

Climate resilient agriculture for environmental sustainability

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Climate change poses a significant challenge to agriculture and food production, as it leads to extreme weather conditions, elevated temperatures and unpredictable rainfall, all of which adversely affect crops, soil and water resources. In India, the impact of climate change is anticipated to be particularly severe, especially in the northern regions, with increased heat and uncertain rainfall during the kharif season. To address these challenges, it is imperative to adopt sustainable farming practices that maintain soil health, prevent erosion and sequester carbon. Climate-resilient agriculture (CRA) is crucial for preserving environmental health and achieving the 2030 sustainability goals. To enhance the resilience of agriculture to climate change, it is essential to implement targeted nutrient management, organic farming, conservation agriculture, crop diversification and water-efficient farming practices. However, there are challenges in implementing these methods, even with governmental support. To promote the widespread adoption of CRA in India, a comprehensive long-term strategy and a multifaceted approach is required. Disseminating knowledge on adaptation and mitigation strategies is vital for broader acceptance. A robust CRA framework can contribute to the attainment of sustainable development goals, many of which emphasise climate change, agriculture, natural resources, and food security.

Keywords: Agro-biodiversity, Climate change, Climate resilient agriculture, Digital tools, Soil health improvement, Watersmart farming

CLIMATE change represents a significant challenge in contemporary society, primarily driven by greenhouse gas emissions from human activities. The sectors of agriculture and food production are particularly vulnerable to the impacts of climate change, which in turn affects food and water security. The increasing difficulty in food production necessitates the development of innovative adaptations to maintain sustainability in order to meet the demand of growing population. Extreme weather events such as heavy rainfall, floods, droughts and heatwaves adversely impact crops, soil and water resources. These climatic changes disproportionately affect rural areas, where many small-scale farmers depend on rainfall for their agricultural activities. It is projected that staple food yields could decline by up to 30% due to crop failures and reduced productivity. To ensure food, nutrition and environmental security, it is imperative to enhance food production while minimizing carbon and energy inputs. According to Indian Meteorological Department (IMD) 2022 report, temperature in certain regions of India exceeded normal levels by 3–8°C. Approximately 70% of India was affected by heatwaves, which led to reduced crop yields and water stress. Climate change is anticipated to have a profound impact on Indian

agriculture. The minimum temperature is expected to rise more significantly than the maximum temperature, with the northern regions likely to experience greater heat than the southern regions. Rainfall during *kharif* season is expected to become unpredictable and temperature is projected to rise following the rainy season. These changes in seasonal patterns, temperature and precipitation can lead to challenges such as drought, floods resulting in substantial losses in yield. These effects will vary depending upon region, crop type, soil conditions, and farming practices. However, global warming is likely to diminish both the quality and quantity of crops. This is attributed to shorter growing periods due to high temperatures, increased prevalence of weeds and pests, reduced soil fertility and heightened soil erosion from erratic rainfall. Prolonged dry spells at the beginning, middle and end of the growing season can adversely affect crop production. A delayed onset of the monsoon followed by an extended dry period can result in early season drought. Insufficient soil moisture between rainfall events can lead to mid-season drought, while late season drought occurs when the monsoon concludes prematurely.

Promoting sustainable agriculture is crucial for addressing climate change within the agricultural

sector. This involves implementing practices to maintain soil health, reduce erosion and enhance carbon sequestration. Climate resilient agriculture is essential for maintaining environmental sustainability in the face of climate change. Integrating traditional knowledge with modern scientific advancements facilitates development of localised strategies for climate resilience. Climate resilient agriculture should prioritise long term sustainability contributing to the achievement of 2030 sustainability agenda, which encompasses climate change, natural resource conservation and food security. With its adaptation and mitigation strategies, climate resilient agriculture is vital for sustainable development. To effectively address climate change, it is imperative to utilise crops that can withstand diverse weather conditions and to refine farming practices tailored to specific regions. Important adaptation measures include cultivating robust stress tolerant crop varieties, employing soil conservation farming techniques, managing nutrients based on specific regional needs and utilising advanced irrigation methods such as micro irrigation. Some of the key approaches to enhance the resilience of agriculture to climate change are discussed below.

Soil health improvement

Site specific nutrient management: Excessive application of fertilizers, such as nitrogen and phosphorus, to enhance crop yield has resulted in water pollution and degradation of terrestrial and coastal ecosystems, subsequently diminishing biodiversity. While nutrients are essential for global sustenance, it is crucial to apply fertilizers judiciously to promote crop growth and ensure sustainable agricultural practices. Ensuring application of balanced fertilizers is crucial for enhancing crop yields and maintaining agricultural sustainability. Nitrogen is among the essential nutrients needed for soil fertility. Nitrogen is a vital nutrient for enhancing crop growth; however, only less than 30% of the applied N has been utilised effectively. Inefficient fertilizer use and suboptimal water management are primary contributors to reduced crop productivity. The production and application of N fertilizers are energy-intensive processes that contribute to carbon emissions. Integrated Nutrient Management (INM) offers a viable solution to these adversaries. INM enhances soil nutrient and water retention, carbon sequestration and nutrient utilisation efficiency.

Organic farming: Organic farming represents a sustainable approach to land management. This approach can mitigate environmental impacts and enable farms to better adapt to climate change compared to conventional farming. It reduces greenhouse gas (GHG) emissions, enhances farm biodiversity, maintains soil health and bolsters food security and farmer autonomy. Although organic farming yields are lower than those of conventional farming, it remains a sustainable option. Organic products can fetch higher prices, thereby improving the profit margin, albeit with low productivity due to higher market prices. The

focus of organic farming on maintaining soil fertility and health contributes to climate change adaptation. It employs closed nutrient loops, minimises losses from runoff and evaporation and avoids synthetic fertilizers. Consequently, organic farming exhibits higher soil organic carbon than conventional farming. They also support greater species diversity and cultivation of local varieties, enhancing resilience to extreme weather conditions. It also demonstrates superior water retention with 15–20% improvement in groundwater recharge, rendering organic farms drought resistant.

Conservation agriculture: Conservation Agriculture (CA) is implemented on 3.5 Mha in India. The key practices within CA encompass zero tillage, raised bed planting, direct seeded rice, utilization of crop residues and crop diversification. CA represents a sustainable approach to farming that can maintain or enhance crop yield, profitability and environmental health. CA contributes to improved soil quality, facilitates water filtration, retain soil moisture and reduces soil erosion and runoff. Reduced run off results in fewer nutrients, such as nitrate and phosphorus, being washed away from fields into water bodies thereby mitigating issues like water pollution. In conventional farming, there is a higher risk of nitrate leaching into groundwater. It is an integral component of climate smart agriculture as it enables quicker planting, minimise the soil disturbance and reduces fossil fuel consumption. Compared to conventional farming, CA sequester more carbon in the soil, support greater soil biodiversity and emit fewer GHGs making it a climate friendly practice.

Agro-biodiversity

Resilient crop varieties: The development of stress-tolerant crops is essential for addressing weather changes and supporting farmers. The improved varieties of crops that withstand adverse conditions such as drought, extreme temperatures, and floods have been developed through National Agricultural Research System in India. The development of these varieties is crucial for maintaining and enhancing crop production in the face of climate change. A crop's stress tolerance indicated its ability to grow and yield effectively even under adverse conditions. Under the National Innovations in Climate Resilient Agriculture (NICRA) programme of ICAR, high-yielding and stress-tolerant varieties of wheat and maize have been developed that can endure heat and drought stress. In Uttar Pradesh, adoption of flood tolerant rice variety BinaDhan 11 has enhanced income by ₹ 10,890/ha.

Crop diversification: Cereal based cropping systems are resource intensive and contribute significantly to greenhouse gas emissions, carbon and energy footprints and groundwater pollution. The inclusion of legume crops diminishes the requirement of N fertilizers. Legumes exhibit a smaller carbon and water footprint compared to cereals due to their lower GHG emissions. Legumes also contribute nitrogen to the soil potentially reducing global CO₂ emissions. In the Indo-Gangetic Plains, conventional rice-wheat cropping system is a



Conservation agriculture practice in maize



In situ soil moisture conservation in maize

significant source of GHG and exhibits higher global warming potential due to increased methane emission. Consequently, it is imperative to transition these systems especially the rice-wheat system to alternatives that are more carbon and energy efficient productive and environmentally sustainable. The implementation of direct seeding for rice and zero tillage for wheat along with the addition of crop residues substantially reduced GHG emissions which demonstrated that global warming potential can be decreased by 44–47% by transitioning from traditional systems of tilled wheat and transplanted rice to zero till wheat and direct seeded rice or zero tillage wheat with rice residue and direct seeded rice without compromising productivity. Additionally, inclusion of millets enhances energy productivity, system productivity and economic efficiency in the diverse agricultural zones of eastern India. Integrating millets or legumes into cereal based systems can reduce C foot print of crops by 32–315%.

Integrated farming system: To ensure food security while addressing land degradation and C emissions, implementation of Integrated Farming system (IFS) is recommended. IFS employs a holistic approach encompassing livestock management, provision of ecosystem services and development of resilient and adaptable farms. These systems enable farms to effectively respond to climate variations by diversifying plant species and employing varied land resource management strategies. IFS integrate crops,

livestock, aquaculture and other activities within a single farm. These multifaceted systems demonstrate higher productivity, greater resilience to environmental changes and reduced adverse impacts compared to simpler farming models. The inclusion of trees and legumes enhances species diversity and farm resilience, while also contributing to GHG emission reductions. The foliage from certain trees and legumes improves the nutritional intake of farm animals, which in turn reduces methane emissions per unit of product, thereby decreasing overall emissions. This approach is particularly beneficial for small holder farmers, who play a vital role in India's agriculture sector.

Water smart farming

Effective water management is crucial for agriculture globally due to declining groundwater levels and increasing freshwater pollution. In response to climate change, farmers are adapting their water usage practices by implementing strategies such as rainwater harvesting and the combined use of groundwater and surface water. To ensure the sustainability of water resources, it is essential to employ appropriate irrigation techniques. In India, farms in arid regions are adopting micro-irrigation systems, including drip and sprinkler systems, to address water stress exacerbated by climate change. This initiative is part of the National Mission on Micro-Irrigation. Reports indicated that micro-irrigation systems can achieve energy savings



Integrated farming System





Various Components of IFS

by 39%. Rainwater harvesting, a traditional method in arid regions, remains a valuable practice for water conservation. The integration of rainwater harvesting in farm ponds and community tanks can enhance crop production. Additionally, strengthening existing watersheds through various farm-level measures can mitigate the impacts of climate change and drought, thereby enhancing resilience in drought-affected areas.

Digital tools

Precision agriculture represents a significant advancement in farming, leveraging cutting-edge technology to enhance sustainability. This approach enables farmers to increase profitability while minimizing resource usage and environmental impact. The implementation of Decision Support Systems facilitates farm management by utilizing tools such as GPS, drones and satellite imagery to create maps that illustrate variations in crop yields, soil types and moisture levels. Sensors play a crucial role in data collection, contributing to improved crop yields and energy conservation, thereby promoting a sustainable future. By adhering to sustainable practices, precision agriculture optimizes crop management with reduced reliance on fertilizers, pesticides and other limited resources such as water and energy. Automated systems monitor and irrigate crops, employing sensors to assess soil conditions, including temperature and moisture. This data informs decisions regarding water and fertilizer application. Additionally, sensors measure soil moisture, which is vital for effective irrigation and enhanced crop growth. The integration of robotics, automated systems, and artificial intelligence has significantly advanced modern agriculture. Drones are becoming integral to environmentally sustainable farming practices. In precision agriculture, drones equipped with sensors perform various tasks, including

soil and field analysis, crop monitoring, spraying of pesticides and crop health assessment. This technology enables precise soil management, encompassing soil organisms and plant inputs, based on real time monitoring of soil, crops and environment. Android based applications are also developed which assist in location specific forewarning of pests in different crops.

Renewable energy sources

The agriculture sector is heavily reliant on fossil fuels for food production, posing significant threats to food security and sustainable practices. Traditional farming methods that utilize fossil fuels contribute to environmental pollution through GHG emissions. Reducing fossil fuel consumption would decrease GHG emissions and transitioning to renewable energy could decouple energy use from GHG emissions. Future agricultural practices must incorporate renewable energy and nutrient recycling to mitigate energy expenses and combat global warming. Renewable energy is derived from inexhaustible natural sources such as sunlight,





Mobile app for pest forewarning

wind, water and geothermal heat, which are particularly advantageous in rural areas. Utilizing renewable energy in agriculture can enhance food, environmental and social security, resulting in increased profitability and autonomy for farmers.

SUMMARY

The implementation of CRA practices encounters challenges even with existing government policies and initiatives. To effectively promote CRA across India, a long term strategy is essential. These insights can aid in formulating strategies for Indian agriculture aligning it with sustainability and the SDGs. Climate smart villages represent a viable approach to expanding adaptation options. Locations specific conservation strategies for water efficient farming such as cover crops and rainwater harvesting can be promoted with

farmers demonstrating these technologies in their fields. Different climate change initiatives like NMSA, NICRA, NDMA can be integrated with national agricultural policies on food security, disaster management and natural resource conservation. A multi-intervention approach including crop management practices is necessary to promote climate resilient crops. The dissemination of knowledge on adaptation and mitigation measures among stakeholders is crucial for broader acceptance. A comprehensive CRA approach can contribute to achieving the sustainable agenda objectives as many SDG goals address climate change agriculture production, natural resource conservation and food security.

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