



Climate-smart agriculture: Concepts, principles, frameworks, and government initiatives in India: A review

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Abstract

Climate change poses substantial challenges to agricultural productivity, food security, and rural livelihoods through rising temperatures, erratic precipitation, droughts, floods, heat stress, and the degradation of natural resources. Climate-Smart Agriculture (CSA) has emerged as an integrated approach to address these challenges by sustainably increasing agricultural productivity and incomes, strengthening adaptation and resilience, and reducing or removing greenhouse gas emissions where possible. This review examines the conceptual foundations, guiding principles, implementation framework, and practical applications of CSA, with particular emphasis on government initiatives in India. The review synthesizes relevant scientific literature, international policy documents, and official government publications to explore climate-smart practices in crop production, livestock management, agroforestry, soil and water conservation, biodiversity management, energy use, and post-harvest systems. The three pillars of CSA are discussed in relation to sustainable intensification, climate risk management, resource-use efficiency, and low-emission agricultural development. Indian initiatives, including the National Innovations in Climate Resilient Agriculture (NICRA), National Mission for Sustainable Agriculture (NMSA), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Soil Health Card Scheme, Paramparagat Krishi Vikas Yojana (PKVY), and agroforestry-related policies, are examined for their potential contributions to climate-resilient farming. The review also discusses the relationship between CSA and the United Nations Sustainable Development Goals, particularly SDGs 1, 2, 6, 12, 13, and 15. Despite its potential, the adoption of CSA is constrained by financial limitations, inadequate extension services, fragmented institutional coordination, uneven access to climate information, and uncertainties regarding the costs and benefits of individual practices. The review concludes that CSA should be implemented through locally appropriate, evidence-based strategies supported by effective institutions, farmer participation, accessible finance, and outcome-oriented monitoring. Such an integrated approach can strengthen agricultural resilience while supporting sustainable food systems and climate action.

Keywords: Climate-smart agriculture, climate change adaptation, agricultural productivity, greenhouse gas emissions, climate resilience, sustainable agriculture, agroforestry, India

Introduction

Agriculture is fundamental to food security, rural employment, economic development, and the livelihoods of millions of people worldwide. However, agricultural production is highly sensitive to climatic conditions, including temperature, precipitation, humidity, and the frequency and intensity of extreme weather events. Climate change is altering these conditions, increasing the risks associated with crop production, livestock management, water availability, and agricultural ecosystems. The Intergovernmental Panel on Climate Change (IPCC, 2022) identifies climate change as a major source of risk to food production and livelihoods, with impacts varying according to geographical location, socioeconomic conditions, and adaptive capacity.

India is particularly concerned with agricultural climate resilience because of the importance of rainfed farming, the diversity of agroecological conditions, and the dependence of many rural households on climate-sensitive resources. Increasing temperatures, irregular monsoon rainfall, droughts, floods, heat stress, soil degradation, and changing pest and disease patterns can affect agricultural productivity and farm income. These challenges require approaches that address not only short-term production losses but also the

long-term sustainability of agricultural systems. Conventional agricultural development strategies have often emphasized increasing production through improved seeds, irrigation, fertilizers, and mechanization. Although these interventions have contributed to agricultural growth, their environmental and economic outcomes depend on how resources are managed. Excessive fertilizer use, inefficient irrigation, soil disturbance, and inappropriate land-use changes can create additional environmental pressures. Climate change therefore requires agricultural systems to become more productive while improving their capacity to withstand climatic shocks and minimizing avoidable environmental impacts.

Climate-Smart Agriculture (CSA) was promoted by the Food and Agriculture Organization of the United Nations (FAO) as an approach to guide the transformation and reorientation of agricultural systems towards sustainable development and food security under changing climatic conditions. CSA is based on three interconnected objectives: sustainably increasing agricultural productivity and incomes, adapting to climate change and building resilience, and reducing or removing greenhouse gas emissions where possible (FAO, 2013; Lipper et al., 2014) [7]. An important feature of CSA is its context-specific nature. It does not

prescribe a single technology or universal package of practices. Instead, it provides a framework for selecting and combining interventions according to local climatic conditions, farming systems, socioeconomic circumstances, institutional capacity, and development priorities. For example, rainwater harvesting may be particularly useful in water-limited regions, whereas improved drainage and flood-tolerant crops may be more suitable in flood-prone areas. Agroforestry, crop diversification, conservation agriculture, improved nutrient management, and climate information services may contribute to several CSA objectives simultaneously, although their effectiveness varies by location.

India has introduced several programmes that support components of CSA, including NICRA, NMSA, PMKSY, the Soil Health Card Scheme, and agroforestry initiatives. These programmes provide opportunities to integrate climate adaptation with agricultural development, natural resource conservation, and livelihood improvement. Against this background, this review examines the concepts and principles of CSA, its major implementation areas, the FAO framework, national initiatives in India, and its contribution to the Sustainable Development Goals (SDGs). It also critically discusses adoption barriers and identifies priorities for strengthening the implementation of climate-smart practices.

Objectives of the Review

The objectives of this review are:

1. To explain the concept, definition, and fundamental principles of Climate-Smart Agriculture.
2. To examine the three pillars of CSA and their relationship with sustainable agricultural development.
3. To review the FAO framework and major areas of climate-smart agricultural intervention.
4. To discuss Indian government programmes supporting climate-resilient and sustainable agriculture.
5. To examine the contribution of CSA to the United Nations Sustainable Development Goals.
6. To identify implementation challenges, research gaps, and policy priorities for wider adoption of CSA in India.

Materials and Methods

1. Review approach

This paper adopts a narrative review approach to synthesize the conceptual, scientific, and policy dimensions of Climate-Smart Agriculture. The review draws on FAO publications, peer-reviewed research articles, international climate assessments, Indian government policy documents, and official programme information.

2. Literature sources and thematic organization

Relevant materials were identified through searches of academic literature and official institutional websites, including FAO, IPCC, the Government of India, the Indian Council of Agricultural Research (ICAR), and publications addressing agricultural adaptation and climate mitigation.

The literature was organized into five themes:

1. Definition, conceptual foundations, and principles of CSA.
2. Productivity, adaptation, and mitigation practices.
3. FAO's CSA framework and implementation areas.
4. Indian government programmes and policy support.

5. CSA contributions to the SDGs, implementation barriers, and future priorities.

Priority was given to publications that explicitly discuss the three pillars of CSA, agricultural resilience, sustainable intensification, climate-smart practices, and institutional arrangements for implementation.

3. Scope and limitations

The review synthesizes published evidence and policy information rather than presenting original field data or experimental results. It is a narrative review, not a systematic review or meta-analysis. No formal database-specific screening protocol, quantitative effect-size analysis, or comprehensive evaluation of individual government programmes was undertaken. Consequently, programme descriptions indicate their relevance to CSA, but should not be interpreted as proof that every programme independently achieves all three CSA pillars.

Concept and Definition of Climate-Smart Agriculture

1. Definition

Climate-Smart Agriculture is an integrated approach to agricultural development that aims to sustainably increase productivity and incomes, strengthen adaptation and resilience to climate change, and reduce or remove greenhouse gas emissions where possible.

FAO introduced CSA as an approach to help guide actions that transform and reorient agricultural systems to support food security and development under changing climatic conditions (FAO, 2013). The approach recognizes the interdependence of agricultural production, natural resource management, climate risks, and rural livelihoods.

CSA is not a specific farming system, a single technology, or a certification scheme. It is a decision-making framework for identifying and combining suitable practices, technologies, institutional arrangements, and investments. The appropriate combination depends on local conditions and the relative importance of productivity, adaptation, and +mitigation objectives.

2. Conceptual foundations

The concept of CSA emerged from the recognition that agricultural development must address food security and climate change together. Climate change affects agricultural production, while agricultural activities can contribute to greenhouse gas emissions through fertilizer use, livestock production, rice cultivation, energy consumption, and land-use change.

CSA seeks to address these linked challenges through an integrated approach. It emphasizes the importance of increasing resource-use efficiency, reducing production risks, improving farmers' adaptive capacity, and identifying opportunities for emission reduction.

According to Lipper et al. (2014)^[7], CSA requires coordinated action across research, policy, institutional development, and agricultural finance. Campbell et al. (2014)^[1] similarly emphasize that sustainable intensification can contribute to CSA but should be accompanied by broader strategies for risk management, diversification, and institutional support.

3. Why is CSA necessary?

Agricultural systems face several interconnected climate-related and environmental challenges:

- Increasing temperatures and heat stress during sensitive crop growth stages.
- Irregular rainfall and uncertainty in sowing and harvesting periods.
- Greater exposure to droughts, floods, and other extreme events.
- Declining soil quality and unsustainable groundwater use.
- Emerging and changing pest and disease pressures.
- Rising production costs and unstable farm incomes.
- Greenhouse gas emissions associated with agricultural production.
- Loss of agricultural biodiversity and degradation of ecosystem services.

CSA addresses these challenges by combining productivity improvement with risk reduction, sustainable resource management, and mitigation opportunities.

The Three Pillars of Climate-Smart Agriculture

The CSA framework is based on three principal objectives. These objectives are interrelated but not automatically achieved together. Their relative importance depends on local needs, available technologies, environmental conditions, and the socioeconomic circumstances of farmers (FAO, 2013; Lipper et al., 2014)^[7].

1. Pillar I: Sustainably increasing agricultural productivity and incomes

The first pillar seeks to improve agricultural production and farm incomes while maintaining the natural resource base. Increasing productivity is essential for food security, particularly where land and water resources are limited.

Climate-smart productivity improvement may involve improved crop varieties, appropriate planting dates, integrated nutrient management, efficient irrigation, better livestock feeding, improved animal health, crop diversification, and mechanization suited to local conditions.

Sustainable productivity improvement should not be measured solely by crop yield. It should also consider profitability, input efficiency, soil health, water use, production stability, and long-term environmental effects.

For example, balanced fertilizer application based on soil testing can improve nutrient-use efficiency. Similarly, suitable crop rotations and integrated farming systems can diversify farm outputs and reduce dependence on a single production component.

The main outcomes of this pillar include improved food availability, more stable agricultural output, increased farm income, and more efficient use of natural resources.

2. Pillar II: Adapting and building resilience to climate change

The second pillar focuses on strengthening the capacity of agricultural systems and farming communities to anticipate, absorb, and recover from climate-related disturbances.

Resilience involves more than surviving a single extreme event. It includes the ability to maintain essential agricultural functions, recover from losses, adjust management practices, and adapt to changing climatic conditions over time.

Important adaptation practices include:

- Cultivation of locally suitable drought-, heat-, or flood-tolerant crop varieties.
- Diversification of crops and farming enterprises.
- Rainwater harvesting and improved irrigation management.
- Conservation agriculture, mulching, and soil moisture conservation.
- Agroforestry and integrated crop–livestock systems.
- Weather forecasting, early warning systems, and agricultural advisories.
- Crop insurance and other appropriate risk-management mechanisms.
- Improved storage, drainage, and farm infrastructure.

Diversification can reduce exposure to the failure of a single crop or enterprise. Agroforestry may provide additional products and income, improve microclimatic conditions, and protect soil, depending on species selection and management. Timely climate information can help farmers adjust planting dates, irrigation schedules, and harvesting decisions.

The effectiveness of adaptation measures depends on access to land, water, finance, knowledge, markets, and extension services. Therefore, strengthening farmers' adaptive capacity requires both technological interventions and supportive institutions.

3. Pillar III: Reducing or removing greenhouse gas emissions

The third pillar seeks to reduce agricultural greenhouse gas emissions and enhance carbon storage where technically feasible and environmentally appropriate.

Agricultural emissions arise from several sources, including methane from ruminant livestock and flooded rice systems, nitrous oxide from nitrogen inputs and agricultural soils, and carbon dioxide associated with energy use and land-use change.

Potential mitigation practices include:

- Improved fertilizer management and efficient nitrogen application.
- Alternate wetting and drying in suitable rice-growing systems.
- Improved livestock feeding and manure management.
- Reduced or optimized tillage where appropriate.
- Agroforestry and integration of trees into agricultural landscapes.
- Maintaining soil organic matter and suitable cover crops.
- Efficient use of energy and renewable energy technologies.
- Reducing food losses and improving resource efficiency across supply chains.

The mitigation potential of these practices varies according to local conditions. For instance, reduced tillage does not guarantee an increase in total soil carbon under every soil and climatic condition, while alternate wetting and drying requires appropriate water control and management. Mitigation benefits should therefore be assessed using suitable baselines and reliable measurements.

Importantly, mitigation must not undermine food production, farmer incomes, or adaptation objectives. CSA seeks to identify balanced options that address local development needs while reducing avoidable emissions.

Table 1: Three pillars of Climate-Smart Agriculture and their major interventions

CSA pillar	Principal objective	Representative practices	Expected outcomes
Productivity and income	Improve sustainable agricultural output and farm profitability	Improved varieties, integrated nutrient management, efficient irrigation, crop diversification	Improved yields, income, and resource-use efficiency
Adaptation and resilience	Reduce vulnerability to climate variability and extreme events	Drought-tolerant crops, agroforestry, water harvesting, diversified farming, climate advisories	Lower production risks and improved recovery capacity
Mitigation	Reduce or avoid greenhouse gas emissions and increase carbon storage where appropriate	Improved nitrogen management, rice water management, manure management, tree-based farming	Lower emissions intensity and potential carbon sequestration

Source: Adapted from FAO (2013), Lipper et al. (2014)^[7], and Campbell et al. (2014)^[1].

The three pillars should be treated as complementary objectives rather than a guarantee of simultaneous benefits. A practice may strongly support adaptation but have limited mitigation potential, or it may improve productivity while increasing energy use. Site-specific evaluation is therefore essential.

Principles of Climate-Smart Agriculture

The following principles provide a practical basis for planning and implementing CSA.

1. Sustainable natural resource management

CSA promotes efficient and responsible use of soil, water, biodiversity, and energy. Practices such as soil conservation, integrated nutrient management, rainwater harvesting, and appropriate irrigation scheduling can reduce resource degradation and support long-term agricultural productivity.

2. Resilience and adaptation

Agricultural systems should be capable of withstanding climatic shocks and recovering from losses. Crop diversification, resilient varieties, agroforestry, improved farm infrastructure, and access to climate information can strengthen this capacity.

3. Sustainable productivity enhancement

CSA seeks to improve agricultural output and profitability without creating unacceptable environmental costs. Improved seed quality, integrated crop management, efficient input use, and suitable mechanization can support this objective.

4. Greenhouse gas mitigation

Where feasible, agricultural practices should reduce avoidable emissions and enhance carbon storage. Relevant interventions include balanced fertilizer use, improved manure management, suitable tree-based farming systems, and efficient energy use.

5. Context-specific decision-making

No single CSA technology is appropriate for all locations. Practices should be selected according to local climate, soil, water availability, farming systems, financial capacity, and market access. Participatory assessments are important for identifying feasible interventions.

6. Integration of scientific and traditional knowledge

Scientific research, farmer experience, indigenous knowledge, and climate information can complement one

another. Combining these knowledge systems can improve the suitability of interventions and strengthen local participation.

7. Risk management and preparedness

CSA emphasizes planning before climate-related losses occur. Weather forecasts, early warning systems, contingency plans, suitable insurance arrangements, and improved access to agricultural advisories can help farmers make timely decisions.

8. Social inclusion and institutional support

Climate-smart development should consider the different capacities and needs of small and marginal farmers, women farmers, tenant cultivators, and other vulnerable groups. Access to finance, land, extension services, technologies, and markets influences the ability to adopt CSA practices.

9. Evidence-based monitoring and evaluation

CSA interventions should be assessed against clearly defined objectives. Monitoring should consider changes in productivity, farm income, resilience, resource use, and greenhouse gas emissions rather than assuming that every intervention delivers all intended benefits.

FAO Framework for Climate-Smart Agriculture

1. Overview

FAO provides international guidance for incorporating climate considerations into agricultural policies, investment decisions, technologies, and management practices. Its Climate-Smart Agriculture Sourcebook explains the conceptual basis of CSA and presents options for planning and implementation across agricultural sectors and landscapes (FAO, 2013).

The framework is flexible rather than prescriptive. It encourages decision-makers to assess climate risks, identify suitable practices, establish priorities, and coordinate interventions among farmers, researchers, government agencies, and other stakeholders.

FAO's broader CSA approach also emphasizes the importance of generating evidence, strengthening institutions, improving policy coherence, and linking agricultural and climate finance (Lipper et al., 2014)^[7].

2. Major implementation areas

CSA can be applied across crop production, livestock, forestry, fisheries, natural resource management, and food systems.

Table 2: Major implementation areas within the CSA approach

Implementation area	Principal interventions	Potential climate-smart contribution
Integrated farming systems	Integration of crops, livestock, trees, and resource recycling	Diversified production and improved resource efficiency
Crop production	Improved varieties, adjusted planting dates, crop diversification, integrated nutrient management	Productivity improvement and adaptation
Livestock	Improved feed quality, animal health, breeding, and manure management	Resilience and potential emission reduction
Forestry and agroforestry	Tree integration, sustainable forest management, landscape restoration	Carbon storage, soil protection, and livelihood diversification
Urban and peri-urban agriculture	Efficient water use, protected cultivation, local food production, and resource recycling	Improved resource efficiency and food-system resilience
Genetic resources and biodiversity	Conservation of crop diversity, livestock genetic resources, and associated biodiversity	Improved adaptive options and ecosystem stability
Fisheries and aquaculture	Climate-informed production, sustainable resource management, and suitable aquaculture practices	Reduced vulnerability of aquatic food systems
Land and water management	Soil conservation, watershed development, efficient irrigation, and land restoration	Improved soil and water security
Drought management	Early warning, contingency planning, drought-tolerant varieties, and water storage	Reduced losses during water stress
Energy	Efficient machinery, renewable energy, and reduced post-harvest energy losses	Improved energy efficiency and potential emission reductions
Food loss and waste	Improved storage, processing, transport, and value-chain management	Reduced resource wastage and avoidable emissions
Agricultural research and specialized technologies	Climate modelling, isotopic techniques, improved diagnostics, and monitoring	Better evidence for resource management and adaptation

Source: Synthesized from FAO (2013) and Lipper et al. (2014) [7].

The table presents broad application areas rather than a formal list of twelve equally ranked FAO pillars. Nuclear and isotopic techniques, for example, are specialized research tools that may support soil–water studies, nutrient management, and agricultural monitoring; they are not themselves a separate core pillar of CSA.

3. Planning and implementation process

The CSA framework can be operationalized through the following steps:

1. **Assess climate risks:** Identify climatic hazards, exposed farming systems, and vulnerable populations.
2. **Establish baseline conditions:** Document existing agricultural productivity, resource use, income, and relevant emissions.
3. **Identify potential interventions:** Evaluate suitable practices and technologies for local farming systems.
4. **Assess trade-offs and synergies:** Determine how proposed interventions affect productivity, adaptation, mitigation, costs, and equity.
5. **Develop institutional and financial support:** Define responsibilities and identify appropriate funding, extension, and technical resources.
6. **Implement and monitor:** Introduce interventions with farmer participation and track progress against measurable indicators.
7. **Review and adapt:** Modify practices according to observed outcomes, changing climate conditions, and stakeholder feedback.

This process helps ensure that CSA is treated as an adaptive planning framework rather than a fixed package of agricultural technologies.

Major Climate-Smart Agricultural Practices

1. Crop diversification and climate-resilient varieties

Crop diversification reduces dependence on a single crop and can spread production risks across seasons and markets.

Introducing suitable pulses, oilseeds, millets, or other locally adapted crops may improve resource-use efficiency and provide additional income.

Climate-resilient varieties can reduce losses associated with drought, heat, floods, or other stresses. However, varietal selection must consider local agroecological suitability, yield potential, seed availability, consumer preferences, and market demand.

2. Soil health and conservation agriculture

Healthy soils support nutrient cycling, water retention, root development, and crop productivity. Soil testing, balanced fertilizer application, organic matter management, suitable crop rotations, mulching, and erosion control can improve soil quality.

Conservation agriculture practices, including reduced soil disturbance, permanent soil cover, and crop diversification, may contribute to resilience and soil conservation. Their effectiveness depends on cropping systems, weed pressure, residue availability, equipment access, and local soil conditions.

3. Efficient irrigation and water harvesting

Water management is particularly important in regions affected by irregular rainfall and groundwater stress. Drip irrigation, sprinkler systems, rainwater harvesting, farm ponds, watershed development, and improved irrigation scheduling can support more efficient water use.

These practices must be implemented with attention to local water availability. Improving irrigation efficiency at the farm level does not always translate into lower total water consumption if irrigated area or water-intensive production expands. Basin-level planning and groundwater governance remain important.

4. Agroforestry and tree-based farming

Agroforestry integrates trees with crops and/or livestock to diversify agricultural production and improve selected

ecosystem services. Depending on the species and management system, agroforestry can provide timber, fodder, fruits, fuelwood, shade, soil protection, and additional income.

Tree-based systems may also store carbon and improve landscape connectivity. However, tree density and species choice should account for competition for light, water, and nutrients. The suitability of agroforestry depends on rainfall, soil conditions, farm size, market access, and the availability of suitable planting material.

5. Livestock management

Livestock resilience can be strengthened through improved feeding, veterinary services, suitable breeds, heat-stress management, water access, and better housing. Improved manure management can support nutrient recycling and reduce avoidable emissions.

Livestock interventions should consider productivity, animal welfare, local feed resources, and the risk of increased production costs. Appropriate management differs between intensive dairy systems, mixed crop–livestock farms, and pastoral systems.

6. Integrated farming systems

Integrated farming combines two or more production components, such as crops, livestock, trees, fisheries, or horticulture. Such systems can recycle resources, diversify income, and reduce dependence on individual commodities. Their success depends on farm size, labour availability, technical knowledge, local markets, and compatibility between production components. Integrated farming should therefore be promoted through locally tested models rather than universal recommendations.

7. Climate information and digital agriculture

Weather forecasts, seasonal climate information, pest alerts, and digital agricultural advisories can support timely decisions about planting, irrigation, fertilizer application, and harvesting.

The effectiveness of digital agriculture depends on forecast quality, local relevance, language accessibility, connectivity, and farmers' ability to act on the information. Extension workers and local institutions remain important for translating climate information into practical recommendations.

8. Post-harvest management

Storage losses, inefficient transport, and food wastage reduce the effective productivity of agricultural systems. Improved storage structures, suitable drying technologies, cold chains where justified, and better market coordination can help preserve food and reduce avoidable resource losses.

Post-harvest interventions can contribute to CSA by improving food availability and reducing the waste of land, water, energy, and other production inputs.

Government Initiatives Supporting Climate-Smart Agriculture in India

India has several agricultural programmes that support individual or multiple components of CSA. These programmes differ in objectives, administrative structures, eligibility, and implementation arrangements. They should therefore be understood as complementary instruments rather than as a single integrated CSA scheme.

Table 3: Major Indian programmes and their relevance to Climate-Smart Agriculture

Programme or policy	Year introduced or launched	Principal focus	Relevance to CSA
Rashtriya Krishi Vikas Yojana (RKVY)	2007	State-led agricultural development and investment	Can support locally relevant agricultural innovations, subject to programme guidelines
National Innovations in Climate Resilient Agriculture (NICRA)	2011	Climate-risk research, technology demonstrations, and agricultural resilience	Directly supports climate adaptation and selected mitigation research
National Mission for Sustainable Agriculture (NMSA)	2014	Sustainable agriculture, soil and water management, and resilience	Supports resource conservation and climate-resilient farming
National Agroforestry Policy	2014	Integration of trees into agricultural landscapes	Supports diversification, ecosystem services, and potential carbon storage
Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	2015	Irrigation access and water-use efficiency	Supports water management and adaptation
Soil Health Card Scheme	2015	Soil testing and nutrient recommendations	Supports balanced nutrient management and input efficiency
Paramparagat Krishi Vikas Yojana (PKVY)	2015	Organic farming and related production systems	May support soil health and resource management where locally appropriate

Source: Government of India programme documents; ICAR NICRA information; NMSA operational guidelines; Ministry of Agriculture and Farmers Welfare publications.

Note: The years refer to the respective programme or policy's introduction or launch, as commonly reported. Programme components, names, eligibility, and operational guidelines can change over time and should be checked against current official documents before submission.

1. National Innovations in Climate Resilient Agriculture

NICRA is an ICAR-led network project launched in February 2011. It supports strategic research, technology demonstration, vulnerability assessment, and awareness-building related to climate change in agriculture (ICAR, n.d.).

The project covers adaptation and mitigation research and includes work related to crops, livestock, fisheries, and natural resource management. Its approach is relevant to CSA because it links scientific research with demonstrations of technologies under farmers' field conditions.

NICRA can contribute to the identification of vulnerable agricultural areas and the development of location-specific

practices. The extent of benefits depends on local adoption, access to resources, the suitability of technologies, and the continuity of extension support.

2. National Mission for Sustainable Agriculture

NMSA was developed under India's broader climate policy framework to promote sustainable agricultural development. Its focus includes rainfed-area development, soil health, water-use efficiency, and improved farming practices (Government of India, 2014).

The mission's objectives overlap with CSA's productivity and adaptation pillars. Measures such as resource conservation, improved soil management, and sustainable farming practices can help reduce vulnerability while maintaining agricultural production.

However, the achievement of CSA outcomes requires interventions to be selected and monitored according to local climate risks and environmental conditions.

3. Pradhan Mantri Krishi Sinchayee Yojana

PMKSY supports irrigation development and water-use efficiency through its applicable programme components. Efficient irrigation can improve the reliability of crop production and help farmers manage water scarcity.

The contribution of irrigation to CSA depends on sustainable water availability, suitable technology, appropriate scheduling, and effective groundwater management. Irrigation expansion should therefore be coordinated with watershed and basin-level planning.

4. Soil Health Card Scheme

The Soil Health Card Scheme provides farmers with information about soil nutrient status and recommendations for nutrient management. It can support better fertilizer decisions and reduce nutrient imbalances when recommendations are followed and appropriately updated.

The scheme's contribution to CSA can be strengthened through integration with extension services, soil organic matter management, balanced nutrient application, and regular monitoring of soil condition.

5. Paramparagat Krishi Vikas Yojana

PKVY supports organic farming and related production systems. Organic and integrated soil management practices may improve soil structure, nutrient cycling, and biodiversity in appropriate contexts. However, organic farming does not automatically reduce greenhouse gas emissions or increase yields under all conditions. Outcomes depend on crop type, nutrient availability, production system, transport, and the methods used for comparing environmental performance.

6. National Agroforestry Policy

The National Agroforestry Policy provides a policy basis for promoting tree-based farming systems and improving coordination among relevant institutions. Agroforestry can contribute to CSA through livelihood diversification, soil conservation, microclimatic benefits, and carbon storage.

Its practical implementation requires suitable species selection, quality planting material, extension support, access to tree products markets, and an enabling regulatory environment.

7. Rashtriya Krishi Vikas Yojana

RKVY supports agricultural development through state-led planning and investment. Depending on the relevant guidelines and approved projects, it may support infrastructure, innovation, and locally appropriate agricultural interventions that contribute to climate resilience.

Its contribution to CSA should be evaluated at the project level because the programme is broader than climate adaptation or mitigation alone.

8. Institutional coordination and extension

The success of CSA depends on cooperation among agricultural research institutions, state agricultural departments, Krishi Vigyan Kendras, universities, extension agencies, local authorities, and farmers.

Government programmes are more likely to support sustained adoption when technical advice, seed availability, irrigation services, credit, markets, and climate information are coordinated. Extension systems should also collect feedback from farmers to identify practical constraints and improve programme design.

10. Climate-Smart Agriculture and the Sustainable Development Goals

The United Nations Sustainable Development Goals provide a global framework for addressing poverty, hunger, environmental degradation, and climate change. CSA contributes to several SDGs through its emphasis on agricultural productivity, climate resilience, resource conservation, and sustainable food systems.



Fig 1: Sustainable Development Goals

1. SDG 1: No Poverty

CSA can contribute to poverty reduction by improving farm productivity, diversifying livelihoods, and reducing exposure to climate-related losses. The magnitude of these benefits depends on access to resources, markets, finance, and institutional support.

2. SDG 2: Zero Hunger

CSA supports food security through sustainable productivity improvement, resilient farming systems, and better management of agricultural resources. Its contribution extends beyond yield to include food availability, income stability, and the capacity to maintain production during climatic stress.

3. SDG 6: Clean Water and Sanitation

Water harvesting, efficient irrigation, watershed management, and soil moisture conservation can support more sustainable water use. Their effectiveness depends on local hydrological conditions and governance arrangements.

4. SDG 12: Responsible Consumption and Production

CSA promotes efficient resource use, better nutrient management, reduced post-harvest losses, and improved agricultural value chains. These practices can reduce avoidable wastage and environmental pressure.

5. SDG 13: Climate Action

CSA contributes to climate adaptation through resilience-building practices and can contribute to mitigation through suitable emission-reduction and carbon-storage interventions. Its effectiveness depends on the measurement and durability of the outcomes achieved.

6. SDG 15: Life on Land

Agroforestry, soil conservation, biodiversity management, and ecological restoration can contribute to the protection and sustainable use of terrestrial ecosystems. Interventions should be designed to protect native biodiversity and avoid inappropriate land-use changes.

Table 4: Relationship between CSA pillars and selected SDGs

CSA dimension	Relevant SDGs	Potential contribution
Sustainable productivity and incomes	SDG 1 and SDG 2	Improved livelihoods, agricultural productivity, and food security
Adaptation and resilience	SDG 2, SDG 6, and SDG 13	Greater capacity to manage climate risks and water stress
Mitigation and resource efficiency	SDG 12 and SDG 13	Reduced resource wastage and potential emission reductions
Agroforestry and ecosystem management	SDG 13 and SDG 15	Carbon storage, soil protection, and ecosystem conservation
Integrated climate-smart development	SDG 1, SDG 2, SDG 6, SDG 12, SDG 13, and SDG 15	Joint contributions to livelihoods, food security, resilience, and environmental sustainability

Source: FAO (2013) and United Nations (n.d.).

Challenges and Limitations in Implementing CSA

1. Financial constraints

Many climate-smart technologies require initial investment in equipment, planting material, irrigation infrastructure, improved seed, or training. Farmers with limited access to credit may be unable to adopt practices even when they could generate long-term benefits.

Financial support should therefore be designed to address initial investment barriers while avoiding the promotion of technologies that are unsuitable for local conditions.

2. Limited technical knowledge and extension support

CSA practices frequently require changes in management, timing, or resource allocation. Inadequate technical guidance can lead to poor adoption or disappointing results. Strengthening extension services, farmer training, field demonstrations, and locally adapted advisory systems can help overcome these barriers.

3. Inadequate climate information

Farmers require reliable, timely, and location-specific information about rainfall, temperature, drought risk, and extreme weather. Limited access to relevant information can reduce the usefulness of otherwise suitable technologies.

Climate services should be communicated through accessible channels and integrated with practical agricultural recommendations.

4. Regional variation and context specificity

A practice that performs well in one agroecological region may be ineffective or inappropriate elsewhere. For example, irrigation investments may be beneficial where water resources are sustainable but could intensify groundwater depletion in water-stressed areas.

CSA interventions should therefore be selected through local assessment and tested under relevant conditions before wider scaling.

5. Trade-offs among productivity, adaptation, and mitigation

CSA's three objectives do not always align automatically. Some technologies may increase yields but also raise energy consumption or fertilizer-related emissions. Tree planting may increase carbon storage but compete with crops for water if poorly designed.

Trade-off assessments are essential to avoid shifting environmental costs from one part of the agricultural system to another.

6. Institutional fragmentation

Agricultural development, water management, forestry, climate policy, rural finance, and disaster management may be administered through different institutions. Poor coordination can result in overlapping interventions, inconsistent priorities, or gaps in implementation.

Improved institutional coordination and clearly defined responsibilities are therefore essential for effective CSA implementation.

7. Uncertain economic and environmental outcomes

The benefits of CSA practices vary across farms and years. Initial costs, labour requirements, market prices, climatic conditions, and maintenance needs can influence the overall result.

Long-term evaluation should measure farm profitability, production stability, resource use, emissions, and resilience rather than relying only on short-term yield changes.

8. Equity and inclusion

Farmers differ in landholding size, access to credit, labour availability, technology, and decision-making power. Without suitable support, better-resourced farmers may benefit more readily from CSA interventions.

Inclusive programme design should consider the needs of smallholders, women farmers, tenant cultivators, and resource-dependent communities.

Research Gaps and Future Priorities

Further research is required to assess how CSA practices perform under different agroecological and socioeconomic conditions. Priority areas include:

1. **Long-term field evaluation:** Measure changes in productivity, farm income, soil health, water use, and resilience across multiple seasons.
2. **Economic assessment:** Evaluate initial costs, labour requirements, profitability, and the distribution of benefits among different farm categories.
3. **Greenhouse gas measurement:** Improve the estimation of emission reductions and carbon storage under locally relevant production systems.
4. **Climate risk assessment:** Identify the effectiveness of CSA practices under drought, heat stress, flooding, and changing rainfall patterns.
5. **Agroforestry research:** Examine species selection, tree–crop interactions, carbon storage, livelihood benefits, and biodiversity outcomes.
6. **Extension and adoption studies:** Investigate how access to climate information, farmer training, credit, and institutional support influences adoption.
7. **Programme evaluation:** Assess the outcomes of NICRA, NMSA, PMKSY, and other relevant initiatives using comparable indicators.
8. **Equity-focused research:** Examine how CSA adoption and benefits vary according to gender, landholding size, income, and access to resources.
9. **Digital climate services:** Evaluate the accuracy, accessibility, and practical usefulness of agricultural weather advisories.
10. **Integrated food-system assessment:** Extend analysis beyond the farm to include storage, processing, transport, market access, and food loss reduction.

Recommendations

The following measures could strengthen CSA implementation in India:

1. **Promote location-specific CSA packages:** Practices should be selected according to agroclimatic conditions, soil type, water availability, farming systems, and local socioeconomic circumstances.
2. **Strengthen agricultural extension:** Universities, ICAR institutions, Krishi Vigyan Kendras, and state agricultural departments should provide practical training and accessible climate-related advice.
3. **Improve access to finance:** Appropriate credit, targeted support, insurance, and investment mechanisms can help farmers overcome initial adoption barriers.
4. **Integrate CSA with natural resource management:** Soil conservation, groundwater management, watershed development, and agroforestry should be coordinated with agricultural development plans.
5. **Encourage sustainable agroforestry:** Tree-based farming should prioritize ecologically appropriate species, farmer needs, biodiversity, and long-term management.
6. **Strengthen climate information services:** Timely forecasts and location-specific advisories should be

made available in accessible formats and local languages.

7. **Improve programme coordination:** Government initiatives should complement one another and avoid fragmented implementation across agriculture, irrigation, forestry, and climate-related institutions.
8. **Establish measurable performance indicators:** Monitoring should include productivity, profitability, water-use efficiency, soil condition, adaptation outcomes, and greenhouse gas emissions where relevant.
9. **Support farmer participation:** Farmers should be involved in identifying priorities, testing practices, evaluating outcomes, and adapting technologies to local conditions.
10. **Promote inclusive CSA adoption:** Policies should account for the needs of small and marginal farmers and other groups that face barriers to agricultural investment.

Conclusion

Climate-Smart Agriculture offers an integrated approach to addressing the challenges of climate change, food security, and sustainable agricultural development. Its three pillars—sustainably increasing productivity and incomes, strengthening adaptation and resilience, and reducing or removing greenhouse gas emissions where possible—provide a framework for selecting and evaluating agricultural interventions. The FAO framework emphasizes that CSA is context-specific and requires the integration of scientific knowledge, farmer experience, appropriate technologies, institutional coordination, and financial support. Practices such as crop diversification, improved soil and water management, agroforestry, climate-resilient varieties, integrated farming, and efficient nutrient management can contribute to climate-smart outcomes when adapted to local conditions.

In India, programmes such as NICRA, NMSA, PMKSY, the Soil Health Card Scheme, PKVY, and agroforestry-related initiatives support various dimensions of sustainable and climate-resilient agriculture. Their contribution depends on effective implementation, extension support, adequate financing, and the suitability of interventions to local agricultural systems. CSA also contributes to several Sustainable Development Goals, particularly those related to poverty reduction, food security, water management, responsible production, climate action, and terrestrial ecosystems.

However, its implementation faces important challenges, including limited financial resources, inadequate technical support, regional variability, institutional fragmentation, and potential trade-offs among productivity, adaptation, and mitigation. Ultimately, CSA should not be treated as a universal technology package or as a guarantee of simultaneous gains across all three pillars. It is best understood as an adaptive framework for making informed agricultural decisions under climate uncertainty. Evidence-based planning, farmer participation, inclusive institutional support, and systematic monitoring will be essential for strengthening agricultural resilience and promoting sustainable food systems in India.

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