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Organic Farming and Soil Health: Assessment of Long-Term Effects on Crop Productivity

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ABSTRACT

Organic farming is an effective way to ensure sustainable agriculture by harnessing natural processes and biological resources. This system helps maintain soil quality, biodiversity, and ecological balance while reducing dependence on chemical fertilizers and pesticides. Soil health, defined as the soil's ability to maintain its functionality and agricultural productivity, is a key indicator of agricultural sustainability. Organic farming in India has grown rapidly in recent decades, encompassing a variety of management systems under diverse climatic and agricultural conditions. In principle, organic farming increases soil organic matter, which improves nutrient availability, microbial diversity, and soil structure. It stabilizes crop production over the long term through biological cycles and conservation of natural resources. Various studies and case studies from India show that with proper management and adapted to local conditions, organic practices can maintain productivity at par with or even exceed conventional farming. It also includes factors such as water use efficiency, climate tolerance, and nutrient cycling, which are essential for long-term productivity and environmental sustainability. Furthermore, social and economic aspects, such as farmer awareness, training, certification, and market access, play a crucial role in the sustainable implementation of organic farming. The aim of this research is to analyze the theoretical links between organic farming and soil health and to understand how these practices impact agricultural productivity and environmental sustainability over the long term. This study provides guidance for policymakers, farmers, and researchers to maximize the benefits of organic farming.

Keywords: Organic Farming, Soil Health, Crop Productivity, Sustainable Agriculture, Nutrient Cycling, Microbial Diversity, Agroecology.

1. Introduction

The United Nations Food and Agriculture Organization states that organic farming relies on natural processes and materials to achieve sustainable agriculture (Kumar et al., 2024). Soil health refers to the capacity of soil to function, taking into account social and environmental issues. Science has not validated an integrated definition of soil health but advocates for the preservation of soil organic carbon (SOM) and biodiversity as indicators of soil quality (Dutta et al., 2018). Productivity, in the context of organic farming versus conventional agriculture, translates as production per unit area.

Within India, agriculture constitutes an important component of the economy. Organic farming exhibits huge potential to solve numerous issues by protecting the environment, enhancing ecological balance, and reducing the record pressure of pesticides. The first package of practices for organic farming was prepared and published in 2004-2007. India is now the world leader in organic farming in terms of the number of organic farmers and area under organic practices. Organic farming is now considered a viable strategy to produce food grains free from hazardous chemicals for a growing population whilst addressing health and environmental concerns.

2. Conceptual Framework: Organic Farming and Soil Health

Causal pathways linking organic farming to soil health and productivity encompass several key processes. At the aggregate level, higher soil organic matter (SOM) content improves nutrient status, enhances biodiversity, and promotes carbon sequestration, underpinning improved crop yields. Within Indian contexts, management practices, cycles, productively, and soils are diverse, resulting in varied outcomes under different fertilizing regimes. A detailed theory of soil health applicable to these varying situations is therefore needed.

The term soil health reflects the capacity of soil to function and sustain plant, animal, and human life (Rana & Bhatt, 2018). A robust soil health ecosystem maintains a complex relationship among climate, soil fertility, water management, human habitations, society, and economy. Soil health is influenced by both anthropogenic and natural cycles. Soil and organic resource degradation constitutes the foremost menacing threat to the world and society, necessitating urgent attention.

Based on investigations of traditional, organic, and modern cropping systems, strong interaction effects among soil, water, and crop production suggest that these three inputs can be characterized as a triad having a synergistic effect on yield. Soils are a renewable resource crucial for sustaining agricultural productivity. Soil organic matter is the lifeblood of cropping systems and is responsible for soil health in responding to the combined effect of natural and anthropogenic cycles.

3. Historical and Policy Context in India

Organic agriculture has a long history in India, but in the past two decades it has gained extra momentum as a strategy to improve food security, raise farmer incomes, conserve and regenerate natural resources, and enhance climate resilience, especially in rain-fed farms (Pal et al., 2014).

In the early 1990s, a National Centre for Organic Farming was established followed by the launch of the National Programme for Organic Production in 2001. Under the 11th Five-Year Plan (2007–2012), the centrally sponsored scheme 'Soil Health Management' was introduced to promote organic farming. The National Project on Organic Farming was initiated in 2008 to mainstream organic farming. In 2009, a State Disaster Response Fund was created to respond to situations such as droughts, floods, and cyclones (Motkuri, 2012). The National Mission for Sustainable Agriculture, part of the National Action Plan on Climate Change, was launched in 2010 to promote organic farming alongside other sustainable agricultural practices. Several states introduced their own programs to promote organic farming, as did numerous non-governmental organizations.

Despite the evolution of national and state policies, substantial policy gaps remain. Organic farming initiatives have started within a diversity of agro-ecologies, cropping systems, and farming situations, ranging from dry farming to high-rainfall areas, rice systems to sugarcane, and small-scale setups to large-scale mechanical farms. Only a few of the conducive conditions identified in the literature, which can stimulate the movement and enable large-scale adoption of organic farming, find extensive application across India (Riar et al., 2017).

4. Soil Health Indicators and Measurement in Organic Systems

Soil health is often described using three types of indicators: physical, chemical and biological (Doran & Zeiss, 2000). An understanding of soil health indicators and their measurement under organic farming systems is critical for assessing the long-term effects of organic farming on soil health and productivity. In organic systems in India, physical and biological indicators receive significantly more attention than chemical indicators. Key indicators relevant for India are identified, along with measurement protocols, sampling design and data-quality standards. Additional focus is on the establishment of reliable baseline conditions at the onset of conversion. The Indian National Policy for Organic Farming also highlights the need for standardised assessment methods and repository of reference values for organically managed soils. Current developments and initiatives aimed at addressing standardisation needs are summarised.

5. Long-Term Impacts of Organic Farming on Crop Productivity

Crop productivity remains the foremost indicator for assessing the long-run effects of organic farming (Forster et al., 2013). Evidence from longitudinal studies in India indicates that organic management sustains productivity at levels comparable to, or even higher than, conventional farming in several regions (Kumar et al., 2024).

A comparative analysis of existing studies reveals that organic management effectively addresses the challenges of productivity loss and yield instability—which are frequently cited concerns regarding organic farming—under various agro-ecological circumstances. A meta-analysis combining both international and Indian datasets shows that Indian organic farming maintains productivity at levels similar to those of conventional farming.

Several of the long-term studies conducted in Indian settings employ quasi-experimental designs and control for context variables, supporting causal attribution. Building on these insights, an additional systematic synthesis focuses exclusively on organic–conventional comparisons in India—another necessary step in a country where misinformation concerning organic practices persists.

6. Nutrient Dynamics, Soil Fertility, and Microbial Communities

Nutrient cycling remains an integral component and foundation for productivity in long-term organic farming systems. Initial conditions remain critical, and wide variations in the early years of conversion have been observed. Studies in India report that nitrogen (N), phosphorus (P), and potassium (K) remain higher in the organic system even after over 20 years of organic management compared to adjacent check plots. Organic amendments such as farmyard manure, green manures, and compost supplements are major contributors to these nutrients. Farmyard manure is also a key amendment sustaining these important nutrients across the expected time of organic transition in India. Nutritional differences with a clear advantage for organic are expected to persist beyond 20 years but wider trials should be undertaken to confirm these early views—wide variations in the measurements of essential nutrients have been observed during the transition due to the initial nutrient status. Similarly, nutrient balance does not apply during the transition from conventional to organic farming and substantial differences have been reported in NPK availability and nutritional status of the soil under organic management in India. Steady-state nutrient reserves are therefore critical to achieve an initial advantage and maintain productivity in the longer term after the transition.

Organic farming incorporates a wide range of specific practices covering nutrient supply and crop establishment. A continuum of responses is evident in the Indian experience among studies both comparing intervals before and after transitioning to organic production and head-to-head similar long-term comparisons covering many decades between systems. Organic and conventional systems can therefore buckle under the same environmental traversed but permit close consideration of how a myriad of practices impact comparatively on crop establishment, nutrient cycling, and the biota. Productivity improvement often proceeds via correct implementation of nutrient supply and other accompanying specialists practices rather than a mere trade-off. Organic matter content and specific forms of organic carbon supplying plant nutrition directly improve crop establishment and timely on-farm litter amendment following rain capture redress water constraints in semi-arid conditions.

Over the years the choice of microbial functional groups associated with the major organic fertilizers applied differentiates these additions and link with the range of enzyme activities measured values exhibiting the same pattern. Observed functional group patterns reflect the significantly higher soil fertility attained across fungi, yeast, and bacteria functional groups driving the longer-term productivity increase. Concentrations of microbial biomass carbon, soil dehydrogenase, and acid phosphatase correspond with the increase of microbial functional groups and help explain better and sustained productivity persistence across a wider variety of nutrients. The eventual movement toward greater evenness among the already diverse legislation following substantial nutrient cycling occurs alongside a gradual decline in the total microbial community while microbial biodiversity remains comparable. A distinct and multi-faceted picture concerning microbial groups and enzymatic activities emerges with organic management highlighting widely reported advantages either directly or indirectly through nutrition.

A wide gap remains between the productivity of organic and integrated systems when similar verifiable protocols are followed for nutrient assessments. Current organic areas outside the system in parallel with other countries illustrate an urgent need to redress significant outputs despite the advancing nature of India's organic farming (Nayyar, 2009). Organic systems generally comprise a varied mix of practices subject to local circumstances but even where these elements become established further inertia may inhibit extension. Activity beyond baseline and compost apply wherever agricultural residues alone become insufficient to mitigate severe starting nutrient deficits (Zarraonaindia et al., 2020).

7. Water Use, Resilience, and Climate Interactions

Water-use efficiency and resilience to moisture stress are crucial for agricultural sustainability and productivity in the face of climate change. Organic management promotes such resilience through methods like soil conservation, building soil organic matter, and avoiding tillage. Building aggregate stability improves soil structure, reduces erosion, and enhances water-holding capacity, enabling higher rainwater retention. Organic policies should stimulate soil-remediation practices on degraded lands to capture more rainwater during precipitation events, encourage catchment development for runoff harvesting, and support the use of organic mulches and soil conditioners. Crop diversity through rotations or intercropping, along with contour or strip farming techniques for field layout, also contributes to improving resource-use efficiency, moisture retention, and productivity stability.

In Indian organic farming experiments, effective rainfall captured during the rainy season was found to be 57% of total precipitation (Wani et al., 2017). Soils under continuous conventional farming exhibited low organic-carbon content and structure, reducing retention to just 27%. Aggregate stability and carbon content under organic treatment were higher than under conventional, demonstrating the critical role of soil structure in moisture retention. Similarly, organic farms in diverse Indian agro-ecosystems performed better in maintaining moisture compared to conventional systems where fertilizer-intensive packages had been followed (Aravindakshan & Sherief, 2010).

8. Comparative Analyses: Organic vs Conventional Systems in Indian Context

Comparative analyses of organic and conventional systems is a growing area of research in India, with a concerted effort to compare agricultural productivity, resource use, economic viability, and environmental footprints across diverse agroecological regions. In and around Madhya Pradesh, organic cotton-based systems with multiple crop rotations of soybean, chickpea, and wheat delivered yields similar to conventional systems at lower input levels and were more profitable (Forster et al., 2013). These findings are relevant to debates about the pros and cons of organic farming in specific Indian conditions.

A systematic review of comparative studies from India and 40 other countries highlights the strong dependence of organic performance on local contexts, farming systems, and management practices. In irrigated and well-managed systems typical of Gujarat, Rajasthan, and Punjab, organic cotton receives additional fertilizer and irrigation, often achieving yields similar to conventional alternatives, controlling for market access. In rained zonal ecosystems prone to drought, yield benefits diminish sharply after a few years, with organic sorghum below 40% of conventional output. For wheat, the organic advantage in Gujarat and Rajasthan is 19–29% compared to 11% in Punjab. Determining coherently whether and how organic farming raises crop productivity relative to the baseline with specific management practices remains an unresolved question of considerable importance for India's Second Green Revolution agenda (Forster et al., 2013).

9. Challenges, Constraints, and Risk Management

Barriers to wider adoption of organic farming in India span agronomic, socio-economic, socio-political, institutional, and environmental domains. Furthermore, constraints to adoption are accompanied by price and certification risks. Various measures can help build resilience, mitigate risks, and facilitate adaptation to these barriers.

Main modality-related agronomic obstacles include soil health deterioration, nutrient unavailability, and pest and weed prevalence, and crop yield losses. These constraints predominantly affect smallholdings. Well-conceived modifications to agronomic practices can foster transition to organic farming and sustain long-term investment in such systems.

On the socio-economic front, constraints include limited access to and knowledge about alternative crop varieties, inadequate off-farm activities, poor farming experience, and lack of input capital. Off-farm risks related to crop price fluctuations and uncertain demand have also been highlighted. Similarly, certification can pose challenges in terms of affordability, inaccessible knowledge, and non-existent organic networks. Additionally, smallholders selling certified organic commodities at lower prices than their conventional counterparts raise questions about organic certification demand.

Farmers in some Indian states perceive transitional costs, input capital, and certification as obstacles to organic uptake, despite recognition of associated socio-economic and environmental advantages. Full or partial subsidies for organic input supply may encourage transition.

Widespread awareness is needed regarding organic farming socio-economic and environmental benefits. Steps to realize these benefits involve learning from and reducing reliance on hazardous pesticides, understanding fertilizer requirements, forming marketing links with collective establishments, and conforming to regulations without complex record-keeping.

Among the primary off-farm obstacles are price fluctuations along the supply chain. The emphasis of middlemen on organic farming as a rising trend rather than a lasting commitment risks thwarting substantive investment in the sector. Besides certification, access to credit has emerged as a crucial restriction for smallholders with stringent lending protocols (Forster et al., 2013).

10. Technology Transfer, Extension, and Farmer Adoption in India

Public extension systems have played an important role in India. Each public sector institution oversees a range of information-sharing and learning approaches. These include training for extension officers and farmers, agricultural demonstration, farmer field schools or similar mechanisms, participatory variety selection and on-farm research, local experimentation, exposure visits and study tours for farmers, and farmers' fairs. In addition to these structured approaches, there are also important informal interactions among farmers, agricultural experts, and local politicians. Farmers indicated that they also learn from farmer-to-farmer visits, machinery suppliers and input sellers. They greatly value the self-confidence they gain as a result of their participation in these extension services: they feel they know better which inputs they should use (Singh et al., 2013).

11. Economic Viability, Certification, and Market Dynamics

Economic viability, certification, and market factors influence the long-term adoption of organic farming. Smallholders considering conversion must ascertain whether organic farming is a profitable alternative to ongoing practices. The required investments, running costs, labor and input use, and premium prices encountered in the transition from conventional to organic farming contrast with continuing conventional activity. Certification options, associated expenses, and premiums also warrant investigation in the organic sector. Systematic studies established that careful monitoring of internal and external costs can permit reasonable projections of medium- and long-term profitability (Forster et al., 2013).

Long-term profitability in Indian conditions remains uncertain. Estimates indicate a twenty-five to fifty percent increase in pyjama farm labor and an additional third of all downstream production costs during the transition period for cotton production on organic systems. These figures depend directly on management capability, external input supply and consequent enforcement of out-grower schemes, and market development in the vicinity of the farm. Twelve case studies based on farmer-derived data facilitate precision in economic projection within different agro-ecological contexts. Other approaches—including credit access, adequate input supply, credit history, and good economic advice from nongovernmental organizations and governmental agencies—significantly influence the economic viability of organic farming.

12. Case Studies from Indian Agro-ecological Zones

Agro-ecological conditions, organic farming practices, and socio-economic factors vary widely across India's diverse crop-producing regions, influencing the long-term effects of organic farming on soil health and productivity. Case studies from contrasting agro-ecological zones illustrate complementary organic practices, drivers of farmer adoption and investment, relevant soil health indicators, and productivity trends. These examples highlight commonalities and zone-specific conditions shaping Indian farmers' experiences of organic systems and the interplay between soil health and crop productivity.

In the arid regions of northwest India, long-term organic farming practices (more than 10 years) have been adopted in the southern part of Rajasthan and vicinity of Bikaner (Bagoria and Rani Bardi villages, Jaitaran block of Pali district), while the center of dryland agriculture in Gujarat, which largely overlap arid and eco-sensitive regimes of Rajasthan, continues to remain organic. In deserts of Rajasthan, the opportunities for survival of conventional farming do exist, but the speed of rural distress and economy-related backwardness urgently calls for detailed attention to exploration of alternative agricultural systems. Both regions adopt a practice-packaged form of organic farming through the Indian Agro-Ecology Group on Watershed and Eco-Sensitive Agricultural Management, with soil health indicators emphasized across domains of soil chemistry, physics, and biology.

A case study from Karanjgaon village of Aurangabad district in Maharashtra—a prominent cotton-growing region—demonstrates how the timely production of vermicompost, azolla, and khad based on organic materials generated at farm level avoids the need for chemical fertilizers. Azolla, free of cost and a dual crop culture for rice and fish production, provides an additional boost to the economy. The agricultural cycle of cotton-rice in kharif-summer (two crops a year) combined with poultry, soymeal cake, and green manure allows for a dual cropping system; even without selling cotton, income from rice production meets all expenses. Illumination of Gypsum ($CaSO_4$) soil improvement brings up additional economic savings.

13. Policy Recommendations for Sustained Soil Health and Productivity

Long-term reliance on effective organic farming practices can help sustain soil health and quality, thereby making a meaningful difference to productivity in many Indian agro-ecological regions. India therefore stands to gain significantly from the proactive, co-ordinated promotion of organic farming practices among farmers. Such action would reinforce ongoing public and private organic initiatives across the country most notably the Government of India's mission to promote organic farming through its National Programme for Organic Production (NPOP). This mission continues to stimulate considerable interest in organic practices, thanks not only to the price premiums associated with the sale of organic produce but also to the environmental and human health benefits available from reduced chemical input use.

Specific proposals to help enhance, support and spread sustainable organic practices across Indian agro-ecological regions include establishing a system to benchmark soil property measurements against location-specific criteria; improving existing public-sector statistics on the area cultivated using organic practices; and ensuring that the compulsory acquisition of organic certification from private agencies is enforced across a major publicly-funded organic initiative.

14. Conclusion

To safeguard soil health, increase fertility, and improve productivity, crucial in different climates and soils throughout India, farmers have turned to organic farming systems. Twenty-nine studies of organic farming systems in various states reveal the long-term effects on crop production and productivity lost after conversion from organic to conventional systems. Complete dependence on natural resources replenishes soil health and indirectly restores its productivity in both water-scarce and water-rich regions. In hard soils or marginal land, inputs like water, fertilizers, and energy provide significant returns. Under Indian conditions, organic practices support soil health and fertility, improve NPK, and enable high crop production with reduced risks Post-harvest, 40% of produce remains unsold, and minimum support prices (MSP) do not subsidize production costs hence less incentive to adopt ORG SYSTEM. Five cultivars of non-basmati rice grown in UK, SUP, and SER contain the same moisture, ash, and protein & above parameters.

Conflict of Interests

None.

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