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STRATEGIES TO ACHIEVE LOW CARBON FOOTPRINTS IN INDIAN FOOD PRODUCTION SYSTEMS

Rajagopal Vadivel

ICAR-National Institute of Abiotic Stress Management, Malegaon Khurd, Baramati, Pune 413115 Maharashtra

**Corresponding Author Mail ID: rgpssac@gmail.com*

Abstract

Indian agriculture is a significant source of greenhouse gas (GHG) emissions, contributing to 17.6% of the country's total emissions, primarily from methane (CH4) and nitrous oxide (N2O). These emissions stem from a range of operations including land preparation, irrigation, fertilization, and post-harvest handling. Differences in emissions between irrigated and rainfed systems are notable, with irrigated rice-based systems being the largest emitters. This article outlines various strategies to reduce the carbon footprint from agriculture by focusing on conservation agriculture, water-saving techniques, integrated nutrient management, residue recycling, and improved post-harvest practices. Mitigation potential varies across practices: Alternate Wetting and Drying (AWD) in rice can reduce CH4 by 30–50% (~1.5 t CO2-eq ha^{-1} yr^{-1}), zero tillage can sequester 0.3–0.6 t CO2-eq ha^{-1} yr^{-1}, and improved fertilizer practices can reduce N2O emissions by 20–30%. These strategies offer considerable scope for future research, especially in quantifying region-specific benefits and integrating them into climate policy.

Introduction

Agriculture in India has been a cornerstone of food security and rural livelihoods. However, it also significantly contributes to GHG emissions, accounting for about 17.6% of India's total emissions (MoEFCC, 2021). The bulk of these emissions come from enteric fermentation in livestock, methane emissions from flooded rice fields, and nitrous oxide emissions from fertilizer use. Since the 1970s, with the advent of the Green Revolution, the intensification of agriculture has led to a steep rise in emissions. This transformation, while boosting food production, has also resulted in extensive environmental degradation. Socially, climate-induced uncertainties such as unseasonal rainfall and droughts severely affect farmers' income, increasing their vulnerability.

The urgency to mitigate emissions from agriculture stems from its dual role as both a contributor to and a victim of climate change. With rising temperatures, altered rainfall patterns, and frequent extreme weather events, agricultural productivity is at risk. Therefore, implementing mitigation strategies is vital not only for climate goals but also for securing the livelihoods of millions of farmers and ensuring sustainable food production.

GHG Emissions Across Agricultural Operations

Greenhouse gas emissions in agriculture arise from both direct and indirect sources across various stages of food production. These include land preparation, crop establishment, intercultural operations like weeding and irrigation, nutrient management, harvesting, and post-harvest processing.

Table 1. Greenhouse gas emsision for range agriculture activities in India

Operations	**Crop**	**Emission sources**	**GHGs emission (t CO2 eq ha^{-1} seasson^{-1})**	**References**
Tillage	Rice, Wheat	Diesel use, soil carbon loss	0.15–0.25	Pathak et al., 2011
Irrigation	Rice	Methane from flooded fields	1.0–1.5	Sapkota et al., 2015
Fertilizer Application	Rice, Wheat	Nitrous oxide from nitrogen fertilizers	0.6–0.7	Majumdar et al., 2013
Weeding	Rice, Wheat	Manual labor, herbicide production	0.05–0.1	Bhattacharyya et al., 2012
Pesticide	Rice wheat	Production, transportation and soil interactions	0.25-0.45	Pathak et al., 2011
Residue Burning	Rice, Wheat	CO_2, CH_4, N_2O emissions	1.46 per tonne of residue burned	Lal, 2004
Post-Harvest Handling	Rice, Wheat	Diesel use in machinery	0.1–0.2	Pathak et al., 2010

Comparing Irrigated and Rainfed Systems

Irrigated systems, especially rice-wheat systems, have a significantly higher carbon footprint due to continuous flooding, intensive fertilizer use, and residue burning. In contrast, rainfed systems like coarse cereals, pulses, and oilseeds generally have a lower footprint but suffer from lower productivity. However, variability in rainfall and poor soil fertility often compel farmers to intensify inputs in rainfed areas as well, which can increase emissions.

Mitigation Strategies for achieving low carbon foot from Indian food production systems

1. *Conservation Agriculture*

Conservation Agriculture, through practices like zero tillage, crop residue retention, and crop diversification, enhances soil health while mitigating greenhouse gas emissions. Zero tillage helps sequester 0.3–0.6 t CO_2-eq ha^{-1} yr^{-1} by preserving soil structure and reducing N_2O release (Jat et al., 2020). Crop residue retention boosts soil organic matter, sequestering 0.5–1.0 t CO_2-eq ha^{-1} yr^{-1}. Crop rotation, especially with legumes, lowers N_2O emissions by 20–30%. Efficient fertilizer use under CA can reduce emissions by 0.3–0.5 t CO_2-eq ha^{-1} yr^{-1}. These practices also improve soil moisture retention and microbial activity, reducing irrigation and chemical input needs.

2. *Alternate Wetting and Drying:*

Alternate Wetting and Drying (AWD) in rice cultivation reduces methane (CH_4) emissions by intermittently draining fields, disrupting anaerobic conditions that produce CH_4. Studies show AWD can cut CH_4 emissions by 30–70% compared to continuous flooding, while maintaining yields and improving water-use efficiency, making it a key climate-smart practice (Sapkota et al., 2015).

3. *Site-Specific Nutrient Management (SSNM)*

The SSNM optimizes fertilizer application based on crop needs and soil nutrient status, reducing excess nitrogen use and associated nitrous oxide (N_2O) emissions. SSNM can lower N_2O emissions by 20–30% (0.3–0.5 t CO2-eq ha^{-1}) while enhancing nutrient use efficiency, crop productivity, and minimizing environmental impacts, supporting sustainable and climate-smart agriculture (Majumdar et al., 2013).

4. Biochar Application:

Biochar application enhances soil carbon sequestration by stabilizing organic carbon for long periods. It also improves soil fertility and water retention, reducing the need for fertilizers and irrigation. Studies report GHG emission reductions of 1.0–3.0 t CO_2-eq ha^{-1} yr^{-1}, making biochar a promising tool for climate-smart agriculture (Lehmann et al., 2006).

5. Integrated Crop-Livestock Systems

Integrated Crop-Livestock Systems (ICLS) reduce greenhouse gas emissions by recycling nutrients, enhancing soil organic carbon, and minimizing synthetic input use. Manure from livestock improves soil fertility, while diversified cropping reduces emissions intensity. ICLS can mitigate up to 1.5 t CO_2-eq ha^{-1} yr^{-1} (Herrero et al., 2016; Thornton & Herrero, 2010), promoting resilience and sustainability in agroecosystems.

6. Improved Post-Harvest Management:

Improved Post-Harvest Management reduces greenhouse gas emissions by minimizing food loss and waste, which otherwise contribute to methane (CH_4) and carbon dioxide (CO_2) emissions in landfills. Efficient storage, transportation, and processing can cut emissions by up to 0.2–0.5 t CO_2-eq ha^{-1} yr^{-1} (FAO, 2013; Smith et al., 2007), enhancing overall sustainability. Further, Use of renewable energy in drying, efficient transportation, and storage can reduce indirect emissions by 10–20%.

Conclusion

Reducing carbon footprints in Indian agriculture is a multi-pronged task that requires systemic changes from land preparation to post-harvest. Rainfed and irrigated systems require tailored approaches. While AWD and SSNM offer immediate benefits in irrigated rice, conservation agriculture and agroforestry are more suitable for rainfed regions. Policymakers must support region-specific mitigation packages and incentivize low-carbon technologies. Future research should focus on long-term trials, socio-economic assessments, and the integration of GHG metrics into national agricultural planning.

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