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CLIMATE RESILIENT AGRICULTURAL STRATEGIES FOR ENHANCED SUSTAINABILITY AND FOOD SECURITY: A REVIEW

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ABSTRACT

Climate change is referred as the sustained, significant change in earth's climate patterns, stemming primarily from human-induced greenhouse gas emissions, leading to increase in temperature and associated environmental shifts. The impending threats posed by climate change have been extensively witnessed across the globe. Effectively mitigating climate risks requires a forward-looking strategy focused on enhancing adaptability and strengthening resilience measures. Climate resilience is a cornerstone of climate risk management. Agricultural system has the potential to predict, plan for, adapt to, absorb, and rebound the effects of climate variations and extreme weather events. Crop diversification, conservation agriculture, precision agriculture, climate smart agriculture, weather forecasting, genetic engineering are some of the agricultural approaches to mitigate climate change. These strategies aim to safeguard the livelihoods of farming community, preserve ecosystems, and secure a stable food source for thriving populations, ultimately contributing to a more sustainable and secure food security in a changing climate.

Key words : Climate change, Climate resilient, Food security, Mitigation, Strategies.

Introduction

Climate change is a formidable adversary that poses remarkable threats to our planet and well-being of generations yet to come. Climate change could cut crop yields, especially in the world's most food-insecure regions. During El Niño year, warming phenomenon takes place in the central and eastern equatorial pacific region altering atmospheric circulation, disrupting moisture transport and rainfall distribution patterns over the Indian subcontinent leading to decreased rainfall and drought conditions in some parts of India (Kakoti *et al.*, 2023). At the same time, agriculture, forestry and land use change are responsible for about 25% of greenhouse gas emissions (World Bank, 2023). It is a global crisis driven by the excessive accumulation of greenhouse gases, primarily carbon dioxide, methane, nitrous oxide and other gases in the earth's atmosphere. These gases trap the solar radiation (specially the short-wave radiations), which leads to a gradual rise in global temperature, commonly known as global warming. The global significance of climate change is extensive and ominous. Some of them include more recurrent and severe weather phenomenons such as droughts, hurricanes, floods and wildfires. In Polar Regions, melting of glaciers and ice caps contributes to rising sea levels, endangering coastal life-form worldwide. Meanwhile, ecosystems are disrupted while species struggle to adapt or encounter extinction. Anthropogenic activities are the primary drivers of this calamity, stemming from the combustion of fossil fuels for energy, industrial activities, deforestation, use of air conditioners and refrigerators, use of automobiles, shifting cultivation etc.

Addressing climate change requires sustainable strategies and innovative technologies along with global cooperation. Resilience is the capacity of the system to bounce back and fundamentally involves judicious and better management of natural resources, land, water, soil, along with genetic resources through adoption of elite practices (Srinivasa Rao *et al*., 2016). Climate resilient agricultural strategies are indispensable for ensuring food security amid changing climate conditions. Conservation agriculture practices, crop diversification, precision agriculture, raised bed system, drought-resistant crop varieties, crop rotation along with efficient water management strategies are some of the key elements. Additionally, integrating silviculture within agricultural landscapes can boost microclimates, carbon sequestration and intensify overall resilience efficiently.

These practices can boost farmer's adaptability to shifting weather patterns, reduce risks of yield loss and establish a sustainable base for food production to compete with global demands while efficiently mitigating the adverse effects of climate change.

Climate resilient agricultural strategies

1. Crop diversification

It is a process of growing more than one crop in an area. Diversification is the premise of growing varieties of crops, which reassure biodiversity, improves nutrient cycling along with resiliency and health of the soil (Williams *et al*., 2023). Planting a variety of crops can significantly reduce the risk of total crop failure due to adverse weather conditions, infestation by pests and diseases. Diverse crops ensure a secure food supply and income source for farmers. It has mainly two types:

a. Horizontal diversification : This refers to multiple cropping, cover cropping, inter-cropping or mixed cropping system of cultivation. It is especially useful for small farmers with a small land area. This helps them to get higher returns by escalating cropping intensity.

b. Vertical diversification : It refers to the integration of industrialisation along with multiple cropping. Farmers invest their land for horticulture, livestock rearing, integrated farming system, agroforestry, culture of aromatic plants etc.

2. Drought-resistant crop varieties

These crops have the capacity to thrive with limited water, enhancing resilience in water-scarce regions. They can withstand dry spells and maintain yield stability. For examples: Pearl millet (Varieties: Dhanshakti, HHB 234, Mandor Bajra Composite 2 etc.), Barley (Varieties: RD 2660, K603 etc.), Groundnut (Varieties: Ajaya, Girnar 1, TAG-24, Kadiri 6 etc.), Soybean (Varieties: NRC 7, JS 95-60 etc.), Sorghum (Varieties: CSH 19 R, CSV 18, CSH 15R etc.), Wheat (Varieties: PBW 527, HI 1531, HI 8627, HD 2888, HPW 349 etc.), Maize (Pusa Hybrid Makka 1, HM 4, Pusa Hybrid Makka 5 etc.), Rice (Varieties: Sahabhagi Dhan, Vandana, Anjali, Satyabhama etc.).

3. Submergence/water logging tolerance crop varieties

Climate change can compound water logging problem by altering rainfall patterns and increasing the intensity and frequency of extreme weather events like storms and heavy rain. Rising temperatures also escalate evaporation rates resulting in heavy precipitations. Change in climatic patterns globally made water logging occurrences more regular, severe, and unexpected (Paul *et al*., 2023). To mitigate this issue, famers can go for water logging tolerance varieties for sustainable productivity, ensuring secure income and food security. For example, Rice (Varieties: Swarna Sub-1, Sambha Mahsuri Sub-1, Durga, Jaladhi 1, Gayatri, etc), Maize (Varieties: HM-5, PMH-2, Seed Tech-2324, HM-10 etc.), Jute (Varieties: JRC 532, JRO 7835, JRC 321, JRO 878, JRC 7447 etc.),sugarcane (Varieties: Co 98014, Co 0233, Co 05009, Co 0238, Co 0239 etc.).

4. Conservation agriculture

United Nations' Food and Agriculture organization (FAO) defined conservation agriculture as farming system that promotes maintenance of a permanent soil cover with minimum soil disturbance along and diversification of plant species. It augments biodiversity and natural biological processes in the rhizosphere zone, which contribute to increased nutrient and water and use efficiency. CA is a process of soil management that entails crop residues from the previous year on fields before and after planting the current crop to minimize soil erosion and runoff enhancing carbon sequestration (Talukdar *et al*., 2023). Moreover, agronomic practices like no tillage and minimum tillage minimizes energy consumption by farm machinery, enhance soil drainage, facilitates food supplies for insects and birds due to wider availability of crop residues and weed seeds in the soil. Indeed, a number of ecosystem services are provided by the minimum soil

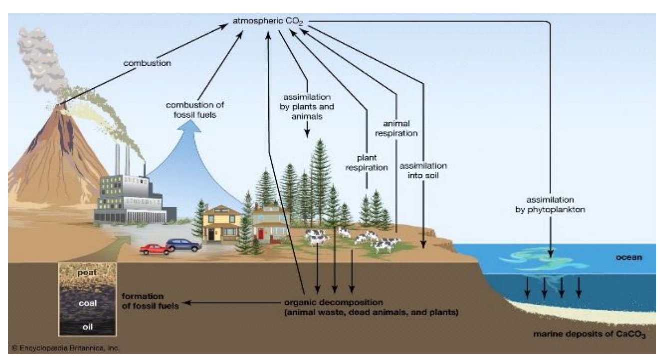

Fig. 1 : Showing mechanism of carbon sequestration.

disturbance, including: carbon storage, soil stability, prevention from surface soil erosion, enhanced water infiltration and soil fertility through enhanced nitrogen stocks (in the long term), improved soil, water and air quality and reduction in fuel use, thus making farms more resilient towards extreme climatic conditions.

5. Precision agriculture

Precision agriculture refers to the management strategy which gathers, processes and analyzes temporal, individual and spatial and data and incorporate it with other information to support management decisions for improved resource use efficiency, productivity, profitability, quality and sustainability of agricultural production (ISPA, 2019). It is the modern approach of improving crop productivity and assisting field management strategies using high technology sensor and analysis tools. It uses technologies like global positioning system (GPS), sensors, geographic information system (GIS), unmanned aerial vehicle (UAV) and dusters, remote sensing, internet of things (IoT), artificial intelligence (AI) etc. The 5 Rs of precision agriculture include: applying the right input, in right amount, at the right place, at the right time and in the right manner. This improves the planning of agricultural operations for an extended period, adjusting the real-time strategy adapting to changing climatic conditions, thus playing an essential part in solving the global problem of hunger.

6. Climate smart agriculture

Climate Smart Agriculture (CSA) is a combination of farming techniques aimed to increase the resilience of agricultural production to climate variability through better adaptation to climate change, reducing agriculture's contribution to global warming. CSA approach integrates climate change phenomenon into the planning and development of sustainable agricultural systems for enhanced productivity. CSA encompasses sustainable agricultural practices, which ultimately contribute to increase in crop productivity and gross revenue, adaptation and extended resilience to climate change and depletion of GHGs emission as much as possible (MacNun *et al*., 2020). Many studies done at farm level proposed that adoption of CSA technologies has been proven to enhance and increase productivity and quality, net income, efficacy usage of inputs and most crucially reduced GHGs emissions" (Sapkota *et al*., 2014). Site specific nutrient management (SSNM), use of leaf color chart (LCC), nano fertilizers, integrated disease management (IDM), Concentrate Feeding for livestock, green manuring, mulching, agro-forestry and fodder management are some of the key practices of CSA.

7. Weather forecasting in agriculture

Agriculture is highly reliant on weather conditions and accurate forecasts can significantly influence crop yields, resource utilization and allocation with overall farm profitability. It is the process of predicting precisely the condition of the atmosphere at a specific location and time in the future. It involves data analysis and computer models to estimate various meteorological parameters namely temperature, precipitation, wind speed and direction, humidity, air pressure, cloud cover etc. According to Indian Meteorological department (IMD), operational weather forecasts are traditionally classified into five groups namely 1. Now-casting (Ranging from 0-3 hours description of current weather variables) 2. Very short-range forecast (Up to 12 hours forecast) 3. Short range forecast (From 12-72 hours forecast description) 4. Medium range forecast (Beyond 72 hours up to 240 hours forecast description) 5. Long range forecast (More than 10 days, up to one year forecast description). For a successful crop production, farming community should be well prepared of the upcoming weather conditions or climatic changes as the overall returns from the crop is highly dependent upon the weather conditions. Thus, timely communication of weather forecasts to farmers for pre-planning of agricultural operations is of utmost importance as many crucial operations related to food security and economics rely on these forecasts.

Fig. 2 : Showing weather monitoring technologies.

8. Genetic engineering

Use of biotechnological tools to produce climate resilient crops is a prominent approach. Breeding programs focused at mitigating the adverse impacts of abiotic stress caused by aberrant climate change have indeed demonstrated highly effective in enhancing food production and bolstering resilience in agricultural crops. To encounter the challenges posed by climate change, it is peremptory to examine deeply into the physiological, genetic and molecular underpinnings of these crops. Recognizing and prioritizing traits that confer resilience to climatic stressors stands as a prime objective for the advancement of next-generation breeding (NGB) strategies. Genetically modified (GM) plants help to sequester millions of tons atmospheric carbon dioxide, for example soybean crop which is herbicide resistant (Roundup Ready™ resistant) proved to sequester about 63,859 million tons carbon dioxide (CO_2) in USA and Argentina (Brimner *et al*., 2005). It enables scientists to develop one or more ideotypes in short time span to fulfil breeding requisite and to discover superior alleles/ haplotypes for breeding programs (Taranto *et al*., 2018). Some key techniques used in genetic engineering are QTL Mapping and Marker-Assisted Selection, Mutation Breeding, Genome Editing (GE), Oligonucleotide-Directed Mutagenesis etc.Some prominent works under genetic engineering are as follows:

- Monsanto developed drought resistant maize named as 'MON 87460' which are highly adaptive and withstand drought situations with higher productivity in perspective of intense droughts in United States.
- Salt tolerance has also been improved in *Arabidopsis thaliana* by over expression of 40 transcription factors.
- The transgenic lines in maize were produced, which were highly tolerant to drought due to improved stomatal conductance, increased photosynthesis, high chlorophyll content and ultimately high productivity of grains (Nelson *et al*., 2007).
- In rice, DEEPER ROOTING 1 (DRO1) locus was identified and structural design of roots have been improved which enhanced drought tolerance capacity and crop yield meanwhile improving nitrogen acquisition due to shift in vertical root directions with deeper root penetrations (Arai-Sanoh *et al*., 2014).
- Bacterial cold shock proteins (Csps) have been developed by Monsanto researchers which can facilitate enhanced stress adaptation to several plant species.
- In tobacco (*Nicotiana tabacum* L.), NtAQP1 gene was identified responsible for aquaporin coding which is reported to safeguard transgenic plants against salinity stress, shoot/root hydraulic failure prevention by assisting better water use efficiency in salt tolerant genetically modified tomato (*Solanum lycopersicum*) (Sinclair *et al*., 2004).

New novel technology permit studies of climatic stress responses using the OMICS data involving transcriptomes, proteomes and metabolomes at a molecular level worldwide. For example, SNAC1 gene (NAC transcription factor) was identified in rice through microarray experiments in stress conditions by which salt and drought tolerance of rice improved.

9. Efficient water management

Water management is a key element of climate-resilient agriculture, playing a crucial role in mitigating the adverse effects of climate change on food production. As the climate becomes increasingly uncertain, with altered precipitation patterns and more recurrent droughts, effective water management is pivotal to sustain agricultural productivity and secure food security.

Key strategies for climate-resilient water management are as follows:

a) Efficient irrigation : Utilizing advanced irrigation techniques like drip or sprinkler systems, reduces water wastage and ensures that crops receive the optimum amount of moisture, even in changing climate conditions, adapting seamlessly to shifting climate patterns.

b) Fertigation : It is a technique of dissolving fertilizers in irrigation water and applied directly to crops. Fertigation offers the possibility to reduce fertilizer losses, meanwhile conserving water resources and promoting sustainable and environmentally accountable farming practices (Sarma *et al*., 2023a).

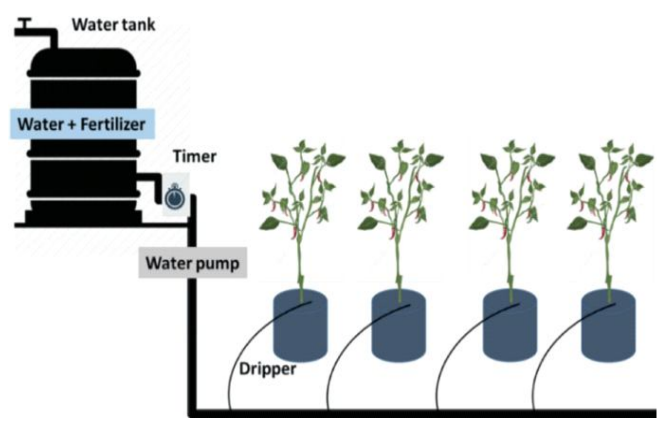

Fig. 3 : Showing fertigation technology.

c) Rainwater harvesting : Collecting and storing rainwater during rainy periods provides a buffer stock of water against dry spells, reducing the reliance on groundwater or surface water sources.

d) Water recycling and reuse : Reusing of agricultural wastewater plays a vital role in sustainable farming practices. Contaminated water is treated properly by removing contaminants and pollutants. The treated

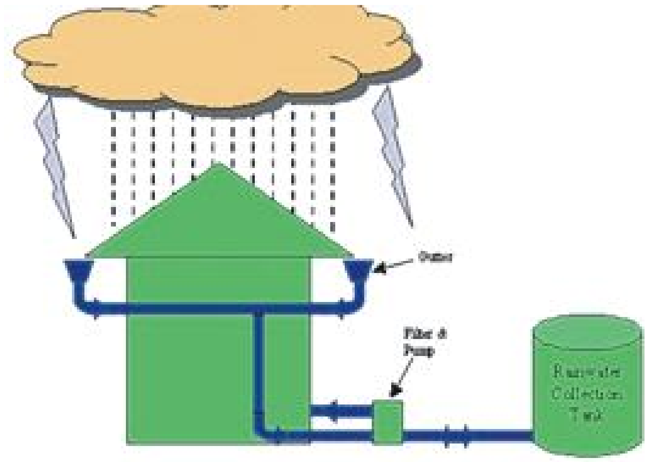

Fig. 4 : Showing rain water harvesting.

water can then be safely reintroduced into the irrigation system, thus reducing the demand for freshwater resources. This practice enhances environmental sustainability by alleviating water pollution and reducing the depletion of natural water sources, while simultaneously bolstering the long-term viability of agriculture in respect of climate change.

e) Soil moisture monitoring : Utilizing soil moisture sensors with remote sensing technology can equips farmers with precise insights into soil moisture conditions. This data-driven approach enables them to calibrate irrigation schedules, thus ensuring crops receive optimal moisture levels. It enhances water efficiency by conserving resources, and supporting sustainable agriculture in spite of changing climate patterns.

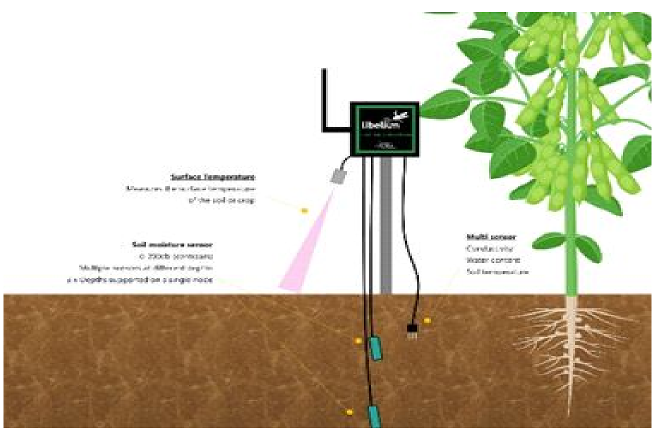

Fig. 5 : Showing soil monitoring based on IOT (Internet of things).

10. Agroforestry approaches

Agroforestry integrates agricultural crops along with trees or livestock, offering multifaceted benefits for climate-resilient agriculture. Alley cropping is of the approaches where rows of trees are planted amidst crops, providing shade and acting as windbreaks while their leaves contribute organic matter to the soil. Additionally,

Fig. 6 : Alley cropping system.

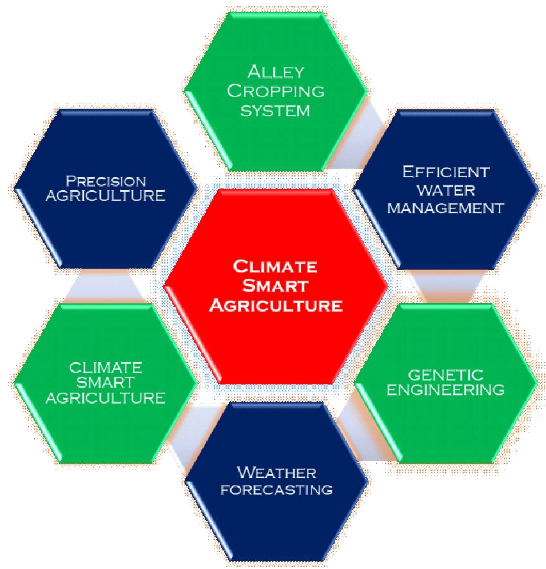

Fig. 7 : Combined approaches of Climate smart Agriculture.

silvopastoral systems combine trees and livestock, improving soil fertility and microclimates. Organic matter is constantly supplied by the biomass and leaf litter of trees and shrubs, Moreover, climate-resilient agriculture not only safeguards food production, but also contributes to environmental conservation. Practices such as cover cropping, reduced tillage and organic matter addition promote healthier soils, reduce greenhouse gas emissions, and protect biodiversity. This synergy between food security and environmental sustainability is a critical aspect of our collective response to climate change, which enhances soil structure and boosts water-holding capacity (Mbow *et al.*, 2014). Agroforestry enhances carbon sequestration, mitigates greenhouse gas emissions, conserves water and offers diverse income sources. It fosters biodiversity, reducing pest pressure, while the roots of trees stabilize soil and mitigate erosion. Aerial seed bombing is an innovative approach for large scale ecological restoration which has emerged as a ground breaking tactic for overcoming the strains associated with large-scale vegetation recovery in different landscapes (Sarma *et al.*, 2023 b). Thus, agroforestry principles can mitigate greenhouse gas emissions by enhanced carbon sequestration, conserving water and offering diverse income sources. It fosters biodiversity, while the roots stabilize soil and mitigate erosion, thus adapting to climate change.

Conclusion

Climate-resilient agricultural strategies are crucial for enhancing sustainable food production and security in a dynamically evolving world. As climate change leads to unpredictable weather patterns along with extreme events and fluctuating temperatures, our agricultural approaches must be resilient enough to mitigate these challenges. These strategies consist of wide range of innovative approaches, ranging from crop diversification, conservation agriculture, climate smart agriculture, weather forecasting to agroforestry approaches.

By holistically integrating these methods into our agricultural systems, we can enhance the resilience of our farmers against climate-induced shocks. Although, attaining wide scale adoption of these strategies requires joint efforts from governments, researchers, farmers along with private sector. Research and development must continue to achieve new advancements and innovations in this segment. As caretaker of earth, we must enthusiastically embrace these strategies to frame a sustainable, robust and resilient future.

Conflict of interest : All the authors have no conflict of interest.

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