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Climate Based Smart Agriculture: Need for Food Security and Sustainability

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A variety of climate-smart agriculture technologies, practices, and services have been introduced in climate-smart villages as adaptation strategies to cope with climate risks and ensure stability and sustainability in agricultural production. Farmers who utilize climate-smart agriculture adaptation strategies have been shown to achieve higher output, yield, and return compared to those who do not. There are promising opportunities to scale out these strategies and immense potential to enhance crop yields and farm incomes while reducing greenhouse gas emissions.

Strengthening agricultural extension services and agricultural finance by linking climate finance to traditional agricultural finance could play a significant role in scaling out climate-smart agriculture practices and technologies. This would make agriculture more sustainable and climate-resilient, thereby becoming a viable source of livelihood and food security for millions of farmers in the country. Zero budget natural farming is a climate-resilient farming system that can enhance food and nutritional security while allowing farmers to improve soil fertility and yields at lower costs, risks, and irrigation requirements. This system protects the ecosystem by improving soil organic matter, water retention, and biodiversity, while reducing air and water pollution as well as greenhouse gas emissions.

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1. INTRODUCTION

"The global agricultural system has been facing momentous challenges due to various factors such as population growth, urbanization, climate change, and environmental stresses. These factors have placed tremendous pressure on the use of natural resources, including land, water, and energy. The report focuses on Sub-Saharan Africa, South Asia, and Southeast Asia, highlighting how rising global temperatures are endangering the health and livelihoods of their most vulnerable populations. It follows a previous report, "Turn Down the Heat: Why a 4°C World Must Be Avoided," which predicted a 4°C warming by the century's end" [1]. "The World Bank Group (WBG) is expanding its efforts towards climate-smart agriculture, which aims to increase productivity, build resilience, and reduce emissions. In its first Climate Change Action Plan (2016-2020) and upcoming update for 2021-2025, the World Bank is committed to collaborating with countries to achieve this triple win" [2]. "The United Nations Food and Agriculture Organization (FAO) has projected that food production will need to be increased by a minimum of 60% in order to meet the dietary needs of the projected global population of 9 billion by the year 2050" [3]. "The agriculture industry in the 21st century is confronted with various challenges that require attention. One of the major challenges is to increase food and fiber production to sustain a rapidly growing population with a reduced rural labor force. Additionally, the industry has to provide more feedstocks to cater to the potentially extensive bioenergy market. Another challenge is to contribute to overall development in many developing countries where agriculture is a primary source of income. Moreover, there is a need to adopt more efficient and sustainable production methods to mitigate the negative impacts of agricultural practices on the environment. Furthermore, the industry must adapt to the consequences of climate change that have direct and indirect impacts on agricultural activities. the world's population is anticipated to increase by approximately 2.3 billion people, or more than a third of the current population, between the years 2009 and 2050" [4].This anticipated growth rate has significant implications for various aspects of human life, including food security and the environment. The expected growth rate for the world's population between 2009 and 2050 is much slower compared to the previous four decades. During that period, the global population increased by more than 90 percent, or 3.3 billion people. It is anticipated that urbanization will continue at a rapid pace, with urban areas expected to comprise approximately 70 percent of the world's population by 2050. This represents a significant increase from the current figure of 49 percent. In contrast, the rural population is expected to peak sometime in the next decade and then begin to decline. India is particularly susceptible to the effects of climate change due to various reasons. Firstly, there is widespread poverty, with a large portion of the population relying on agriculture for their livelihoods. Secondly, agriculture in India is heavily dependent on natural resources, which are already under strain due to environmental degradation. Lastly, the country has limited coping strategies to deal with the impacts of climate change. Although the adoption of improved technologies, such as high-yielding varieties, fertilizers, and irrigation, in the mid-1960s led to unprecedented growth in food grain production and the introduction of a green revolution in Indian agriculture, there are concerns about the sustainability of this growth. "The increasing population in the country, coupled with the challenges posed by climate change, has raised questions about the ability of Indian agriculture to ensure food security and sustainability in the long run. Therefore, it is crucial for the country to adopt more sustainable agricultural practices to address these challenges and ensure food security for its population. The green revolution technologies brought about a significant transformation in Indian agriculture, making the country self-sufficient in food grains. However, despite these successes, India still faces significant challenges related to food insecurity, malnutrition, poverty, and hunger. The 2022 Global Hunger Index ranked India 107 out of 121 countries, classifying it in the 'serious category' with a score of 29.1" [5]. This situation highlights the need for India to address the underlying causes of food insecurity, including poverty, and unequal distribution of resources. While India has made strides in reducing hunger in recent years, much more work needs to be done to ensure that all citizens have access to adequate, nutritious food. The intensive use of traditional agricultural practices has led to environmental problems such as groundwater depletion and deteriorating soil health, which have adversely affected crop production and growth. [6] found that "the growth rate of food grain production in India has decelerated from 2.85 percent in the 1980s to 2.02 percent in the 1990s and 2.12 percent in the 2000s.The Food and Agriculture Organization (FAO) of the United Nations stresses the importance of climate-smart agriculture in addressing the challenges of global food security and managing agricultural systems and natural resources". [3] recognizes that "climate change poses a critical threat and emphasizes the need to enhance the capacity of rural communities to adapt to climate variability and build resilience to climatic shocks". "By promoting climate-smart agriculture practices. The demand for food from the growing global population necessitates a transformation of the agricultural sector. To achieve this, there is a need to alter the current management practices of land, water, soil nutrients, and genetic resources. When evaluating measures and strategies aimed at mitigating climate change, it is important to consider not only their environmental impact but also their financial and economic implications" [7,8]. "The objective is to ensure the more efficient and sustainable use of these resources, thereby increasing agricultural productivity and resilience. The agricultural production system must adapt to climate change and variability to guarantee food and livelihood security for farming communities. The climate smart agriculture (CSA) approach contributes towards achieving food and livelihood security and other developmental goals by (a) sustainably increasing agricultural productivity and incomes, (b) adapting and building resilience to climate change and (c) reducing and/or removing GHG emissions, where possible [9,10]. The concept of climate-smart agriculture (CSA) involves the integration of climate change considerations into the planning and implementation of sustainable agricultural strategies. It aims to create resilient food production systems that can provide food and livelihood security for farming communities under the impacts of climate change and variability. This approach has been extensively discussed in literature" [11,12]. "The CSA approach recognizes the interconnections between food security, adaptation, and mitigation, and seeks to leverage these relationships to inform policy and reorient agricultural practices in response to climate change" [11]. "The approach aims to integrate climate change considerations explicitly into sustainable agricultural development by identifying and operationalizing relevant strategies. However, a location-specific, integrated approach is essential to successfully implement CSA practices" [3]. "The CSA approach encompasses several key features. First, it addresses adaptation and builds resilience to climatic shocks. Second, it recognizes climate change mitigation as a potential co-benefit. Third, it is location-specific and knowledge-intensive, requiring tailored strategies for each context. Fourth, it identifies integrated options that create synergies and reduce trade-offs. Fifth, it identifies barriers to adoption and provides appropriate solutions. Sixth, it strengthens livelihoods by increasing access to services, knowledge, and resources. Finally, it integrates climate financing with traditional sources of agricultural investment" [3].

2. STRATEGIC CLIMATE SMART APPROACHES

Climate-smart Village: "To achieve sustainable agricultural development, it is essential to adopt strategies that enhance the implementation of CSA. The Consultative Group on International Agricultural Research (CGIAR) has been working with rural communities in partnership with national programs under the Research Program on Climate Change, Agriculture and Food Security (CCAFS). The aim is to develop Climate-Smart Villages (CSVs) that serve as models for local actions to ensure food security, promote adaptation, and build resilience to climatic stresses. The Climate-Smart Village (CSV) approach is a community-led effort towards sustainable agricultural development. It involves collaboration between farmers, researchers, local partners, and policymakers to select appropriate technological and institutional interventions based on global knowledge and local conditions. The approach aims to increase productivity and incomes, achieve climate resilience, and enable climate mitigation. The CSV approach integrates village developmental and adaptation plans, as well as local knowledge and institutions, into the program. The strength of the Climate-Smart Village (CSV) approach lies in its inclusiveness, as it brings together farmers, policymakers, researchers, and local organizations to work on implementing a set of climate-smart technologies and practices. The goal is to adapt agriculture to climate change, ensuring the food and livelihood security of farmers in vulnerable regions" [13]. "The process of building a CSV involves various steps. Firstly, the location of the CSV is selected based on its climate risk profile, alternate land-use options, and the willingness of farmers and local government to participate in the project.

Secondly, existing community groups are engaged, comprising of farmers, researchers, rural agro-advisory service providers, and village officials. Thirdly, a baseline study is conducted to assess the current socioeconomic situation, resource availability, average production and income, and risk management approaches of village households. Fourthly, stakeholders' discussion is held to prioritize the most appropriate climate-smart technologies and practices for the local conditions, indicating the actions they would be willing to carry out. Fifthly, capacity building is provided through regular training sessions for farmers on good agricultural practices, including the use of rain gauges, improved seed varieties, new livestock breeds, tree seedlings, simple machinery such as zero-till machines, subsidies on index-based insurance premiums, and discounts on cell phone SIM cards. Sixthly, progress of the chosen farm activities of the participating farmers is monitored and evaluated. Finally, the message of CSA is disseminated through videos on success stories and testimonials from the pilot villages, screening them in nearby villages and publicizing them widely through local, national, and international media" [13]. "CCAFS' CSVs are designed to address climate change hotspots in Africa, Asia, and Latin America. The approach is a comprehensive strategy for sustainable agricultural development, with critical climate-smart interventions in key areas. The CSVs focus on encouraging the adoption of weather-smart activities such as weather forecasts, ICT-based agro-advisories, index-based insurance, stress-tolerant crops and varieties, and climate analogues. Water-smart practices include resilient water management practices, aquifer recharge, rainwater harvesting, community management of water, laser land levelling, water conservation, drip irrigation, raised bed planting, crop diversification, alternate wetting and drying in rice. Carbon-smart practices involve agroforestry, livestock and manure management, conservation tillage, diversified land-use systems, and residue management, which enhance carbon content in the soil. Nitrogen-smart practices encompass leaf-colour charts, hand-held crop sensors and nutrient decision-maker tools for site-specific nutrient management and precision fertilizer application using nutrient expert decision support tools, residue management, and legume catch cropping. Energy-smart technologies and practices include fuel-efficient agricultural machinery, residue management, biogas systems, and minimum tillage, which conserve energy and reduce GHG emissions. Knowledge-smart activities involve cross-site visits of farmers, farmer-to-farmer learning, capacity enhancement on CSA, seed packets of adapted varieties, community seed and fodder banks, and market and off-farm risk management systems. The goal is to build the resilience of village communities to climatic stresses and ensure food and livelihood security for farmers. climate change and its increasing variability are likely to worsen the food security situation by putting additional environmental pressure on agricultural systems, it is critical to strengthen the resilience of Indian agriculture to cope with these changes. This is particularly important for small and marginal farmers who are more vulnerable to the effects of climate change and variability. Climate-Smart Agriculture (CSA) is particularly relevant in light of the World Bank's (2013) estimate that total crop production would increase by 60 percent by 2050 without climate change, but the increase would be limited to only 12 percent in the event of a 2°C warming caused by climate change by the 2050s" [14]. "The CSV (Climate-Smart Village) approach was first implemented in Haryana and Bihar in 2011, where 27 CSVs were piloted in the Nilokheri, Indri, Gharaunda, and Nissing blocks of Karnal district in Haryana. Among these villages, Taraori has emerged as a model CSV, with farmers who are receptive to new technologies and have adopted progressive farming practices, such as zero-tillage. It is worth noting that burning of residues is very low in the village. Notably, a tonne of rice and wheat residues, which comprises 40% carbon, contains 5–8 kg of nitrogen, 1–2 kg of phosphorus, and 11–13 kg of potassium" [14]. "This information highlights the potential benefits of reducing burning of residues and utilizing them as a valuable resource for soil fertility management. Implementing zero-tillage practices can lead to significant improvements in water and nutrient retention while also reducing diesel usage by up to 80-85% compared to traditional tilling methods. Incorporating residue management and crop diversification in zero-tillage techniques can also decrease the demand for fertilizer by as much as 20% after three years. Utilizing direct-seeded rice instead of the conventional transplanting method can reduce methane emissions by 40% and water usage by 25%. Similarly, raising maize and wheat from the soil and planting them directly can also reduce water usage by 30-35%. Farmers can use tools such as leaf-colour charts and Green Seeker technology to determine the nitrogen requirements of their crops and optimize their use of fertilizer. They also rely on weather information and technology to measure soil moisture. Additionally, the adoption of zero tillage and line sowing of seeds has led to an increase in rice and wheat yields by 10-15%. The success of trials in 27 Climate-Smart Villages (CSVs) in Karnal has opened up opportunities to scale out the CSV model and incorporate Climate-Smart Agriculture (CSA) into development programmes and policies in multiple regions of the country that are experiencing environmental stresses" [13]. "The state of Haryana has plans to extend this model to 500 more villages, while Bihar is also looking to scale it up. Currently, trials under the CCAFS programme are being conducted in 70 villages in Punjab, Odisha, Karnataka, Haryana, and Bihar. With climate change and the increasing variability of rainfall and temperature, as well as greater risks from pests and diseases, the weather-index-based crop insurance scheme (WBCIS) was introduced in India in 2007 as an alternative to the existing yield-index-based National Agricultural Insurance Scheme. This program has successfully encouraged farmers to invest in their crops, increase agricultural productivity, and mitigate climate change, thereby enhancing the resilience of smallholder production systems and safeguarding the food security of farming families" [14]. "Over the years, the number of farmers insured under the WBCIS has significantly increased, as has the amount of pay-outs. The number of farmers insured rose from 1,000 in 2003-2004 to approximately 12 million in 2011-2012. The weather-index-based crop insurance scheme has the potential to significantly increase food production by reducing farmers' risks when investing in farm inputs such as improved seeds and fertilizers", according to [15]. "The Economic Survey of 2017-2018 by the [16] highlights the importance of using crop insurance programs like the Pradhan Mantri Fasal Bima Yojana to determine losses and compensate farmers quickly". "The Integrated Agro-meteorological Advisory Service (IAAS), introduced in 2007, has also helped farmers to maximize their income from crop production by providing them with guidance to manage climate-induced risks in the short term. Meteorological services in India provide crucial weather-related information, including five-day forecasts and warnings of severe weather, according to specialists from the Indian Council of Agricultural Research (ICAR), state departments of agriculture, and agricultural universities. These experts translate the information into agricultural advisories to alert farmers to weather-related events and advise them on actions to protect their crops. The advisories are conveyed to farmers in local languages through various channels, such as SMS messages on mobile phones, local radio and newspapers, and face-to-face advisory and extension services. Currently, the advisories reach approximately 2.5 million smallholder farmers across the country. Empirical studies suggest that farmers receiving Integrated Agro-meteorological Advisory Service (IAAS) advisories have obtained 10-15% higher yields with 2-5% lower costs compared to farmers not receiving the advisories" [15]. "CRISAT (International Crops Research Institute for the Semi-Arid Tropics) has been actively involved in developing and implementing five different approaches to build Climate-Smart Villages (CSVs) and help farmers cope with climate change. These approaches include watershed management, futuristic multi-model, digital technologies, meteorological advisory and farm systems, climate and crop modelling. ICRISAT has developed climate-resilient dryland crops and a pool of climate-smart technologies that are used in all of its climate-smart project interventions. The focus is on empowering farmers to use climate-smart scientific interventions and innovations, diversify their livelihoods, link to markets, make agriculture profitable, rehabilitate and restore their environment and influence policymakers. One of the approaches, the climate and crop modelling approach, has been successful in the drought-prone Kurnool district of Andhra Pradesh. Farmers who followed cropping advisories based on seasonal climate forecasts earned 20 per cent more than those who did not follow them. This success has prompted the project to be extended to other villages in Andhra Pradesh and neighbouring Karnataka" [17].

National Initiative on Climate-Resilient Agriculture: "The Indian Council of Agricultural Research (ICAR) launched the National Initiative on Climate Resilient Agriculture (NICRA) in 2011 to address the challenges of climatic changes on Indian agriculture. This multi-institutional and multi-disciplinary project aims to enhance the resilience of Indian agriculture to climate change and variability by developing climate-resilient agricultural technologies and demonstrating climate-smart practices to help farmers cope with the emerging problems associated with climate change. Participatory on-farm demonstration of site-specific technologies and practices is considered crucial for coping with climate change and ensuring adaptation gains, along with possible reductions in GHG emissions" [18].

Natural Resource Management Module: In the natural resource management module, practices such as in-situ moisture conservation, tube well recharge, rainwater harvesting by check dams, micro-irrigation systems, resource conservation technology, rotavator and mobile chopper, summer deep ploughing, laser land leveler, field bunding, residue management through happy seeder, zero-till wheat green manuring, and bio gas unit are implemented. Rainwater harvesting and recycling for supplemental irrigation are also undertaken by renovating old check dams, constructing new farm ponds, and village water ponds. Soil amendment and soil test-based nutrient application and green manuring for improving soil health are also prioritized. For soil reclamation, the intervention of gypsum application and organic compost is used.

Crop Production Module: The crop production module includes practices such as short-duration varieties, drought-tolerant cultivars, spray of growth regulator and micronutrient, crop diversification, FIRB sowing method, soybean-mustard mixed cropping, intercropping of soybean+maize and soybean+urd beans (5:2 row), wilt-resistant variety, salt-tolerant varieties, and integrated pest management in different crops.

Livestock and Green Fodder Production: The livestock and green fodder production module focuses on animal breed up-gradation, animal housing and manger, fodder maize silage, balanced animal nutrition (UMMB, mineral mixture supplementation), vaccination, and deworming.

3. CONSERVATION AGRICULTURE

Conservation Agriculture is a scientifically proven farming system that helps to prevent arable land losses and regenerate degraded lands. This approach promotes the maintenance of a permanent soil cover, minimum soil tillage, and diversification of plant species, which enhances biodiversity and natural biological processes both above and below the ground surface. These practices lead to improved water and nutrient use efficiency, resulting in sustained crop production. In addition to improving crop yields, Conservation Agriculture also helps to reduce greenhouse gas emissions by lowering energy inputs and improving nutrient use efficiency. This approach has been shown to be 20 to 50 percent less labor-intensive than traditional agriculture, making it an attractive option for farmers looking to improve their efficiency while promoting sustainable farming practices.

Conservation Agriculture is a farming system that is based on three main principles, which are adapted to reflect local conditions and needs.

Minimum Mechanical Soil Disturbance: the principle of minimum mechanical soil disturbance involves avoiding tillage through direct seed and/or fertilizer placement. This helps to reduce soil erosion and preserves soil organic matter.

Permanent Soil Organic Cover: permanent soil organic cover is maintained by leaving at least 30 percent of crop residues and/or cover crops on the soil surface. This protective layer of vegetation helps to suppress weeds, protects the soil from the impact of extreme weather patterns, preserves soil moisture, and prevents soil compaction.

Diversification: species diversification is achieved through varied crop sequences and associations that involve at least three different crops. A well-designed crop rotation promotes good soil structure, fosters a diverse range of soil flora and fauna that contributes to nutrient cycling and improved plant nutrition, and helps to prevent pests and diseases. These principles have been advocated by the FAO and are crucial for sustainable agriculture [19]. Intercropping Setaria (foxtail millet, SIA-3085) with pigeonpea (5:1) in July proved highly profitable with the highest benefit cost ratio over 3 years, despite a 25-day dry spell in 2012 [20].

4. NATURAL FARMING

Natural farming is a diverse farming system that integrates crops, trees and livestock, facilitating optimal use of functional biodiversity. It is based on natural or ecological processes that exist on or near farms and uses only natural inputs. Natural farming provides a strong basis for increasing farmers' income while providing many other benefits, such as restoration of soil fertility and environmental health, and mitigation or reduction of greenhouse gas emissions. Natural farming has the potential to manage land patterns and sequester carbon from the atmosphere in soils and plants, where it is actually useful rather than harmful. [21].

Table 1. Benefits of natural farming [22]

Improved yield	Farmers who adopt natural farming practices have reported similar yields to those who practice conventional farming. In some cases, higher yields per crop have also been reported as a result of improved resilience.
Environment protection	Natural farming promotes better soil biology, increased agrobiodiversity, and more judicious use of water with much lower levels of carbon and nitrogen inputs.
Low cost of production	Natural farming aims to significantly reduce production costs by encouraging farmers to prepare the required inputs using natural and household resources.
Ensuring better health	Since no synthetic chemicals are used in natural farming, the health risks and hazards associated with synthetic chemicals are eliminated.
Less water consumption	Natural farming optimizes the amount of 'crop-per-drop' by planting a variety of crops that benefit each other and cover the soil to prevent unnecessary water loss through evaporation.
Job creation	Natural farming is a labor-intensive farming practice, which generates new employment opportunities.
Livestock sustainability	Livestock sustainability Cows play a major role in natural farming. Eco-friendly agricultural inputs such as Jeevamrit and Bijamrit are prepared from cow dung, urine, and other natural products. The integration of livestock into the farming system helps to restore the ecosystem.
Elimination of application of synthetic chemical inputs	The application of synthetic fertilizers, particularly urea and insecticides, as well as other mitigation interventions, alter soil biology and structure, leading to a loss of soil organic carbon and fertility. This not only affects crop yields but also the income of farmers, who are forced to increase their use of expensive synthetic inputs to maintain yields.
Innovation in soil health restoration	The most immediate effect of natural farming is on soil biology, including microbes and other living organisms such as earthworms. Soil health depends entirely on the living organisms present in it, which are at high risk under conventional agriculture.

Table 2. State –wise natural farming area covered [23]

Sl. No.	States	Area in Ha
1.	Andhra Pradesh	100000
2.	Chhattisgarh	85000
3.	Kerala	84000
4.	Himachal Pradesh	12000
5	Jharkhand	3400
6.	Odisha	24000
7.	Madhya Pradesh	99000
8.	Tamil Nadu	2000
Total		**409400**

The implementation of natural farming practices has led to the coverage of 4.09 lakh hectares of land in 8 states throughout the country, including Tamil Nadu [23].

5. CONCLUSION

Climate smart agriculture, the main objective of agriculture is to minimize the damage to the farming community due to the fluctuating temperature, for this the government has started different projects, such as NICRA, natural farming, conservation farming etc. Farmers have benefited through this medium. Today's modern farming is causing damage to the environment very fast, the amount of carbon dioxide is increasing, ozone gas is getting damaged, farmers' crops are ripening before time. For all these reasons, along with climate smart farming, the initiative of Climate Smart Village is also good, apart from this, the Village Climate Resilient Management Committee of NICRA Project also gives information related to climate change in the village.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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