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ORGANIC COTTON

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Organic Cotton at the Crossroads: Ideology, Evidence, and the Road Ahead

Organic cotton has long occupied a contentious space in global agricultural debates. The central question has remained remarkably persistent: why grow organic cotton at all when it risks lower yields and deliberately forgoes powerful technological tools such as biotech seeds, synthetic fertilizers, and chemical pesticides, that have demonstrably increased productivity, reduced drudgery, and improved farm incomes in conventional systems? For critics, this question expands into a broader skepticism about organic agriculture itself, especially at a time when the world faces the urgent challenge of producing sufficient food, feed, and fibre for a rapidly growing population. Organic agriculture has often been dismissed as archaic or ideologically driven, with detractors arguing that it romanticizes environmental ideals without sufficient scientific grounding. Historically, critics have emphasized that lower yields translate into poorer land-use efficiency, potentially accelerating deforestation and encroachment into wetlands and grasslands. Labour intensity further compounds these concerns. Organic farming depends heavily on biological inputs such as, composts, manures, biofertilizers, and botanical pesticides that require labour for production, handling, and application. Weed management presents an especially acute challenge: with synthetic herbicides prohibited, organic cotton relies largely on manual weeding and cultural practices, which are labour-intensive, increasingly costly, and difficult to sustain in regions facing rural labour shortages.

Conservation tillage illustrates the dilemma clearly. In conventional systems, herbicides, often combined with herbicide-tolerant crops that facilitate minimum tillage and soil conservation. Organic farmers, constrained to non-GM crops and non-chemical weed control, must rely on manual or mechanical approaches to achieve similar outcomes, making conservation tillage far harder to implement. Likewise, although Bt cotton has dramatically reduced insecticide use against bollworms in conventional systems, philosophical and ethical divides between organic and biotech paradigms have precluded its use in organic cotton, even though it could theoretically eliminate the need for most pest control inputs in organic systems.

This special review was not intended to defend organic cotton uncritically, nor to dismiss modern agricultural technologies. Rather, its purpose has been to replace perception-driven arguments with a nuanced assessment of evidence. And the literature does, in fact, arm both sides of the debate.

Organic agriculture is, at its core, consumer-driven. Despite persistent criticism and relatively limited investment in organic-specific technological development, the organic sector has expanded steadily. Organic farmland now accounts for about 2.1% of global agricultural area, managed by over 4.3 million farmers. Organic cotton mirrors this trend. Its global share has grown from 1.08% in 2009 to 2.8% in 2024, while production expanded nearly sixfold over the past decade—from 112,483 tonnes in 2015 to 659,567 tonnes in 2024. This growth reflects rising consumer demand, stronger brand commitments, and expanding certification infrastructure, even if organic cotton remains a niche within the global cotton economy.

Yield performance remains a central concern. The literature consistently shows that organic cotton yields are lower during the mandatory transition period of two to three years. However, once farms are fully converted and organic systems stabilize, yields are not necessarily inferior and, in some cases, approach or even match conventional systems. More striking is the economic picture: despite lower yields in many contexts and high certification costs, net profits on organic cotton farms are frequently higher than on conventional or biotech farms. Lower input costs, reduced dependence on purchased agrochemicals, and price premiums often compensate for yield gaps. This raises the deeper question: why do producers and consumers prefer organic cotton at all, given that the final fabric, whether organic, conventional, or biotech, is broadly similar and safe, with pesticide residues typically well below regulatory thresholds? The answer lies not in the fibre itself, but in the production systems and values embedded in them. For smallholders, organic farming may be attractive because costly technological inputs are unaffordable, or because it reduces exposure to hazardous pesticides. For consumers, motivations are often ideological concerns about environmental protection, biodiversity loss, climate change, and social responsibility. Importantly, these concerns are not merely rhetorical. A substantial and growing body of scientific evidence shows that organic and other biologically based farming systems exert strong positive effects on soil health, soil biodiversity, above-ground ecological diversity, ecosystem functioning, carbon sequestration, and greenhouse gas mitigation. Life-cycle assessments consistently demonstrate lower emission intensity and superior environmental profiles for organic cotton compared with conventional systems.

Yet here lies a paradox. While the original proponents of organic agriculture envisioned a holistic, systems-based approach to regenerating soils and ecosystems, contemporary organic standards are largely substitution-oriented, mainly focused on lists of approved and prohibited inputs. In this sense, modern organic farming often falls short of its own philosophical aspirations. This disconnect has helped fuel the rise of “regenerative agriculture” and “regenerative organic agriculture,” which emphasize outcomes -soil carbon, biodiversity, resilience over rigid input exclusion. Organic cotton remains inherently vulnerable to yield losses and pest outbreaks because it relies heavily on ecosystem services, particularly natural biological control. Without strong, context-specific scientific support, these vulnerabilities are magnified, especially in small-scale, resource-constrained systems. Addressing them will require climate-resilient cultivars, improved pest and disease tolerance, and agronomic designs rooted in ecological engineering. Equally critical are robust certification, verification, and traceability systems to protect market integrity in a sector where premiums create incentives for fraud.

Looking ahead, regenerative agriculture may increasingly outcompete organic farming in farmer preference. Regenerative systems may soon command similar premiums, impose fewer certification burdens, and crucially do not prohibit GM seeds or synthetic inputs, at least for now. This flexibility allows farmers to manage risk, stabilize yields, and adapt to climate variability while still delivering measurable environmental benefits. Carbon markets and ecosystem service payments further strengthen this appeal. As technologies evolve, it is conceivable that the stark dichotomy between “organic” and “conventional” will soften. Future agricultural technologies may be inherently climate-smart and environmentally benign, making outright prohibitions unnecessary. If that future arrives, the debate may finally shift from which technologies to ban to which outcomes truly matter. One can only hope all of us live to see that day.

-Keshav Kranthi

A Global Research Review on Organic Cotton

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INTRODUCTION

Organic agriculture is best known as a method of agriculture where no synthetic fertilizers and pesticides are used (FAO 1998). Organic agriculture, as practiced worldwide, is intended to produce food, feed, and fibre through the use of natural or organically derived inputs and biologically based processes, while explicitly prohibiting irradiation, sewage sludge, genetic engineering, the prophylactic use of antibiotics, and nearly all synthetic pesticides and fertilizers. Through these principles and practices, organic farming seeks to enhance soil quality, diversified crop rotations, plant and animal biodiversity, ecological processes, and animal welfare (Reganold & Wachter, 2016).

Consumer Driven: Organic farming has evolved primarily as a market-responsive production system, catering to consumer demand for organic food, feed, and fibre across many regions of the world.

The continued expansion and economic viability of organic agriculture are closely linked to the willingness of consumers to pay price premiums for products perceived to be safer, healthier, or environmentally benign (Crowder & Reganold, 2015; Willer et al., 2023).



Figure-1. A consumer examining a label

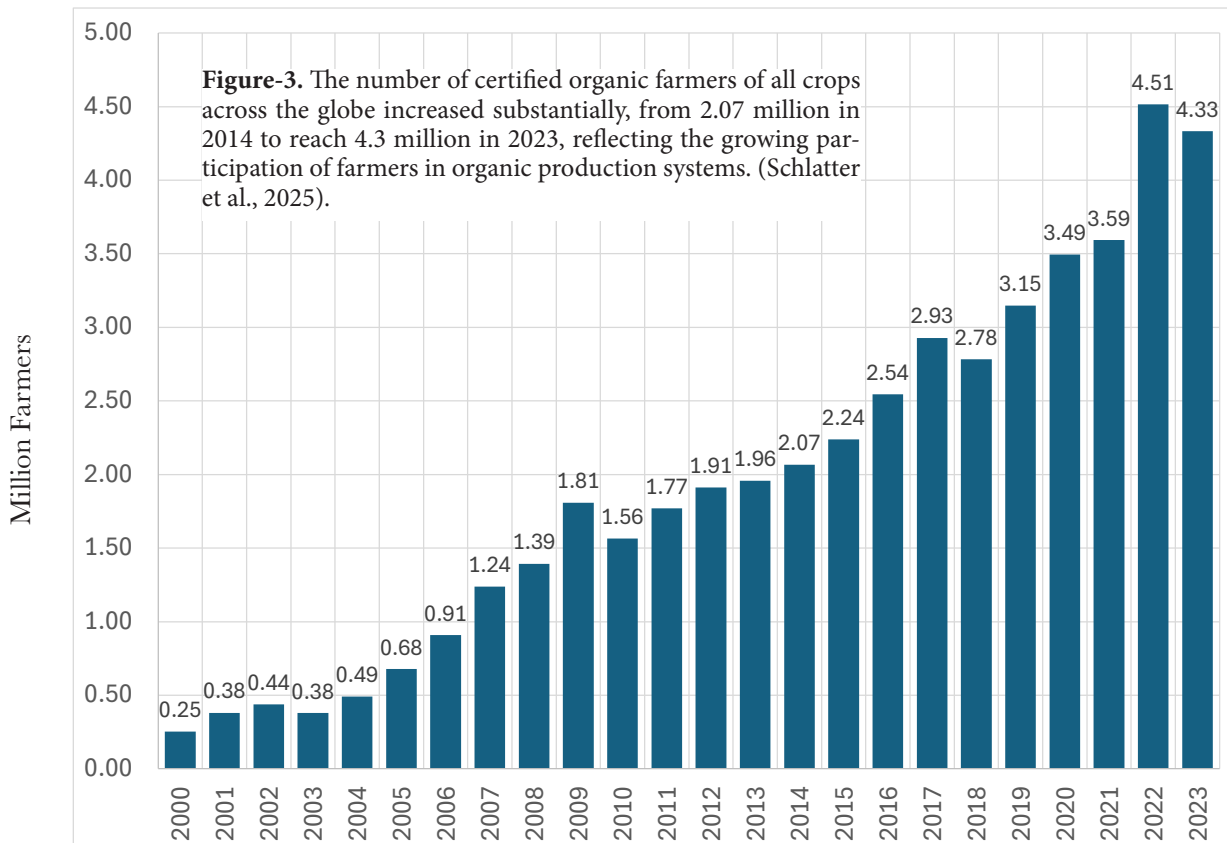
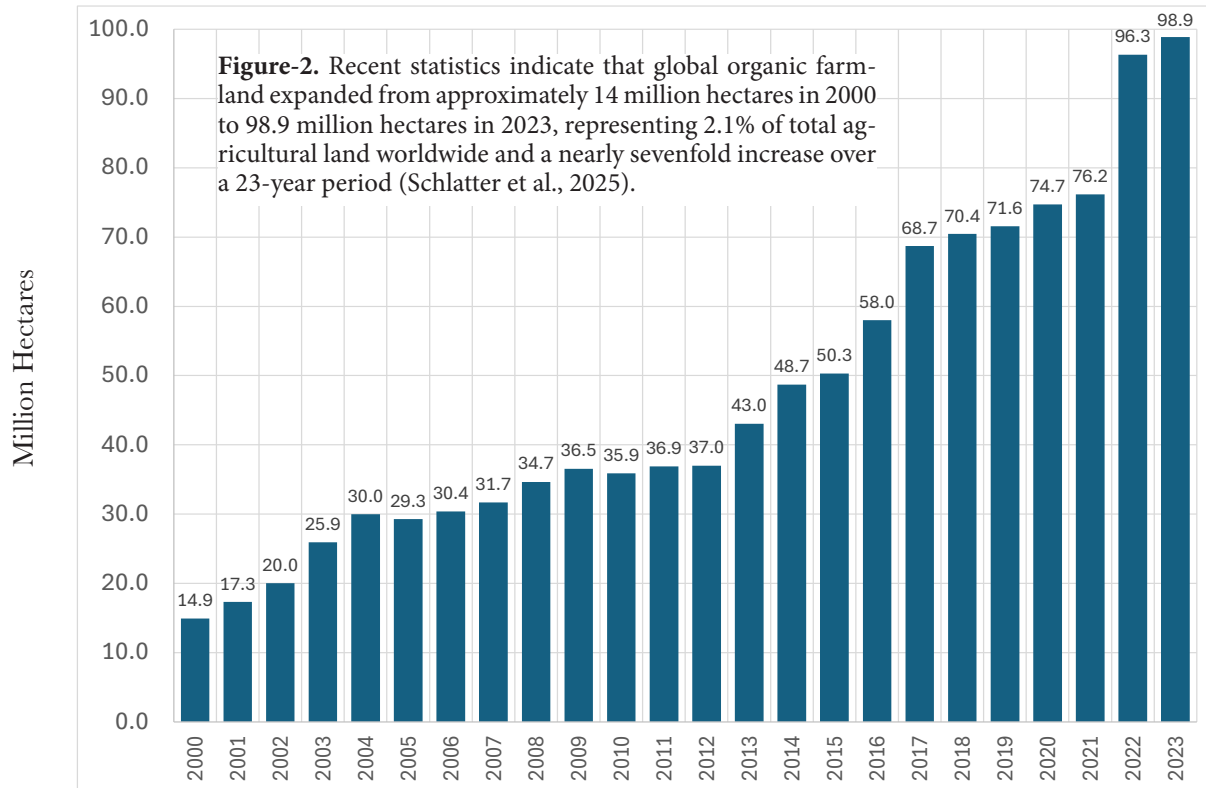
For example, Ellis, et al. (2012) reported that consumers were willing to pay 25% more for organic cotton T-shirts. As long as such demand persists, organic farming systems are likely to remain viable and continue to expand within specific market segments.

Global Status: Recent statistics indicate that global organic farmland expanded from approximately 14 million hectares in 2000 to 98.9 million hectares in 2023, representing 2.1% of total agricultural land worldwide and a nearly sevenfold increase over a 23-year period (Schlatter et al., 2025). In parallel with this expansion, the number of certified organic producers also increased substantially, exceeding 4.3 million producers globally in 2023, reflecting the growing participation of farmers in organic production systems. Despite constituting only a niche market, global demand for organic products continues to grow steadily, driven by consumer concerns related to food safety, environmental sustainability, biodiversity conservation, and perceived health benefits (Willer et al., 2023; Reganold & Wachter, 2016). Although organic farmers constitute a relatively small fraction of the global farming community, there exists a committed group of producers who consciously adhere to the principles of organic agriculture, motivated by ecological ethics, reduced dependence on external inputs, and long-term soil and ecosystem health. These farmers continue to sustain and expand the organic sector, thereby contributing to niche but growing markets for certified organic commodities worldwide (IFOAM, 2020; Crowder & Reganold, 2015).

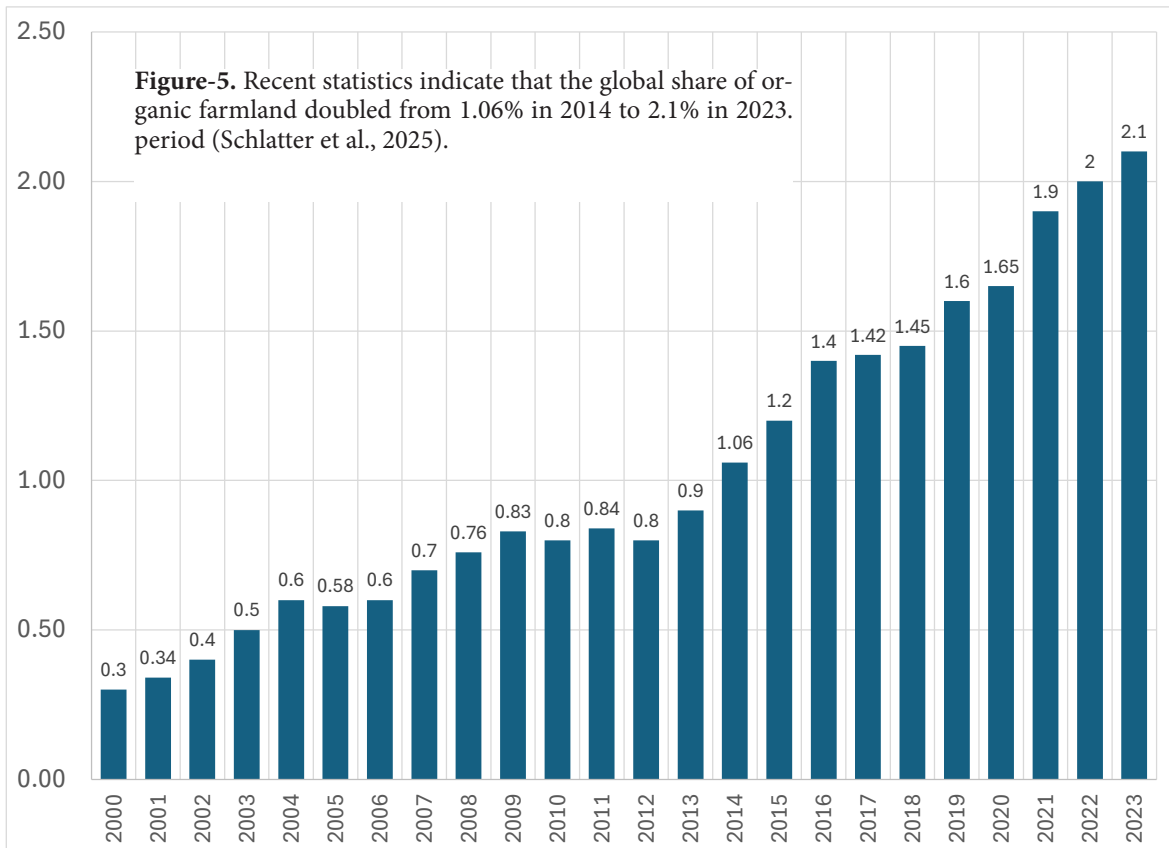
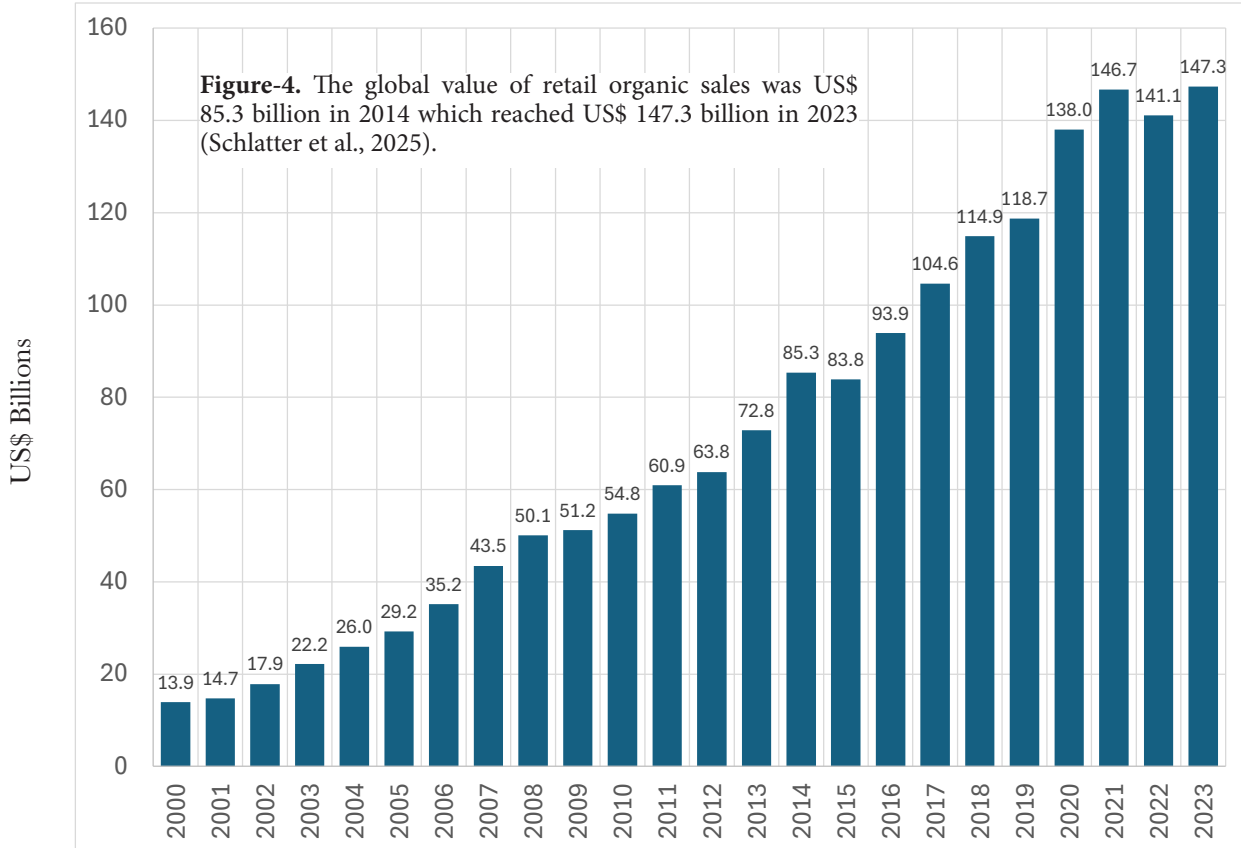
Organic cotton is produced through organic farming methods in certified organic farms. Organic cotton fabrics are manufactured from 'organic cotton fibres' using textile technologies that are accepted by certification agencies. Organic cotton production, by excluding agrochemicals, is considered as an "environmentally friendly" system (Galanopoulos-Sendouca and Oosterhuis, 2003).

Conventional and Organic Fibres: Because the use of synthetic fertilizers, synthetic pesticides, and genetically modified organisms is prohibited in organic cotton production, the presence of pesticide residues in organic cotton fibres or textiles is, in principle, expected to be negligible, except in cases of inadvertent contamination arising from spray drift from neighboring conventional fields or cross-contamination during harvesting, transport, or processing. Studies conducted on cotton produced under conventional farming systems have reported the presence of pesticide residues in fibres, both above the established maximum residue limits (MRLs) (Bhamare, 2018; Kumari and Duhan, 2011; Diwan et al., 2006) and below the MRLs in some cases (Battu et al., 2003; Blossom, 2004; Pandiselvi et al., 2010; Karthikeyan and Jayakumar, 2000; Jasmine et al., 2011; Preetha et al., 2018; Thakor, 2014).

GLOBAL ORGANIC FARMING: AREA & NUMBER OF PRODUCERS



GLOBAL ORGANIC FARMING: RETAIL SALES & FARMLAND SHARE



Distinction between organic and conventional textiles: However, studies also indicate that many commonly used cotton pesticides exhibit short environmental half-lives, resulting in rapid dissipation of residues in the field, often within one to two weeks of application (Battu et al., 2009; Zongmao et al., 1997). Moreover, pesticide residues present in raw cotton fibres are further substantially reduced or eliminated during textile processing, including scouring, bleaching, and washing steps (Serat et al., 1982). Consequently, with respect to the final textile product, both organic and conventionally produced cotton are generally unlikely to contain pesticide residues at levels considered harmful to human health. Thus, the distinction between organic and conventional cotton lies not in inherent differences in the final product itself, but in the production systems and processing methods through which the cotton is cultivated and the fibres are processed.

DEFINITIONS



The Unites States Department of Agriculture (USDA, 2015): “Organic farming is the application of a set of cultural, biological, and mechanical practices that support the cycling of on-farm resources, promote ecological balance, and conserve biodiversity. These include maintaining or enhancing soil and water quality; conserving wetlands, woodlands, and wildlife; and avoiding use of synthetic fertilizers, sewage sludge, irradiation, and genetic engineering. Organic producers use natural processes and materials when developing farming systems—these contribute to soil, crop and livestock nutrition, pest and weed management, attainment of production goals, and conservation of biological diversity.”



The FAO/WHO Codex Alimentarius commission (1999): “Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system.” (FAO/WHO Codex Alimentarius Commission, 1999).

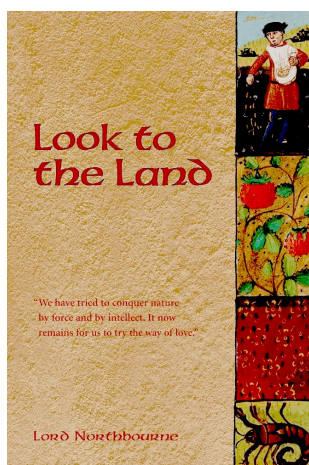


International Federation of Organic Agriculture Movements (IFOAM, 2008): “Organic Agriculture is a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.”

BACKGROUND

Organic production systems follow a set of practices that are cultural, mechanical and natural organic agricultural methods, while strictly prohibiting the use of synthetic fertilizers, pesticides and genetically modified technologies.

Albert Howard had first set up an institute of Plant Industry in India in 1921 to foster Indian traditional farming methods. Howard returned to Britain in the 1930s and started applying scientific principles to various traditional and natural methods, that he promulgated later as a system of ‘organic farming’ (Lotter, 2003; Stinner, 2007).



Before the introduction of synthetic fertilizers in the 19th century and chemical pesticides in the 1940s, agriculture by default was believed to be organic. In 1940, Lord Northbourne coined the term ‘organic farming’ in his book titled ‘Look to the Land’ (Northbourne, 1940).

Albert Howard, who is considered as the father of organic farming was the first to adopt the term ‘organic farming’ in his book ‘An Agricultural Testament’ that was published in 1940 (Paul, 2006).

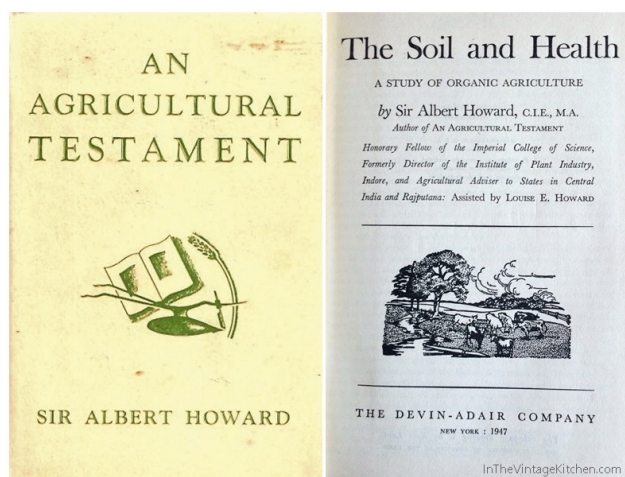


Figure-6. Coverpage of the book ‘look to the land’

Figure-7. Coverpage of the book ‘An agricultural testament’



Figure-8. Agricologenic phenomenon

Agricologeny: Historically, ‘organic farming’ was proposed as a system to restore and sustain soil health, thereby reducing and even eliminating most pest and disease problems (Howard, 1947). Proponents of organic farming believe that resurgence of insect pests and diseases are mainly due to an ‘agricologenic’ phenomenon (Kuepper, 2010), which means, pestilence induced by farmer interventions such as agrochemicals, new crop varieties and intensive crop husbandry methods that interfere with agricultural ecosystems thereby resulting in crops that are physiologically unhealthy due to nutrient imbalance and agrochemical influence (Hodges and Scofield, 1983; Mickley and Fox, 1986).

The foundational philosophy of organic farming is rooted in the idea that avoiding interventions responsible for the “agricologenic phenomenon” can help conserve the natural balance of ecosystems. This balance can be further supported through naturally occurring biological control and introduced biological methods of managing soil health, weeds, and pests, thereby enabling the production of healthier crops within an organically managed and ecologically integrated cropping system. In the modern agricultural context, organic farming systems are often perceived as utopian or impractical, particularly in comparison with conventional input-intensive agriculture.

Organic amendments and biological interventions typically rely on ecological processes such as microbial mineralization, biological control, and crop–soil interactions, which are slower and more variable in their response compared with readily soluble synthetic fertilizers and chemical pesticides (Reganold & Wachter, 2016; van Bruggen et al., 2018). As a result, organic production systems may experience yield limitations, especially during transitional periods, which can in turn constrain profitability when not adequately compensated by price premiums.

IS ORGANIC FARMING TRULY HOLISTIC?

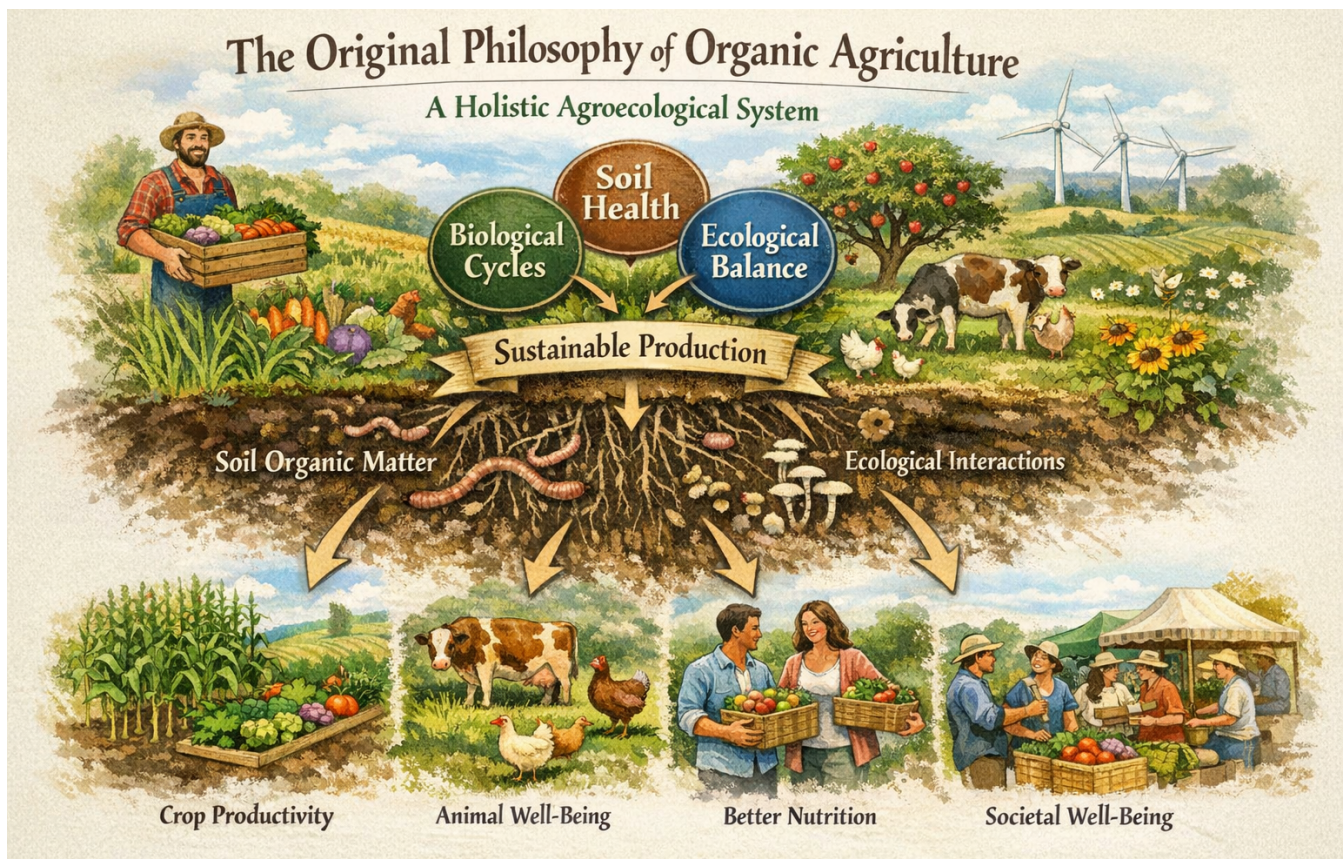


Figure-9. A schematic image depicting the original philosophy of organic agriculture

THE ORIGINAL PHILOSOPHY: HOLISTIC

Holistic approach: The original philosophy of organic agriculture was conceived as a holistic agroecological system, in which soil health, biological cycles, and ecological balance formed the foundation of sustainable production. Early organic pioneers emphasized that improvements in soil organic matter, soil biology, and ecological interactions would cascade through the farming system, benefiting crop productivity, animal health, human nutrition, and societal well-being (Howard, 1940; Balfour, 1943; Lampkin, 1990; Reganold & Wachter, 2016). In this classical conception, organic farming was not defined merely by the absence of synthetic inputs, but by the design and management of self-regulating agroecosystems, in which ecological processes replaced external interventions. Soil regeneration, biodiversity enhancement, and resilience were central objectives rather than incidental outcomes.

THE CURRENT SUBSTITUTION APPROACH

Substitution approach: In contrast to the holistic vision articulated by the early proponents of organic agriculture, contemporary organic regulations across countries exhibit limited conceptual variation and are predominantly structured around an input-based paradigm, rather than system-level or outcome-oriented principles (Seufert & Ramankutty, 2017).

Most standards define “organic” primarily through lists of permitted and prohibited substances, distinguishing “natural” inputs from “synthetic” or “artificial” ones, while placing comparatively little explicit emphasis on outcome-oriented goals such as soil regeneration, carbon sequestration, or climate-change mitigation. As a result, organic agriculture has been widely operationalized as compliance with input restrictions, rather than as a performance-based, systems-oriented approach focused on ecological outcomes (Lockeretz, 2007).

This regulatory narrowing is reflected in the definition adopted by the FAO/WHO Codex Alimentarius Commission, which characterizes organic agriculture as “holistic” while simultaneously recommending the replacement of synthetic inputs with agronomic, biological, and mechanical alternatives to fulfil specific functions. This functional substitution logic is inherently contradictory to true holism, as it prioritizes what inputs are avoided over how agroecosystem processes are restored and sustained, thereby reinforcing the widespread interpretation of organic farming as largely “chemical-free” agriculture.

These conceptual tensions are particularly evident in organic cotton standards, including national regulations (e.g. USDA NOP, EU Organic Regulation, India’s NPOP) and private textile standards such as Global Organic Textile Standard (GOTS). While these standards play a crucial role in excluding synthetic fertilizers, synthetic pesticides, and genetically modified seeds from cotton production and processing, they remain predominantly input-focused, with limited requirements for measurable improvements in soil health, biodiversity, or ecosystem services.

Consequently, organic cotton certification often assures the absence of prohibited inputs but does not necessarily guarantee regenerative outcomes, such as increased soil carbon stocks or enhanced agroecosystem resilience. This disconnect between foundational philosophy and regulatory implementation has prompted renewed calls to reorient organic standards, particularly in fibre systems like cotton, toward outcome-based, soil-centred criteria, consistent with the original agroecological vision of organic farming (Reganold et al., 2011; IFOAM, 2005). In this context, the recent emergence of regenerative agriculture and regenerative organic agriculture can be interpreted as a corrective response, seeking to explicitly embed soil regeneration, carbon sequestration, biodiversity enhancement, and social equity within certification frameworks that go beyond input substitution and toward genuinely holistic system design.

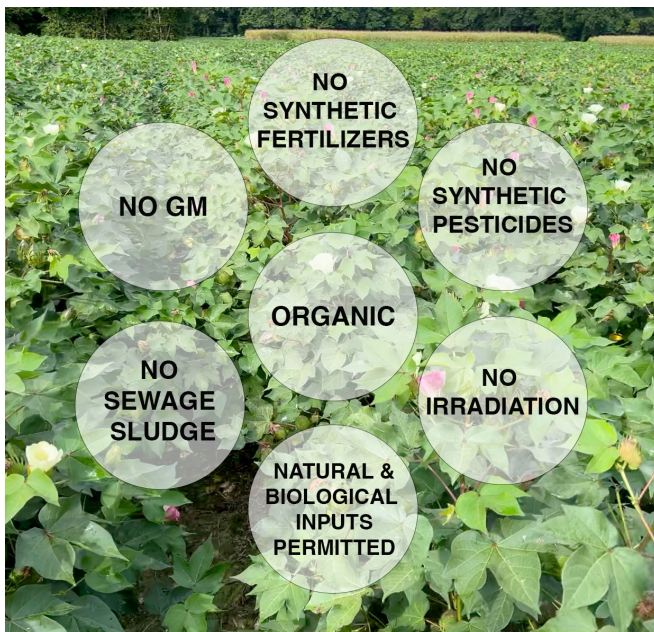


Figure-10. Basic standards followed in ‘Organic farming’

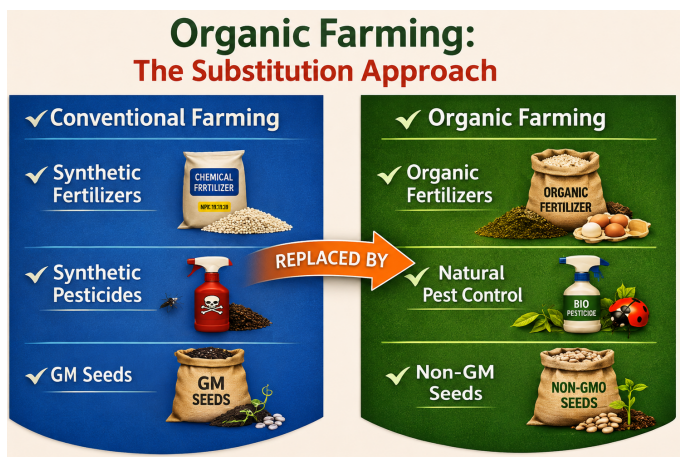


Figure-11. Most organic certifications are based on input substitution approach

BIOTECH COTTON V/S ORGANIC

Genetically modified (GM) cotton is explicitly prohibited in organic farming systems (Larbourga et al., 2020). This exclusion is rooted in the IFOAM “Mar del Plata Declaration” (1998), which rejects genetic engineering on the grounds that it may entail negative and potentially irreversible environmental impacts, the release of non-recallable organisms, unacceptable risks to human health, and the erosion of choice for farmers and consumers. Proponents of organic cotton argue that organic agriculture is founded on holistic, systems-based principles that emphasize cooperation with natural processes, whereas genetic engineering is viewed as reductionist, relying on single-trait technological fixes to address complex agroecological challenges, and therefore represents a fundamentally different philosophical and ethical framework (Koechlin, 2002; Riddle, 2005; Kuepper, 2010).

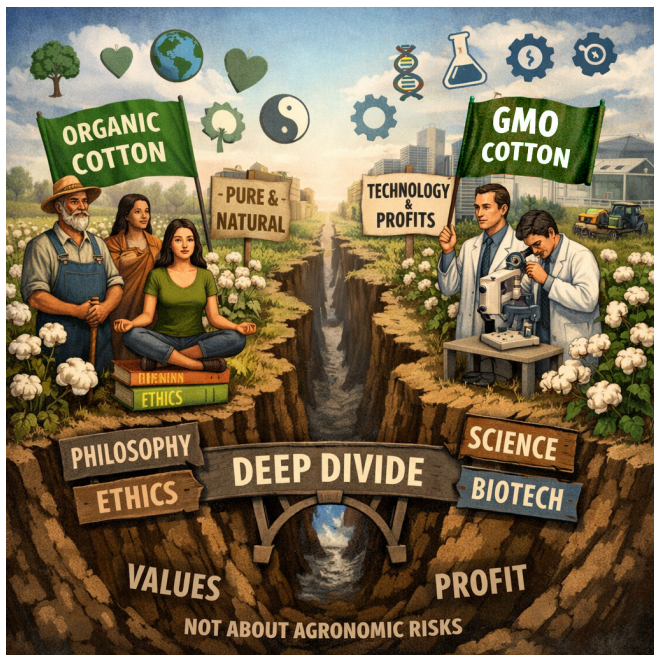


Figure-12. Proponents of organic cotton generally regard biotech or genetically engineered (GE) cotton as fundamentally incompatible with organic production systems, reflecting a deep cognitive, ethical, and philosophical divide rather than a disagreement limited to agronomic risk alone (Herring, 2010; Flachs, 2016; Scott et al., 2018).

In contrast, several scientists contend that genetic engineering is not inherently riskier than conventional breeding or earlier genetic modification techniques, and argue that crops engineered for insect resistance, disease tolerance, or enhanced nitrogen-use efficiency could reduce reliance on synthetic pesticides and fertilizers (Herring, 2010; Hussaini & Sohail, 2018). Empirical evidence supports this position in part: the widespread adoption of *Bt* cotton has been associated with substantial reductions in insecticide use targeting lepidopteran pests (Reisig et al., 2018; Kranthi & Stone, 2020). However, countervailing evidence indicates that the large-scale deployment of herbicide-tolerant GM crops has contributed to increased herbicide use, particularly in sys-

tems characterized by herbicide-based weed management (Peerzada et al., 2019; Desquilbet et al., 2019). These contrasting perspectives underscore the philosophical and practical divergence between organic agriculture and GM-based production systems, which remains a central point of debate in the context of organic cotton.



Figure-13. *Bt* cotton: the main advantages and disadvantages



Figure-14. HT cotton: the main advantages and disadvantages

Philosophical divide: Proponents of organic cotton generally regard biotech or genetically engineered (GE) cotton as fundamentally incompatible with organic production systems, reflecting a deep cognitive, ethical, and philosophical divide rather than a disagreement limited to agronomic risk alone (Herring, 2010; Flachs, 2016; Scott et al., 2018). Within the organismic view of nature, the structure and integrity of DNA and species are seen as the outcome of millions of years of evolutionary processes, and intentional alteration of this order is perceived as a violation of the inherent benevolence and integrity of nature itself (Herring, 2001; Scott & Rozin, 2020). Empirical evidence from social surveys supports this moral framing: Scott et al. (2016) reported that 64% of Americans opposed GE plants and animals, and among these opponents, 71% were “moral absolutists”, asserting that genetic engineering should be prohibited regardless of potential benefits or minimal risks. For some respondents, GE was viewed as “playing God” or “interfering with God’s creation,” reinforcing the perception of GE crops as unnatural, particularly in light of perceived natural barriers between species (Herring, 2001; Hossain & Onyango, 2004).

In contrast, many molecular biologists challenge this interpretation, arguing that there are no inherently distinct “bacterial,” “fish,” or “plant” genes, but rather shared genetic material organized differently across life forms, and that genetic exchange at the molecular level is a natural phenomenon (Herring, 2001; Roy, 2010). From this perspective, genetic engineering represents a continuation of human-mediated crop improvement rather than a categorical break from nature. Taken together, these contrasting views suggest that the tension between organic agriculture and genetic engineering is rooted less in empirical risk assessment and more in divergent moral, philosophical, and ideological worldviews, which continue to shape standards, consumer perceptions, and policy debates surrounding organic cotton.

THE ALTERNATIVE CONCEPTS

Several alternative farming concepts that focused on natural resources and opposed the use of synthetic chemical inputs in agriculture, evolved either in parallel to organic farming or after its establishment. A few notable such concepts are biodynamic farming, natural farming, permaculture, spiritual farming or zero budget natural farming (ZBNF), syntropic farming, and regenerative agriculture.

Biodynamic Agriculture: In 1924, Austrian philosopher, Rudolf Steiner proposed a biodynamic approach to agriculture, wherein spiritual and mystical perspectives are considered to govern ecologically interrelated tasks of livestock, soil fertility and crops (Paul Kristiansen and Charles Mansfield, 2006). Biodynamic farming is practiced and formally certified in several regions worldwide, most notably in Europe, Australia, the United States, Mexico, India, and Egypt.



Figure-15. Rudolf Steiner proposed ‘biodynamic approach’ to agriculture incorporating spiritual and mystical perspectives.

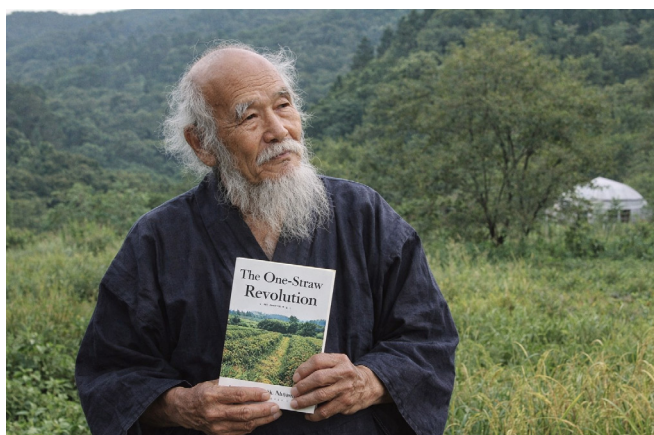


Figure-16. Masanobu Fukuoka introduced the concepts of ‘Natural farming’ to rejuvenate soil fertility and biodiversity

Natural Farming: Masanobu Fukuoka a Japanese farmer, introduced the term ‘Natural Farming’ through his book ‘The One-Straw Revolution’(Fukuoka, 2009). The concept emphasizes on natural ways of farming to rejuvenate soil fertility and biodiversity by avoiding tillage, weeding, pruning, manufactured inputs (fertilizers, pesticides, herbicides etc.) and the use of equipment and machinery. Fukuoka demonstrated that natural farming produced comparable yields to that of modern farming (Fukuoka, 2012).

Permaculture: The term ‘Permaculture’ was coined by Bill Mollison and David Holmgren, to represent permanent agriculture that can be established through land management and settlement designs based on arrangements that exist and flourish in natural ecosystems (Holmgren, 2007). Permaculture aims for sustainable and self-sufficient ecosystems and often includes the planting of perennials and trees, which have immense potential to capture and sequester carbon. However, its broader design principles cover more than just agriculture, and while it has climate benefits, it does not explicitly target soil carbon sequestration as a primary goal.

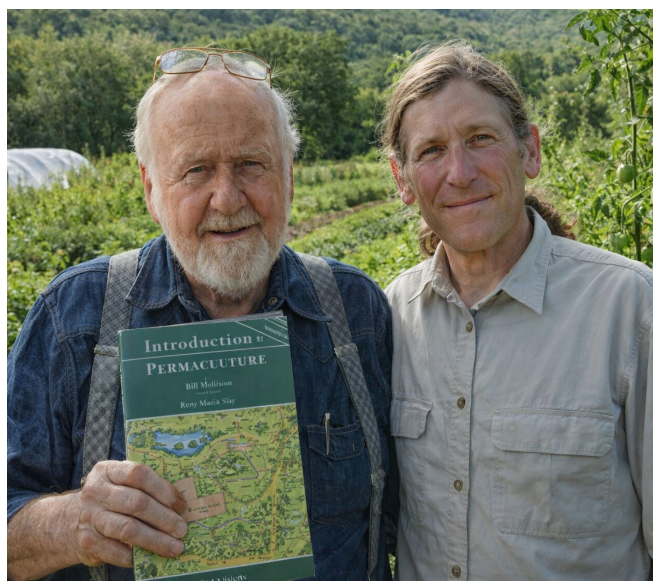


Figure-17. Bill Mollison and David Holmgren, coined the term ‘permaculture’ to represent permanent agriculture

Zero Budget Natural Farming: Subash Palekar, an Indian agricultural researcher proposed ‘spiritual farming’ as a variant of natural farming, which he later rechristened as ‘Zero Budget Natural Farming (ZBNF)’ (Khadse et al., 2017).

ZBNF is based on four main components, namely, jeevamrit (microbial consortium for soils) and beejamrit (microbial inoculant for seeds), achhadana (crop and residue mulch) and waaphasa (humus for soil aeration and moisture).

Microorganisms from healthy soils are multiplied through fermentation-based inoculation, in which a small quantity of fertile soil is introduced into a solution containing sugar, lentil flour, cow dung, and cow urine.

After approximately one week of fermentation, the enriched microbial culture is used to prepare Beejamrit for seed treatment and Jeevamrit for soil application, thereby inoculating seeds and soils with beneficial microorganisms. ZBNF also deploys other components such as biological pest control, crop rotation, intercropping, animal husbandry, green manure, and composting.



Figure-18. Subash Palekar proposed ‘spiritual farming’ as a variant of natural farming, which he later rechristened as ‘Zero Budget Natural Farming (ZBNF)’



Figure-19. Ernst Götsch proposed ‘syntropic farming’ as a cumulative process of life that mimics natural forest strategies.

Syntropic Farming: Ernst Götsch, a Swiss scientist proposed ‘syntropic farming’ as a cumulative process of life that mimics natural forest strategies of regeneration to develop farming interventions to recreate agricultural biodiversity that simulates a forest ecosystem. Syntropic farming focuses on creating biodiverse and resilient ecosystems through successional planting and strategic pruning. While it can contribute to carbon sequestration through the development of agroforestry systems, its primary goal isn’t climate mitigation but rather creating a self-sustaining system.

Regenerative Agriculture: Robert Rodale (1930-1990), founder of the Rodale institute coined the term ‘regenerative agriculture’ in the 1980s (Rhodes, 2017), the concepts of which were later pioneered by Allan Savory (Zimbabwe). Regenerative agriculture primarily aims to rejuvenate soil health by building beneficial soil microbial populations through six main techniques, namely, avoidance of harmful chemicals, no-till, maintaining crop diversity, organic soil mulch, cover crops and crop rotations as a live cover for living roots and integrating animal husbandry into farming practices to provide manure. Other practices such as organic mulches, green manuring, legume crops, composting, biochar, cell grazing, etc., help to enrich soil ecology, nutrients, soil organic matter, air and water assist enrichment of soil microbiology.



Figure-20. Robert Rodale proposed coined the term ‘regenerative agriculture’ in the 1980s (Rhodes, 2017), the concepts of which were later pioneered by Allan Savory (Zimbabwe)

Regenerative Organic Agriculture: Regenerative organic agricultural (ROAg) systems build upon baseline organic standards and incorporating additional regenerative practices, including the integration of livestock with explicit attention to animal welfare, the use of cover crops, enhanced crop diversity and rotations, conservation tillage of minimum soil disturbance, active promotion of soil carbon sequestration, conservation of biodiversity, and commitments to social fairness and equity. Thus, regenerative organic agriculture (ROAg), unlike regenerative agriculture, explicitly prohibits the use of genetically engineered seeds and products, as well as all synthetic pesticides, fertilizers, and other synthetic or artificial chemicals, in accordance with organic standards.

ORGANIC METHODS

Organic cotton production, like other organic cropping systems, is founded on the use of organically derived and naturally available resources to rejuvenate soil health and manage pests in ways that cause minimal environmental disturbance, thereby supporting the maintenance of ecological balance. Beyond the use of approved organic inputs, organic farming relies heavily on ecological processes and system-level design, including habitat management and cropping-system diversification, to enhance the natural biological control of insect pests and pathogens. As in regenerative agriculture, soil health in organic farms is restored and sustained through practices such as the incorporation of nitrogen-fixing crops, cover crops, diversified crop rotations, organic mulches, organic manures, composting, decomposition of crop residues, and conservation tillage, which collectively improve soil structure, biological activity, and long-term productivity.

Organic standards worldwide prescribe detailed lists of approved and prohibited materials and practices for the management of weeds, diseases, insect pests, nematodes, and soil health. Although these lists are often comprehensive in principle, the practical availability of approved organic inputs -particularly those that are locally accessible, affordable, and available in a timely manner, remains a major constraint in many countries. In practice, relatively few authentic, certified organic inputs are consistently available in commercial markets, especially when compared with the wide array of synthetic fertilizers and pesticides accessible to conventional farmers. Consequently, organic farming systems in many regions rely predominantly on locally prepared inputs derived from natural botanical and biological resources, complemented by cultural, mechanical, and agronomic practices for the management of weeds, pests, diseases, and soil fertility.

Soil moisture management is a foundational pillar of organic farming, as these systems rely primarily on soil organic matter, biological activity, and soil structure to regulate water availability rather than on external inputs. Organic practices such as mulching, cover cropping, compost and biochar application, conservation tillage, and diversified cropping systems enhance soil aggregation, infiltration, and water-holding capacity. By improving soil physical and biological properties, organic farming systems reduce evaporation losses, buffer crops against drought stress, and improve water-use efficiency, particularly in rainfed and climate-vulnerable environments (Reganold & Wachter, 2016; Lal, 2018; van Bruggen et al., 2018).



Figure-21. Organic mulching in cotton to conserve soil moisture.

Weed management in organic farms relies primarily on preventive and cultural strategies, including stale or sterile seedbed preparation, mulching, conservation tillage, high-density planting, intercropping, cover crops, and manual weeding. In the stale seedbed approach, weeds are encouraged to germinate prior to crop establishment and are then destroyed to deplete the soil weed seed bank. In addition, certain organic or naturally derived substances, such as clove oil, citric acid, vinegar, and acetic acid, are permitted in some countries for limited use in weed control.



Figure-22. Manual weeding.

Pest management in organic farms employs a wide range of ecologically based techniques, including pheromone traps for insect monitoring, mating disruption and mass trapping; light traps; trap crops; and the inoculative or inundative release of insect parasitoids and predators.

These approaches are complemented by the use of botanical and microbial biopesticides and biofertilizers that are compatible with organic ecosystems.

While synthetic chemical pesticides and genetically modified seeds are prohibited in organic cotton production and fibre processing, organic standards in many countries allow a restricted list of approved substances, including pheromones, certain naturally derived materials, and a limited number of synthetic compounds, for use in insect pest and disease management, soil remediation, and soil fertility enhancement.



Figure-23. Bird perches and pheromone traps



Figure-27. Encarsia wasp ovipositing in a whitefly pupa



Figure-24. A coccinellid grub feeding on aphid.



Figure-28. A yellow sticky trap for monitoring whiteflies



Figure-25. A chrysopid grub feeding on aphid.



Figure-29. Commercial biofertilizers and biopesticides.



Figure-26. Biochar prepared from cotton stalks



Figure-30. Freshly prepared vermicompost

GLOBAL STATUS OF ORGANIC COTTON PRODUCTION

Globally, certified organic cotton has been produced since the mid-1980s; however, its share of total cotton production remained negligible for nearly two decades. Organic cotton accounted for more than 0.1% of global cotton production only after 2005, subsequently expanding to 1.08% in 2009, 2.0% in 2023, and approximately 2.8% in 2024, reflecting a steady upward trend in its global share. Over the past decade, organic cotton production has expanded substantially, increasing by nearly 5.8-fold, from 112,483 tonnes in 2015 to 659,567 tonnes in 2024. This growth reflects rising consumer demand and expanded certification, albeit from a relatively small base within the global cotton sector.

Data from the Textile Exchange Organic Cotton Market Reports indicate that between 15 and 25 countries cultivated organic cotton during the period 2012–2024. Throughout this period, India consistently remained the dominant producer, accounting for approximately 55.4% of the total global organic cotton output of about 3.2 million tonnes produced in 13 years. China contributed 11.5%, followed by Türkiye (8.9%), Kyrgyzstan (5.7%), Tanzania (4.2%), Tajikistan (3.5%), Kazakhstan (2.5%), United States (2.1%), Pakistan (1.6%), and Uganda (1.2%). Collectively, these top ten producing countries accounted for approximately 96.5% of total global organic cotton production over the 2012–2024 period, highlighting the high geographic concentration of organic cotton supply.

Table-1. Global production (Metric Tonnes) of certified organic cotton 2015-2024. Source: Data compiled from organic cotton market reports <https://textileexchange.org/>

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24
India	75,251	60,184	59,470	85,530	122,668	124,244	130,849	156,600	270,635	436,648
China	13,145	14,817	22,521	38,586	41,247	30,589	33,687	57,300	41,548	49,343
Turkey	7,304	7,577	7,741	12,894	22,839	24,288	80,830	83,300	5,821	4,100
Kyrgyzstan	5,543	7,981	8,019	22,309	23,637	29,415	30,945	20,000	16,000	18,547
Tanzania	2,146	3,229	3,773	4,890	5,281	11,285	20,932	21,150	22,611	24,048
Tajikistan	1,000	6,620	6,405	8,999	12,178	10,471	13,648	13,080	20,799	18,610
Kazakhstan							14,893	15,250	29,704	17,840
USA	2,432	4,524	4,529	5,101	5,175	6,913	5,821	7,630	9,726	8,904
Pakistan		366			398	2,026	1,925	2,532	16,710	28,400
Uganda	795	300	765	765	2,581	4,734	2,551	2,700	10,694	12,042
Uzbekistan						165	465	590	11,800	10,980
Azerbaijan									9,538	9,880
Greece			850	1,045	1,168	1,720	1,827	1,830	2,048	5,655
Benin	377	407	699	713	998	1,373	1,893	3,060	1,323	1,320
Peru	553	312	338	502	558	712	694	760	1,318	2,502
Zambia									187	9,401
Egypt	2,150	1,023	437	438	287	238	437	700	270	346
Burkina Faso	1,067	469	491	538	453	574	647	624	741	340
Mali	526	136	130	77	84	85	63	62	53	28
Brazil	22	17	43	22	97	134	70	77	143	182
Israel	14	14							305	312
Ethiopia	145			60	130	148	60	62	19	63
Senegal	13	1	4	6		3			18	10
Spain							26	26	23	25
Italy									33	41
Total	112,483	107,977	116,215	182,475	239,779	249,117	342,263	387,333	472,068	659,567

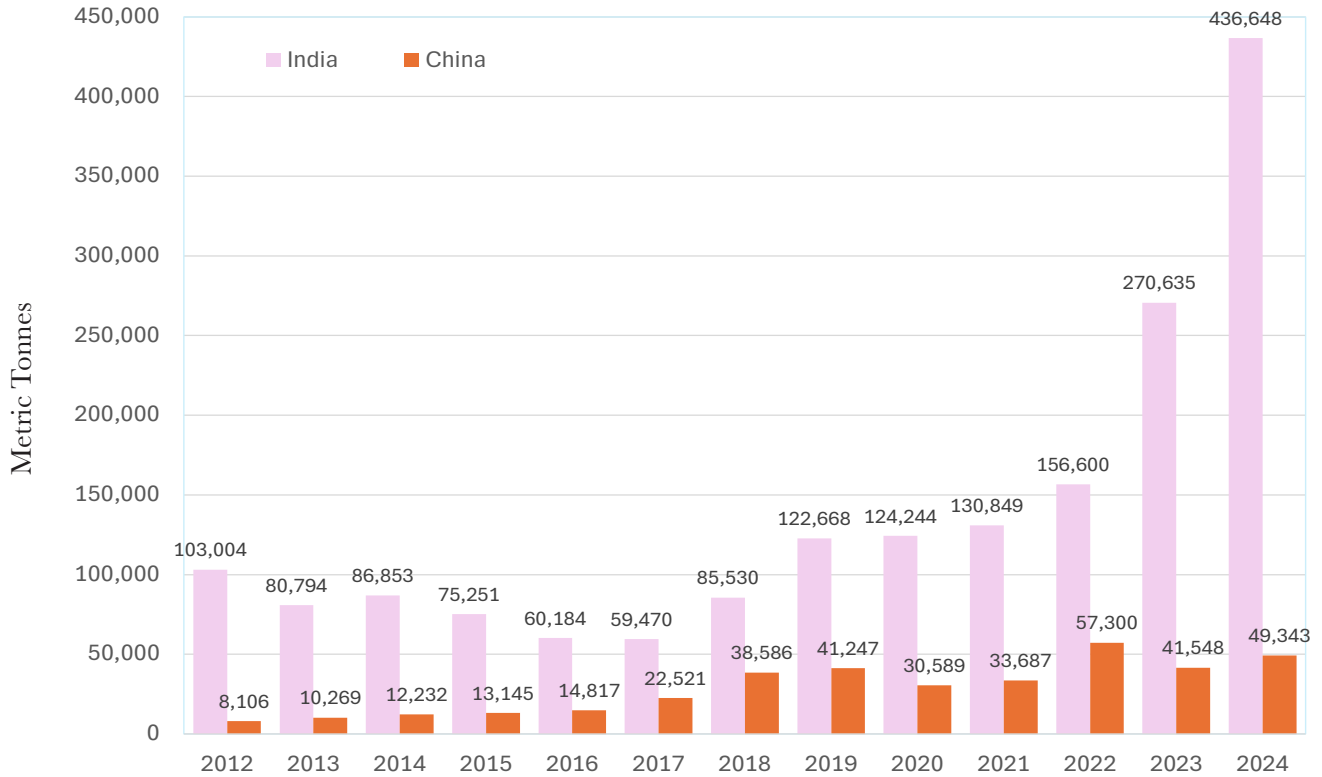


Figure-31. Production (Metric Tonnes) of organic cotton 2012-2024 in India and China. Source: Data compiled from organic cotton market reports <https://textileexchange.org/>

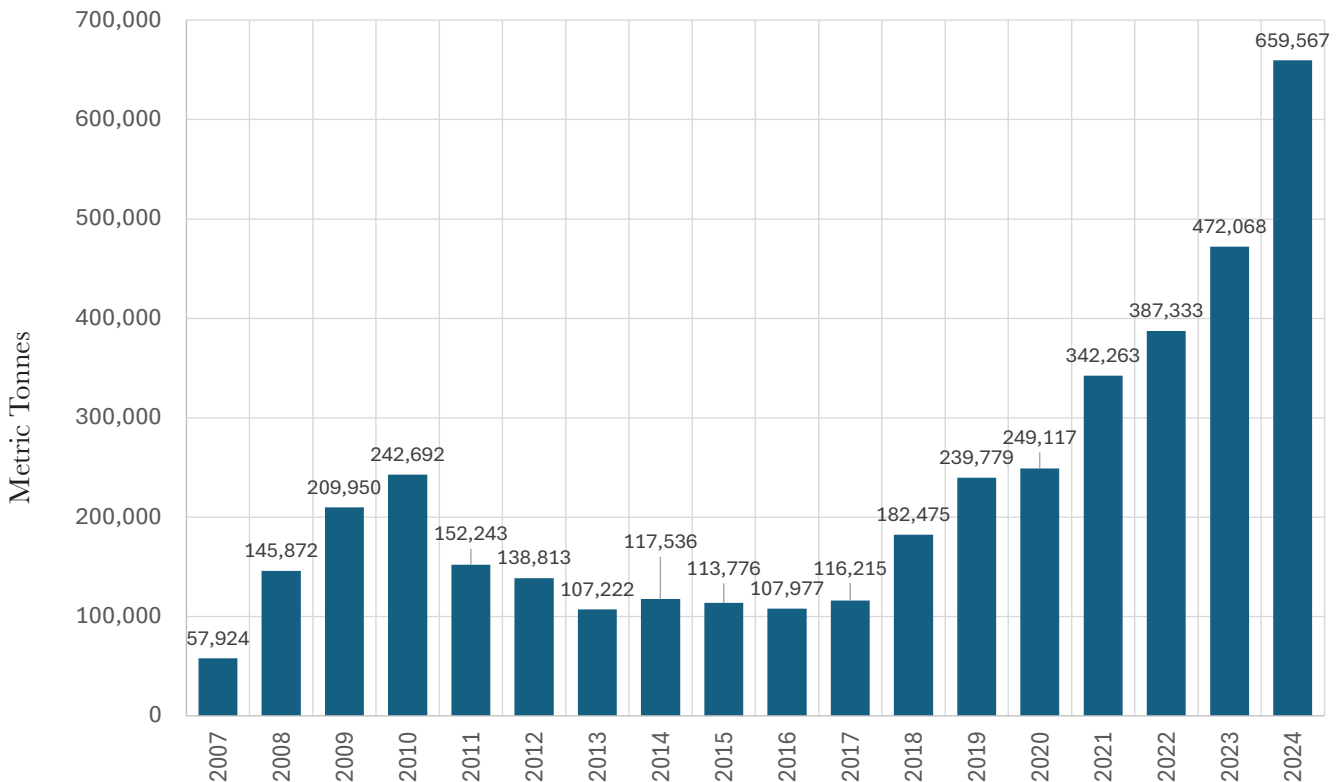


Figure-32. Global production (Metric Tonnes) of organic cotton 2007-2024. Source: Data compiled from organic cotton market reports <https://textileexchange.org/>

Indian dominance in organic cotton production: Available data indicate that India has dominated the global organic cotton production landscape over the past two decades. India's share of global organic cotton production ranged from 6.5% to 15.4% during 1992–2000, but increased sharply from 24.9% in 2004 to a peak of 81.8% in 2009. Thereafter, India continued to account for the largest share of global organic cotton output, maintaining levels above 67% until 2015. Although India's absolute production of organic cotton increased substantially from 59,140 tonnes in 2017 to 436,648 tonnes in 2024, its share of global production declined from 51% in 2018 to 38% in 2021 and back to 66.2% in 2024, reflecting rapid expansion of organic cotton cultivation in other producing countries, notably Türkiye, Tanzania, China, Kyrgyzstan, Tajikistan, and Kazakhstan.

It is noteworthy that global fluctuations in organic cotton production have historically been driven largely by changes in India, given its dominant share in total output. Variations in Indian production have been closely linked to price premiums, shifts in market demand, and periodic reputational shocks, including negative publicity arising from fraudulent claims or bogus certification by a small number of unscrupulous actors (Hannah, 2020).

ORGANIC COTTON YIELDS

The success of organic cotton production and its ability to achieve satisfactory productivity depend critically on soil health, the selection of appropriate varieties, and effective management of pests, diseases, and weeds (Galanopoulou-Sendouca, 1998). Achieving yields comparable to those of conventional systems remains challenging (Table 3), as conventional cotton production relies heavily on synthetic agrochemicals that provide rapid, highly targeted effects on crop nutrition and pest control, whereas organic inputs and biologically based interventions generally act more slowly and with lower intensity.

Table-2. Difference in yields of organic cotton compared to conventional production systems during conversion (transition) phase and in certified organic farms.

Country	Period	Yield difference (Organic vs Conventional)	Reference
India	1994–2000	25% lower in organic	Blaise (2006)
India	2007–2010	14% lower in organic	Forster et al. (2013)
India	2007	Lower (unspecified %)	Andres et al. (2014)
Kyrgyzstan	2009	10.0% lower in organic	Bachmann (2012)

Table-3. Difference in yields of certified organic cotton compared to conventional production systems

Country	Period	Yield difference (Organic vs Conventional)	Reference
Benin	–	24.9% lower in organic	Bonou-Zin et al. (2019)
Greece	–	28.2% lower in organic	Tzouvelekas et al. (2001)
India	2018	45.7% lower in organic	Kumar (2023)
India	–	22–28% lower in organic	Angidi & Bogati (2020)
Pakistan	2019–2021	27.98% lower in organic	Shahid et al. (2023)
Turkey	–	12.84% lower in organic	Adanacioglu & Olgun (2012)
USA	1996–2001	34.3% lower in organic	Swezey et al. (2007)
India	2003–2004	Comparable	Eyhorn et al. (2007)
Tanzania	–	Comparable	Mbwana (2019)
Tanzania	–	Comparable	Bwana et al. (2020)
Tanzania, Uganda & Benin	–	Comparable	Williamson et al. (2005)
Greece	2006–2010	Comparable or higher	Bilalis et al. (2010); Patsiali et al. (2014)
Egypt	-	Similar	Mehmeti et al (2024)
India	2001–2005	Similar or slightly higher in organic	Venugopalan et al. (2010)
India	2002–2004	Higher in organic	Blaise (2006)
India	–	13.0% higher in organic	Lanting et al. (2005)
India	–	16.2% higher in organic	Patel (2006)
India	2008–2010	Higher in organic	Andres et al. (2014)
India	2019	20.4% higher in organic	Kumar (2023)

A dominant perception, supported by a substantial body of empirical evidence, is that organic crop yields are typically lower than those of conventional systems, particularly in the short to medium term. This yield gap is largely attributed to constraints in nutrient availability, weed and pest management, and the comparatively slower or less predictable efficacy of inputs permitted under organic standards (Seufert et al., 2012; de Ponti et al., 2012; Ponisio et al., 2015). Meta-analyses indicate that, on average, organic yields are approximately 20–25% lower than conventional yields across crops and regions (de Ponti et al., 2012; Ponisio et al., 2015; Seufert et al., 2012). In addition, organic farming systems are generally more labour-intensive, requiring increased manual effort for weed control, compost preparation, crop diversification, and on-farm management of organic inputs, which can raise production costs and potentially constrain profitability (Pimentel et al., 2005; Crowder & Reganold, 2015).

In the context of cotton, studies comparing yields under organic and conventional systems report highly divergent outcomes (Table 3). While several studies indicate higher yields under conventional cotton production, others demonstrate that organic cotton yields are comparable to, or even exceed, conventional yields, particularly after the completion of the 2–3 year transition period required for organic system stabilization.

The following discussion primarily focuses on evidence from India, where the largest body of empirical research on organic cotton yield performance is available, with brief references to comparable findings from other regions for context. In India, organic cotton yields have been reported to be 13.0% higher than those of conventional farms (Lanting et al., 2005), while yields were found to be comparable in Tanzania, Uganda, and Benin (Williamson et al., 2005).

A five-year study (2001–2005) in India reported that mean organic cotton yields were either similar to or slightly higher than those under conventional systems (Blaise, 2006; Venugopalan et al., 2010), while a two-year comparative study across 170 cotton fields in central India found yield parity between organic and conventional farms (Eyhorn et al., 2007). Patel (2006) further reported higher seed-cotton yields under organic management (2407 Kg/ha) compared with conventional practices (2072 Kg/ha), attributing the advantage in part to more effective organic pest-management strategies.

Other studies highlight contrasting outcomes. Bt cotton yields were reported to be 22–28% higher than organic cotton yields in some Indian contexts (Angidi & Bogati, 2020), whereas Monicaa et al. (2023) showed that organic pest management outperformed synthetic chemical control, producing higher seed-cotton yields in both 2021–22 and 2022–23. Long-term systems research further underscores variability: an eight-cycle experiment comparing biodynamic, organic, conventional non-Bt, and conventional Bt systems reported that organic cotton yields averaged 93% of conventional non-Bt yields and 82% of Bt yields, with substantial year-to-year

variation (Riar et al., 2025). Although the Bt system achieved the highest mean gross margins, differences among the other systems were not statistically significant, partly reflecting higher seed and fertilizer costs in Bt cotton.

Pronounced interannual and spatial variability has also been documented in India, with organic yields being 45.7% lower than conventional yields in 2018 but 20.4% higher in 2019 (Kumar, 2023), and district-level contrasts showing lower organic yields in Wardha, Nanded, and Yavatmal but slightly higher yields in Aurangabad (Dhunde et al., 2022).

Studies from Tanzania indicate that organic cotton yields are broadly comparable to those obtained under conventional systems (Mbwana, 2019; Bwana et al., 2020). Importantly, organic practices in these systems often generated higher net returns, largely due to premium prices for organic cotton and lower production costs (Bwana et al., 2020). However, yield outcomes differ across regions. In the Northern San Joaquin Valley (California), organic cotton yields averaged 34.3% lower than conventional yields over a six-year period (1996–2001) (Swezey et al., 2007), although this yield gap may have been partially influenced by the deployment of different cotton varieties in the two systems during two of the six study years (Forster et al., 2013). Yield penalties for organic cotton have also been reported in Turkey (-12.84%) (Adanacioglu & Olgun, 2012), Kyrgyzstan (-10%) (Bachmann, 2012), Greece (-28.2%) (Tzouvelekas et al., 2001), and Benin (-24.9%) (Bonou-Zin et al., 2019). Notably, longer-term studies from Greece demonstrate that after completion of the conversion phase, organic cotton yields became comparable to or exceeded those of conventional systems (Bilalis et al., 2010; Patsiali et al., 2014), emphasizing the importance of system maturity and duration of organic management in determining yield performance.

Comparisons of yield performance between organic and conventional cotton systems present substantial methodological challenges, particularly in heterogeneous production environments such as India.

Conventional Bt cotton is typically cultivated using expensive hybrid seeds and high-input management practices on relatively fertile, irrigated land, whereas organic cotton -often based on low-cost, non-GM seed is more commonly grown under rainfed conditions by farmers who lack access to, or cannot afford, costly seeds and synthetic chemical inputs. As a result, organic cotton production tends to be concentrated among marginal and resource-constrained farm households practicing low-input agriculture (Witharanage et al., 2024).

For these farmers, price premiums and assured farm-gate procurement frequently compensate for lower yields, making organic cotton economically viable. Consequently, except in well-designed experimental settings, direct yield comparisons between irrigated, high-input conventional cotton grown on fertile soils and rainfed, low-input organic cotton cultivated on marginal lands are methodologically inappropriate. This is particularly true where organic cotton is intercropped or occupies only a portion of the total farm area, yet



Figure-33. Comparisons of yield performance between conventional and organic cotton systems present substantial methodological challenges, particularly in heterogeneous production environments. Conventional Bt cotton is typically cultivated using expensive hybrid seeds and high-input management practices on relatively fertile, irrigated land, whereas organic cotton -often based on low-cost, non-GM seed is more commonly grown under rainfed conditions by farmers who lack access to, or cannot afford, costly seeds and synthetic chemical inputs.

yields are often calculated over the entire landholding, thereby artificially depressing yield estimates. Such comparisons conflate differences arising from agroecological conditions, resource endowments, cropping patterns, and farmer typologies, rather than reflecting the intrinsic performance of the production systems themselves.

Conversion (transition) phase: Across studies, organic cotton yields are consistently lower than conventional yields during the conversion phase (Table-2), reflecting the withdrawal of synthetic inputs and the time required to re-establish soil biological processes and agroecosystem functioning. Yield penalties are most pronounced during this transition period, when conventional farms are progressively converted to organic management until a new equilibrium is reached. However, evidence indicates that after completion of the conversion phase, organic cotton yields generally converge with, or exceed, those of conventional systems. A 15-year critical review reported that yields under organic management became comparable to conventional practices after a transition period of approximately five years (Moyer et al., 2017).

Empirical evidence supports this pattern across regions. In Kyrgyzstan, organic cotton yields were 10.0% lower than

conventional yields in 2009 during the conversion phase (Bachmann, 2012). In India, the mean organic cotton yield during the transition phase (2007-2010) was 14% lower than under conventional farming (Forster et al., 2013), and yields during the first six years of conversion (1994-2000) were 25% lower (Blaise, 2006).

Notably, once conversion was completed, organic cotton out-yielded conventional cotton by 227 kg/ha during 2002-2004 (Blaise, 2006), and yield parity was observed beyond the first year of conversion in subsequent studies (Andres et al., 2014). Collectively, these findings underscore that yield outcomes in organic cotton are strongly influenced by the duration of organic management, rather than organic practices per se.

Overall, the literature indicates that organic cotton yields are generally lower than conventional yields during the conversion phase, whereas yield performance in certified organic systems could either be lower or higher compared to conventional farms, but is highly context-specific, shaped primarily by agroecological conditions, duration of organic management, and access to inputs, rather than by organic production per se.

ECONOMICS

Numerous studies and farm-level surveys indicate that organic cotton is often more profitable than conventional cotton, primarily due to lower input costs and premium prices obtained for certified organic fibre (Eyhorn, 2007; Bachmann, 2012; Forster et al., 2013; Angidi & Bogati, 2020). Net profitability reflects the balance between gross revenue and production costs, and available data (Table 4) suggest that, in general, organic cotton systems outperform conventional systems economically, largely because of reduced expenditures on costly inputs. In most cases, the cost of producing organic cotton is lower than that of conventional cotton, mainly due to the high costs associated with biotech seed and synthetic agrochemicals, including fertilizers and pesticides, in conventional production. However, exceptions have also been reported: in some contexts, the greater labour requirements associated with organic management, along with the costs of biological inputs and their application, have increased production costs, partially offsetting the economic advantage of organic cotton.

Table-4. Differences in cost of production and net profits of organic cotton compared to conventional production systems

Differences in production costs	Country	Reference
Net profits were more than double in conventional	Greece	Tzouvelekas et al., 2001
Input costs were 42% less & net profits were 20-27% higher in organic cotton farming	Kyrgyzstan	Bachmann, 2012
Production cost for 1.0 Kg lint was US\$ 1.04 for organic & US\$ 0.85 for conventional.	Turkey	Adanacioglu and Olgun, 2012
Net profits were higher in organic because of low cost of production and higher yields.	India	Jackson, 2005
Production cost in organic was 13-20% lower & net profits were 51.8- 62.5% higher.	India	Eyhorn, et al., 2007
Net profit: 26.5% higher in organic cotton farms in Gujarat, but 9.8% lower in Punjab	India	Charyulu and Biswas, 2010
Production cost was 38% less and net profits were 8.9% higher in organic	India	Forster et al., 2013
No significant differences in net profits from organic, conventional and BCI.	India	Hoop et al., 2018
Cost of cultivation of organic cotton was 21% lower & net profits were higher than Bt-cotton	India	Angidi and Bogati, 2020
Net profits from organic cotton were higher by US\$ 202 and US\$ 202 in two seasons	Tanzania	Mbwana, T.N, 2019
Incomes were 10% to 20% higher in organic	India	Rieple & Singh, 2010
Gross margins were 32% higher in organic	India	Riar et al., 2017
Net profits were higher in organic due to lower input costs & comparable gross incomes	Benin	Westerberg, 2017
Net profits from organic farms were 20.1%, 9.3% & 119.72% higher compared to conventional cotton in Wardha, Nanded and Aurangabad districts of central India respectively, but 16.61% lesser in Yavatmal	India	Dhunde et al., 2022

Evidence from multiple countries indicates that the economic performance of organic cotton relative to conventional systems is highly context-specific, influenced by differences in input costs, yield levels, and the availability of price premiums. In Greece, net profits from conventional cotton were reported to be more than double those from organic cotton (Tzouvelekas et al., 2001). In contrast, in Kyrgyzstan, although organic cotton yields were 10% lower than conventional yields, gross margins were 27% higher, owing to 42% lower input costs and higher price premiums for organic cotton (Bachmann, 2012). In Turkey, the unit cost of producing organic seed cotton was higher (US\$ 1.04 per Kg lint) than for conventional cotton (US\$ 0.85 per Kg), indicating that the profitability of organic cotton depended critically on premium prices (Adanacioglu & Olgun, 2012).

In India, organic cotton has frequently demonstrated economic advantages. Production costs as low as US\$ 0.17 per Kg of seed cotton during 2002–2004 resulted in gross prof-

it margins of US\$ 823 to 1,287 per hectare, exceeding those of conventional cotton (Jackson, 2005). Variable production costs in organic systems were 13–20% lower, while net margins were 51.8–62.5% higher than conventional cotton in central India (Eyhorn et al., 2007). However, regional contrasts exist: net profits were 26.5% higher in Gujarat but 9.8% lower in Punjab under organic cotton (Charyulu & Biswas, 2010). During 2007–2010, conventional cotton incurred 38% higher variable costs, yet organic cotton achieved 8.9% higher net profits (Forster et al., 2013).

Several studies attribute higher organic profitability primarily to lower production costs and organic price premiums. Certified organic cotton farms in India recorded 10–20% higher incomes than conventional systems (Rieple & Singh, 2010), while 32% higher gross margins were reported in 2010 due to low input costs and favorable premiums (Riar et al., 2017). Even where yields were 22–28% lower than Bt cotton, organic cotton achieved higher net profits owing to 21% low-

er production costs (Angidi & Bogati, 2020). Similar trends were observed in Benin, where gross revenues from organic and conventional cotton were comparable, but lower costs resulted in higher net profits for organic cotton (Westerberg, 2017), and in Tanzania, where organic cotton generated US\$ 202–206 higher gross margins per season than conventional cotton (Mbwana, 2019).

Nonetheless, not all studies report clear economic advantages. A comparative analysis of organic, conventional, and Better Cotton Initiative (BCI) systems in India found no significant differences in net profits, and when family labor costs were fully accounted for, all three systems exhibited negative net margins (Hoop et al., 2018). Similarly, Monicaa et al. (2023) reported that net returns from biological pest management in organic systems were comparable to those achieved with synthetic chemical pest control. Dhunde et al. (2022) further demonstrated strong spatial variability, with organic cotton net returns exceeding conventional returns by 20.1% in Wardha, 9.3% in Nanded, and 119.72% in Aurangabad, but being 16.61% lower in Yavatmal, underscoring the location-specific nature of economic outcomes.

Crowder and Reganold (2015), in a meta-analysis encompassing studies from North America, Europe, and India, reported that organic farming is, on average, more profitable than conventional farming, despite generally lower yields and higher labour requirements. Similarly, a global meta-analysis by Smith et al. (2019) found that although organic systems exhibit lower yields and greater yield variability, their overall production costs were comparable to those of conventional systems, resulting in higher profitability driven primarily by organic price premiums. This economic advantage was largely attributed to reduced expenditure on synthetic inputs and the price premiums obtained for certified organic products.

However, other studies caution that organic price premiums are not always sufficient, stable, or reliably accessible to offset yield penalties, increased labour demands, and certification-related expenses, particularly in developing-country contexts (Seufert & Ramankutty, 2017; Schader et al., 2014). A major contributor to these constraints is the organic verification and certification system, which is often rigorous, documentation-intensive, and costly, requiring periodic inspections, extensive record-keeping, residue testing, and third-party audits. Collectively, these compliance-related costs can significantly erode farm-level profitability, especially where market access is uncertain or organic price premiums are volatile or weak (Willer et al., 2023; Kleemann et al., 2014). To obtain organic certification, farms are required to undergo a mandatory conversion period, typically three years during which the use of synthetic inputs is prohibited, yet organic price premiums cannot be claimed (IFOAM, 2020; USDA-NOP, 2023). This transition phase presents significant structural and economic challenges, as farmers frequently experience yield penalties without corresponding financial compensation, rendering the conversion process economically risky. These constraints are particularly acute for smallholder farmers, for whom limited financial buffers

and restricted access to credit can make the transition to certified organic farming especially difficult (Schader et al., 2016). Based on a survey of 1,416 cotton farmers in Benin, Mounirou and Bassongui (2023), found that expansion of organic cotton acreage was associated with adverse welfare outcomes, irrespective of the welfare indicator used. Specifically, a 10% increase in organic cotton production was linked to a 7.76% reduction in household income and a 9.15% increase in the probability of farmers falling below the poverty threshold.

ORGANIC COTTON FIBRE QUALITY

Numerous studies indicate that the fibre quality of organic cotton is generally comparable to, and in some cases superior to, that of conventional cotton, although results vary by location, management, and measurement criteria. Several investigations report no significant differences between organic and conventional systems in cotton growth, yield, and fibre quality, suggesting that organic management per se does not consistently enhance fibre properties (Venugopalan et al., 2010; Bilalis et al., 2010). However, other studies have documented specific fibre-quality advantages under organic cultivation. For example, Joshi et al. (2018) found that organic cotton exhibited fibre properties similar to conventional cotton, except for higher fibre strength, and that fabrics produced from organic cotton showed better drape, crease recovery, extensibility, and lower stiffness, although conventional cotton fabrics exhibited higher tensile and tear strength.

Evidence from long-term field studies further suggests that organic nutrient management can improve certain fibre attributes. Cotton grown under organic conditions showed significantly greater fibre length (25.1 mm vs. 24.0 mm) and strength (18.8 vs. 17.9 g/tex) compared with conventional cotton (Blaise, 2006), while higher fibre uniformity ratios and lint percentages were observed in farmyard-manure-treated plots relative to plots receiving synthetic fertilizers (Blaise et al., 2005). Multi-year studies have also shown that organic cotton fibres can be superior with respect to spinning consistency index, an important parameter for textile processing (Bilalis et al., 2015). At the fabric level, organically produced cotton has demonstrated functional advantages, including improved durability, strength, absorbency, and thermal comfort in knitted fabrics (Islam et al., 2014). The smoother, more circular, and relatively coarser fibre morphology of organic cotton has been associated with higher air permeability, contributing to enhanced wearer comfort. In addition, naturally dyed organic cotton fabrics exhibited superior shrinkage resistance, bursting strength, abrasion resistance, and colour fastness compared with fabrics dyed using synthetic chemicals (Ramasamy, 2015). Collectively, these findings suggest that while organic cotton does not universally outperform conventional cotton in all fibre parameters, it can offer equal or superior fibre and fabric qualities, particularly when assessed in terms of processing performance, comfort, and functional textile properties.

PESTICIDE RESIDUES

A key perceived advantage of organic cotton fibre is that it is produced without the use of synthetic agrochemicals, thereby minimizing potential risks to human health and the environment.

However, it has also been argued that the “organic-ness” of cotton does not reside inherently in the fibre itself, but rather in the production processes, value systems, and institutional arrangements through which organic farming and commodity certification are defined and authenticated (Bunin, 2001).

Because synthetic pesticides are prohibited in certified organic cotton production, studies have consistently reported the absence of pesticide residues on lint from organic farms (Joshi, 2011).

In contrast, several studies have detected insecticide residues on cotton lint produced under conventional farming systems, with concentrations reported both above maximum residue limits (MRLs) (Diwan et al., 2006; Kumari & Duhan, 2011; Bhamare, 2018) and below MRLs (Battu et al., 2003; Blossom, 2004; Karthikeyan & Jayakumar, 2000; Pandiselvi et al., 2010; Jasmine et al., 2011; Preetha et al., 2018; Thakor, 2014).

In some cases, only trace levels of residues were detected (Battu et al., 2009). Importantly, experimental evidence indicates that many commonly used insecticides have short environmental half-lives (often <4 days) and that residue levels on lint can dissipate below detection limits within one to two weeks (Battu et al., 2009; Zongmao et al., 1997). Moreover, residues are rapidly removed during textile processing, often

within a few hours, further reducing the likelihood of detectable residues in finished textile products (Serat et al., 1982).

Thus, while conventional cotton production can result in pesticide residues on raw lint to varying extents, time and processing substantially mitigate residue presence in the final product.

Nevertheless, it remains important to emphasize that cotton produced under certified organic systems is expected to be entirely free of synthetic agrochemical residues, including herbicides, insecticides, and defoliants, at the farm level.

Beyond fibre residues, the occupational health implications of cotton production systems are increasingly recognized.

Jean-Noël Dado Koussé et al. (2025) reported that chronic respiratory symptoms were significantly more prevalent among conventional cotton farmers than among organic cotton farmers in Burkina Faso, indicating a clear comparative effect associated with production practices.

Conventional farmers applying synthetic pesticides exhibited markedly higher prevalence of rhinitis (54.45% vs. 34.92%), chest pain (41.28% vs. 23.81%), cough (33.45% vs. 24.34%), and especially breathlessness (31.67% vs. 4.23%) compared with their organic counterparts.

These findings suggest that, even where final textile products may be largely residue-free, the primary human-health benefits of organic cotton lie in reduced occupational exposure during cultivation, rather than in intrinsic differences in the fibre itself.



Figure-34. The final textile products may be largely residue-free, but the primary human-health benefits of organic cotton lie in reduced occupational exposure, ecological and environmental benefits during cultivation, rather than in intrinsic differences in the fibre itself.

SUSTAINABILITY

Organic cotton production is widely regarded as a strong expression of sustainable agriculture, as it emphasizes the conservation of natural resources while minimizing negative environmental externalities. By relying on biological processes and system-level management rather than synthetic inputs, organic farming contributes to the protection of soil health, water resources, energy efficiency, and biodiversity, while reducing pollution and ecological degradation. In this sense, organic agriculture functions as a largely self-regulating and resource-efficient production system, aligning closely with the core principles of agricultural sustainability (Tsvetkov et al., 2018).



Figure-35. By relying on biological processes and system-level management rather than synthetic inputs, organic farming contributes to the protection of soil health, water resources, energy efficiency, & biodiversity, while reducing pollution and ecological degradation.

Biodiversity: A wide range of research findings and meta-analysis reports show that organic farming systems consistently support higher levels of biodiversity than conventional systems, although responses vary among taxonomic groups (Bengtsson et al., 2005; Hole et al., 2005; Kasperczyk & Knickel, 2006).

A meta-analysis of 42 comparative studies reported that species richness was, on average, 30% higher on organic farms, with particularly strong effects in intensively managed landscapes; positive responses were observed for plants, arthropods overall, carabid beetles, other predatory insects, and birds, but were less consistent for non-predatory arthropods and soil microorganisms (Bengtsson et al., 2005).

Similarly, a review of 76 studies found positive effects of organic farming on species abundance and/or richness in 66

cases, neutral or mixed outcomes in 25 cases, and negative effects in only eight cases, with generally positive responses for plants, birds, and arthropods, less predictable outcomes for soil microorganisms, and limited evidence for mammals (Hole et al., 2005).

Broader meta-analyses further reinforce this pattern: 327 out of 396 cases showed higher biodiversity under organic farming (Rahmann, 2011), while Tuck et al. (2014) conducted a hierarchical meta-analysis of studies that compared biodiversity under organic and conventional farming methods for 184 observations garnered from 94 studies and reported 34% higher overall species richness, including 50% higher richness of pollinators and 12% higher richness of predators in organic systems. This result has been robust over the last 30 years of published studies and shows no sign of diminishing.

Biological Control: Numerous studies demonstrate that organic cotton farms consistently support higher populations and diversity of beneficial natural enemies than conventional farms, largely attributable to the avoidance of synthetic insecticides and the maintenance of more ecologically complex habitats.



Figure-36. Ladybird beetle feeding on aphid



Figure-37. *Chrysoperla carnea* adult

In China, organic cotton fields monitored during 2004-2006 harbored significantly greater densities of key predatory insects, including ladybird beetles, lacewings, hoverflies, and spiders with average annual predator populations (excluding adult lacewings) being approximately 200% higher than those in conventional fields, and overall predator abundance ranging from 1.6- to 3.0-fold higher (Lu et al., 2015). Similarly, organic cotton fields in California (USA) supported 17–56% more natural enemies and a greater proportion of generalist predators than conventional fields (Swezey et al., 2007), while additional field assessments documented higher populations of Dolichopodidae, spiders, Orius spp., Geocoris spp., coccinellids, nabids, and neuropteran larvae in organically managed cotton systems (Jackson, 2006).

Shahid et al. (2022) reported that organically managed cotton fields supported significantly higher abundance and diversity of key natural enemies than conventional fields, including two coccinellid species (*Coccinella undecimpunctata* L. and *Coccinella septempunctata* L.), formicids, *Orius insidiosus*

(Say), spiders from the families Thomisidae and Araneidae, and the parasitoid *Encarsia formosa* Gahan.

In a subsequent study, Shahid et al. (2023) showed that insect pest populations were higher in conventional cotton, whereas natural enemies were more abundant in organic cotton fields, and regression analyses confirmed that greater abundance and diversity of natural enemies significantly contributed to the suppression of pest populations. Farmer perceptions in the United States, corroborate these ecological observations: 40% of the 119 organic cotton growers and 29 handlers who were interviewed, reported noticeable increases in beneficial organisms, including lacewings, lady beetles, and soil microbes, on organically managed farms (Delate, 2021).

Collectively, these findings highlight the role of organic cotton systems in enhancing functional biodiversity and strengthening biological pest control services. Lori et al. (2024), in a long-term experiment established in 2007 in India, demonstrated that organic farming exerts a strong positive influence on soil biodiversity and ecosystem functioning. Organic management significantly increased soil organic carbon and nitrogen enhanced microbial abundance and metabolic activity and fostered distinct and functionally diverse microbial communities associated with nutrient mineralization. In contrast, conventional systems favored ammonium-oxidizing bacterial communities, indicative of intensified nitrification processes and a greater risk of nitrogen losses.

Pollination: Although cotton is not directly dependent on insect pollination, pollinator diversity can enhance cotton productivity in organic systems. In Brazil, organic farms exhibited 57.1% higher bee richness and 18.4% higher yields compared to conventional farms, with bee activity increasing fibre weight by >12% and seed number by >17% (Pires et al., 2014). Collectively, these findings demonstrate that organic cotton farming enhances biodiversity across multiple trophic levels, strengthening ecosystem services such as biological pest control, soil functioning, and pollination, which together contribute to greater agroecosystem resilience and sustainability.



Figure-38. Honeybee on a cotton flower

Soil Carbon: A substantial body of evidence indicates that organic farming systems enhance soil carbon stocks and soil health relative to conventional management. A meta-analysis by Gattinger et al. (2012), synthesizing data from 74 studies based on pairwise comparisons of organic and non-organic systems, demonstrated significantly higher soil organic carbon (SOC) concentrations and carbon sequestration rates in organically managed soils. Cotton-specific studies from India corroborate these findings. Analyses of soil samples collected between 2001 and 2005 from four soil pedons and 56 surface soils showed higher organic carbon and available zinc under organic cotton systems compared with conventional cotton farms (Venugopalan et al., 2010). Long-term field experiments further revealed pronounced improvements in soil structure and nutrient status: after 11 years of organic cotton cultivation, SOC in the upper soil layer increased by 74% relative to conventional plots (Blaise, 2006), with organically managed soils exhibiting larger and more stable aggregates, four-fold higher aggregate numbers, and significantly enhanced phosphorus, potassium, and micronutrient availability (Blaise et al., 2004). Although some studies reported no significant differences in soil water retention, SOC, or major nutrients between organic and conventional cotton soils, boron content was 17% higher under organic management (Eyhorn et al., 2007).

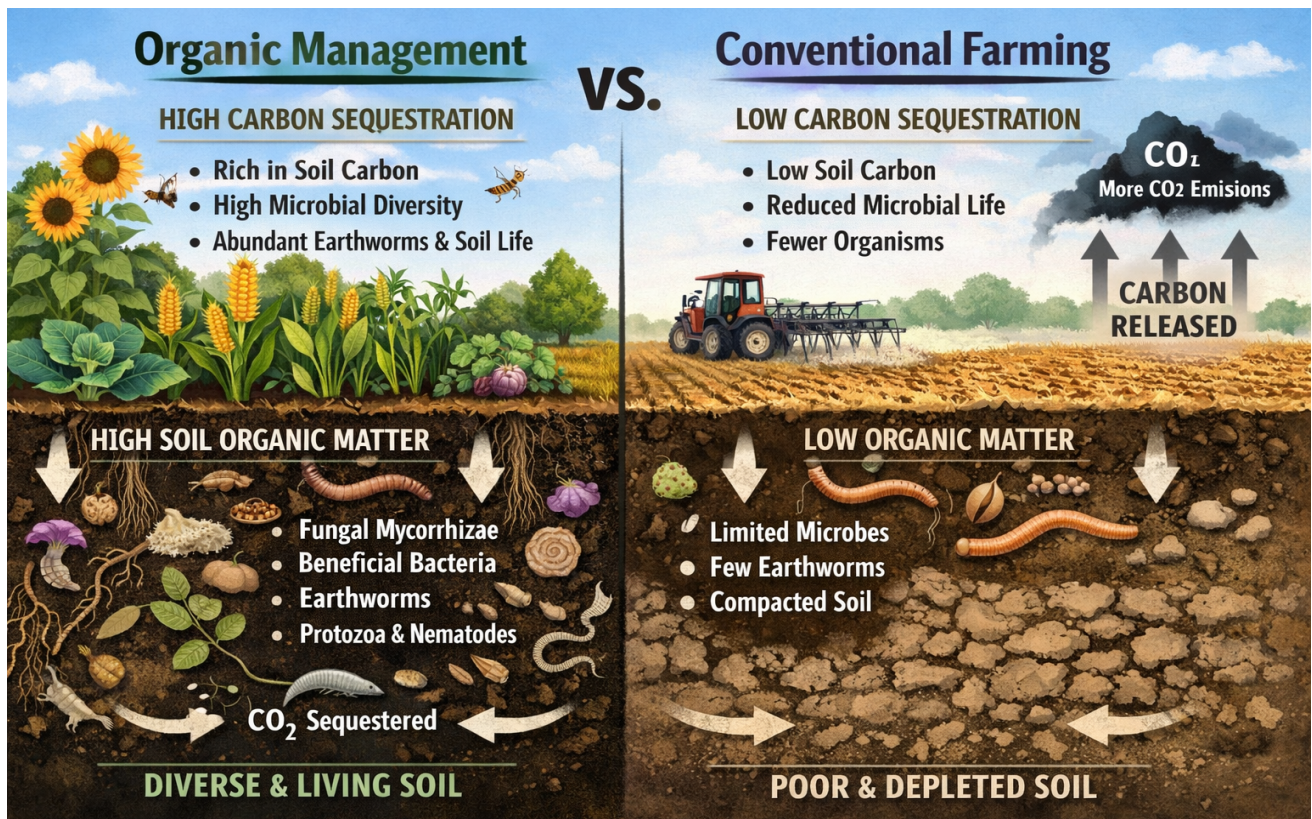


Figure-39. Studies show that organic farming systems enhance soil carbon stocks and soil health relative to conventional management

Soil Biology: Beyond improvements in soil physical and chemical properties, organic cotton systems also deliver climate co-benefits. Survey data from 355 cotton producers in Benin showed that organic cotton production emitted approximately 42% less greenhouse gases than conventional cotton (Bonou-Zin et al., 2019). Complementing these findings, a long-term plant–soil interaction study established in 2007 in India demonstrated that organic management increased soil organic carbon and nitrogen, enhanced microbial abundance and activity, and promoted distinct microbial communities associated with nutrient mineralization, while conventional systems favored ammonium-oxidizing bacteria indicative of higher nitrification and potential nitrogen losses (Lori et al., 2024). Together, these results highlight the role of organic input–based management in strengthening soil biodiversity, nutrient retention, and long-term soil health,

particularly in semi-arid subtropical environments. Despite these benefits, the biophysical sustainability of organic cotton farming is often questioned, particularly regarding the feasibility of supplying large quantities of organic amendments, such as 15–20 t per hectare of farmyard manure at scale (Chonkar & Dwivedi, 2004). However, empirical evidence suggests that sustained productivity in organic systems does not depend solely on high external organic inputs but can be achieved through diversification of soil biota (Ramesh & Rao, 2009) and tightening nutrient cycles through improved recycling and system-level management (Stockdale et al., 2000). These findings reinforce the view that organic cotton systems can enhance soil health and environmental sustainability through ecological intensification rather than input intensification.

Greenhouse Gas Emissions: A growing body of evidence indicates that organic cotton production is associated with substantially lower greenhouse gas (GHG) emissions than conventional cotton systems, both at the farm level and across the textile value chain. A meta-analysis by Lee et al. (2015), encompassing 107 studies and 360 observations published between 1977 and 2012, found that organic farming outperformed conventional farming across key environmental indicators. Specifically, 67.3% of observations showed positive outcomes for energy efficiency (based on 165 observations), while 67.7% of observations indicated positive outcomes for greenhouse gas emissions (based on 195 observations), with the remaining observations reporting neutral or negative effects. Mehmeti et al. (2024) reported that GHG emissions from organic cotton amounted to 4,486.1 kg CO₂-eq per hectare, compared with 8,916.6 kg CO₂-eq per hectare under conventional management, reflecting a pronounced reduction in emission intensity. Similar patterns have been documented across diverse agroecological contexts (Gonzalez et al., 2023; Shah et al., 2018; Avadi et al., 2020; Singh et al., 2018). For instance, organic cotton reduced GHG emissions by 55.2% in Madhya Pradesh, India (594.1 vs. 1,328 kg CO₂-eq per hectare; Singh et al., 2018), 68.8% in Maharashtra, India (456 vs. 1,462 kg CO₂-eq per hectare; Shah et al., 2018), 42% in Benin (462.65 vs. 882.06 kg CO₂-eq per hectare; Bonou-Zin et al., 2019), and 16% in Mali (1,844 vs. 2,194 kg CO₂-eq per hectare; Avadi et al., 2020). At the product level, Gonzalez et al. (2023) estimated a markedly lower global warming potential for organic seed cotton (0.47 kg CO₂-eq per Kg) compared with conventional cotton (1.36 kg CO₂-eq per Kg¹).

Life cycle assessment (LCA): LCA studies of cotton-based products further reinforce these findings. Baydar et al. (2015) showed that Eco T-shirts produced from organically grown cotton in Türkiye exhibited lower environmental impact potentials across all assessed categories, with up to a 97% reduction in aquatic eutrophication, primarily due to the elimination of nitrogen- and phosphorus-based synthetic fertilizers.

Consistent reductions in GHG emissions have also been reported for organic cotton denims and apparel, including 25.7% lower emissions for organic denim (Fidan et al., 2021), 15% lower emissions for organic cotton T-shirts (Sipperly et al., 2016), and 54% lower emissions for organic jersey fabrics (Santos & Abreu, 2025).

Similarly, La Rosa and Grammatikos (2019) reported that conventional cotton generated 2,446 kg CO₂-eq per 1,000 kg fibre, which was 150% higher than emissions from organic cotton (978 kg CO₂-eq per 1,000 kg fibre). At the garment level, Khatun (2024) found that sourcing organic cotton reduced the GHG footprint of jeans by nearly 20% compared with conventional cotton.

Collectively, these LCA and farm-level assessments demonstrate that organic cotton production and processing substantially reduce GHG emissions, energy use, and water consumption, primarily through the avoidance of synthetic fertilizers and lower reliance on fossil-fuel-intensive field operations. These findings underscore the clear climate and environmental advantages of organic cotton systems over conventional cotton production pathways.

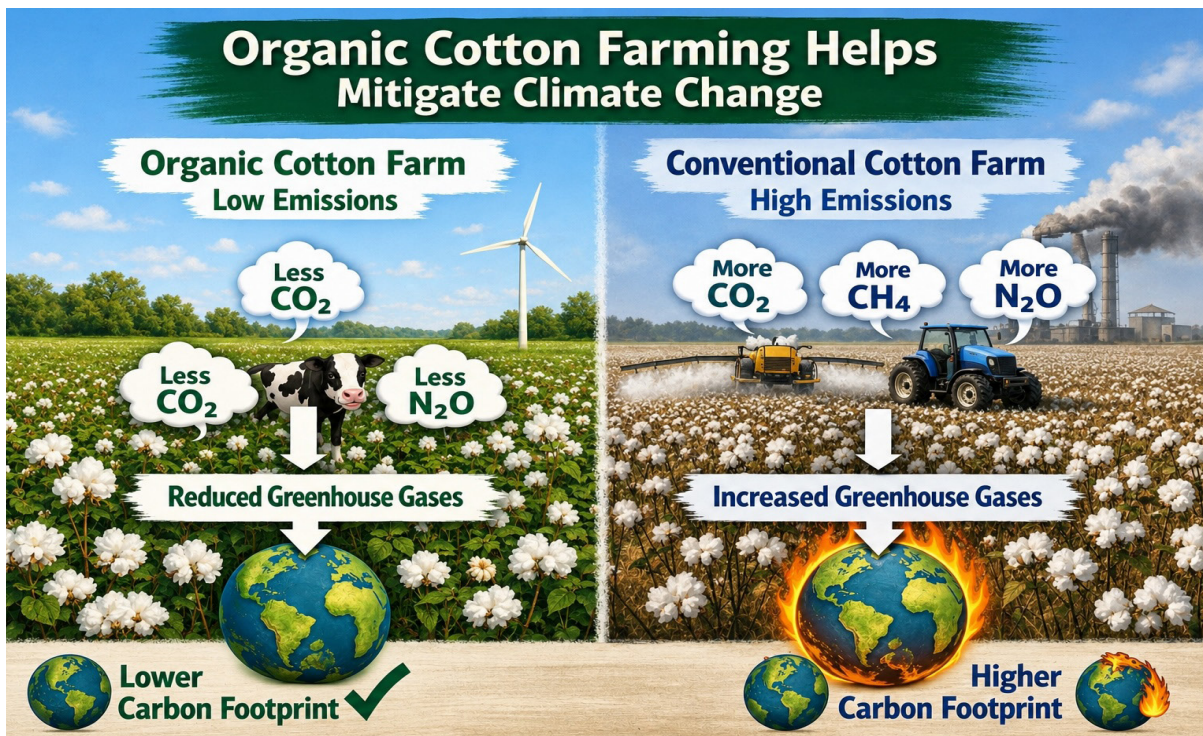


Figure-40. Studies show that organic cotton production is associated with substantially lower greenhouse gas (GHG) emissions than conventional cotton systems, both at the farm level and across the textile value chain

LABOUR

More than 97% of organic cotton farms worldwide are operated by smallholder farmers, predominantly in India, Central Asia, and Africa. In small-scale production systems such as those prevalent in India, where labour is routinely employed for core farm operations including sowing, weeding, spraying, and harvesting, labour requirements in organic and conventional cotton systems are often comparable (Forster et al., 2013; Hoop et al., 2018).

Nevertheless, organic cotton production may require additional labour for on-farm preparation and application of bio-pesticides, compost, and farmyard manure, which can marginally increase labour demand (Eyhorn et al., 2007; Bachmann, 2012; Altenbuchner et al., 2017).

In contrast, in industrialized farming systems where herbicides play a central role in weed management, organic cotton production tends to be more labour-intensive, primarily due to the reliance on manual and mechanical weed control (Nelson et al., 2004; Giovannucci, 2005; Swezey et al., 2007; Witharanage et al., 2024).

For example, labour requirements in organic cotton systems were reported to be 25% higher than in conventional systems in Greece (Tzouvelekas et al., 2001). However, labour-cost patterns vary by region: in Turkey, labour expenditure was 26.5% higher in conventional cotton farms than in organic farms (Adanacioglu & Olgun, 2012), while in Benin, conventional cotton employed 888 man-hours per hectare compared with 777 man-hours per hectare in organic cotton (Bonou-Zin et al., 2019). Extensive field studies from central India consistently indicate that labour inputs and labour costs in organic cotton are broadly similar to those in conventional cotton, with no substantial increases attributable to organic management (Eyhorn et al., 2007; Forster et al., 2013).

Notably, cotton production systems in Madhya Pradesh, India, represent a relatively advanced form of organic adoption, where improved management efficiencies have enabled reduced labour use compared to earlier practices, highlighting the potential for learning effects and system optimization in organic cotton farming (Giovannucci, 2005).



Figure-41. Composting and application of bulk manures and compost in the field requires manual labour



Figure-43. Several organic management operations for conservation tillage & site-specific application of inputs are labour-intensive



Figure-42. Manual weeding is labour intensive and expensive.



Figure-44. Herbicide application in conventional farms

ORGANIC STANDARDS AND CERTIFICATION

Certification of organic textiles is intended to assure consumers of the genuineness and authenticity of organic claims throughout the value chain. Organic textile certification requires compliance with prescribed standards covering on-farm production, ginning, storage, processing, packaging, labeling, and transport, ensuring integrity from fibre to finished product. Certification may be conducted through third-party certification systems or, in some contexts, through participatory guarantee systems (PGS) as recognized by IFOAM – Organics International (IFOAM, 2008), as well as producer-led schemes such as Certified Naturally Grown in the United States.

Different countries have developed distinct regulatory frameworks and certification standards for organic cotton, reflecting variations in agroecological conditions, institutional capacity, and market priorities. These standards generally provide guidelines for organic cotton production systems and establish criteria and procedures for the accreditation and oversight of certification bodies. Countries such as the United States, Canada, India, Australia, the European Union, and Japan have enacted comprehensive legislation governing organic products. In several cases, formal equivalence or mutual recognition agreements exist between countries to facilitate international trade in organic products. Where such agreements are absent, certification bodies from importing countries often certify organic cotton production and processing in exporting countries.

National Standards: Although organic cotton standards vary internationally, almost all are based on common organic principles, notably the prohibition of genetically modified seeds, synthetic fertilizers and pesticides, and irradiation.

Widely adopted national and regional standards include India's National Programme for Organic Production (NPOP), the European Union Organic Regulations (including EEC Regulation 834/2007 and the earlier EU 2092/91), the USDA National Organic Program (NOP), the Australian Certified Organic Standard (ACOS), and Japan's Organic JAS. The EU Organic Regulation, symbolized by the green leaf logo, operates under a unified legal framework, while some countries, such as France (AB) and Switzerland (Bio Suisse)-apply standards that exceed the EU baseline.

The USDA Organic standard is among the most comprehensive, requiring a mandatory three-year chemical-free transition period, detailed livestock welfare provisions, and defined processing requirements.

Organic JAS emphasizes soil health and bears a distinct national logo, while Canada Organic is closely harmonized with USDA Organic.

India's NPOP allows greater flexibility to accommodate diverse local production systems, and Mexico's Organic Products Law (LPO) regulates domestic production while requiring specific certification for certain imports.



Figure-45. Widely adopted National, regional and international organic standards across the globe.

Beyond government-led frameworks, international and private standards play a critical role in shaping global organic certification. IFOAM – Organics International provides overarching principles for organic agriculture and accredits its certification bodies to ensure consistency and credibility worldwide. To improve harmonization, IFOAM introduced the IFOAM Family of Standards, aiming to simplify equivalence assessments through a single global reference—the Common Objectives and Requirements of Organic Standards (COROS) -rather than relying solely on bilateral agreements (IFOAM, 2011).

At the textile and processing stage, chain-of-custody and product-specific certification schemes are essential for maintaining organic integrity beyond the farm. The most widely used programmes include the Organic Content Standard (OCS), Global Organic Textile Standard (GOTS), Content Claim Standard (CCS), OEKO-TEX®, and the Nordic Swan Ecolabel. According to Textile Exchange, in 2021 there were 12,340 GOTS, 11,885 OCS, and 113 CCS certified facilities worldwide, highlighting the scale and complexity of organic cotton supply chains. Private certifiers such as ECOCERT and the Soil Association Organic frequently apply standards that meet or exceed national requirements, with strong emphasis on environmental protection, biodiversity, and product integrity. In non-food sectors, the COSMOS standard governs natural and organic cosmetics and is widely adopted by these certification bodies.



Figure-46. Organic standards operating in the European Union

Transition Phase: Organic farms are typically certified after a transition period of 2–3 years, during which synthetic inputs are prohibited. Final textile products are labeled based on the percentage of certified organic fibre content. In India and many other countries, products containing ≥95% certified organic fibre may be labeled as “organic” or “organic in conversion”, provided processing complies with organic standards; the remaining non-organic content may consist of regenerated or man-made fibres. Products containing 70–95% organic fibre are generally labeled as “made with organic fibre”. Together, these layered certification and labeling systems form a complex but interconnected global framework, enabling market access while responding to regional production realities and consumer expectations.

Consumer Choice: Most global food and fibre markets continue to be driven primarily by price competitiveness, product quality, and supply reliability, often with limited consideration of sustainability attributes (Seufert & Ramanakuty, 2017; OECD, 2020). In contrast, organic markets are largely consumer-driven, shaped by ethical, health-related, and environmental values rather than purely economic considerations (Aschemann-Witzel & Zielke, 2017). Consumer motivations for purchasing organic products are heterogeneous. A significant segment of consumers is primarily concerned about potential health risks associated with synthetic pesticides, chemical residues, and additives in food and textiles (Mie et al., 2017; Smith-Spangler et al., 2012). Another segment is motivated by broader concerns related to environmental protection, biodiversity conservation, animal welfare, and climate change mitigation, and views organic consumption as a means of supporting global sustainability initiatives (Reganold & Wachter, 2016; Hughner et al., 2007). Regardless of motivation, the price premium paid for organic products creates a strong expectation of authenticity and credibility, placing considerable importance on robust certification and verification systems.

Fraudulence: One of the biggest challenges to consumers is adulteration, counterfeiting and fraudulent practices in agricultural products and certification systems, particularly in high-value, premium-labelled commodities that include organic cotton and textiles. Documented forms of fraud include adulteration, mislabelling, substitution, dilution, counterfeiting, and falsification of origin or production methods (Spink & Moyer, 2011; Johnson, 2018). Numerous high-profile cases have been reported globally, such as fake genetically modified seeds, pesticides, synthetic milk manufactured using urea and melamine, adulterated honey and olive oil, counterfeit saffron and vanilla, cassia sold as cinnamon, and falsified wine, sugar products etc. (Moore et al., 2012; Evers-tine et al., 2013; OECD, 2016).



Figure-47. Counterfeiting and fraudulence are not uncommon

Fraudulent practices in the certification and trade of organic cotton have been increasingly documented, raising concerns about the integrity of organic supply chains. Investigations and compliance actions have uncovered cases where cotton has been mislabeled as organic despite failing to meet certified organic production standards, often through falsified documentation, forged certificates, and manipulated traceability systems (GOTS, 2020; Seufert & Ramankutty, 2017). Such fraudulent activities can include fabrication of conversion histories, use of non-organic fibre in organic batches, and the issuance of unauthorized or counterfeit certificates, undermining both consumer trust and market premiums (Willer et al., 2023; Textile Exchange, 2022). The problem is compounded in regions with complex multi-tiered supply chains and weaker regulatory oversight, where economic incentives associated with price premiums create opportunities for deliberate misrepresentation and adulteration (Seufert et al., 2018; Spink & Moyer, 2011). These documented fraud mechanisms emphasize the need for improved traceability, verification technologies, and stronger governance to safeguard the credibility of organic cotton markets.

THE CHALLENGES

Smallholder farmers, particularly in regions such as India and sub-Saharan Africa, may be relatively more inclined to adopt organic and regenerative agriculture, as many of the principles resonate closely with long-established traditional farming practices of low input farming. Historically, smallholder systems in these regions have relied on low external inputs and ecological processes, which align well with regenerative concepts aimed at improving soil health, enhancing biodiversity, and sustaining productivity over time.

Many smallholder farmers already practice elements that are now formally recognized as organic and regenerative. These include intercropping and mixed cropping systems, crop rotations, and the use of organic mulches and composts derived from on-farm residues. Traditional approaches to natural pest and disease management, manual or mechanical weeding, animal-based tillage, natural grazing, and the integration of livestock with cropping systems are also common in smallholder agriculture. Collectively, these practices contribute to nutrient cycling, soil organic matter maintenance, and resilience of farming systems under variable climatic conditions.

Despite this inherent compatibility, the transition to fully organic systems presents several challenges. One of the most significant constraints is the risk of reduced yields during the initial transition period, when soils and agroecosystems take time for the rejuvenation of soil and terrestrial biodiversity and are still adjusting to reduced external inputs. In addition, the limited availability of non-genetically modified seeds, and biological inputs, particularly in cotton and other commercial crops, can restrict adoption. Organic and regenerative systems that rely on reduced tillage often require labour-intensive weed management, which can be difficult to sustain where labour availability is limited or costly. Further challenges relate to soil fertility management, as producing or sourcing high-quality compost and organic amendments at sufficient scale is often difficult for smallholders. Maintaining year-round ground cover with cover crops can also be problematic in rainfed systems, especially in semi-arid regions where water availability is highly seasonal. Pest and disease management poses additional hurdles, as farmers must transition away from synthetic pesticides and develop confidence in traditional or biological control strategies, which may require new knowledge, skills, and risk tolerance.

The integration of livestock -a cornerstone especially of regenerative agricultural systems can also be constrained by the lack of resources, infrastructure, or technical expertise needed to manage animals effectively alongside crops.

Finally, certification and market access remain major barriers. Certification schemes for regenerative or organic systems are often costly, complex, and documentation-intensive, placing them beyond the reach of many smallholder farmers. These barriers limit the ability of smallholders to capture price premiums or ecosystem-service payments, despite practicing many regenerative principles in their fields.

CHALLENGES FACED BY ORGANIC COTTON GROWERS:

Yields: Low yields remain one of the principal challenges confronting organic cotton production, particularly during the conversion phase and in resource-constrained environments. The prohibition of synthetic fertilizers, pesticides, and genetically modified seeds limits the speed and intensity with which nutrient deficiencies, weed pressure, and pest outbreaks can be corrected, often resulting in yield penalties relative to conventional systems, especially in the short to medium term.



Figure-48. Low yields present a significant risk for organic farmers

These constraints are further compounded in rainfed and marginal production areas—where organic cotton is frequently adopted—by climatic variability, limited access to quality organic inputs, and labour constraints. Although yields may stabilize or improve as soil health and biological regulation processes strengthen over time, persistently lower yields can reduce competitiveness, amplify income risks for smallholders, and constrain wider adoption of organic cotton, particularly in the absence of reliable price premiums and institutional support. Nevertheless, enhancing yields of organic cotton is a major challenge for scientists and producers.

Non-GM Seeds: Organic cotton production requires the use of non-GM seeds, preferably organically produced seed, to comply with organic standards and maintain system integrity. In countries where cotton cultivation is overwhelmingly dominated by GM varieties, producing and maintaining pure non-GM seed lines free from genetic or physical contamination poses a major challenge. Widespread cultivation of GM cotton increases the risk of genetic contamination through pollen flow and physical admixture during seed multiplication, handling, storage, and ginning, making segregation difficult and costly. The limited availability of certified non-GM and organic seed thus remains a critical bottleneck for the expansion and credibility of organic cotton, particularly in landscapes saturated with GM cotton.



Figure-49. Non-GM seeds are not easy to get in countries where GM cotton seeds have virtually saturated the market.

Labour: Most agronomic operations that are specific to organic cotton, particularly those involving the preparation and application of biological inputs, tend to be labour-intensive, especially in organic farms that operate under diversified or multi-cropping systems. Rising labour wages and the physically demanding nature of several of these operations, such as manual weed control, compost handling, and on-farm bio-input preparation pose significant economic and operational challenges to the viability and scalability of organic cotton production systems.



Figure-50. Manual weeding is labour intensive in organic farms

Organic inputs: Biological inputs, including manures, composts, botanical pesticides, microbial biopesticides, biofertilizers, parasitoids, predators, and pheromones are central to organic cotton production. However, across most regions, the high cost of these inputs, inconsistent quality, limited quantities, and lack of timely availability, together with labour-intensive and often inefficient application methods, constitute major constraints to the effective and large-scale adoption of organic cotton systems.



Figure-51. Biological inputs are often difficult to procure and are frequently associated with inconsistent quality, limited availability in adequate quantities, and delays in timely supply, all of which pose significant challenges for organic farming systems.

Input-use efficiency: When organic cotton yields are low, the input-use efficiency per unit of output (kg of lint) for key resources such as land, water, nutrients, labour, and other inputs declines substantially, even when absolute input use per hectare may be modest. Lower lint yields mean that fixed and semi-fixed inputs, such as land occupation, rainfall or irrigation water, labour for field operations, and baseline soil nutrient investments, are spread over a smaller quantity of

produce, resulting in higher resource intensity per kilogram of lint. This effect is particularly pronounced for land-use efficiency, where more area is required to produce the same quantity of cotton, and for water-use efficiency, especially in rainfed systems subject to climatic variability.

Similarly, labour inputs that are already relatively high in organic systems due to manual weed control and biological input preparation translate into higher labour intensity per unit of output when yields are depressed. Nutrient-use efficiency may also appear lower, as nutrients supplied through composts, manures, or biological processes are not fully converted into harvestable lint under suboptimal yield conditions. Consequently, low yields undermine the per-unit environmental and economic efficiency of organic cotton, highlighting the critical importance of yield stabilization through improved cultivars, soil health management, and ecological pest regulation to enhance overall sustainability performance.



Figure-52. In general low yields undermine the per-unit environmental and economic efficiency of organic cotton.

Scientific Support: Organic cotton farmers are often compelled to rely on high-yielding varieties originally bred for high-input conventional systems, which are poorly adapted to organic production conditions (Roos et al., 2018).



Figure-53. Very few scientific efforts are focussed on developing varieties suited for organic farming systems.

Such cultivars typically exhibit weak weed competitiveness, shallower rooting depth, and greater susceptibility to pests and diseases, limitations that are normally compensated for in conventional systems through the use of synthetic fertilizers and pesticides (van Bueren et al., 2011).

Despite the expanding footprint of organic cotton, research and breeding efforts tailored specifically to organic systems have received relatively low priority within mainstream agricultural research in many regions.

As a result, few cultivars have been developed explicitly for organic cotton production, and system-specific agronomic packages optimized for organic conditions remain largely underdeveloped, constraining productivity and resilience in organic cotton systems.

Premium: Price premiums for organic cotton are neither uniform nor guaranteed. While some farmers are able to secure attractive premiums, many organic cotton producers across regions receive only modest premiums or none at all for significant periods. In the absence of reliable price incentives above prevailing market rates, risk mitigation becomes a major challenge, undermining the economic viability of organic cotton production and discouraging wider adoption.



Figure-54. Price premiums for organic cotton are neither uniform nor guaranteed.

Transition: The transition from conventional to organic cotton farming presents significant agronomic and economic challenges for producers. Globally, the mandatory conversion period of 2–3 years is characterized by the withdrawal of synthetic inputs, during which yield reductions are commonly observed as soils and agroecosystems adjust to organic management. During this phase, farmers are typically ineligible for organic price premiums, yet must absorb the costs of lower productivity, increased labour, and compliance with organic standards. The absence of effective risk-mitigation mechanisms, such as transition subsidies, price support, or insurance schemes—even in regions where organic premi-

ums are available after certification—makes the conversion period financially precarious and remains a major deterrent to wider adoption of organic cotton farming.

Certification: Certification remains a major bottleneck in organic cotton production, particularly for small-scale farmers. Organic certification procedures are often tedious, documentation-intensive, and costly, involving multi-year transition periods, detailed record-keeping, periodic inspections, residue testing, and third-party audits. For smallholders with limited administrative capacity and financial resources, navigating the multi-layered conversion process and repeatedly demonstrating compliance to certification agencies can be both time-consuming and discouraging. These barriers not only delay access to organic price premiums but also increase uncertainty and transaction costs, thereby constraining farmer participation and the expansion of certified organic cotton systems.

Integrity: Within the broader context of food and agricultural fraud, fraudulent certification and misrepresentation of products as “organic” have emerged as significant concerns, particularly given the premium prices associated with organic labels (Johnson, 2018; Willer et al., 2023). While grading standards and certification systems for food, feed, and fibre are widely practiced across countries, fraudulent certification is not uncommon, including within organic supply chains. Such integrity failures undermine consumer trust and pose challenges similar to those observed in other premium-certified commodities, including organic cotton, where mislabelling and counterfeit certification have been repeatedly documented (Seufert & Ramankutty, 2017; GOTS, 2020).

Traceability: Authentic labelling and traceability of organic cotton across the value chain remain particularly challenging because production, processing, and trade typically involve multiple intermediaries, geographic dispersion, and frequent aggregation and segregation of fibres. Cotton from numerous smallholders is often pooled at gins, traders, and spinning mills, increasing the risk of mixing with conventional cotton, whether inadvertent or deliberate. Traceability is further complicated by paper-based documentation systems, inconsistent record-keeping capacity among smallholders, and asymmetric incentives, where price premiums create motivation for mislabelling or over-reporting organic volumes.

Downstream processing steps, such as ginning, spinning, weaving, dyeing, and garment manufacturing often occur in different countries, each with varying regulatory oversight, audit rigor, and enforcement capacity. Ensuring chain-of-custody integrity therefore requires costly mass-balance or physical segregation systems, frequent audits, and third-party verification, which are difficult to implement consistently at scale. These structural complexities make organic cotton particularly vulnerable to fraud, dilution, and credibility risks, underscoring the need for robust traceability mechanisms, harmonized standards, and digital verification tools across the entire supply chain.

Contamination: Organic cotton cultivation coexists with biotech (GM) cotton in all countries where GM cotton has been approved for commercial cultivation. In major cotton-producing countries such as India, China, and the United States, where biotech cotton accounts for more than 95% of the total cotton area, preventing genetic and physical contamination of organic cotton with GM seeds or fibres poses a significant challenge. The risk is particularly acute in India and China, where small organic cotton holdings are often embedded within landscapes dominated by GM cotton, increasing the likelihood of genetic contamination through pollen flow and physical admixture during harvesting, storage, and ginning. The latter is especially problematic where seed cotton from multiple farms is pooled and processed in common ginning facilities, making strict segregation difficult and raising serious concerns for the integrity and certification of organic cotton.



Figure-55. small organic cotton holdings are often embedded within landscapes dominated by GM cotton, increasing the likelihood of genetic contamination through pollen flow



Figure-56. Physical contamination of organic fibres with GM cotton is possible at ginning mills, which poses a significant risk for certification and marketing.

FUTURE

Historically, critics have viewed organic farming as ideologically driven and inherently inefficient, arguing that its lower yields require more land to produce the same quantity of food as conventional agriculture (Trewavas, 2001; Emsley, 2001). From this perspective, large-scale adoption of organic farming is seen as potentially exacerbating land-use pressures, including deforestation and the encroachment of wetlands and grasslands.

Reflecting such concerns, the then U.S. Secretary of Agriculture Earl Butz famously remarked in 1971, “Before we go back to organic agriculture in this country, somebody must decide which 50 million Americans we are going to let starve or go hungry” (Lockeretz, 2007).

Skeptics have consequently argued that organic agriculture is constrained by fundamental agronomic limitations (Trewavas, 2001) and may diminish in relevance under future food-security and population-growth pressures (Pickett, 2013).

Interestingly, despite a long history of skepticism and comparatively limited scientific investment in organic-farming technology, organic cotton production has expanded rapidly. Global output increased from 25,400 metric tonnes in 2004 to 241,700 tonnes in 2009, and further to 659,567 tonnes in 2024 (Textile Exchange, 2025). Parallel growth has occurred across the broader organic sector, with steady increases in the number of farms, cultivated area, research attention, and market size (Willer & Lernoud, 2015).

According to recent statistics, the global area under organic management expanded from 11.0 million hectares in 1999 to 98.9 million hectares in 2023, accounting for 2.1% of global arable land; during the same period, the number of organic producers rose from 0.2 million to 4.3 million, while the global organic market value increased from US\$ 17.9 billion in 2000 to US\$ 147.3 billion in 2023 (Schlatter et al., 2025).

The International Cotton Advisory Committee Task Force on Cotton Identity Programs (TFCIP) reported a steady expansion in the number of countries producing organic cotton over two decades (ICAC, 2014), reflecting sustained growth in both supply and demand.

Market commitment has strengthened in parallel: 38 companies signed the 2025 Sustainable Cotton Challenge, pledging that 100% of the cotton they use will come from sustainable sources by 2025, while around 50 companies now run significant organic cotton programmes and approximately 1,500 brands and retailers participate in the global organic cotton market. Leading organic cotton-consuming brands include C&A, H&M, Tchibo, Inditex, Nike, Decathlon, Carrefour, Lindex, Williams-Sonoma, Stanley/Stella, Walmart, and Anvil Knitwear.

Collectively, these trends indicate that rising consumer demand and brand-level commitments are likely to continue stimulating growth in organic cotton production in the coming years.

Organic cotton production is inherently vulnerable to yield losses and pest outbreaks because it relies predominantly on ecosystem services, particularly the natural biological control of pests and diseases. In the absence of robust and context-specific scientific support, these systems remain exposed to persistent production risks, which are especially pronounced in small-scale and resource-constrained farming systems. Strengthening organic cotton therefore requires the development of climate-resilient cultivars with improved tolerance to major insect pests and diseases, alongside farming practices that enhance system resilience.

The long-term success of organic cotton will depend heavily on the integration of regenerative agricultural practices that rebuild soil health, enhance functional biodiversity, and stabilize agroecosystem processes. This calls for focused efforts by agronomists and plant protection specialists to design organic production technologies combined with ecological engineering approaches capable of sustaining high yields without reliance on synthetic pesticides and fertilizers. In parallel, credible certification, input-use verification, and traceability systems are essential to ensure authenticity, requiring reliable methods to document pre-certification input histories and robust technologies to track cotton fibres through processing and supply chains. Ultimately, strong and sustained consumer demand for verified organic products can drive expansion of organic cotton cultivation and contribute to a broader reduction in dependence on hazardous agrochemical inputs.

In the near future, regenerative agriculture may increasingly be preferred over organic farming by farmers, not only because it can command comparable price premiums, but also because it offers greater management flexibility, lower compliance and certification burdens, and more immediate agronomic and economic benefits, while still prioritizing soil health, ecosystem functioning, and climate resilience. Unlike organic farming, regenerative agricultural systems do not, at least at present, prohibit the use of genetically modified (GM) seeds or synthetic fertilizers and pesticides, allowing farmers to retain critical risk-management tools when needed.

This flexibility enables producers to stabilize yields, manage severe pest or weed pressures, and adapt to climate variability without violating system principles. Regenerative practices, such as cover cropping, reduced tillage, diversified rotations, residue retention, and integrated livestock can be adopted incrementally and contextually, without a mandatory multi-year transition period or costly certification requirements, thereby avoiding the yield penalties and financial risks often associated with organic conversion. Moreover, emerging carbon markets, ecosystem service payments, and corporate sustainability initiatives increasingly reward regenerative outcomes, such as soil carbon sequestration, biodiversity enhancement, and water-use efficiency, rather than strict input exclusion. Collectively, these features position regenerative agriculture as a more pragmatic, scalable, and risk-tolerant pathway for farmers, particularly smallholders and producers operating under climatic and market uncertainty.

Disclaimer: Organic cotton production data used in this paper were compiled primarily from the Materials Market Reports published by Textile Exchange. In a few instances where data points were missing, supplementary information was obtained by the author through country-specific interviews. Except for these limited clarifications, the authors bear no responsibility for the data presented or the interpretations drawn in this paper. The authors declare no conflict of interest. All views, analyses, and conclusions expressed herein are solely those of the authors and do not represent, nor should they be construed as representing, the views or positions of the ICAC or any other organizations.

REFERENCES:

- Adanacioglu, H., Olgun, A., 2012. Evaluation of the efficiency of organic cotton farmers: A case study from turkey. *Bulgarian Journal of Agricultural Science* 18(3), 418-428.
- Adanacioglu, H., 2009. A research on determination of the efficiency of marketing channels for organic and conventional cotton and developing most favourable marketing models in terms of the farmers.
- Altenbuchner, C., Vogel, S., Larcher, M., 2018. Social, economic and environmental impacts of organic cotton production on the livelihood of smallholder farmers in Odisha, India. *Renewable Agriculture and Food Systems* 33(4), pp.373-385.
- Andres, C., Forster, D., Verma, R., Zundel, C., Messmer, M., Mäder, P., Bhullar, G.S., 2014. Yields and gross margins of cotton-based production systems under organic and conventional management in India. In Abstracts from the 1st International Global Food Security Conference.
- Angidi, S., & Bogati, A. (2020). A comparative assessment on production cost and output yield of organic and Bt cotton farmers. *Int J Eng Sci Comput*, 10 (7), 26591-26595
- Aschmann-Witzel, J., & Zielke, S. (2017). Can't buy me green? A review of consumer perceptions of and behavior toward the price of organic food. *Journal of Consumer Affairs*, 51(1), 211-251.
- Bachmann, F., 2012. Potential and limitations of organic and fairtrade cotton for improving livelihoods of smallholders: evidence from Central Asia. *Renewable Agriculture and Food Systems* 27(2), pp.138-147.
- Balfour, E. B. (1943). *The living soil: Evidence of the importance to human health of soil vitality, with special reference to post-war planning.* Faber & Faber.
- Battu, R.S., Joia, B.S., Dhawan, A.K., Udeaan, A.S., 2003. Harvest-time residues of different insecticides in cotton seed and lint in Punjab. *Pesticide Research Journal* 15(2), 190-192.
- Battu, R.S., Sahoo, S.K., Jyot, G., 2009. Persistence of acephate and cypermethrin on cotton leaves, cottonseed, lint and soil. *Bulletin of Environmental Contamination and Toxicology* 82(1), 124-128.
- Baydar, G., Ciliz, N., & Mammadov, A. (2015). Life cycle assessment of cotton textile products in Turkey. *Resources, Conservation and Recycling*, 104, 213-223.
- Bengtsson, J., Ahnström, J., Weibull, A.C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology* 42(2), 261-269.
- Bhamare, 2018. Acetamiprid residues in cotton lint, seed, oil and soil *Journal of Pharmacognosy and Phytochemistry* 2018, 2744-2748.
- Bilalis, D.J., Patsiali, S., Karkanis, A., Konstantas, A., Makris, M., Eftimiadou, A., 2010. Effects of cultural system (organic and conventional) on growth and fiber quality of two cotton (*Gossypium hirsutum* L.) varieties. *Renewable Agriculture and Food Systems* 25(3), 228-235.
- Bilalis, D.J., Patsiali, S., Kakabouki, I., Travlos, I.S., Karkanis, A., 2015. Effects of Cropping System (Organic and Conventional) on the Fiber Quality Index, Spinning Consistency Index and Multiplicative Analytic Hierarchy Process of Cotton (*Gossypium hirsutum* L.). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 43(2), pp.388-391.
- Blaise, D., 2006. Yield, boll distribution and fibre quality of hybrid cotton as influenced by organic and modern methods of cultivation. *Journal of Agronomy and Crop Science* 192, 248-256.
- Blaise, D., Rupa, T.R., Bonde, A.N. 2004. Effect of organic and modern method of cotton cultivation on soil nutrient status. *Communications in Soil Science and Plant Analysis* 35, 1247-1261.
- Blaise, D., Singh, J.V., Bonde, A.N., Tekale, K.U., Mayee, C.D. 2005., Effects of farmyard manure and fertilizer on yield, fibre quality and nutrient balance of rainfed cotton (*Gossypium hirsutum*). *Bioresource Technology* 96:345-349
- Blossom, S.B., 2004. Monitoring of insecticide residues in lint in Punjab. *Pesticide Research Journal* 2004, 16(1), 79-82.
- Bonou-zin, R.D., Allali, K., Fadlaoui, A., 2019. Environmental efficiency of organic and conventional cotton in Benin. *Sustainability* 11(11), p.3044.
- Bunin, L.J., 2001. "Organic Cotton: The Fabric of Change." Unpublished Ph.D dissertation, University of California, Santa Cruz.
- Bwana, T. N., Amuri, N. A., Semu, E., Olesen, J. E., Henningsen, A., Baha, M. R., & Hella, J. (2020). Yield and profitability of cotton grown under smallholder organic and conventional cotton farming systems in Meatu District, Tanzania. In *Climate impacts on agricultural and natural resource sustainability in africa* (pp. 175-200). Cham: Springer International Publishing.
- Charyulu, D.K., Biswas, S., 2010. Economics and efficiency of organic farming vis-à-vis conventional farming in India. *Indian Institute of Management*.
- Chonkar, P.K., Dwivedi, B.S., 2004. Organic farming and its implications on India's food security. *Fertilizer News* 49 (11), 15-18
- Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. *Proceedings of the National Academy of Sciences*, 112 (24), 7611-7616.
- De Ponti, T., Rijk, B., & Van Ittersum, M. K. (2012). The crop yield gap between organic and conventional agriculture. *Agricultural systems*, 108, 1-9.
- Delate, K., Heller, B., Shade, J., 2021. Organic cotton production may alleviate the environmental impacts of intensive conventional cotton production. *Renewable Agriculture and Food Systems* 36, 405-412
- Desquilbet, M., Bullock, D.S., d'Arcangelo, F.M., 2019. A discussion of the market and policy failures associated with the adoption of herbicide-tolerant crops. *International Journal of Agricultural Sustainability* 17(5), 326-337.
- Dhunde, A. D., Naik, V. G., Malve, D. B., Kadam, J. R., Dhekale, J. S., Torane, S. R., & Sundaramoorthy, C. (2022). An Evaluation of Organic and Conventional Cotton Production in Maharashtra, India. *Int. J. Environ. Clim. Change*, 12(12), 1780-1785.
- Diwan, K., Shah, P.G., Raj, M.F., 2006. Pesticide Residues in Cotton Seed and Lint. *Pesticide Research Journal* 18(2), 193-195.
- Ellis, J.L., McCracken, V.A., Skuza, N. (2012). Insights into willingness to pay for organic cotton apparel. *J. Fash. Mark. Manag.*

- Int. J., 16, 290–305
- Emsley, J. 2001. Going one better than nature? *Nature* 410, 633–634.
- Everstine, K., Spink, J., & Kennedy, S. (2013). Economically motivated adulteration (EMA) of food: Common characteristics of EMA incidents. *Journal of Food Protection*, 76(4), 723–735.
- Eyhorn, F., Ramakrishnan, M., Mäder, P., 2007. The viability of cotton-based organic farming systems in India. *International journal of agricultural sustainability* 5(1), 25-38.
- FAO (1998) Evaluating the potential contribution of organic agriculture to sustainability goals. FAO's technical contribution to IFOAM's Scientific Conference Mar del Plata, Argentina, 16-19 November 1998. <https://www.fao.org/4/ac116e/ac116e00.htm#Toc>
- FAO/WHO Codex Alimentarius. 1999. <https://www.fao.org/3/X0075e/X0075e.htm>
- Fidan, F. S., Aydoğan, E. K., & Uzal, N. (2021). A comparative life cycle assessment of conventional and organic cotton in denim fabric. In 8th International Conference on Sustainable Solid Waste Management, Thessaloniki, Yunanistan (pp. 23-26).
- Fidan, S. F., Kızılkaya Aydoğan, E., & Uzal, N. (2023). The impact of organic cotton use and consumer habits in the sustainability of jean production using the LCA approach. *Environmental Science and Pollution Research*, 30(4), 8853-8867
- Flachs, A., 2016. Redefining success: the political ecology of genetically modified and organic cotton as solutions to agrarian crisis. *Journal of Political Ecology* 23(1), 49-70.
- Forster, D., Andres, C., Verma, R., Zundel, C., Messmer, M.M., Mäder, P., 2013. Yield and economic performance of organic and conventional cotton-based farming systems—results from a field trial in India. *PLoS One* 8(12), p.e81039.
- Fukuoka, M., The one-straw revolution: an introduction to natural farming. New York Review of Books; 2009 Jun 2.
- Fukuoka, Masanobu., 2012. Sowing seeds in the desert: natural farming, global restoration, and ultimate food security. Larry Korn. White River Junction, Vt.: Chelsea Green Pub. pp. xix. ISBN 978-1-60358-418-0. OCLC 759171802.
- Galanopoulou-Sendouca, S., 1998. Towards a more competitive and sustainable cotton production. *Freer Trade, Sustainability, and the Primary Production Sector in the Southern EU: Unraveling the Evidence from Greece*, pp.112-127.
- Galanopoulou-Sendouca, S., Oosterhuis, D.M., 2003. Agronomic concepts and approaches for sustainable cotton production -2002. *Proceedings, Cotton World Conference – 3*. Cape Town, 3-6 March 2003.
- Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., Scialabba, N.E.H., Niggli, U., 2012. Enhanced topsoil carbon stocks under organic farming. *Proceedings of the National Academy of Sciences* 109(44), 18226-18231.
- Giovannucci, D., 2005. Organic agriculture and poverty reduction in Asia: China and India focus.
- Global Organic Textile Standard (GOTS). (2020). GOTS detects evidence of organic cotton fraud in India.
- Gonzalez, Victoria, Xingqiu Lou, and Ting Chi. "Evaluating environmental impact of natural and synthetic fibers: a life cycle assessment approach." *Sustainability* 15, no. 9 (2023): 7670.
- Hannah, A., 2020. "Fake organic cotton found by GOTS in India." https://www.just-style.com/news/fake-organic-cotton-found-by-gots-in-india_id139975.aspx
- Herring, R.J., 2001. "Promethean Science, Pandora's Jug: Conflicts Around Genetically Engineered organisms in India." The 2001 Mary Keatinge Das Lecture, Columbia University.
- Herring, R.J., 2010. Epistemic brokerage in the bio-property narrative: contributions to explaining opposition to transgenic technologies in agriculture. *New Biotechnology* 27(5), 614-622.
- Hodges, R. D., & Scofield, A. M. (1983). Agricologenic disease. A review of the negative aspects of agricultural systems. *Biological Agriculture & Horticulture*, 1(4), 269-325.
- Hole DG, Perkins AJ, Wilson JD, et al. (2005). Does organic farming benefit biodiversity? *Biol Conserv* 122: 113–30.
- Holmgren, David., 2007. "Essence of Permaculture" (PDF). *Permaculture: Principles & Pathways Beyond Sustainability*: 7.
- Hoop, T.D., Mcpike J., Vasudevan, S., Holla, C.U., Taneja, M., 2018. Social and Economic Impact Assessment of Cotton Farming in Madhya Pradesh. American Institute for Research. <https://www.air.org/sites/default/files/Social-and-Economic-Impact-Assessment-Cotton-Farming-India-September-2018.pdf>
- Hossain, F., Onyango B., 2004. Product attributes and consumer acceptance of nutritionally enhanced genetically modified foods. *International Journal of Consumer Studies* 18,225–267
- Howard, A. (1940). *An agricultural testament*. Oxford University Press.
- Howard, Albert., 1947. *The Soil and Health: A Study of Organic Agriculture* (1972 edition). Schocken Books, Devin-Adair Company, New York. p. 12.
- Hughner, R. S., McDonagh, P., Prothero, A., Shultz, C. J., & Stanton, J. (2007). Who are organic food consumers? A compilation and review of why people purchase organic food. *Journal of Consumer Behaviour*, 6(2–3), 94–110.
- Husaini, A.M., Sohail, M., 2018. Time to redefine organic agriculture: Can't GM crops be certified as organics? *Frontiers in Plant Science* 9, p.423
- ICAC, 2014. Report of the Task Force on Cotton Identity Programs (TFCIP) Source: www.icac.org
- IFOAM, 2008. <https://www.ifoam.bio/why-organic/organic-landmarks/definition-organic>
- IFOAM, 2008a. Participatory Guarantee System. http://ifoam.org/about_ifoam/pdfs/PGS_PDFs/Studies_Book_Web_20091030ILB.pdf
- IFOAM, 2011. IFOAM Family of Standards http://www.ifoam.org/about_ifoam/standards/family_of_standards/family_of_standards.html
- IFOAM. (2020). *The World of Organic Agriculture – Principles and Certification Systems*.
- IFOAM (2005) International Federation of Organic Agriculture Movements. *The principles of organic agriculture*. IFOAM.
- Islam, M.M., Rokon, M.A.A., Rubel, M.M.C., Ahmed, M., Islam, M.A., 2014. Investigation on Comfort Properties of Conventional Cotton and Organic Cotton of Knitted Fabric Structures. *Manufacturing Science and Technology* 2(3), 62-66.
- Jackson, G.J., 2005. Organic cotton farming in Kutch, Gujarat, India. *Agrocel, Gujarat, India*.
- Jackson, L. D., 2006. Beneficial and Pest Insect Populations in Conventional and Organic Cotton, and Organic Cotton with Habitat. In: *The 2005 ESA Annual Meeting and Exhibition*, Chicago, USA. 2006.
- Jasmine, R.S., Kuttalam, S., Stanley, J., 2011. Harvest Time Residues of Abamectin 1.9 EC in Cotton Seed, Lint and Oil. *Madras Agricultural Journal* 98(4/6), 173-175.
- Johnson, R. (2018). Food fraud and economically motivated adulteration of food and food ingredients. *Congressional Research Service*.
- Joshi, A., 2011. Impact of Pesticide Residues on Physico-Chemi-

- cal Properties of Organic and Non-Organic Cotton (Doctoral Dissertation, Acharya NG Ranga Agricultural University, Hyderabad, India).
- Joshi, A., Anitha, D., Mahesh, G., 2018. Physical properties of organic and non-organic cotton: comparative study. *Man-Made Textiles in India*, 46(7).
- Karthikeyan, P.K., Jayakumar, R., 2000. Residues of chlormequat chloride in cotton lint, cotton seed and cotton seed oil. *Pesticide Research Journal* 12(2), 251-253.
- Kasperczyk N and Knickel K. (2006). Environmental impacts of organic farming. In: Kristiansen P, Taji A, and Reganold J (Eds). *Organic agriculture: a global perspective*. Collingwood, Australia: CSIRO Publishing.
- Khadse, A., Rosset, P.M., Morales, H., Ferguson, B.G., 2017. Taking agroecology to scale: the Zero Budget Natural Farming peasant movement in Karnataka, India, *The Journal of Peasant Studies* 45(1). DOI: 10.1080/03066150.2016.1276450
- Khatun, M. (2024). Life cycle assessment of jeans production using organic and conventional cotton. *Tekstilec*, 139-150.
- Kleemann, L., Abdulai, A., & Buss, M. (2014). Certification and access to export markets: Adoption and return on investment of organic-certified pineapple farming. *World Development*.
- Koechlin, F., 2002. Genetic engineering versus organic farming. IFOAM (International Federation of Organic Agricultural Movements), Okozentrum Imsbach, Tholey-Theley, Germany.
- Koussé, J. N. D., Ilboudo, S., Ouédraogo, A. R., Ouédraogo, J. C. R. P., Hunsmann, M., Ouédraogo, G. G., ... & Ouédraogo, S. (2024). Pulmonary function assessment among conventional and organic cotton farmers exposed to pesticides in the Central-West region of Burkina Faso. *International Archives of Occupational and Environmental Health*, 97(6), 681-693.
- Kranthi, K.R. and Stone, G.D., 2020. Long-term impacts of Bt cotton in India. *Nature plants* 6(3), 188-196.
- Kuepper, G., 2010. A brief overview of the history and philosophy of organic agriculture. *Kerr Center for Sustainable Agriculture, Poteau (Okla.)*.
- Kumar, N. (2023). Evaluation of different insect pest management strategies in natural, organic and inorganic systems of cotton (Doctoral dissertation, Haryana Agricultural University Hisar, India).
- Kumari, B., Duhan, A., 2011. Persistence of dicofol residues in cotton lint seed, and soil. *Environmental Monitoring and Assessment*, 182(1-4), p.129.
- La Rosa, A. D., & Grammatikos, S. A. (2019). Comparative life cycle assessment of cotton and other natural fibers for textile applications. *Fibers*, 7(12), 101.
- Lakhal, S.Y., Sidibé, H., H'Mida, S., 2008. Comparing conventional and certified organic cotton supply chains: the case of Mali. *International Journal of Agricultural Resources, Governance and Ecology* 7(3), 243-255.
- Lampkin, N. H. (1990). *Organic farming*. Farming Press.
- Lanting, H., Raj, D.A., Sridhar, K. Ambatipudi, A., Brenchandran, S., 2005. Case study on organic versus conventional cotton in Karimnagar, Andhra Pradesh, India. In M.S. Hoddle (ed.) *Second International Symposium on Biological Control of Arthropods* (pp. 302-317). Riverside, USA: USDA Forest Service Publication FHTET.
- Larbouga, B.O., Ester, K.A., Mahamadou, S.A., Michel, F.O., 2020. Bt cotton seed purity in Burkina Faso: status and lessons learnt. *Journal of Cotton Research*. (3):30. <https://doi.org/10.1186/s42397-020-00070-4>
- Lee, K.S., Choe, Y.C., Park, S.H., 2015. Measuring the environmental effects of organic farming: A meta-analysis of structural variables in empirical research. *Journal of Environmental Management* 162, 263-274.
- Lockeretz, W. (2007). *Organic farming: An international history*. CABI Publishing (ed. Lockeretz, W.) 1-8. <https://doi.org/10.1079/9781845932893.0000>
- Lori, M., Kundel, D., Mäder, P., Singh, A., Patel, D., Sisodia, B. S., ... & Krause, H. M. (2024). Organic farming systems improve soil quality and shape microbial communities across a cotton-based crop rotation in an Indian Vertisol. *FEMS Microbiology Ecology*, 100(11), faie127.
- Lotter, D.W., 2003. "Organic agriculture". *Journal of Sustainable Agriculture* 21 (4), 59-128.
- Lu, Z.Z., Perkins, L.E., Li, J.B., Wu, W.Y., Zalucki, M.P., Gao, G.Z., Furlong, M.J., 2015. Abundance of *Aphis gossypii* (Homoptera; Aphididae) and its main predators in organic and conventional cotton fields in north-west China. *Annals of Applied Biology* 166(2), 249-256.
- Mbwana, T.N., 2019. Environmental performance of smallholder organic and conventional cotton production systems in Meatu, Tanzania (Doctoral dissertation, Sokoine University of Agriculture).
- Mehmeti, A., Abdelhafez, A. A. M., Ellssel, P., Todorovic, M., & Calabrese, G. (2024). Performance and Sustainability of Organic and Conventional Cotton Farming Systems in Egypt: An Environmental and Energy Assessment. *Sustainability* (2071-1050), 16(15).
- Menezes, E., 2007. Organic cotton processing. *New Cloth Market* 37-41
- Mickley, L. D., & Fox, M. W. (1986). The case against intensive farming of food animals. In *Advances in Animal Welfare Science* 1986/87 (pp. 257-272). Dordrecht: Springer Netherlands.
- Mie, A., Andersen, H. R., Gunnarsson, S., Kahl, J., Kesse-Guyot, E., Rembiałkowska, E., ... Grandjean, P. (2017). Human health implications of organic food and organic agriculture: A comprehensive review. *Environmental Health*, 16, 111.
- Monica, M., Krishnan, R., Sunitha, R., Sanbagavalli, S., Manickam, S., Senthil, A., & Sangeetha, S. P. (2023). Comparing the influence of natural farming on cotton (*Gossypium hirsutum*) yield and economics with integrated and organic farming. *Journal of Applied and Natural Science*, 15(3), 1268.
- Moore, J. C., Spink, J., & Lipp, M. (2012). Development and application of a database of food ingredient fraud and economically motivated adulteration. *Journal of Food Science*, 77(4), R118-R126.
- Mounirou, I., & Bassongui, N. (2023). Welfare impact of organic cotton adoption in Benin. *Economics Bulletin*, 43(2), 907-921.
- Moyer, J., Nichols, K., Bhosekar, V., 2017. A fifteen-year review summarizing effects of conventional and organic farming systems on soils, nutrition, environment, economics and yields (1981-1995). *Asian Journal of Science and Technology* 8, (4), 4628-4634.
- Nelson, L., Giles, J., MacIlwain, C., Gewin, V., 2004. Organic FAQs. *Nature* 428, 796-798.
- Northbourne, Lord., 1940. *Look to the Land*: J. M. Dent. London.
- OECD. (2016). *Illicit trade: Converging criminal networks*. OECD Publishing.
- OECD. (2020). *Consumer policy and sustainable consumption*. OECD Publishing.
- Pandiselvi, S., Sathiyarayanan, S., Ramesh, A., 2010. Determination of spirotetramat and imidacloprid residues in cotton seed, lint, oil and soil by HPLC UV method and their dissipa-

- tion in cotton plant. *Pesticide Research Journal* 22(2), 168-173.
- Patel, B.H., (2006). Impact of arthropod natural enemies on insect pest suppression in organically raised hybrid cotton-10, Ph.D. thesis Anand Agricultural University, Anand, India. 112 pp
- Patsiali, S., Papastilianou, P., Travlos, I.S., Bilalis, D.J., 2014. Organic Cropping System Effects on Fiber Quality of Three Cotton Cultivars in Greece. *Agronomy Journal*, 106(4), 1365.
- Paul, Kristiansen., Charles, Mansfield., 2006. "Overview of organic agriculture", in Paul Kristiansen, Acram Taji, and John Reganold (2006), *Organic Agriculture: A global perspective*, Collingwood, AU: CSIRO Publishing
- Paull, John., 2006. The Farm as Organism: The Foundational Idea of Organic Agriculture Elementals ~ *Journal of Biodynamics Tasmania* 83, 14–18.
- Peerzada, A.M., O'Donnell, C., Adkins, S., 2019. Optimizing Herbicide Use in Herbicide-Tolerant Crops: Challenges, Opportunities, and Recommendations. *Agronomic Crops: Volume 2: Management Practices*, pp 283-316.
- Pickett, J.A., 2013. Food security: intensification of agriculture is essential, for which current tools must be defended and new sustainable technologies invented. *Food Energy and Security* 2, 167–173.
- Pimentel, D. et al. (2005). Environmental, energetic, and economic comparisons of organic and conventional farming systems. *BioScience*.
- Pires, V. C., Silveira, F. A., Sujii, E. R., Torezani, K. R., Rodrigues, W. A., Albuquerque, F. A., ... & Pires, C. S. S. (2014). Importance of bee pollination for cotton production in conventional and organic farms in Brazil. *Journal of Pollination Ecology*, 13, 151-160.
- Poniso, L. C., M'Gonigle, L. K., Mace, K. C., Palomino, J., De Valpine, P., & Kremen, C. (2015). Diversification practices reduce organic to conventional yield gap. *Proceedings of the Royal Society B: Biological Sciences*, 282(1799), 20141396.
- Preetha, G., Stanley, J., Manoharan, T., 2018. Harvest time residues of imidacloprid in cotton seed, lint, oil and bhendi (Okra) fruits. *Journal of Entomological Research* 42(3), 391-393.
- Pretty, J. (2008). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 447–465. <https://doi.org/10.1098/rstb.2007.2163>
- Rahmann, G., 2011. Biodiversity and Organic farming: What do we know? *Agriculture and Forestry Research* 3, 189-208.
- Ramasamy, K.M., 2015. Comparative study of organic and regular cotton knitted fabrics. *Research Journal of Textile and Apparel* 19(3), 45-51.
- Ramesh, P., Rao, A.S., 2009. *Organic Farming: Status and Research Achievements*, 74 pp. Indian Institute of Soil Science. Bhopal, India.
- Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century. *Nature Plants*, 2 (2), Article 15221. <https://doi.org/10.1038/nplants.2015.221>
- Reganold, J. P., Elliott, L. F., & Unger, Y. L. (1987). Long-term effects of organic and conventional farming on soil erosion. *Nature*, 330(6146), 370–372. <https://doi.org/10.1038/330370a0>.
- Reganold, J. P., Jackson-Smith, D., Batie, S. S., Harwood, R. R., Kornegay, J. L., Bucks, D., ... McKinney, M. (2011). Transforming U.S. agriculture. *Science*, 332(6030), 670–671. <https://doi.org/10.1126/science.1202462>
- Reisig, D.D., Huseeth, A.S., Bacheler, J.S., Aghaee, M.A., Braswell, L., Burrack, H.J., Flanders, K., Greene, J.K., Herbert, D.A., Jacobson, A. and Paula-Moraes, S.V., 2018. Long-term empirical and observational evidence of practical *Helicoverpa zea* resistance to cotton with pyramided Bt toxins. *Journal of Economic Entomology* 111(4), 1824-1833
- Rhodes, C.J., 2017. The imperative for regenerative agriculture. *Science Progress* 100(1), 80-129.
- Riar, A., Sisodia, B., Keller, C., Patidar, I., Stuerz, S., Goldmann, E., ... & Bhullar, G. S. (2025). Long-term economic and yield comparison of organic and conventional cotton-based production systems with wheat and soybean rotations in central India. *European Journal of Agronomy*, 171, 127814.
- Riar, M., Poswal, R.S., Mandloi, L.S., Messmer, M. M., Bhullar, G.S. 2017. A diagnosis of biophysical and socio-economic factors influencing farmers' choice to adopt organic or conventional farming systems for cotton production. *Frontiers in Plant Science* 8.
- Riddle, J., 2005. The constellation of organic values. The Rodale Institute, Kutztown, Pennsylvania. newfarm.rodaleinstitute.org/features/2005/1105/constellation/riddle.shtml
- Rieple, A., Singh, R., 2010. A value chain analysis of the organic cotton industry: The case of UK retailers and Indian suppliers. *Ecological Economics* 69(11), 2292–2302.
- Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C. Watson, C.A., 2018. Risks and opportunities of increasing yields in organic farming. A review. *Agronomy for Sustainable Development* 38(2), p.14.
- Roy, D., 2010. Of choices and dilemmas: Bt cotton and self-identified organic cotton farmers in Gujarat. *Asian Biotechnology and Development Review* 12(1), 51-79.
- Rozin, P., Spranca, M., Krieger, Z., Neuhaus, R., Surillo, D., Swerdlin, A., Wood, K., 2004. Preference for natural: instrumental and ideational/moral motivations, and the contrast between foods and medicines. *Appetite* 43(2), 147-154.
- Santos, R., & Abreu, M. J. (2025). Impact assessment and product life cycle analysis of different jersey fabrics using conventional, post-industrial, and post-consumer recycled cotton fibers. *Sustainability*, 17(13), 5700.
- Schader, C. et al. (2014). The role of organic farming in a sustainable food system. *Organic Agriculture*.
- Schader, C. et al. (2016). How the organic food system contributes to sustainability. *Sustainability*.
- Schlatter, B., Trávníček, J., Helbing, M., & Willer, H. (2025). Current statistics on organic agriculture worldwide: area, operators, international trade and retail sales. In *The World of Organic Agriculture. Statistics and Emerging Trends 2025* (pp. 32-86). Research Institute of Organic Agriculture FiBL and IFOAM–Organics International.
- Scott, S.E., Inbar, Y., Wirz, C.D., Brossard, D., Rozin, P., 2018. An overview of attitudes toward genetically engineered food. *Annual Review of Nutrition* 38, 459-479.
- Scott, S.E., Inbar, Y., Rozin, P., 2016. Evidence for absolute moral opposition to genetically modified food in the United States. *Perspectives in Psychological Science* 11, 315–324.
- Scott, S.E., Rozin, P., 2020. Actually, natural is neutral. *Nature Human Behaviour* 4(10), 989-990
- Serat, W.F., Van Loon, A.J., Serat, W.H., 1982. Loss of pesticides from patches used in the field as pesticide collectors. *Archives of Environmental Contamination and Toxicology* 11(2), 227-234.
- Seufert, V., & Ramankutty, N. (2017). Many shades of gray—The context-dependent performance of organic agriculture. *Science Advances*, 3 (3), e1602638. <https://doi.org/10.1126/>

- sciadv.1602638
- Seufert, V., Ramankutty, N., & Foley, J. A. (2012). Comparing the yields of organic and conventional agriculture. *Nature*, 485(7397), 229-232.
- Seufert, V., Ramankutty, N., & Foley, J. A. (2018). Comparing the yields of organic and conventional agriculture: Challenges and opportunities for improving organic production. *Agricultural Systems*, 160, 152–160. (Contextual on systemic vulnerabilities and incentives.)
- Seufert, V., Ramankutty, N., & Mayerhofer, T. (2017). What is this thing called organic? –How organic farming is codified in regulations. *Food Policy*, 68, 10-20
- Shah, P., Bansal, A., & Singh, R. K. (2018). Life cycle assessment of organic, BCI and conventional cotton: a comparative study of cotton cultivation practices in India. In *designing sustainable technologies, products and policies: from science to innovation* (pp. 67-77). Cham: Springer International Publishing.
- Shahid, M., Farooq, M. O., Razaq, M., Adnan, M., Zahid, S., Husain, A., & Shah, F. M. (2023). Organic fertility management in cotton *Gossypium hirsutum* L. fosters arthropod biodiversity and complements pest suppression. *Journal of Applied Entomology*, 147(10), 1001-1013.
- Shahid, M., Razaq, M., Farooq, M.O., Adnan, M., Zahid, S., Husain, A., 2022. Organic farming of cotton *Gossypium hirsutum* L. mediates species richness and evenness of generalist predators. *Research Square*. DOI: <https://doi.org/10.21203/rs.3.rs-1520742/v1>
- Sipperly, E., Edinger, K., Teamhy, S., & Jasper, N. (2016). Life Cycle Assessment of conventional and organic cotton cultivation for the production of a t-shirt. *London Journal of Research in Science*.
- Smith-Spangler, C., Brandeau, M. L., Hunter, G. E., Bavinger, J. C., Pearson, M., Eschbach, P. J., ... Bravata, D. M. (2012). Are organic foods safer or healthier than conventional alternatives? *Annals of Internal Medicine*, 157(5), 348–366.
- Smith, O.M., Cohen, A.L., Rieser, C.J., Davis, A.G., Taylor, J.M., Adesanya, A.W., Jones, M.S., Meier, A.R., Reganold, J.P., Orpet, R.J., Northfield, T.D., 2019. Organic farming provides reliable environmental benefits but increases variability in crop yields: A global meta-analysis. *Frontiers in Sustainable Food Systems*, 3, p.82.
- Spink, J., & Moyer, D. C. (2011). Defining the public health threat of food fraud. *Journal of Food Science*, 76(9), R157–R163.
- Stinner, D.H., 2007. "The Science of Organic Farming". In William Lockeretz (ed.). *Organic Farming: An International History*. Oxfordshire, UK & Cambridge, Massachusetts: CAB International (CABI). ISBN 978-1-84593-289-3.
- Stockdale, E.A., Lampkin, N.H., Hovi, M., Keatinge, R., Lennartsson, E.K.M., Macdonald, D.W., Padel, S., Tattersal, F.H., Wolfe, M.S., Watson, C.A., 2000. Agronomic and environmental implications of organic farming systems. *Advances in Agronomy* 70, 261–327.
- Swezey, S.L., Goldman, P., Bryer, J., Nieto, D., 2007. Six-year comparison between organic, IPM and conventional cotton production systems in the Northern San Joaquin Valley, California. *Renewable Agriculture and Food Systems* 22(1), 30-40.
- Textile Exchange. 2022. Organic Cotton Market Report 2022. https://textileexchange.org/app/uploads/2022/10/Textile-Exchange_OCMR_2022.pdf
- Thakor, P.K., 2014. An investigation into the status of pesticide residues and heavy metals in water, soil, vegetables and cotton lint from vegetable and cotton growing area of middle Gujarat (Doctoral dissertation, AAU, Anand).
- Trewavas, A., 2001. Urban myths of organic farming. *Nature* 410, 409–410.
- Tsvetkov, I., Atanassov, A., Vlahova, M., Carlier, L., Christov, N., Lefort, F., Rusanov, K., Badjakov, I., Dincheva, I., Tchamitchian, M., Rakleova, G., 2018. Plant organic farming research –current status and opportunities for future development. *Biotechnology and Biotechnological Equipment*, 32(2), 241-260.
- Tuck, S.L., Winqvist, C., Mota, F., Ahnström, J., Turnbull, L.A., Bengtsson, J., 2014. Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. *Journal of Applied Ecology* 51, 746–755.
- Tzouvelekas, V., Pantzios, C.J., Fotopoulos, C., 2001. Economic efficiency in organic farming: evidence from cotton farms in Viotia, Greece. *Journal of Agricultural and Applied Economics* 33(1), 35-48.
- USDA National Organic Program (NOP). (2023). Organic Certification and Transition Requirements.
- USDA, 2015. <https://www.ams.usda.gov/publications/content/fact-sheet-introduction-organic-practices>.
- van Bruggen, A. H. C., Goss, E. M., Havelaar, A., van Diepeningen, A. D., Finckh, M. R., & Morris, J. G. (2018). One Health—Cycling of diverse microbial communities as a connecting force for soil, plant, animal, human and ecosystem health. *Science of the Total Environment*, 664, 927–937. <https://doi.org/10.1016/j.scitotenv.2019.02.091>
- Van Bueren, E.L., Jones, S.S., Tamm, L., Murphy, K.M., Myers, J.R., Leifert, C., Messmer, M.M., 2011. The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: a review. *NJAS-Wageningen Journal of Life Sciences*, 58(3), 193-205.
- Venugopalan, M.V., Rajendran, T.P., Chandran, P., Goswami, S.N., Challa, O., Damre, P.R., 2010. Comparative evaluation of organic and non-organic cotton (*Gossypium hirsutum*) production systems. *Indian Journal of Agricultural Sciences* 80(4), 287–92
- Westerberg, V., 2017. The economics of conventional and organic cotton production. A case study from the municipality of Banikoara, Benin. *The Economics of Land Degradation Initiative*. https://d1bf23g64f8xve.cloudfront.net/sites/default/files/downloads/best-practices//ELD_Benin.pdf
- Willer, H. et al. (2023). *The World of Organic Agriculture: Statistics and Emerging Trends*. FiBL & IFOAM.
- Willer, H., Lernoud, J., 2015 (eds) *The World of Organic Agriculture: Statistics and Emerging Trends 2015* (FiBL-IFOAM, 2015).
- Willer, H., Schlatter, B., Trávníček, J., (Eds.) 2023. *The World of Organic Agriculture. Statistics and Emerging Trends 2023*. Research Institute of Organic Agriculture FiBL, Frick, and IFOAM – Organics International, Bonn.
- Williamson, S., Ferrigno, S., Vadouhe, S.D., 2005. Needs-based decision-making for cotton problems in Africa: A response to Hillocks. *International Journal of Pest Management* 51(4), 219–224
- Witharanage, K. N., Bosch, C., Graf, S., Kushwah, S., Patidar, S., Birner, R., & Singh, A. (2024). Who benefits from organic cotton? Intersectional labour dynamics of gender, caste and class in Central India. *Hohenheim Working Papers on Social and Institutional Change in Agricultural Development 026-2024*. University of Hohenheim.
- Zongmao, C., Haibin, W., 1997. Degradation of pesticides on plant surfaces and its prediction—a case study on tea plant. *Environmental Monitoring and Assessment* 44(1-3), 303-313.

