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Climate-Smart Agriculture: Growing More with Less Emissions

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Abstract: -

Indian agriculture, a cornerstone of the nation's economy and livelihoods, faces an unprecedented dual challenge: ensuring food security for a growing population while mitigating its significant contribution to greenhouse gas (GHG) emissions. This sector is highly vulnerable to climate change, with heat stress, rainfed dependency, and increasing climate extremes threatening productivity and farmer incomes. Climate-Smart Agriculture (CSA) emerges as an integrated and transformative approach designed to achieve a "triple win": sustainably increasing productivity and incomes (food security), enhancing resilience to climate change (adaptation), and reducing and/or removing emissions (mitigation). This paper outlines the core practices of CSA, spanning crop, livestock, nutrient, water, and weather management and analyses the key drivers of agricultural emissions in India, highlighting enteric fermentation and agricultural soils as dominant sources. Despite significant government-led interventions, the widespread adoption of CSA faces formidable barriers, including financial and infrastructure gaps, institutional constraints, and socio-informational challenges. The paper concludes that CSA is an imperative necessity and provides strategic recommendations for enabling policies, enhanced research, technology access, and infrastructure support to secure a resilient and sustainable future for Indian agriculture.

Keywords: Climate Smart Agriculture, Climate Change, Food Security, Sustainability

INTRODUCTION:

Agriculture is India's lifeblood, offering sustenance to about half the workforce and contributing a sizeable portion to the gross domestic product. Yet underneath this superstructure rests a totally under documented sector now faced with unprecedented challenges of climate change, jeopardizing national food security and the wage of

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millions. Ironically agriculture hugely contributes to greenhouse gas (GHG) emissions; it is a twin plight to increase production for a growing population and minimize environmental impacts. In the scenario above, Climate-Smart Agriculture (CSA) has appeared as a powerful and integrated approach to transforming agricultural systems towards sustainable development and resilience.

THE IMPERATIVE FOR CLIMATE-SMART AGRICULTURE (CSA)

It is estimated that by 2050 the human population will reach 9.1 billion, and hence, food production will have to increase 70% FAO, 2009. According to FAO, Climate-Smart Agriculture (CSA) is an integrated approach to managing landscapes-cropland, livestock, forests, and fisheries-to achieve a "triple win":

Increased Productivity: Sustainably increasing agricultural yields and incomes.

Enhanced Resilience (Adaptation): Building capacity to adapt to climate change and mitigate associated risks.

Reduced Emissions (Mitigation): Reducing and/or removing greenhouse gas emissions where possible.

INDIAN AGRICULTURE & CLIMATE VULNERABILITY

Indian agriculture is highly vulnerable to climate change, characterized by:

Heat Stress: Extreme heat reduces crop productivity and severely affects animal health and milk yield, directly impacting farmer incomes.

Rainfed Dependency: Approximately 60% of India's net sown area is rainfed and creates a high dependency on unpredictable monsoons and leads to significant vulnerability.

Increased Climate Extremes: Droughts, floods, and cyclones are increasing in intensity and frequency, causing widespread damage to crops, infrastructure, and rural communities.

Yield Fluctuations: Climate variability causes sharp yield declines, resulting in harvest instability and subsequent economic losses to farmers.

MILESTONES IN THE DEVELOPMENT OF CLIMATE-SMART AGRICULTURE

The evolution of CSA has been marked by key global and national initiatives:

2009: Agriculture officially recognized in global climate negotiations at COP15.

2010: FAO coins the term Climate-Smart Agriculture.

2011: India launched the National Innovations on Climate Resilient Agriculture (NICRA).

2014: The Global Alliance for Climate-Smart Agriculture (GACSA) is launched.

2015 onward: CSA is transparently embedded in India's Nationally Determined Contributions (NDCs) and Sustainable Development Goals (SDGs).

CORE PRACTICE OF CLIMATE-SMART AGRICULTURE

The application of CSA is through a group of context-specific smart practices across agricultural domains.

Crop Smart Practices

1. Short-duration and early-maturing varieties: Help to escape terminal heat or late monsoon failure.
2. Crop rotation and Intercropping: Maintains soil fertility and breaks pest cycles.
3. System of Rice Intensification (SRI): It saves water use, conducts wider spacing, and aerates the soil.
4. Conservation Agriculture: It entails minimum tillage, retention of crop residues, and cover cropping.
5. Crop Diversification: Growing multiple crops to reduce risks from climate variability and pest/disease outbreak.
6. Shifting Planting Dates :Adjusting calendars to align crop growth stages with favorable weather conditions.

Livestock Smart Practices

1. Rotational grazing: Preventing overgrazing and aiding pasture regeneration.
2. Improved animal feeding :Balanced and nutrient-rich diets help reduce the methane emissions from enteric fermentation.
3. Improved manure management: Methods in reducing methane/nitrous oxide emissions and to improve composting.
4. Genetic selection: Breeding livestock to be heat tolerant, disease-resistant, and low-input efficient.
5. Animal shelters: Protect the livestock from heat, cold, and extreme weather.
6. Veterinary health services: Preventing climate-induced disease outbreaks and improving herd resiliency.

Nutrient Smart Practices

1. Site-Specific Nutrient Management (SSNM): Determining an individualized approach to nutrient application based on crop demand and soil health.
2. Legume Integration: Intercropping legumes with cereals (e.g., mungbean with maize) for natural nitrogen fixation.
3. Residue Management: Incorporating crop residues instead of burning to enhance soil organic matter.
4. Brown Manuring: Sowing and then knocking down leguminous cover

crops (e.g., Dhaincha) mid-season to enrich soil.

5. Precision Tools: Using tools like Green Seeker (sensor-based N application) and the Leaf Color Chart (low-cost N management).

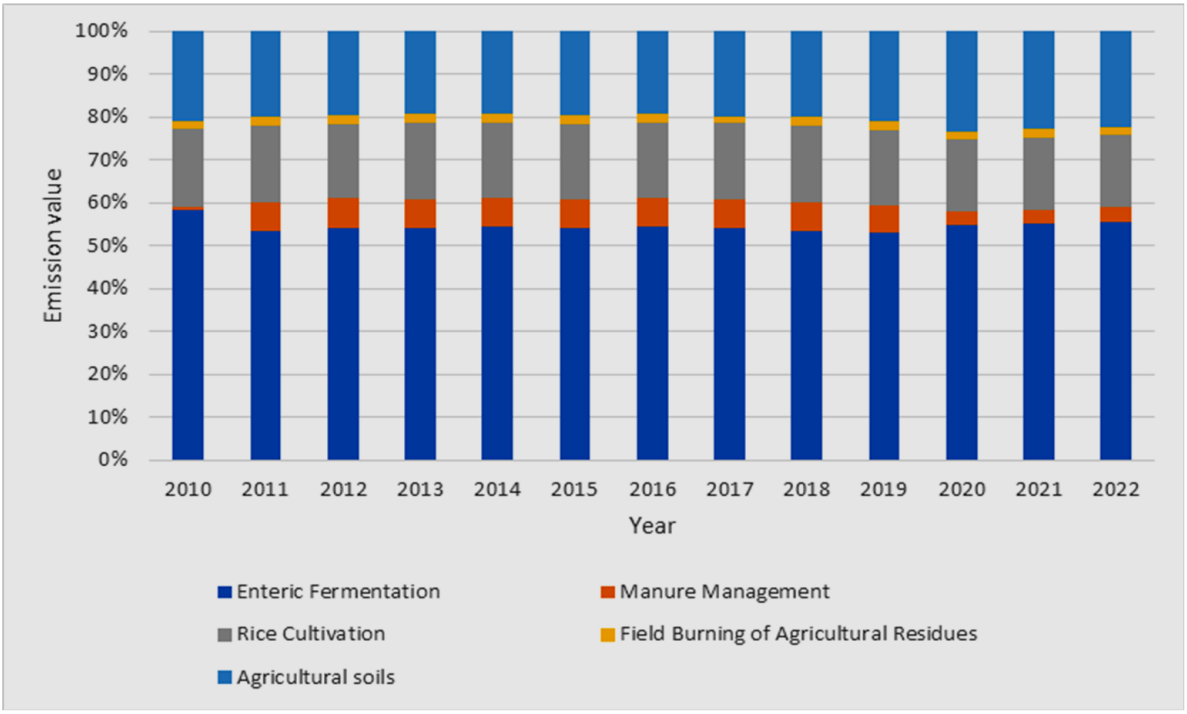
Water Smart Practices

1. Rainwater Harvesting: Building of check dams and farm ponds (successful models in Rajasthan, and Telangana).
2. Drip Irrigation: Water is delivered to the root zone, thus avoiding losses.
3. Alternate Wetting and Drying (AWD) in Paddy Fields: Considerable reduction in water use and methane emission.
4. Mulching: Prevention of surface evaporation and maintains moisture in soil.
5. Scheduling & Precision Irrigation: Timely irrigating based on sensor information and weather data.
6. Solar Powered Irrigation Pumps (SPIS): Which would substitute diesel/electric pumps, thus reducing carbon footprints.

Weather Smart Practices

1. Index-Based Insurance: Provides payouts based on objective weather indices (e.g., rainfall deficit) instead of actual loss assessment.
2. ICT-Based Agromet Services: Mobile apps, SMS alerts, and helplines delivering real-time weather information and advisory.
3. Stress-Tolerant Varieties: Promoting

DRIVERS OF AGRICULTURAL GREENHOUSE GAS EMISSIONS



crop varieties that can withstand drought, flood, heat, or salinity (e.g., Swarna-Sub1, CSR 36).

4. User-Relevant Weather Forecasts: Weather forecasts communicated in a format and language accessible to farmers.

Key Inferences

1. Dominant Source of Emissions: Enteric Fermentation (methane from livestock like cattle and sheep digesting food) is by far the largest source of agricultural GHG emissions throughout the entire period. It consistently accounts for the majority of the sector's emissions.
2. Significant and Growing Contributor: Agricultural soils (primarily) nitrous oxide from fertilizer application and manure) is the second-largest source of emissions. Notably, its relative contribution appears to have increased over time compared to other sources, suggesting it is a growing challenge.
3. Stable but Notable Sources: Manure Management and Rice cultivation (both producing methane) are consistent, mid-level contributors. Their share of total emissions has remained relatively stable over the decade.
4. Minor but Impactful Source: Field Burning of Agricultural Residues is the smallest source of emissions. While its relative contribution is small, it has significant local environmental and health impacts (air pollution) and is often an avoidable practice.
5. Overall Trend: sector-wide reductions in absolute emissions have not yet been achieved over this 12-year period.

Takeaway Points

The Livestock Sector is Central to Mitigation: Any effective strategy to reduce agricultural GHG emissions must prioritize enteric fermentation. Solutions include:

- Improving feed quality and efficiency.
- Using dietary additives (e.g., seaweed supplements) to reduce methane production.
- Advancing animal genetics and health to improve productivity per animal.
- Fertilizer Management is Critical: The rising share of emissions from agricultural soils highlights the urgent need for Improved Nitrogen Management.
- This includes precision farming techniques (using the right amount of fertilizer, in the right place, at the right time).
- Using enhanced-efficiency fertilizers and cover crops.
- Adopting practices that improve soil health and carbon sequestration.

No Single Solution Exists : A multi-pronged approach is essential. While tackling enteric fermentation and soils will yield the largest gains, efforts must also continue to:

Capture methane from manure management (e.g., through anaerobic digesters). Promote water-saving practices in rice cultivation (e.g., alternate wetting and drying). Eliminate the practice of field burning by finding valuable uses for crop residues (e.g., bioenergy, compost, animal bedding).

Progress is Slow and More Action is Needed: The trend indicates that current policies and practices are not sufficient to meet ambitious climate targets (like those in the Paris Agreement). Significantly scaled-up adoption of climate-smart agricultural practices and stronger policy incentives are required to bend the emission curve downward.

KEY CHALLENGES IN IMPLEMENTING CSA IN INDIA :-

Inadequate Storage: Capacity for only 145 million tonnes against 300 million tonnes produced, leading to high post-harvest losses.

Low Mechanization: High costs of machinery; subsidies cover only 40-50%, hindering smallholder adoption.

Credit Deficit: Only ~7.75 crore Kisan Credit Cards (KCCs), excluding many farmers from formal credit.

Insurance Gap: ~55% of PMFBY insurance is from non-loanee farmers, indicating low penetration among smallholders without access to credit.

Fragmented Policy: Lack of coordination between ministries and schemes leads to confusion and inefficiency.

Weak Knowledge Transfer: Only ~3% of farmers are reached by extension services (2024).

Limited Reach: Only ~730 Krishi Vigyan Kendras (KVKs) for over 150 million farming households. Risk Aversion, low education levels, and limited group participation hinder the adoption of new practices.

Climate Information Gaps: Only 30–40% of farmers access timely weather-based advisories (World Bank, 2021). 79% of those who receive information report it as generic or delayed (ICRISAT, 2020).

Adoption Heterogeneity: Uptake of technologies varies widely based on farm size, location, and socio-economic status.

GOVERNMENT-LED CSA INTERVENTIONS IN INDIA

The Indian government has launched several flagship schemes to promote CSA:

National Mission for Sustainable Agriculture (NMSA): The flagship CSA mission.

Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)/Per Drop More Crop (PDMC): Added 30.55 lakh hectares under micro-irrigation in the last 3 years.

Paramparagat Krishi Vikas Yojana (PKVY): 9.74 lakh hectares under organic cultivation since 2015–16 through clusters & FPOs.

NICRA/ICAR: Established 448 Climate Resilient Villages and released 2900 new stress-tolerant crop varieties (2014–24).

PM-PRANAM: Aims to reduce fertilizer use (already reduced by 15.14 lakh tonnes).

Digital Agriculture: Mobile Apps (e.g., Kisan Suvidha), the mKisan portal, and SMS advisories use AI/ML to provide one-stop agri-info access.

Support Schemes: PM-KISAN (₹6,000/year income support), Kisan Credit Card (KCC), and Pradhan Mantri Fasal Bima Yojana (PMFBY) for credit and insurance.

STRATEGIC PATH AHEAD: KEY RECOMMENDATIONS

1. **Enabling Policies & Farmer Support:**
   - ☞ Mainstream CSA into all national and state agricultural policies.
   - ☞ Improve coordination across ministries and implementing agencies.
   - ☞ Provide financial incentives: targeted subsidies, grants, low-interest loans, and rewards for early adopters.
2. **Research & Development:**
   - ☞ Increase investment in CSA-focused R&D for locally adaptable technologies.
   - ☞ Strengthen collaboration with global research institutions.
3. **Awareness, Education & Technology Access:**
   - ☞ Scale up farmer training through expanded extension services and local organizations.
   - ☞ Improve dissemination and affordable access to CSA technologies.
4. **Infrastructure Support**:
   - ☞ Massive investment in irrigation, seed systems, storage, and cold chain infrastructure.
5. Environmental & Social Safeguards:
   - ☞ Monitor the impacts of CSA practices on biodiversity, soil health, water resources, and inclusivity to ensure truly sustainable outcomes.

CONCLUSION :-

Climate-Smart Agriculture is not merely an option but a necessity for ensuring the resilience and sustainability of Indian agriculture. It effectively bridges the gap between traditional farming practices and future-ready systems. With the undeniable

reality of climate change, CSA offers a viable pathway to sustainable growth, ensuring national food security and protecting the livelihoods of millions of farmers. The future of Indian agriculture depends on the smart, concerted, and urgent choices we make today.

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