Conservation Agriculture for Climate Resilience

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ABSTRACT

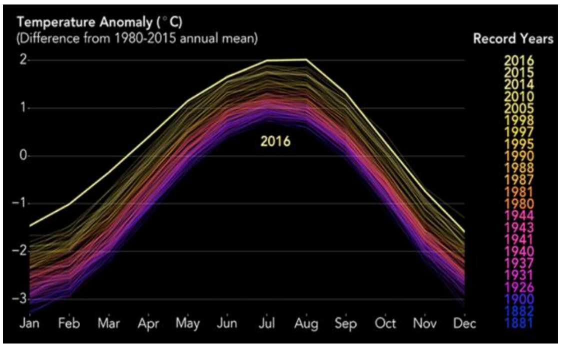
Climate change poses an unprecedented threat to agricultural productivity and food security, particularly in vulnerable regions like Punjab, India, where temperatures have risen +1.24°C above baseline and 80% of the last two decades recorded rainfall deficits. Conventional agriculture already strained by the Green revolution's legacy of soil degradation, groundwater depletion and agrochemical dependence is increasingly ill-equipped to meet projected 35-56% increases in global food demand by 2050. Conservation agriculture built on minimum soil disturbance, permanent soil cover and diversified rotations scalable pathway to sustainable intensification. Its directly mitigates climate threats to soil porosity, organic matter and water availability, while building long-term farm resilience.

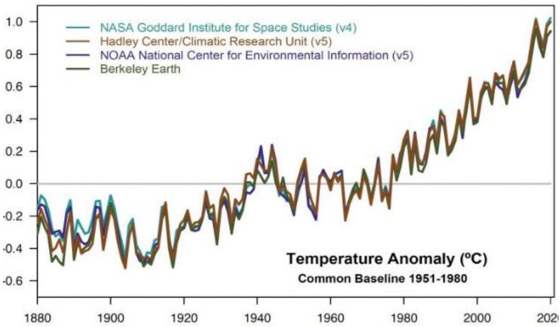
INTRODUCTION

1. The Reality of Climate Change

1.1 A Warming Planet

Climate change is defined as a long-term change in average weather patterns that define Earth's local, regional and global climates. Since the pre-industrial period (1850-1900) global warming is the long-term heating of Earth's surface driven primarily by fossil fuel combustion and the accumulation of heat-trapping greenhouse gases has accelerated at an unprecedented pace. NASA and NOAA data confirm that 2016 and 2022 are tied as the hottest years on record globally, reflecting a consistent upward trajectory in surface temperatures. NASA GISS Surface Temperature Analysis (v4) for the coordinates 31°N, 75°E the approximate location of Punjab, India reveals alarming regional warming figures. The annual zonal mean temperature anomaly stands at +1.24°C above the baseline, with seasonal peaks reaching +1.43°C in January-March and +1.38°C in October-December. These numbers underscore that Punjab is warming faster than the global average in certain seasons, posing significant risks to its predominantly agrarian economy.





1.2 Extreme Weather Events in Northern India

The consequences of climate change are no longer future projections they are present realities. In 2023, devastating floods wreaked havoc across Northern India, affecting states including Himachal Pradesh, Uttarakhand, Delhi, Punjab and Haryana. Satellite imagery from NASA Earth Observatory captured the stark transformation of Punjab's landscape between June 16 and August 19, 2023, as floodwaters from the Sutlej River inundated agricultural fields. Reports indicate that 90% of crop-sown areas in flood-affected zones were damaged its dealing with severe blow to farmers' livelihoods and regional food supplies. India as a whole recorded extreme weather events on 318 out of 365 days in 2023 with every state and Union Territory experiencing at least one such event. The annual mean land surface air temperature averaged over India in 2022 was +0.51°C above the long-term average for the 1981-2010 period (IMD), indicating a steady and concerning rise (Sahastrabuddhe *et al* 2023).

1.3 Changing Monsoon Patterns

India receives approximately 76% of its total annual rainfall from the southwest monsoon during June through September (JJAS). Over the decade 2012-2022 compared to the climatic baseline of 1981-2011, approximately 55% of tehsils witnessed a 10% increase in southwest monsoon rainfall. For Punjab specifically, variability in monsoon duration, rainfall intensity per day and deviation from normal rainfall have all increased over the period 2001-2021(Sahastrabuddhe *et al* 2023). Perhaps most alarming is that over the last five decades (1971-2021) that is 17 out of the last 20 years representing 80% of that period have recorded deficit rainfall. This growing aridity, punctuated by sporadic flooding, creates a deeply unstable environment for agricultural planning.

2. Food Security and the Limits of Conventional Agriculture

2.1 The Green Revolution Legacy

In the decades following independence (1947-1960), India faced a severe food deficit, with per capita food availability as low as 417 g/day/person condition described as 'Ship-to-Mouth syndrome'. The advent of the Green Revolution transformed the country's food landscape (Kingra and Kukal 2024) through the introduction of high-yielding variety seeds, enhanced resource inputs, increased cropping intensity and expanded irrigation infrastructure (Dijk *et al* 2021). India subsequently achieved food self-sufficiency and became a net food exporter. However, the Green Revolution's success came at a cost. Intensive monoculture farming, excessive use of chemical inputs, groundwater depletion and soil degradation are among the unintended consequences that now threaten the very productivity the revolution created. As global food demand is projected to increase by 35-56% by 2050 and India's population is expected to reach 1.66 billion by mid-century requiring a near-doubling of cereal production (Dijk *et al* 2021).

2.2 Multidimensional Role of Agriculture in Sustainable Development

Agriculture is not merely a food production system and it is a cornerstone of sustainable development across multiple dimensions. In alignment with the UN Sustainable Development Goals (SDGs), agriculture serves as:

- A reservoir of water and a crucial driver of the water cycle (Clean Water and Sanitation)
- A support system for agriculture, forestry and animal husbandry, helping increase domestic income and reduce poverty (No Poverty)
- A source of diverse and sufficient food to protect humanity from hunger and nutritional deficiency (Zero Hunger)
- A provider of adequate and safe food to maintain human health (Good Health and Well-being)
- A producer of bioenergy and biofuel feedstocks and a site for sustainable land use (Responsible Consumption and Production)
- An important arena for carbon cycling, carbon storage, and climate action (Climate Action)
- A habitat for biodiversity and all life on Earth (Life on Land)

As one researcher aptly captured: "If we enable rural farmers to innovate and use climate-smart practices, it's not only hunger and poverty that will decline, economic growth increases, jobs are created and climate change's grip on our food supply will loosen."

3. Conservation Agriculture: The Path Forward

Meeting increasing global food demand in the face of climate change can only be achieved through Sustainable Intensification producing more food on existing agricultural land while reducing environmental impact. Conservation Agriculture (CA) represents one of the most evidence-backed frameworks for achieving this goal. Built on three core principles are minimum soil disturbance (reduced or zero tillage), permanent soil cover (crop residues and cover crops) and diversified crop rotations, CA the root causes of soil degradation and builds resilience against climate variability.

By minimizing tillage, CA preserves soil structure, reduces erosion and maintains the pore networks that allow water infiltration and retention. Permanent soil cover protects against surface crusting, moderates soil temperature, retains moisture and feeds soil organic matter directly counteracting the high-impact climate threats to porosity, available water and microbial diversity identified above. Diversified rotations break pest and disease cycles, reduce dependence on chemical inputs and support biodiversity both above and below ground.

In Punjab a state where the rice-wheat cropping system has driven severe groundwater depletion, residue burning and soil health decline CA offers a practical and scalable alternative. Technologies such as Happy Seeder (direct wheat sowing into rice residue), laser levelling and micro-irrigation, combined with CA principles, have demonstrated the ability to reduce water consumption, cut input costs and improve yields while rebuilding soil health.

CONCLUSION

The climate change is already reshaping the conditions under which agriculture is practiced in Punjab and across India. Temperatures are rising above historical baselines; monsoon patterns are becoming more variable and extreme and soil health is under compounding pressure. Conservation agriculture offers a scientifically grounded, practically achievable pathway toward food systems that are productive, resilient and environmentally sustainable. By protecting soils, conserving water and reducing agriculture's carbon footprint, CA directly addresses both the causes and consequences of climate change.

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