

**Indian Farmer**

Volume 13, Issue 10, 2026, Pp. 521-528

Available online at: www.indianfarmer.net

ISSN: 2394-1227 (Online)

Popular Article

Strengthening Environmental Sustainability of Punjab's Rice–Wheat System through Soil Health Management

Ayushi Pal¹ and Shivani Jha²*Department of Extension Education, Punjab Agricultural University, Ludhiana – 141004, Punjab***Corresponding Author: drayushipal@gmail.com**Received: 19/09/2026**Accepted on: 01/10/2026***ABSTRACT**

The rice–wheat cropping system has been the backbone of Punjab agriculture and a major contributor to India's food security for several decades. The system occupies nearly 80 per cent of the cultivated area in Punjab and contributes significantly to the central food grain pool. However, continuous intensive cultivation, excessive groundwater extraction, imbalanced fertilizer application and residue burning have resulted in declining soil fertility, deterioration of soil structure and environmental degradation. Declining soil organic carbon, nutrient imbalance and groundwater depletion have emerged as major sustainability concerns in the state. Soil health management practices such as soil testing–based nutrient management, crop residue recycling, conservation agriculture, balanced fertilization and efficient irrigation technologies provide sustainable solutions to these challenges. These practices improve soil physical, chemical and biological properties while reducing environmental pollution and conserving natural resources. Adoption of soil health–based practices can enhance climate resilience, improve resource-use efficiency and support long-term sustainability of Punjab's rice–wheat production system. The article highlights the importance of integrated soil health management in strengthening environmental sustainability and climate-smart agriculture in Punjab.

Keywords: Balanced fertilization; Climate resilience; Resource conservation; Soil organic carbon; Sustainable intensification; Water management

INTRODUCTION

The rice–wheat cropping system occupies a dominant position in Punjab agriculture and plays a vital role in ensuring national food security. Since the Green Revolution, the system has been characterized by intensive cultivation, assured irrigation and extensive use of chemical fertilizers. These interventions significantly increased food grain production and transformed Punjab into one of the leading agricultural states of India. However, continuous monocropping and excessive dependence on external inputs have placed severe pressure on soil and water resources. Continuous cultivation of rice and wheat has led to degradation of soil structure, decline in soil organic matter and depletion of groundwater resources. Punjab is witnessing rapid groundwater decline due to excessive irrigation requirements of paddy cultivation. In addition, excessive and imbalanced

fertilizer use has disturbed soil nutrient balance and reduced fertilizer-use efficiency. Crop residue burning, commonly practiced for timely wheat sowing, contributes to nutrient loss, greenhouse gas emissions and severe air pollution. Climate variability and increasing environmental concerns have further emphasized the need for sustainable agricultural practices. In this context, soil health management has emerged as an important strategy for balancing productivity with environmental sustainability. Improving soil health not only sustains crop productivity but also enhances resilience against climatic stress, improves nutrient cycling and conserves natural resources.

Soil Health Challenges in Punjab's Rice-Wheat System

The sustainability of Punjab's rice-wheat system is increasingly threatened by deterioration of soil health and overexploitation of natural resources.

Nutrient Imbalance and Soil Fertility Decline

Excessive and imbalanced use of fertilizers, particularly nitrogenous fertilizers, has disturbed soil nutrient balance in Punjab soils. Deficiencies of secondary and micronutrients such as sulphur, zinc and iron are increasingly being reported in intensively cultivated areas. Declining nutrient-use efficiency has also increased production costs and environmental risks.

Declining Soil Organic Carbon

Soil organic carbon is a critical indicator of soil health because it influences nutrient availability, microbial activity and water-holding capacity. Continuous removal or burning of crop residues and limited organic matter addition have caused a steady decline in soil organic carbon levels in Punjab's agricultural soils.

Soil Physical Degradation

Repeated puddling during rice cultivation adversely affects soil structure and reduces permeability. Intensive tillage operations in wheat cultivation further reduce soil aggregation and porosity, leading to poor soil physical condition.

Groundwater Depletion

Rice cultivation requires large quantities of irrigation water, resulting in excessive groundwater extraction. The water table in several districts of Punjab has declined rapidly over the years, creating concerns regarding long-term water security and energy consumption.

Crop Residue Burning

Crop residue burning remains a major environmental issue in Punjab. Burning residues causes nutrient loss, destroys beneficial soil microorganisms and contributes to severe air pollution and greenhouse gas emissions.

Soil Health Management as a Sustainable Solution

Soil health management aims to maintain and enhance the physical, chemical and biological properties of soil for sustainable crop production. Rather than relying solely on external inputs, this approach emphasizes efficient resource use, recycling of organic materials and site-specific management practices.

Adoption of soil health management practices in the rice–wheat system not only improves crop productivity but also reduces environmental pressure and enhances resilience to climatic stress. Integrated soil health management supports efficient nutrient cycling, improves soil organic carbon and promotes long-term sustainability. The interlinkages between soil health management practices, soil processes and sustainability outcomes in the rice–wheat system are illustrated in Figure 1. The framework highlights that adoption of soil health–based practices improves soil physical, chemical and biological properties, leading to efficient use of nutrients and water, reduced input losses and a lower environmental footprint.

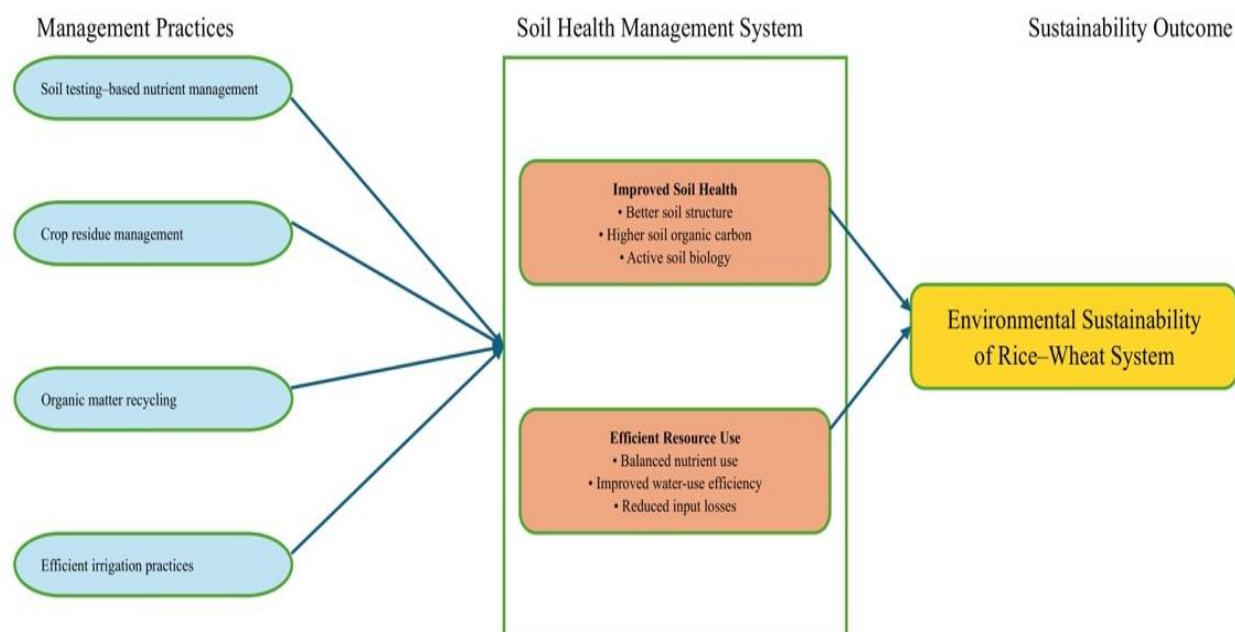


Figure 1: Soil health management framework for sustainable rice–wheat system

Key Soil Health Management Practices in the Rice–Wheat System

Soil Testing–Based Nutrient Management

Soil testing helps farmers apply fertilizers according to crop requirements and existing soil nutrient status. Balanced fertilization based on soil test recommendations improves fertilizer-use efficiency, reduces input costs and minimizes nutrient losses through leaching and volatilization. Site-specific nutrient management also helps maintain soil fertility and prevents excessive use of chemical fertilizers. Farmers adopting soil test–based nutrient management have reported improved crop growth and better soil fertility status.

Organic Matter Recycling

Declining soil organic carbon is a major issue in intensively cultivated rice–wheat systems. Incorporation of farmyard manure, compost, green manure and crop residues improves soil organic matter content, water-holding capacity and microbial activity. Recycling organic matter enhances

nutrient cycling, improves soil aggregation and supports beneficial soil microorganisms. Long-term addition of organic materials also improves soil resilience against climatic stress.

Crop Residue Management

Crop residues should be viewed as valuable resources rather than waste materials. In-situ residue management and mulching practices improve soil fertility, conserve moisture and reduce soil erosion. Avoiding residue burning minimizes environmental pollution and conserves essential nutrients present in crop residues. Farmers adopting residue incorporation practices have reported gradual improvement in soil quality and crop establishment.

Conservation Agriculture Practices

Conservation agriculture practices such as zero tillage, Happy Seeder technology and direct seeded rice (DSR) are increasingly being promoted in Punjab. These technologies reduce soil disturbance, conserve soil moisture and improve soil structure. Zero tillage reduces fuel consumption and production costs, while Happy Seeder technology enables wheat sowing without burning rice residues. Direct seeded rice reduces water requirement and labour costs compared to conventional transplanted rice cultivation.

Efficient Water Management

Efficient water management is essential for sustaining Punjab's rice-wheat system. Practices such as laser land levelling, alternate wetting and drying and improved irrigation scheduling help optimize water use and reduce groundwater extraction. Efficient irrigation practices also reduce energy consumption and enhance water productivity. Improved water management contributes significantly to sustainable intensification of the rice-wheat system.

Climate Resilience through Soil Health Management

Healthy soils improve resilience against drought, heat stress and erratic rainfall by enhancing water retention, nutrient buffering and biological activity. Soil organic carbon acts as an important indicator of climate-smart agriculture because it supports carbon sequestration and reduces greenhouse gas emissions from agricultural systems. Soil health-based practices such as residue retention, balanced nutrient management and conservation tillage improve soil resilience and help crops withstand climatic variability. These practices also contribute to mitigation of climate change by improving carbon sequestration and reducing environmental pollution.

Integrated Benefits Of Soil Health Management Practices

Field-level experiences indicate that soil health management practices provide multiple agronomic, economic and environmental benefits. Improved soil structure and organic matter content enhance nutrient availability and root growth. Balanced nutrient management leads to better crop vigour and yield stability. Reduction in fertilizer and water use lowers production costs and environmental load. Improved soil biological activity enhances nutrient cycling and soil resilience. Together, these benefits contribute to sustainable intensification of the rice-wheat cropping system. The major agronomic and environmental benefits associated with adoption of soil health management practices in the rice-wheat cropping system are summarized in Figure 2. It presents a matrix-style mapping between

major soil health management practices and their associated agronomic and environmental benefits in the rice–wheat cropping system.

Matrix-style infographic: Soil health management practices and benefits

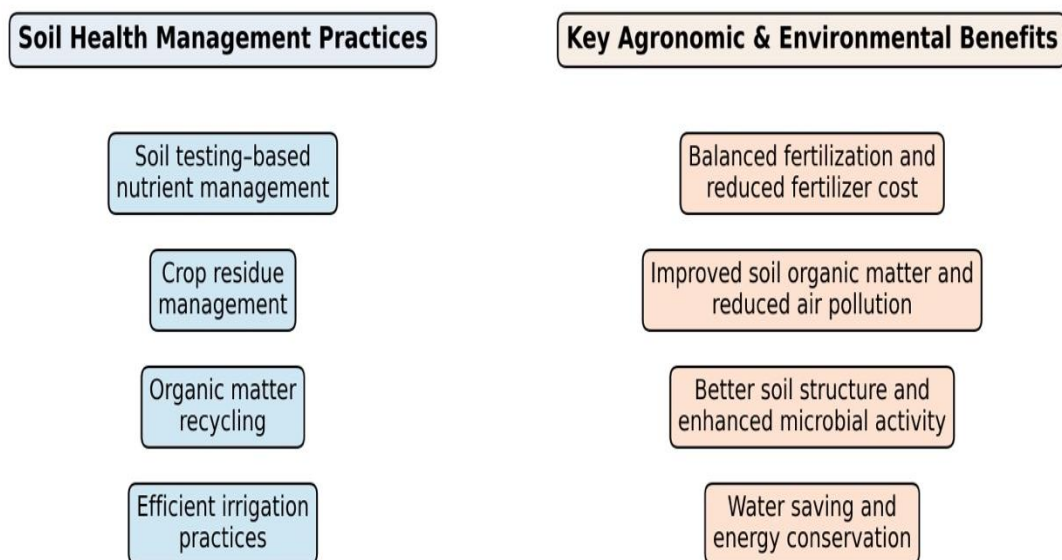


Figure 2. Practice–benefit matrix of soil health management

The visual highlights that practices such as soil testing–based nutrient management, crop residue management, organic matter recycling and efficient irrigation contribute to improved soil quality, efficient resource use and reduced environmental pollution, thereby supporting sustainable rice–wheat production.

Major Soil Health Management Practices and Their Benefits

The information in Table 1 presents the important soil health management practices adopted in Punjab’s rice–wheat cropping system along with their major agronomic and environmental benefits. The table highlights that soil testing–based nutrient management helps ensure balanced fertilizer application and improves nutrient-use efficiency, thereby reducing unnecessary fertilizer consumption and environmental losses. Crop residue incorporation enhances soil organic carbon and promotes nutrient recycling, while application of organic manures improves microbial activity and overall soil fertility. The table further indicates that water-saving technologies such as laser land levelling and alternate wetting and drying contribute to efficient irrigation management and reduction in groundwater extraction. Conservation agriculture practices like zero tillage reduce fuel consumption and improve soil structure by minimizing soil disturbance. Happy Seeder technology enables effective residue management without burning crop residues, thereby reducing air pollution and conserving soil nutrients. Green manuring also contributes to improved soil fertility through addition of organic matter and biological nitrogen fixation. Overall, the practices presented in Table 1 collectively support sustainable intensification, resource conservation and environmental sustainability in Punjab’s rice–wheat production system.

Table 1. Major Soil Health Management Practices and Their Benefits

Soil Health Practice	Major Benefit
Soil testing-based nutrient management	Balanced fertilizer use and improved nutrient efficiency
Crop residue incorporation	Improved soil organic carbon and nutrient recycling
Organic manure application	Enhanced microbial activity and soil fertility
Laser land levelling	Water saving and uniform irrigation
Alternate wetting and drying	Reduced groundwater extraction
Zero tillage	Reduced fuel use and improved soil structure
Happy Seeder technology	Residue management without burning
Green manuring	Improved soil fertility and nitrogen addition

Linking Soil Health Management with Environmental Sustainability

Soil health management directly contributes to environmental sustainability through conservation of soil and water resources, reduction in pollution and improvement of ecosystem services. Improved soil organic carbon enhances carbon sequestration and helps mitigate climate change impacts. Efficient nutrient and water management reduces greenhouse gas emissions and minimizes nutrient losses to the environment. Reduced residue burning lowers air pollution and conserves nutrients present in crop residues. Conservation agriculture practices also improve biodiversity and soil biological activity. Soil health-based practices therefore support environmentally responsible agriculture and long-term sustainability goals.

Role of Extension Services in Promoting Soil Health Management

Extension agencies play a critical role in promoting soil health management through demonstrations, farmer field schools, awareness campaigns and capacity-building programs. Training programs on soil testing, balanced fertilization, residue management and water-saving technologies can improve farmer awareness regarding sustainable agricultural practices. Participatory extension approaches and digital advisories can further accelerate adoption of soil health management practices. Custom hiring centres and cooperative models can also help small and marginal farmers access machinery such as Happy Seeders and laser land levellers at affordable costs.

Challenges in Adoption and the Way Forward

Despite their benefits, adoption of soil health management practices remains uneven due to limited awareness, lack of technical guidance and high initial cost of machinery. Small landholdings, inadequate access to quality organic inputs and delayed availability of residue management machinery also restrict adoption. Strengthening extension services, organizing farmer training programs and promoting custom hiring centres can encourage wider adoption. Policy support and incentive-based programs for soil testing, residue management and efficient irrigation are also necessary. Collaborative efforts involving farmers, researchers, extension personnel and

policymakers are essential for mainstreaming soil health management in Punjab agriculture. Greater emphasis on crop diversification, climate-smart agriculture and resource conservation technologies will further strengthen sustainability of the rice–wheat system.

CONCLUSION

The rice–wheat cropping system of Punjab faces serious sustainability challenges due to soil degradation, groundwater depletion and environmental stress. Soil health management practices offer practical and environmentally sustainable solutions for restoring soil fertility and conserving natural resources. Adoption of balanced nutrient management, organic matter recycling, crop residue management, conservation agriculture and efficient irrigation technologies can improve productivity while reducing environmental impacts. These practices enhance soil quality, improve resource-use efficiency and strengthen climate resilience in agricultural systems. Strengthening farmer awareness, extension support and policy interventions will play a key role in promoting sustainable and resilient rice–wheat production systems in Punjab. Integrated soil health management is therefore essential for ensuring long-term agricultural sustainability and environmental protection.

REFERENCES

- Bhatt, R. and Kukal, S. S. (2018). Soil organic carbon and aggregate stability as affected by tillage in rice–wheat systems. *Soil Use and Management*, 34: 525–532.
- FAO. (2023). *Soil Health and Sustainable Crop Production Guidelines*. Food and Agriculture Organization of the United Nations.
- Gupta, R. K. and Seth, A. (2007). A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the Indo-Gangetic Plains. *Crop Protection*, 26: 436–447.
- Humphreys, E., Kukal, S. S., Christen, E. W., Hira, G. S., Singh, B., Yadav, S. and Sharma, R. K. (2010). Halting the groundwater decline in north-west India. *Current Science*, 98(5): 633–640.
- Indian Council of Agricultural Research. (2021). *Conservation Agriculture for Sustainable Farming in India*. ICAR, New Delhi.
- Jat, M. L., Gathala, M. K., Saharawat, Y. S., Tetarwal, J. P., Gupta, R. and Singh, Y. (2009). Evaluation of precision land levelling and double zero-till systems in rice–wheat rotation. *Soil and Tillage Research*, 105: 112–121.
- Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7: 5875–5895.
- Punjab Agricultural University. (2022). *Package of Practices for Crops of Punjab: Kharif and Rabi*. Ludhiana, Punjab.
- Sidhu, H. S., Singh, M., Humphreys, E., Singh, Y., Singh, B., Dhillon, S. S., Blackwell, J., Bector, V., Singh, M. and Singh, S. (2007). The Happy Seeder enables direct drilling of wheat into rice stubble. *Australian Journal of Experimental Agriculture*, 47: 844–854.

- Singh, Y., Bijay-Singh and Timsina, J. (2005). Crop residue management for nutrient cycling and improving soil productivity in rice–wheat systems. *Advances in Agronomy*, 85: 269–407.
- Yadav, R. L., Dwivedi, B. S., Prasad, K., Tomar, O. K., Shurpali, N. J. and Pandey, P. S. (2000). Yield trends and changes in soil organic carbon and available NPK in a long-term rice–wheat system under integrated use of manures and fertilizers. *Field Crops Research*, 68: 219–246.