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Building Agricultural Resilience: Strategies for Climate Change Adaptation

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Authors' contributions

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

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Review Article

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ABSTRACT

Climate change has a significant impact on India's agriculture, influencing environmental conditions, agricultural techniques, and production. The term "climate-resilient agriculture" refers to technologies, methods, tools, and frameworks aimed at adapting to and mitigating the effects of climate change on agricultural production, food security, and livelihoods. Crop productivity and food security are greatly impacted by climate changes, which calls for creative agricultural methods to maintain food supply while reducing environmental damages. These difficulties are made worse by

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environmental changes and global population expansion, especially in developing countries. Technological advancements, such as geospatial analysis, and eco-friendly farming technologies, play a crucial role in optimizing land use and enhancing food security. Crop variety adaptation and management of seed, water, land, livestock, soil and nutrients, pest management, risk management, and post-harvest management are examples of effective agricultural adaptation strategies. Technological developments like geographic analysis.

Keywords: Climate change; human population; geographic analysis.

1. INTRODUCTION

Food security has become a worldwide concern due to the exponential increase of human population, less agricultural space, change in the worldwide environment, urban expansion and land use change, etc (Rotolo, et al. 2015). Reports from both the IPCC and FAO indicate that the agriculture sector in developing nations is among the most susceptible sector to climatic change related stresses (Manuamorn et al., 2020). Moreover, with the current global population reaching approximately 9.1 billion, there is a projected need for a 50 to 70% increase in worldwide food production by 2050 to sustain current dietary patterns (McIntyre et al., 2009) and it will again further increase by approximately 30% rise in greenhouse gas emissions worldwide from the agriculture (Tubiello et al., 2014) especially in Asian and African countries as the large population relies on agriculture and related livelihoods (Sapkota et al. 2019). Therefore, it's essential to innovate agricultural techniques and approaches to ensure sustainable and adequate food provision for future generations while minimizing environmental harms (Akpoti et al., 2019). Moreover, the availability of food supplies will also diminish the quality and availability of the goods that rely on local agricultural production or imports (FAO, 2006). The climate change can be direct or indirect effects on agriculture, with varying degrees of impact depending on the extent of change in climate, geographic location, and agricultural methods employed. Evaluating these impacts involves conducting controlled experiments and simulation modeling. The findings from these experiments are then applied regionally to project how climate change may affect agriculture under different scenarios. Alterations in productivity, shift in agricultural practices like water management and use of fertilizers, insecticides herbicides, etc. and the environmental impacts, particularly regarding the frequency and intensity of soil drainage which may result in loss of nitrogen through leaching, soil erosion, and decrease of crop diversity are the factors affecting Indian agriculture.

Climatic adaptation entails achieving a balance among ecology, society, and economy to mitigate the adverse impacts of climate change. This involves modifying habits, consumption patterns, and infrastructures to minimize losses resulting from climate change (UNFCCC, 2020). Certain natural and societal systems possess an inherent ability to adapt to adverse conditions, thus being considered resilient. Achieving this resilience often involves adopting the principles of sustainable development (Tompkins and Adger, 20039). To mitigate the impacts of climate change, embracing sustainable development strategies is beneficial globally. Moreover, early adoption of these approaches is essential due to their gradual. Consequently, proactive planning for adaptation becomes imperative. Collaborative efforts are crucial in developing climate-land &water tactics to ensure food and water security for the generations to come (Rockström et al., 2014). Various research documents extensively describe climate- resilient practices aimed at addressing changes in climatic conditions. These practices are designed to boost the resilience of societies and ecosystems, enabling them to withstand and recover from climate-related challenges. Various adaptation strategies across different categories to mitigate the negative effects of climate change were there (Hallegatte, 2009). For instance, supporting utilizing resilient crop varieties with rotation, effective irrigation water use, and promoting agroforestry are considered effective alternatives. Similarly, measures like reducing water loss, implementing water reuse, and Improving treatment facilities are thought to produce more favourable results in minimizing the negative effects of climate change. There are deliberate adaptation measures to address the detrimental effects of climate change including the development of improved crop varieties, creating accessible markets for marginalized farmers, integrating traditional knowledge with modern science, and enhancing irrigation infrastructure among others (Burke and Lobell, 2010).

2. AN OVERVIEW OF A FEW CRA METHODS

The fundamental principles of the Climate-resilient agriculture concept involve improving agricultural productivity, building agricultural resilience against climate change impacts, and reducing GHG emissions from agricultural practices – among others (Fig. 1). In the Climate Smart Agriculture approach, farmers should be provided with access to a range of advanced techniques, including resilient crop and animal varieties, agroforestry options, improved irrigation water management facilities, crop sequencing practices, insurance and soil productivity protection (Olesen et al., 2011). Implementing eco-friendly resource management practices can improve agricultural yields within the existing farming land (Montgomery et al., 2016). Utilizing geospatial and data analysis approaches can enhance the agricultural industry and address food security challenges by optimizing land resources in response to changing climatic conditions (Bonfante et al., 2015). The advancement and adoption of eco-friendly farming technologies are essential for society, driving innovation (Makate 2019). Furthermore, integrating sustainable practices into crop-specific farming is attained by utilizing remote sensing and associated technologies (Akpoti et al., 2019).

2.1 Crop Variety Adaptation and Management of Seed

Techniques for managing crops encompass a range of traditional and modern methods aimed at modifying plant traits or cultivation practices to achieve desired growth, development and yield. More than 6100 improved crop varieties have been released by the Indian Council of Agricultural Research, since its inception, including1622 climate-adaptive cultivars (Khatri-Chhetri, et al., 2016). These improved varieties are widely favoured among CSA adopters, who make up eighty per cent of the targeted group evidenced by a study in the Karnal district of Haryana and Vaishali district of Bihar. The adoption of improved varieties has led to a 19% increase in total production in the rice-wheat system and a net return increase of Rs 15,712 per hectare (Khatri-Chhetri, et al., 2016). Seed banks play a crucial role in ensuring food security by preserving plant genetic species and providing long-term viability. Shortages of seeds can be mitigated by preserving a variety of crop cultivars in seed banks. For instance, by using a variety of finger millet which is appropriate for late planting in the event of delayed monsoons, Nanganahalli village in Tumkur, Karnataka, attained self-sufficiency (Prasad et al., 2014). Regional variances in the timings of planting and harvesting depart from the average due to variations in climate. Planning agricultural production and developing mitigation and adaptation measures, therefore, depend on anticipating changes in these dates in response to climate change (Marcinkowski and Piniewski, 2018).

2.2 Water Management

India possesses around four percent of the water resources of the world, with 80% of this water being utilized by the agricultural sector. To improve agricultural profitability and expand irrigation coverage, the Govt. of India has launched projects like "Har Khet Ko Pani" and "Per Drop More Crop". However, with changing circumstances, the government may need to implement additional interventions to meet the growing water demand. Since dry zones make up around 12% of India's land area and have little access to water, they are especially vulnerable to the negative effects of climate change, such as decreased rainfall. A method called supplemental irrigation (SI) can help ensure adequate yields, especially during periods of insufficient rainfall. Combining SI with water harvesting can enhance water utilization efficiency and boost productivity in dryland and semi-arid areas. In comparison to the prior methods, farmers in the Chenchu hamlet of Petrallachenu (Telangana) saw increased in food security, water productivity, and nutrient availability along with favourable economic returns and also found that the water table had risen as a result of recharging tube wells positioned in front of existing wells (Reddy et al., 2020). Maintaining a distance of around 100 meters between two recharge tube wells and employing silt basins and filters can ensure the endurance of tube wells (Kaledhonkar et al., 2012). Water shortage was a major problem in Sitaram village, Bharatpur, Rajasthan, and this intervention significantly raised the levels of the shallow aquifer (2.5–4 metres). 242 hectares of land could be irrigated as a consequence of the next years' recharging of around 60 tube wells, which raised the water table by 8 to 10 feet (Prasad et al., 2014). It is crucial to evaluate the possibility of water recharge, and an investigation on geo-electrical could be required to find appropriate locations for tube well recharge.

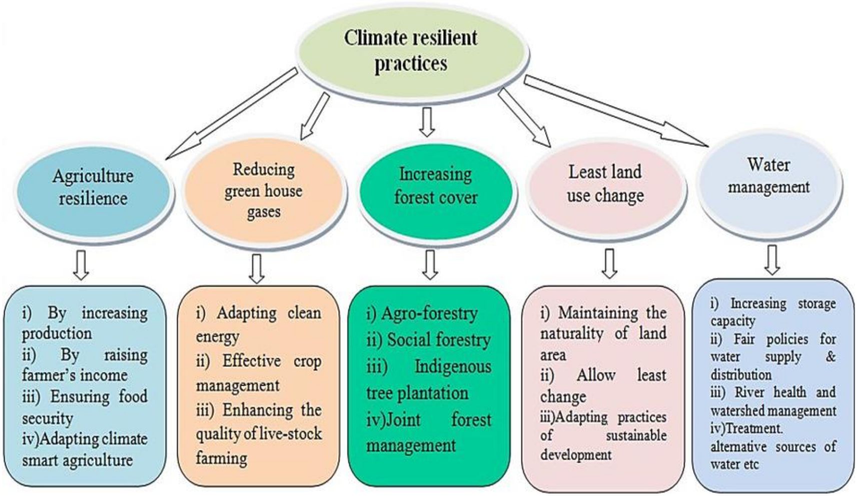

Fig. 1. Climate resilient practices

2.3 Land Management

Compared to monocropping, intercropping increases yield on a given plot of land by growing many crops near together. producing intercropping is more profitable than producing a single crop, according to studies (Elba et al., 2014). By lengthening the growing seasons, relay intercropping has further enhanced land-use efficiency. This has led to greater yields per unit of land and increased total resource capture (de la Fuente et al., 2014).

2.4 Livestock Management

A successful adaptation technique for increasing food security is to improve the crop-livestock system (Herrero et al., 2010). By increasing fertility and plant density, a two-year study conducted in Karnal, Haryana, secured green fodder of higher quality (Choudhary et al., 2016). Improved feeding techniques can enhance cattle production efficiency indirectly as an adaptive approach (Havlík et al., 2013). Breeding practices can be changed to improve an animal's ability to resist infections and heat stress, which will encourage growth and reproduction (Henry et al., 2012). Establishing global gene banks, similar to the In-Trust plant collections for plants, might be a useful tactic to support breeding programs and act as an insurance policy (Thornton et al., 2007). To create data banks, research has been done on native livestock genetic resources by the National Bureau of Animal Genetic Resources (Bureau) at Karnal, Haryana, India. Better-quality ruminant diets result in lower methane emissions per unit of milk and meat produced as well as better milk and meat output. Animal health may be impacted directly or indirectly by climate change, especially by increased temperatures (Nardone et al., 2010). Emerging technological interventions, customized to animal, pet, and livestock needs, include products like medication patches, electronic saddle optimization, and tracking collars, which witness increasing rates of adoption (Neethirajan, 2017). Farmers face ongoing challenges during intense heat or rainfall seasons, which can predispose small ruminants to diseases and increased mortality. Therefore, effective shelter management is crucial for animal well-being. Livestock yields may be greatly increased by practising better grazing management techniques like rotational grazing and stocking rate management.

2.5 Soil and Nutrient Management

Precision farming, cover crops, composting, and the use of manures are establishing methods for managing soil. Farmers gain from micro-dosing, the practice of applying the right amount of fertilizers and other agrochemicals at the right time throughout the planting and development stages, as does the long-term sustainability of the environment. Crop rotation has been effectively introduced in several Indian states, including Punjab and Rajasthan, and has improved production over the long term (Rani et al., 2015). Cover crops are cost-effective and have several positive effects on moisture content, microbial activity, and soil water, hence, they are essential for improving soil health and fostering biodiversity (Sharma et al., 2018). Soil aeration supports plant root metabolism and promotes the activity of enzymes like redoxase, which enhances nutrient absorption rates and root growth (Li et al., 2019). Residue retention and decomposition in fields improve soil health, and nutrient recycling, and boost crop yields (Jakhar et al., 2018). Retaining harvest residue greatly increases the nitrogen and carbon levels of the soil (Tutua et al., 2019). Mulching offers several advantages suppression, reduced evaporation, and maintenance of soil temperature, ultimately enhancing grain yields and water use efficiency (Priya et al., 2016). Organic fertilizers, including farmyard manure and vermicompost, are widely used worldwide and effectively enhance soil nitrogen content over time. Green manure, consisting of leguminous and forage crops, plays a vital role in nitrogen input through nitrogen-fixing plants left in the field (Priya et al., 2016).

2.6 Pest Management

Three groups of bio-pesticides are micro-organisms, semio-chemicals and bio-chemicals. More than 300 different species of organisms, including a wide range of bacteria, viruses and fungi, can act as bio-control agents or be the source of bio-control agents. Bio-fungicides such as Pseudomonas and Trichoderma, bio-herbicides with Phytophthora spp., and bio-insecticides with Pseudomonas spp. and Bacillus spp. are examples of commonly used bio-pesticides (Meena et al., 2020). Among different strains accounting for 2% of all insecticide consumption, *Bacillus thuringiensis* is the most frequently used microbial pesticide in the world (Gaur, 2020). The commercial manufacture and marketing of fungus (*Trichoderma viride, Beauveria bassiana* and *Trichodermaharzianum*) and bacteria-based bio-control formulations are managed by Bio-Control Research Laboratories in India (Mishra et al., 2020).

Some bio-pesticides offer additional benefits beyond controlling pests, such as managing soil nutrients and promoting crop growth. They are environment-friendly, and user-friendly, leave no harmful residues, and, align well with sustainable agriculture practices. However, adherence to proper dosing and safety guidelines during application is essential. Importation (traditional biological control), augmentation, and conservation are examples of biological control tactics used in pest management. Reducing the need for pesticides and minimizing the negative effects of invasive pests on native plants and animals are additional advantages of biological management (Heimpel et al., 2004). Modifying vegetation is one easy and affordable way to conserve natural enemies that have adapted to the environment and the pests they target.

2.7 Management of Risk

Failure of crops stands as a major catalyst for the government's implementation of insurance schemes aimed at addressing uncertainties. In Bihar, India, maize cultivation sees substantial investments with expectations of good yields, yet recurrent crop failures have tragically led to farmer suicides. Evaluating market failures and financial uncertainty in risk management techniques is essential to averting such catastrophes. In the case of crop failure, tools like forward contracting and crop insurance might give farmers cash help as well as credit for the following growing season. Crop insurance, however, usually only covers a limited range of crops and natural disasters, including those brought on by the effects of climate change. The General Insurance Department of the Life Insurance Corporation of India launched India's first insurance plan in 1972 (Mahajan et al. 2012). It was followed by several later failed insurance plans.

Introduced in 1999–2000, the National Agriculture Insurance Scheme (NAIS) offered coverage for all food crops at premiums ranging from 1.5% to 3.5% of the guaranteed amount (Chand et al., 2016). A different approach, the Farm Income Insurance Scheme (FIIS), compensated for losses in minimum support prices on commodities like wheat and rice and concentrated on yield and price protection under single insurance. In 2016, the Pradhan Mantri Fasal Bima Yojana replaced NAIS and MNIAS, addressing their shortcomings by reducing premium rates to 2% and 1.5% for Kharif and Rabi crops, respectively (Xuan et al., 2012). Meanwhile, livestock has emerged as a primary livelihood and supplemental income source for farming households, contributing significantly to income, especially for small farm households. However, despite its importance, livestock insurance remains low, with estimates suggesting coverage of about 9% in Haryana and negligible coverage in Rajasthan (Xuan et al., 2012). Lack of trust in insurers, high premiums, poor delivery mechanisms, absence of indemnity for losses, insufficient renewal information, and difficulties in accessing insurance contribute to approximately 90% of households hesitating to renew their livestock insurance policies (Xuan et al., 2012).

2.8 Post-harvest Management

Evaporation Cooling Chambers represent a post-harvest management technology centred around cooling through evaporation. During this process, the cooling effect arises from the energy extracted from the environment during water evaporation. Compared to electric vapour compression refrigeration systems, evaporative cooling uses a great deal less energy to transport water and air (Kale et al., 2016). According to reports, insufficient storage facilities cause 20–40% of produce to be wasted in India. The Central Institute of Post Harvest Engineering and Technology (ICAR-CIPHET) in Abohar, Punjab, has assessed several cooling chamber designs, including pot-in-pot, charcoal coolers and zero-energy cooling chambers. Thus, these cooling chamber is a method to reduce the post- harvest losess.

3. CONCLUSION

Climate-resilient agriculture denotes agricultural practices, technologies, and systems designed to adapt and mitigate the impacts of climate change on agricultural yields, food security, and livelihoods. It involves strategies that enable farmers to cope with climate variability, extreme weather events, and changing climatic conditions while ensuring sustainable agricultural production. Key elements of climate-resilient agriculture include the use of drought-tolerant crop varieties, efficient water management techniques, soil conservation practices, agroforestry, diversified cropping systems and innovative farming approaches that enhance resilience to climate-related risks. By promoting resilience at the farm level and across agricultural value chains, climate-resilient agriculture aims to build the ability of farmers and agricultural systems to endure and recover from climate-related shocks and stresses, ultimately contributing to food security, poverty reduction and environmental sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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