resistance of pests and weeds to synthetic agrochemicals. The need for a shift towards alternative approaches, notably those advocated by organic farming, is evident. These strategies focus on the restoration of natural habitats and promote on-farm biodiversity, helping to maintain a healthy balance between pests and their natural enemies. This holistic approach not only reduces farmers' dependence on costly external inputs, but also reduces chemical residues in soils, crops and run-off water (Bhullar et al., 2021). By making use of locally available plants for botanical preparations in crop protection, farmers can further strengthen ecological resilience. Adopting such sustainable practices is essential to fostering a more resilient and environmentally sound agricultural system.

The path ahead

Key levers for unlocking the potential of organic farming for sustainable development

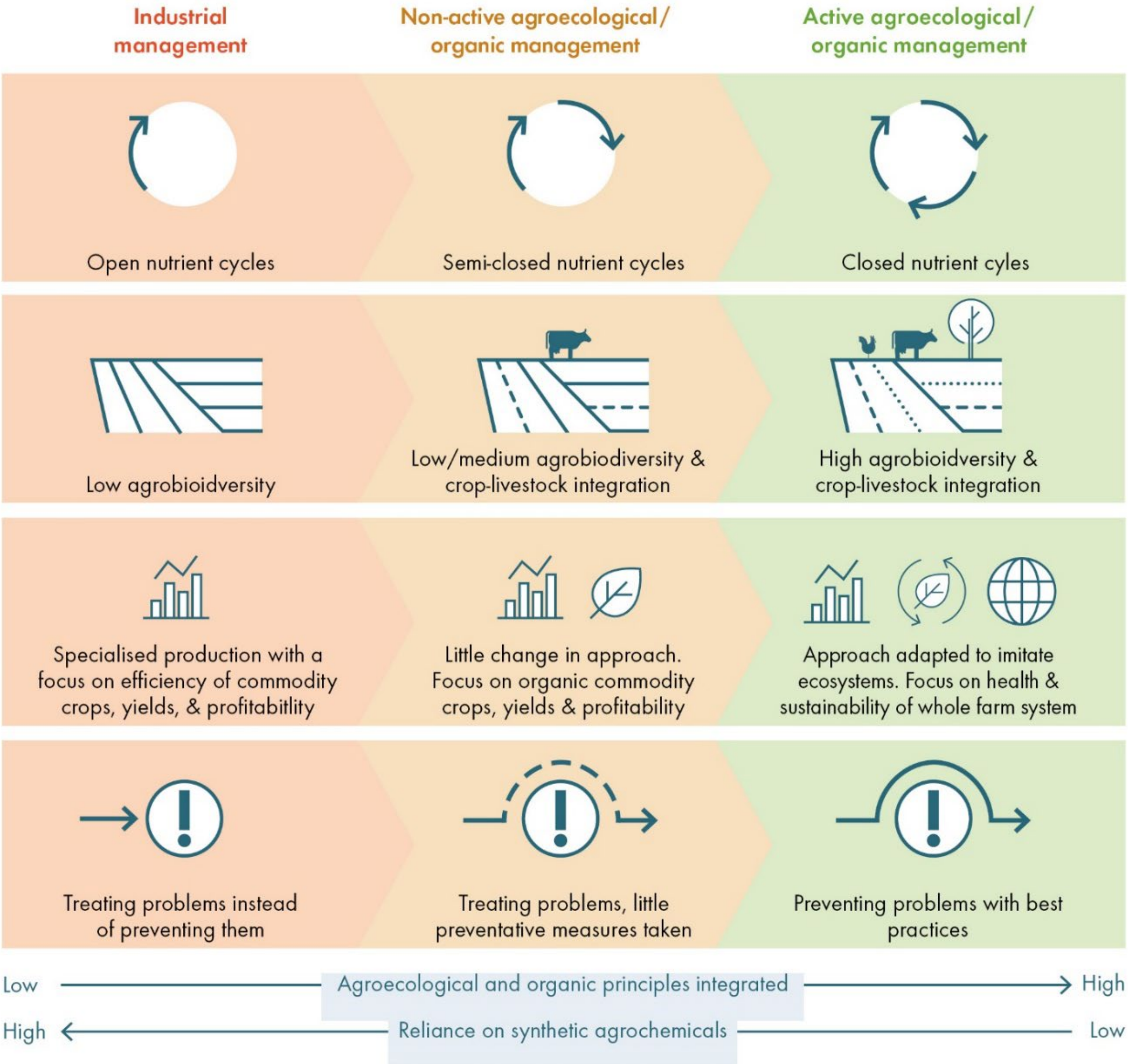

Figure 9: Farm management approaches on a spectrum (FiBL, 2024)

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