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Climate-Resilient Agriculture in Punjab: Role of Sustainable Cropping Systems in Adapting to Climate Change

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Climate change is no longer a distant environmental concern discussed only in scientific reports. It has entered the field, the irrigation schedule, and the crop calendar. Farmers now increasingly deal with delayed monsoon onset, sudden dry intervals, rising temperature during flowering and grain filling, shorter winters, and changing pest behaviour. These shifts are affecting how crops establish, how nutrients are absorbed, and how much water is needed to maintain yield. Under these conditions, sustainable cropping systems are emerging as one of the most practical ways to protect agricultural productivity while conserving natural resources. In Punjab, where intensive rice–wheat cultivation once defined agricultural success, future resilience now depends on crop diversification, conservation agriculture, residue management, and biologically balanced crop planning. Sustainable cropping systems therefore represent not simply an environmental choice, but a practical strategy for maintaining agricultural continuity under climate uncertainty.

Keywords: Sustainable cropping, Irrigation schedule, Productivity, Crop diversification, Natural resources

Introduction

The first signs of climate change in agriculture rarely arrive dramatically. More often, they appear through small changes that repeat across seasons. A wheat crop matures a little earlier because March temperatures rise unexpectedly. Rice demands one additional irrigation because rainfall pauses at a critical stage. Pest outbreaks begin appearing outside their usual seasonal window. For many farmers, these changes now feel familiar enough to be routine, yet together they reveal a deeper shift in how agriculture must function.

For decades, Indian farming depended on seasonal predictability. Farmers planned sowing and harvesting around patterns that remained broadly stable over generations. That reliability has weakened. Rainfall now often arrives late or falls intensely over a short period rather than spreading evenly. Heat waves appear during reproductive stages that were once cooler. Winter periods in north India often shorten before wheat has fully completed grain filling. The Intergovernmental Panel on Climate Change explains that South Asian agriculture remains highly climate-sensitive because crop performance depends directly on closely linked interactions between temperature, water availability, and soil processes (IPCC, 2019).

Punjab offers one of the clearest examples of why climate resilience can no longer remain a theoretical discussion. The state still records one of the highest cropping intensities in India, but this intensity now operates under increasing ecological pressure. Recent field observations indicate that although fertilizer consumption has shown moderation under balanced nutrient-use initiatives, groundwater pressure and soil fatigue remain major concerns in rice–wheat districts. At the same time, gradual improvement in soil organic carbon under sustainable field practices suggests that corrective management is already producing measurable results. This means resilience is not merely a future goal; it is already visible where cropping systems are adjusted scientifically.

When the Cropping System Becomes More Important Than the Single Crop

A single crop may perform well in one season and struggle in the next when climate becomes uncertain. A cropping system behaves differently because it influences how the field responds across many seasons rather than one harvest alone. It shapes how roots occupy soil layers, how residues return to the field, how nutrients move through biological cycles, and how water remains available during stress periods. When the same cereal crop dominates continuously, the field gradually loses flexibility. Similar roots repeatedly remove nutrients from the same depth, similar residues return season after season, and microbial diversity narrows. Soil becomes denser, infiltration slows, and irrigation efficiency gradually weakens. Research across the Indo-Gangetic Plains has shown that cereal monocropping reduces long-term resource-use efficiency unless crop diversity is introduced through pulses, fodder crops, oilseeds, or alternate cereals (Ladha et al., 2009). This is why sustainable cropping systems are increasingly central to climate adaptation. They strengthen resilience not through one dramatic intervention, but through repeated ecological correction over time.

Figure 1. Residue-retained wheat and diversified kharif fields in Punjab show how soil protection and crop diversity improve resilience under climatic variability.

Punjab's Rice–Wheat System: A Success That Now Needs Redesign

Punjab's rice–wheat system transformed India's food economy, but its ecological cost has become increasingly visible in long-term field observations. Years of puddled rice followed by repeated wheat tillage have slowly changed how Punjab soils behave, making them denser, less porous, and more dependent on careful water management. Groundwater withdrawal has intensified because irrigation increasingly compensates for irregular rainfall. A long-duration soil evaluation led by Punjab agricultural scientists showed that diversified systems involving maize, basmati rice, cowpea, mungbean, and berseem improved soil porosity, hydraulic conductivity, and soil quality index significantly compared with continuous rice–wheat fields. One of the most important findings was that diversified systems improved field response during dry spells because organic matter remained more active under varied crop residues. This gives diversification practical value far beyond yield alone.Cropping system diversification enhances soil biological activity and ecosystem stability..

Diversification: Small Changes That Create Large Stability

Crop diversification often begins as a practical adjustment, but its long-term effects are ecological. A maize field behaves differently from a paddy field. A pulse crop leaves behind a different biological environment than a cereal crop. Each crop introduced into a sequence changes nutrient behaviour, root interaction, and residue quality. That is why diversification acts like natural climate insurance. If one crop suffers under heat stress or uneven rainfall, another may still perform reasonably well, reducing total production risk. In Punjab, summer mungbean has become increasingly important because it fits naturally between wheat harvest and rice establishment. Although short in duration, it contributes significantly to nitrogen dynamics through root-associated biological fixation. Punjab Agricultural University repeatedly recommends mungbean inclusion because farmers often observe improved soil tilth and better nutrient response in the following crop. Research by Ahlawat and colleagues confirmed that pulse integration improves nutrient efficiency and strengthens cropping system productivity under variable moisture conditions (Ahlawat et al., 2005).

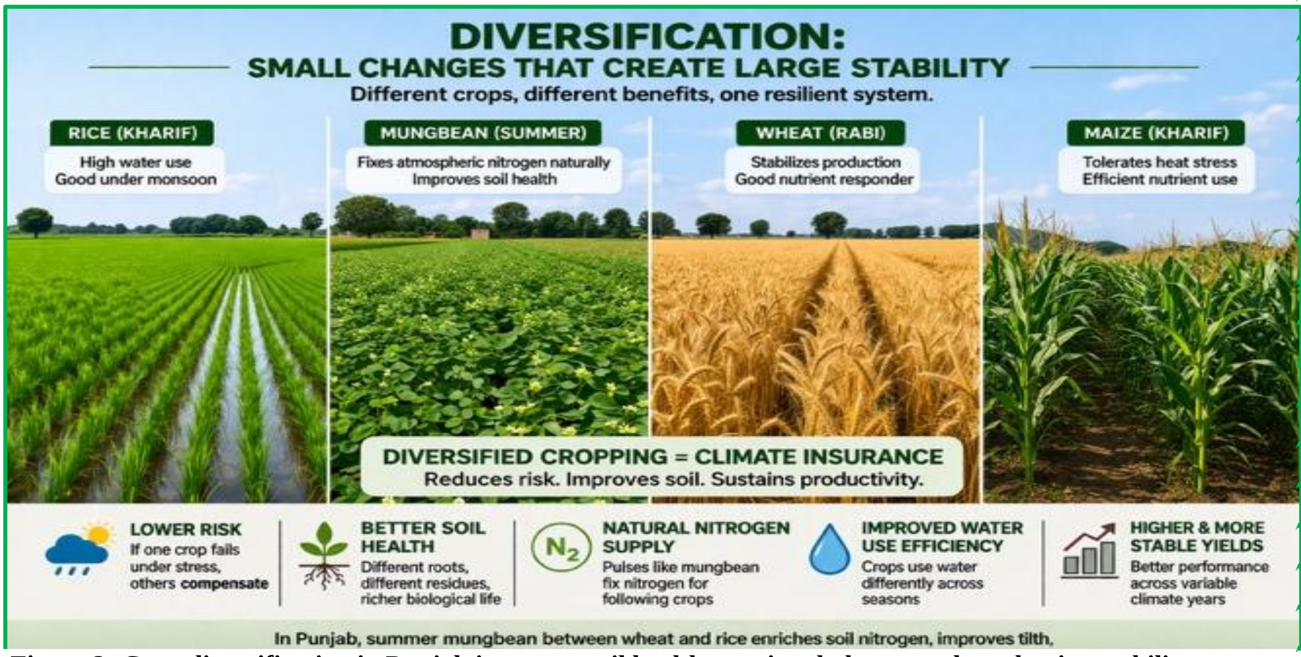

Figure 2: Crop diversification in Punjab improves soil health, nutrient balance, and production stability under variable climatic conditions

Conservation Agriculture: Reducing Disturbance to Build Stability

Conservation agriculture is often introduced through reduced tillage, residue retention, and crop rotation, but its real strength lies in how these principles gradually change soil behaviour. In Punjab, zero till wheat after rice has become especially valuable because it shortens the gap between crops and allows earlier wheat establishment. This matters because delayed sowing increasingly exposes wheat to terminal heat during grain filling. Fields under zero tillage often retain better aggregate stability because the soil is not repeatedly broken apart during land preparation. Root channels from the previous crop remain partly intact, helping water move more effectively into the soil profile. Recent work on sustainable intensification under conservation agriculture has shown that reduced tillage combined with improved crop sequencing increases wheat productivity while lowering energy use and production cost. This becomes especially important under climate stress because reduced soil disturbance preserves pore continuity, improves infiltration during sudden rainfall, and reduces crust formation after irrigation. In practical terms, a field managed under conservation agriculture often becomes easier to manage when weather remains uncertain because the soil responds more steadily to both moisture and temperature variation (Kumar et al., 2024).

Figure 3: Residue retention conserves moisture, supports soil biology, and improves crop establishment, while burning causes biomass and nutrient loss.

Flowchart: how sustainable cropping systems build climate resilience

Climate variability increases across seasons
↓
Conventional monocropping faces higher ecological stress
↓
Diversified sustainable cropping systems introduced
↓
Residue retention + legumes + reduced tillage
↓
Improved soil function and moisture stability
↓
Stable productivity under climate uncertainty

Residue Management: The Field Should Keep What the Crop Leaves Behind

For many years, residue after rice harvest was treated mainly as a management burden because farmers needed quick field preparation before wheat sowing. Burning appeared fast, but its long-term agronomic cost became increasingly clear. When residue remains on the field, it creates a protective layer between soil and atmosphere. This cover reduces direct heating of exposed soil and helps maintain a more moderate temperature near the surface, where germination begins. Residue also slows evaporation because it reduces direct contact between moving air and moist soil particles. Moisture therefore remains available for longer periods, which supports more uniform crop establishment after sowing. As decomposition begins, residue becomes a food source for microbial communities. Bacteria and fungi remain active for longer periods, improving nutrient cycling and helping the soil maintain biological continuity. Residue retention also changes the biological tempo of the field. As residues decompose gradually, they create a slow-release organic environment where microbial communities remain active over extended periods. This influences nutrient mineralisation, root interaction, and moisture buffering during dry intervals. In fields where residue is repeatedly retained, farmers often observe that soil becomes softer, easier to manage, and less prone to rapid drying after irrigation. Over years, these subtle changes become agronomically significant because they improve the field's capacity to absorb climatic shocks rather than merely react to them. Sidhu and colleagues demonstrated that Happy Seeder-based residue retention improves both agronomic and environmental performance in north-west Indian production systems (Sidhu et al., 2015).

Maize in Punjab: A Strategic Crop for a Water-Limited Future

Punjab Agricultural University highlights that maize has re-emerged in Punjab's policy discussions due to growing groundwater concerns, as it requires significantly less water than paddy and reduces pressure on declining water tables. The state's push for maize diversification reflects a long-term structural shift toward aligning kharif cropping with water availability rather than short-term adjustments. Field evidence shows that with proper nutrient and weed management, maize can remain economically viable while lowering irrigation demand, making it a strategic crop for sustainable and climate-resilient agricultural planning.

Punjab Agricultural University and the Shift toward Biologically Smart Productivity

Punjab Agricultural University has expanded climate resilience beyond cereals by promoting alternative crop pathways such as horticulture, maize-based diversification, and climate-suitable short-duration varieties. Through field demonstrations and farmer outreach programmes, it emphasizes reducing dependence on the paddy–wheat cycle while encouraging residue conservation, biological pest regulation, and water-efficient kharif options. This shift highlights a transition from maximizing output to sustaining long-term productivity through biologically smarter farming practices.

Conclusion

Sustainable cropping systems offer a practical pathway to enhance climate resilience in Punjab agriculture. Diversification, conservation agriculture, and residue management improve soil health, water efficiency, and yield stability under changing climatic conditions. Future success will depend on supportive policies, farmer adoption, and region-specific strategies that balance productivity with long-term environmental sustainability.

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