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Climatic Shifts and Agricultural Strategies: A thorough Review on Impact of Climate Change on Food Security and Crop Productivity

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This comprehensive review delves into the intricate change of climate, assessing its profound impact on global food security and crop productivity. The examination addresses key questions, exploring the consequences of climate change on agriculture, with a specific focus on the challenges encountered in vulnerable regions such as sub-Saharan Africa and South Asia. Emphasizing the urgency of adaptive strategies for sustainable global agriculture, the review navigates through the complexities of mitigating climate-induced disruptions in crop growth patterns. Furthermore, it scrutinizes the implications of climate change on biodiversity, acknowledging the interconnectedness of ecological systems. Highlighting the imperative for

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innovation, the review underscores the pressing need for transformative farming methods to effectively tackle the multifaceted challenges posed by climate change. The emphasis is on ensuring the resilience of global agriculture in the face of climatic shifts. In conclusion, the review provides a compelling call to action, advocating for the prompt implementation of innovative farming practices to fortify the global agricultural sector against the evolving challenges brought about by climate change, fostering sustainability and adaptability.

Keywords: Climate change; food security; crop productivity; agriculture adaptation; innovative farming practices.

1. INTRODUCTION

In the cosmic dance of atmospheric forces, climate change takes center stage, weaving a story of resilience, challenge, and adaptation. Climate change refers to any changes in the climate over time. These changes can be due to natural variability or as a result of human activity. Dr. Margaret Chan stated that climate change is the defining issue for the 21st century in terms of public health, according to the World Health Organization. Climate change and its variability are serious concerns for humankind, as the consequences may include the rapid melting of glaciers, changes in precipitation patterns, more frequent extreme weather events, shifting seasons, the spread of pests and diseases, and other socio-economic impacts. The frequency of natural and environmental disasters varies greatly from year to year, with some going by with relatively few losses before a major disaster event takes a large number of lives [1]. The effects of climate change on crop yield are showing a strong and consistent global trend that may have implications for food supplies. There is a chance that climate change will hinder efforts to end world hunger. Climate change is a multifaceted, intergovernmental issue that affects many aspects of the biological, environmental, sociopolitical, and socioeconomic fields on a worldwide scale [2]. With varying spatial and temporal scales, adaptation to climate change is at the nexus of research, communities, and decision-making and is influenced by social issues, financial resources, political context, public awareness, politicization of climate change, or scientific uncertainty [3]. Adaptation and mitigation are the two most important components of addressing the response to climate change. The primary sectors responsible for climate change adaptation and mitigation are forestry, transportation, land use, and agriculture [4]. Climate plays a significant role in overall productivity, biodiversity, food security, and irrigation ecosystem.

2. CLIMATE CHANGE CONSEQUENCES AND ITS IMPACT ON FOOD SECURITY

Currently, over 250 million people suffer from severe hunger, with some of them on the edge of starvation. As a result, by 2080, CC is predicted to put a further 5–170 million individuals at risk of starvation [5]. The progress of nations and the well-being of their citizens depend on food security [6]. Despite an increase in global food supply throughout the previous 50 years, one in seven people do not have enough to eat, and a billion people do not consume enough protein and energy from their diets [7]. Climate change and food security are intertwined challenges that bring volatility to food systems, risking stability. The regional impact may not be immediately clear, but climate variability can worsen food insecurity, especially in areas already facing hunger and undernutrition, as highlighted by Tim Wheeler [8].

2.1 Food Security Based on Crop Yield

Exploring climate change's impact on global food security, with a focus on anticipated strains on crop yields. Climate change is predicted to have a detrimental effect on crop growth, which will put more pressure on attempts to achieve food security for households and regions [9]. Increasing crop intensification and more native vegetation degradation will worsen the environment's ability to supply the world's food demand brought on by population growth and dietary changes [10]. CO_2 fertilization would be mainly outweighed by nutrient restrictions, pollutants, and other interactions with climatic conditions. The study examined the potential impacts of climate change on the yield of crop plants [11]. leveraging the way of physical and biological processes, such as how specific crops respond to elevated CO_2, warmer growing seasons, drought conditions, or altered crop management practices, these models play a crucial role in describing how cropping systems respond to key drivers and helping to forecast farm-level productivity in the future [12,9]. These models are used to compare potential yields to actual yields, analyze various management options, and identify comparable environmental implications.

2.2 Food Security Based on Water Scarcity

Focusing on water scarcity, this section explores the challenges brought by climate change to irrigated agriculture. In the face of future water scarcity, maintaining irrigated agriculture, crucial for meeting food demands, necessitates enhancing irrigation water supplies through improved system management, reduced surface drainage, drip irrigation, water storage facilities, wastewater utilization, and prudent groundwater management [13]. Because of its unpredictable rainfall patterns and declining crop yields, climate change may therefore be a challenge to food security and exacerbate famine [14]. Due to effects on freshwater availability and health risks, climate change has decreased agricultural productivity, threatened traditional livelihoods, restricted access to food, and altered food consumption [15].

2.3 Food Security Based on Temperature Level

Rising temperatures directly jeopardize food security, impacting global production with potential crop yield reductions and immediate consequences for regions facing near-maximum temperatures. If adaptive management is unable to reduce the anticipated production losses, rising temperatures may pose a significant threat to food security. Global food production is expected to be directly impacted by climate change. A rise in the average seasonal temperature can reduce the growing season for many crops, which will lower yield. Warming will have an immediate effect on yields in regions where temperatures are already near the physiological maximum for crops (IPCC, 2007). It was found that higher temperatures during the growing season had a negative effect on the yield of wheat. They concluded that the increase in minimum temperature, which leads to an increase in respiration rate and a decrease in crop duration, is what causes the yield drop [16]. Temperature variations can hasten crop development and, as a result, shorten the growing season. In contrast, poor verbalization and decreased yield may result from such modifications [17].

2.4 Food Insecurity

This section explores how climate change affects food availability and access in vulnerable regions like sub-Saharan Africa and South Asia. As a result, sub-Saharan Africa, where 30% of the population suffers from malnutrition, and South Asia, where 23% do, has higher rates of food insecurity. Locally, it is also more common in areas like Haiti and Afghanistan that are experiencing extreme poverty or conflict (FAO). The availability, accessibility, stability, and usage of food are the four food security outcomes that are impacted by these food system activities (FAO) which are shown in below Table 1.

2.4.1 Four food security outcomes

The above Fig. 1. depicts that the four food security outcomes need to be equalized for a nation to achieve a developed state. Achieving food security is intricately linked with challenges in human development and economic growth, including persistent poverty, health issues, distribution constraints, market distortions, limited food choices, and production limitations. Moreover, the food system plays a pivotal role in climate change, requiring reductions in emissions from sources like soil use, land clearing, animal feed production, and food transportation [18]. As seen by the recent droughts in China and Russia as well as the floods in Australia, India, Pakistan, and Europe, climate change can have a impact on agriculture. Thus, the poor in rural areas will probably also be negatively impacted by rising temperatures [19]. Furthermore, asset losses linked to weather-related disasters are projected to increase due to the higher frequency level of weather occurrences [20]. Millions of people who live in disaster-prone areas are affected by these losses in terms of food insecurity and human casualties.

Table 1. Food system activities (FAO)

Food availability	Food accessibility	Food utilization	Food stability
Production Distribution Exchange	Allocation Preference Affordability	Food Safety Nutritional Value Social Value	Food Storage Available Resource Migration

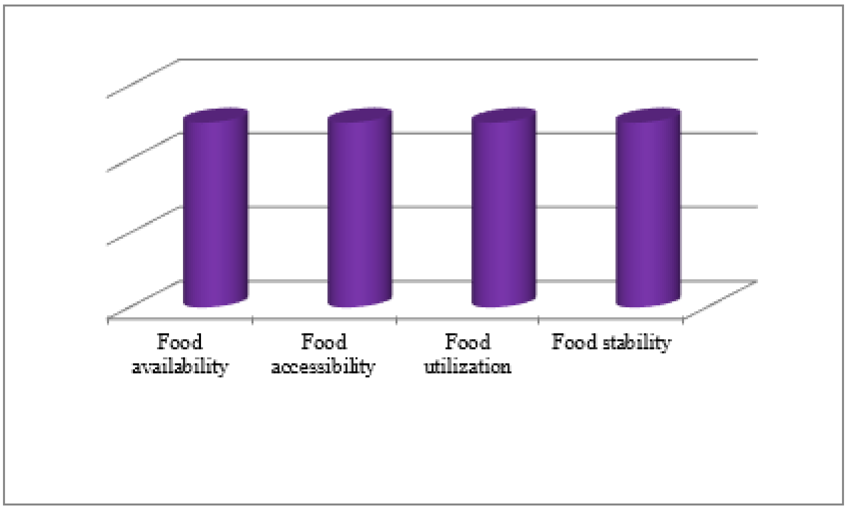

Fig. 1. Relationship between four food security outcomes

2.5 Adaptation Measures to Food Security

Proposing a dual strategy for sustainable agriculture, this section advocates public-private partnerships and innovative farming practices to fortify global food security through adaptive measures. To encourage direct access to food for needy people, FAO proposed the "twin-track approach" for sustainable agriculture and rural development [21]. Additionally, encouraging public-private partnerships would help the agricultural sector flourish; numerous studies have demonstrated that public spending on rural development, such as irrigation and roads, is more crucial than other considerations. Process-based crop growth models and climate projections from general circulation models (GCMs) on air temperature, precipitation, and atmospheric CO_2 are key components of the models used to assess the impact of climate change on the process of food production [12,22].

Importance of GCMs and Crop Models in Climate Impact Assessment: General circulation models serve various purposes, including weather forecasting, understanding climate change, and predicting climate change. These models utilize our knowledge of physical and biological processes to anticipate potential changes in farm-level productivity. While they are effective for studying atmospheric processes, coupled atmosphere–ocean GCMs are not suitable for climate projections. However, these coupled models can simulate interactive climate variability due to their ability to capture dynamic interactions between the atmosphere and the ocean. GCMs offer geographically and physically consistent estimates crucial for impact analysis. They can also predict changes in coastal upwelling intensity caused by alterations in surface winds or ocean overturning [12]. On the other hand, process-based crop growth models aim to forecast yields by simulating plant functions based on inherent plant characteristics and environmental conditions. These mathematical models integrate plant properties and environmental factors systematically, aiding in understanding complex interactions. Notably, process-based models may over-estimate future yields in regions experiencing more frequent hot days during the growing season [22].

A changing set of climatic parameters can be used to adapt agriculture and reduce the effects of climate change. When evaluating the possible effects of climate change on crop productivity and developing adaptation plans for risk management in agriculture, crop simulation models can be very helpful. It is capable of assessing agricultural adaptation plans that are more effective in mitigating climate-related hazards. Studies that solely concentrate on crop production offer a limited understanding of the linkages between food security and climate change since food security encompasses the availability, utilization, and access of food. According to Gregory [23], the main concerns for modifying food systems to reduce their susceptibility to climate change are 1- determining which associated factors are most vulnerable to GEC, 2- improving the efficacy of related factors, and 3- restoring related determinants that have been disturbed.

3. IMPACT OF CLIMATE CHANGE ON CROP PRODUCTIVITY

Broadening the perspective, this part explores how climate change affects growing crops. It considers things like how we use land, changes in usual weather, and the impact of unpredictable weather events.

3.1 Land Use

Climate change and land usage are linked to one another. There are different temporal and spatial scales at which this transformation affects one another. Land use change has had a major impact on ecological factors and climate change in recent decades. The movement of energy, water, and greenhouse gasses through the land and the atmosphere is altered by changes in land cover, which has an ongoing effect on weather and climate on a local to global scale. In India, where a significant amount of the population depends on farming for living and sustenance, it is crucial to evaluate the effects of climate change on crop productivity [24].

Decreases in agricultural land use and increases in wooded and urbanized land were the defining features of previous land use changes. Because of forestation, land usage has become a net sink for greenhouse emissions. Potential policy objectives that aim to lower land-based greenhouse gas emissions and expand land-based sources will also restrain land-use change [25]. Land use may decline as a result of mean temperature, precipitation, and the market effects of climate change on land [26]. According to Avitabile [27], the process of controlling the carbon cycle as a result of net carbon dioxide emissions is known as the "Biogeochemical effect of land on Climate". Land surface changes have the potential to have an even greater influence on local and regional climate than rising greenhouse gas emissions [28].

Numerous empirical investigations have supported how land use affects climate change. The global carbon cycle and elevation of the surface are changed by agricultural management, agroforestry, and the surface modifications that follow, which modify the Earth's radiative balance. Accordingly, after the burning of fossil fuels, land-use change is the second human cause of climate change [29,30]. Examine the connection between climate change and the conversion of agricultural land using data from various income groups. They discovered that while carbon dioxide emissions are rising in high-income countries, agricultural land area is declining in low-income countries, and the opposite is true in high-income countries [31]. However, the main cause of climate change is inappropriate land use.

3.2 Changes in Mean Climate

Heat, unpredictable weather, and a lack of irrigation are likely to cause losses in Indian agriculture [32]. The farming community and the expansion of the agricultural industry as a whole face challenge in understanding weather variations over time and modifying management strategies to achieve greater harvests. Due to its limited ability to adapt, the Indian crop sector is among the most vulnerable and exposed to the effects of climate change [33]. The negative effects of climate change can be mitigated by adaptation techniques such as high input delivery and use efficiency, variety, and improved agronomy [34]. Over the coming decades, yield growth can be sustained by expanding the scope of crop development investments and placing a greater emphasis on global changing variables [35].

4. CLIMATE VARIABILITY AND EXTREME WEATHER EVENTS

4.1 Drought

A drought is “a deficiency of precipitation over an extended period (usually a season or more), resulting in a water shortage.” Indicators of drought include precipitation, temperature, stream flow, ground and reservoir water levels, soil moisture, and snowpack (CCES). India has suffered many major and worst droughts in the last few decades [36]. Depending on the region, 39-60% of the losses relate to agriculture. The total Europe and The United Kingdom damage from drought slightly increased with 1.5°C global warming during 2025 (Source: https://ec.europa.eu/jrc/en/peseta-iv).

Drought is taken as a deficit of water compared with normal conditions [37]. 11% of the area covering six districts in the Godavari River Basin was identified as highly vulnerable, and rice production was drastically reduced, accounting for 41.02% of production loss during the worst-case drought event [38]. The degree to which the direct impacts of rising CO_2 on plant physiology will combine with climate change to alter productivity is highly unknown. Increased water usage efficiency by plants in increasing CO_2 concentrations may also partially counteract drought, while the effects of this are currently uncertain [39].

4.2 Extreme Temperature

It is logical to forecast an increase in the mean temperature, but the effects on production might be more dependent on the intensity and timing of high temperatures [40]. Land use change that are not directly influenced by climate change can have an impact on climate change indicators. With very few exceptions, temperature was not a stronger determinant of the figures of climate change indicators than terrain gradients [41]. High temperatures may cause yield loss in different crops in Tamil Nadu. Fig. 2 shows the maximum annual temperature specifically in Tamil Nadu district.

The mean maximum temperature has a favorable impact on food and non-food crops, except rice, according to research conducted in India between 1961 and 2017 on the effects of climatic factors on the production of main food and non-food crops. Then, non-food crops are negatively impacted by the average minimum temperature, whereas food crops are positively correlated with it [24]. Temperature increases typically hasten phenology, which shortens crop duration and has a major impact on agricultural productivity in India's coastal regions [34]. Increase of temperature and precipitation in Norway until 2100 and the observed crop yield trends in this study, climate change may still be a credible threat to wheat, barley, and potato productivity in some counties of Norway in the future [42].

4.3 Heavy Rainfall and Flooding

Extreme precipitation and flood events in overall climate regions increase as water availability increases from dry to wet regions [43]. Global-scale food assessments have reported both decreases and increases in future foods under global warming [44]. Increase in the intensification of extreme precipitation and flood with the seasonal cycle of water availability [45]. Increase in extreme precipitation and the expected decrease in total precipitation in dry regions [46]. Fig. 3. shows the amount of rainfall received in the Tamil Nadu district (according to latitude) up to 2018.

It is predicted that crop water requirements will rise during planting seasons due to the higher temperatures and lower precipitation. It indicates that by the end of the century, crop yield in South Africa's Olifants basin could drop by as much as 65%. Under the effects of climate change, utilizing rainwater harvesting along with full irrigation application and shifting planting dates will assist in increasing crop productivity in the future [47]. There could be a reduction of 10% in rice grown area that receives rain. The northeast region is most vulnerable to rain-fed rice, with effects ranging from -35% to +5% [48]. The impact on Rwanda's primary agriculture products, where rainfall is expected to increase by 4.5% between 2013 and 2033 and by 6% between 2033 and 2053. Late planting and poor harvest might result from erratic rainfall patterns and the displacement of rainy seasons [49].

4.3.1 Flood management strategies for climate resilience

The impacts of global warming on flood and extreme precipitation intensities are substantial and consistent across various climate regions [50]. Essential management practices encompass (a) optimizing irrigation systems, (b) cultivating crops with lower water requirements, and (c) refining irrigation scheduling and other techniques to minimize wastage [51]. The implementation of these measures could occur through diverse mechanisms and at different levels, subject to political decision-making. Private-sector entities and public authorities might engage in agreements with landowners (e.g., for contractual flood protection), acquire flood-prone land, or establish specific funds for flood event compensation [52]. Government agencies are keen on adopting more efficient technologies for hydrological monitoring, water use, and enhancing water infrastructure, potentially by increasing storage capacity. Suggestions from NGO representatives, government practitioners, and research scientists emphasize the importance of developing guidelines and standards to enhance water use efficiency and integrate climate change factors into flood estimation [53].

4.4 Reduction in Yield Level

Changes in the climate, CO_2, and O_3 can impact crop productivity worldwide. CO_2 trends are expected to raise global yields by about 1.8% every decade over the next three decades. Global yields would drop net as a result of

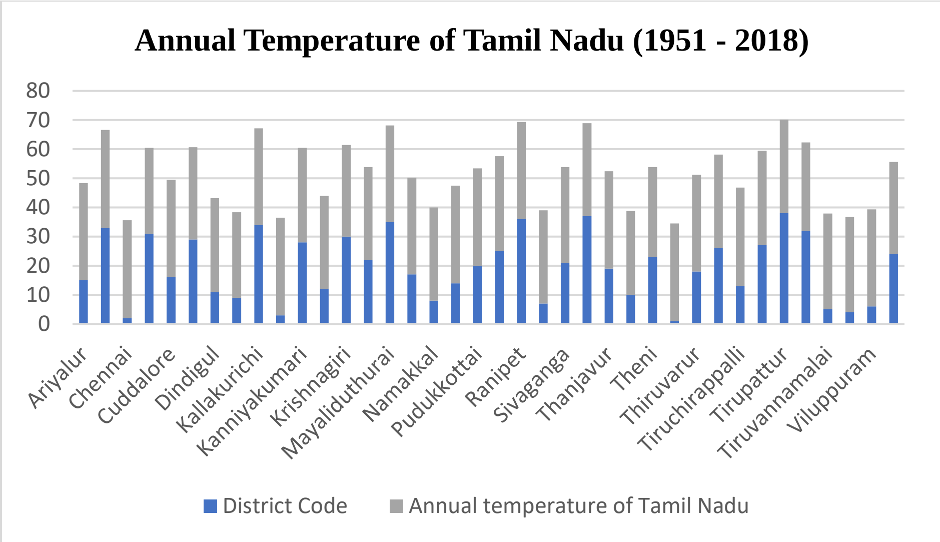

Fig. 2. Annual Temperature (maximum and minimum), spatial resolution is about 1 degree 1951-2018
(Source: http://climatevulnerability.in)

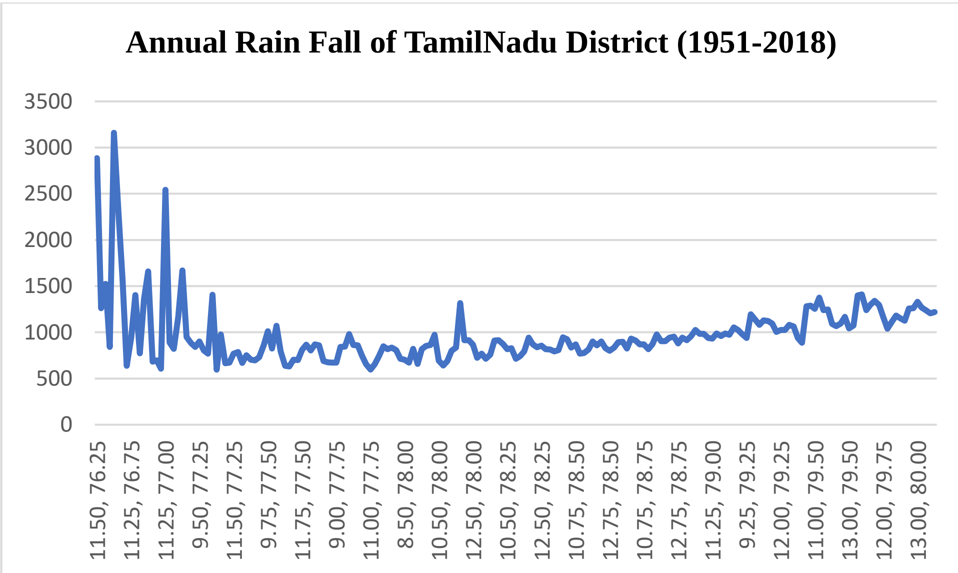

Fig. 3. Annual Rainfall of Tamil Nadu 1951-2018
(Source: http://climatevulnerability.in)

climate change [54]. A significant portion of the coastal districts is expected to see a 10% decrease in irrigated rice yields as a result of the projected impact of climate change on major crops in environmentally sensitive areas by 2030 Kumar [34].

The entire ecosystem is impacted by climate change. For example, rising CO_2 concentrations boost photosynthetic rates, which in turn boost rice's water-use efficiency and yield by 26.4%. In warm weather, rice and wheat saw yield declines of 8.4% and 12.2%, respectively. Ozone depletion has been linked to increased UV radiation exposure, which has been linked to a yield loss of roughly 13%. Increasing crop diversity by intercropping and suitable planting systems is the solution to this problem [32]. In certain Norwegian countries, the productivity of wheat, barley, and potatoes between 1980 and 2019 may still be seriously threatened by climate change. Based on weather variations during particular critical months that correlate with particular crop growth stages, the effects of climate factors on yield fluctuate greatly [42].

5. CLIMATE CHANGE IMPACTS ON BIODIVERSITY

Global biodiversity is one of the most severely affected areas by Climate Change because it is the fastest-emerging source of species loss. Research has shown that a wide range of climatic occurrences are significantly correlated with the massive scale species [55]. Any species that can withstand stressful circumstances, biological interactions, and dispersion limitations is typically a determining factor in its geographic range. Therefore, the local species must only accept, adapt, move, or risk extinction in place of Climate Change but the special species have a better survival capacity for adjusting to new ecosystems [56]. The integrity of ecosystems is impacted by changes in general climate regimes in a variety of ways, including changes in the relative abundance of species, range shifts, timing changes in activities, and utilization of microhabitats. The lack of access to microclimates and insufficient connection between habitats is a significant factor in this situation since it increases the vulnerability to extreme heatwave episodes and climate change. For instance, changes in the worldwide mangrove range owing to climate change are causing variations in the rates of carbon sequestration [57].

Comparably, the disappearance of kelp forests in some areas and their replacement by seaweed turfs have prepared the way for increased herbivory by a large inflow of tropical fish species. Furthermore, the conditions have gotten worse due to the rising water temperatures, which are much below the kelp communities' physiological tolerance threshold [58,59]. The destruction of keystone species poses a further significant risk, as it affects the entire communities within that area more extensively [60]. Eventually, the net ecosystem productivity and carbon storage may suffer from this CC-induced species dispersion. The distribution and abundance of some of the creatures in North American forests are already changing in response to recent climatic shifts, changing the patterns of forest disturbance at the regional and continental levels [61].

Particular species may not be significantly threatened by the migration of species northward since it enables species that live in mountains to find ideal climates. However, because of changes in topography and range, migratory species may find themselves stuck in remote and unsuitable habitats [62]. In addition, biodiversity is susceptible to other CC-related effects including droughts, temperature increases, and some invading pest species. For example, research has shown how warming temperatures have altered the makeup of plankton groups. Changes in these aquatic producer communities—calcareous plants and diatoms, for example—can therefore eventually cause differences in biological carbon recycling. Furthermore, these modifications are identified as a possible cause of the variations in CO_2 between the Pleistocene glacial and interglacial regimes [63].

6. ADAPTIVE STRATEGIES

Particular attention must be paid to adaptation and mitigation on a national and worldwide scale. In recent decades, climate change has become a major global issue, and social and economic advancement requires adaptation to its impacts. International policies and strategies should be developed to adapt to and mitigate climate change [64]. It is necessary to combine adaptation tactics—which try to minimize the adverse effects and take advantage of the opportunities presented by climate change—with mitigation initiatives to cut GHG emissions (IPCC 2014). According to Bhatti [65], the agriculture sector is highly susceptible to climate change, as it both influences and is adversely affected by it at the same time. Building societal resilience to climate change is one of the main goals of adaptation measures [66]. Knowledge of the primary and secondary effects of adaptation to global environmental change by conducting an environmental assessment of adaptation measures. It offers a reliable and efficient means of incorporating environmental factors into decision-making [67]. According to Maponya [68], some of their observed adaptation tactics were,

a. soil management strategies
b. water management strategies
c. other measures including using insurance and subsidies.

6.1 Farmers' Climate Resilience: Soil Management and Crop Diversification

A majority of farmers believe that managing soil fertility is crucial in coping with climate variability and change. They perceive that altering the use of fertilizers, chemicals, and pesticides can enhance their ability to adapt to climate change

[69]. In Limpopo province, farmers are actively employing organic fertilizers produced through composting. Additionally, they embrace crop diversification as an adaptive strategy. Crop diversification acts as a form of insurance against rainfall variability, as different crops respond differently to climate events [68]. Soil degradation is a concern because it reduces productivity due to low resource use efficiency, particularly for Nitrogen and water. While some countries aim to decrease reliance on synthetic fertilizers by cultivating legumes, even biological nitrogen fixation (BNF) presents ecological trade-offs due to certain negative environmental impacts [70].

6.2 Enhancing Flood Management Strategies in Developing Countries: Insights from India

Many developing countries primarily employ ad hoc measures for flood management. In India, where 12% of the land is susceptible to flooding, the annual flood-related losses amount to approximately Rs. 100 million [71,72]. The Indian National Disaster Management Framework emphasizes human resource development. Effective flood management includes implementing land-use regulations and plans, and spatial planning can significantly reduce flood hazards and associated impacts [73]. Maintaining accurate data on disaster impacts, fatalities, and relief support is crucial for evaluations, impact assessments, and flood modeling. Therefore, conducting quality research based on real data contributes to more realistic policy formulation [74] and enhances the potential for effective disaster mitigation.

Promoting adaptation is a crucial component of the climate change policy response. Farmers believed that deforestation, population growth, and growing industrialization were the primary contributors to climate change. Farmers reported using soil conservation schemes (22.72%) and crop variety diversity (26.36%) as adaptation strategies [75]. Gbetibouo [76], who found that creating water-harvesting methods is a common adaptation approach (chosen by persons facing the effects of decreased precipitation), supports these findings. Some farmers in the province of Limpopo have developed adaptation measures.

The goal of adaptation is to lessen the negative effects and take advantage of any possibilities that may arise from the changing climate. Nevertheless, environmental changes occur mostly due to human activity globally [77]. Regarding adaptation, the government's initiatives have been noteworthy in that they have improved agricultural output and developed irrigation systems utilizing present technology, as well as developing new technologies and changing Iranian policy [78]. Future food security is heavily impacted by climate change and population growth. To maintain it, cultivars of crops, public attitudes, and agricultural practices will all need to be altered [79]. To solve the indigenous agricultural difficulties arising from global climate change, more efforts were made to raise awareness of climate change through the distribution of reliable, need-based information, farmers would be much better able to implement more pertinent, successful, and efficient adaptation measures, which would increase agricultural yield and decrease losses [80].

7. INNOVATIVE FARMING PRACTICES

Modern agricultural practices have reduced the dependency of farmers on suitable climate conditions and prevented crop losses due to sudden climate changes. Methods such as conservation tillage, smart precision farming, crop diversification, and agroforestry provide a better environment for crop cultivation.

- **Conservation Tillage**

Tillage, a mechanical soil treatment method, is utilized for tasks such as seedbed preparation, soil loosening, weed control, and the incorporation of fertilizer and residues into the soil [81]. It remains on the ground to prevent soil erosion and conserve moisture. No-tillage and conservative tillage practices, which minimize mechanical soil disturbance, enhance macropore connectivity. This leads to increased infiltration capability and hydraulic conductivities in the low-suction range [82]. Conservative tillage practices are anticipated to gain significance in the future. The impact of tillage on crop development is as varied as its effects on soil physical properties. Crop development relies on local soil characteristics such as texture, structure, type, and depth, along with additional factors like weather conditions and plant-specific traits [83].

- **Smart Precision Farming**

Precision agriculture is an innovative farming approach employing advanced technology and data analysis to optimize crop yields, minimize waste, and boost productivity. This method presents a promising solution to address key challenges in contemporary agriculture, including the need to feed a growing global population while mitigating environmental impact [84]. Initially, in precision agriculture, human intervention was essential for decision-making, with motorized equipment executing agricultural tasks [85]. However, the evolution of remote-sensing technology, such as satellites, drones, ground-based sensors, and crews, empowers farmers to gather high-resolution field data, enabling well-informed decisions about crop management [86]. Precision farming has the potential to improve soil health, reduce water and fertilizer usage, and enhance both crop yield and quality.

- **Crop Diversification**

Diversifying crops has shown improvement in various environmental indicators. Agricultural diversification, involving practices like crop rotation, cover crops, and intercropping, along with low-input management approaches such as agroecology, conservation agriculture, and organic farming, contributes to long-term increases in crop productivity and cropping system resilience [87]. While this approach typically enhances the environmental sustainability of cropping systems, certain specialized high-value cropping systems, which may have elevated environmental impacts, might experience a reduction in economic performance [88].

- **Agroforestry**

Agroforestry, a key strategy to combat climate change and strengthen agriculture, emphasizes the alley cropping and silvopastoral systems for their sustainability and potential to increase farm income and transform animal husbandry [89]. This approach also enhances ecosystem services by improving soil structure, increasing carbon sequestration, and retaining more water. Furthermore, agroforestry practices within the system contribute to mitigating climate change by improving carbon sequestration, thus reducing greenhouse gas emissions [90].

- **Using of Climate Reslient Crop Varieties**

Developing climate-resilient crops is vital for ensuring food security and addressing challenges posed by climate change. The objective is to create crop varieties with improved tolerance to abiotic stresses, maintaining high yield potential and nutritional quality. These endeavors seek to secure food production under progressively adverse climatic conditions [91]. The advent of genome editing technologies, particularly CRISPR-Cas9, has transformed crop improvement. This powerful tool facilitates precise modifications of specific genes, enabling the development of climate-resilient crops with enhanced stress tolerance [92].

- **Effective Irrigation Management**

Water scarcity is a critical issue that threatens sustainable development in drylands. Smart irrigation is a viable option to optimize the use of water resources and improve water productivity in such areas. [93].

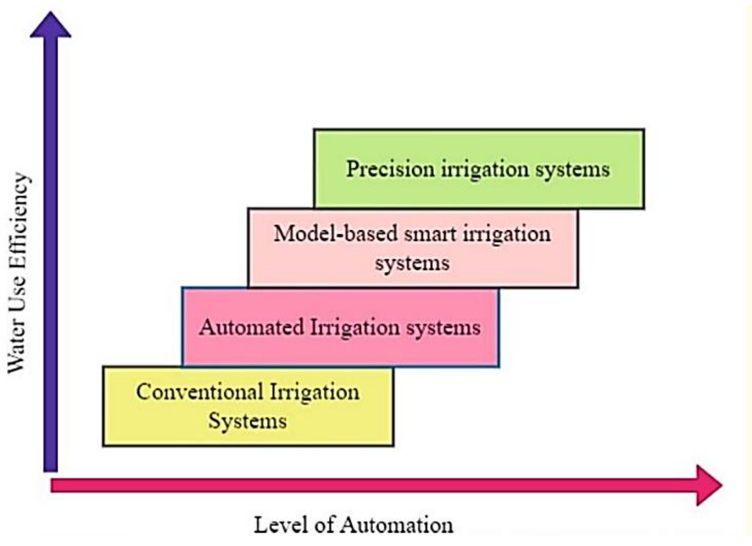

Fig. 4. Relationship between water use efficiency and automation level in irrigation system

This Fig. 4 demonstrates that as automation levels increase in irrigation systems, water use efficiency also increases. Water is delivered through emitters by a distribution system on, under, or above the soil's surface in micro-irrigation systems at low pressure [94]. Precision water application using micro-irrigation systems can save up to 35-65% more water than standard flood irrigation systems, while also increasing crop production [95,96]. The implementation of intelligent sprinkler irrigation systems involves precise control, high intelligence, dependability, easy operation, wireless or wired sensor network tech, and crop water demand data collection devices [97]. Surface irrigation is the oldest irrigation application method in the world. To improve smart irrigation scheduling in surface irrigation systems, Supervisory Control and Data Acquisition (SCADA) software has been deployed in surface irrigation systems to improve the programming, monitoring, and operation of an entire scheme from a central point [98].

8. CONCLUSION

It concludes that modern life on Earth has evolved to adapt to predictable climatic cycles, and it is critical to adjust to these significant fluctuations. At every level, from the local elementary school to the global level, this rapidly increasing unknown demands immediate response because the accelerated changes in climate will make it more difficult to adapt and survive. Certain policy implications, particularly in the most impacted industries like agriculture, can aid in mitigating the effects of climate change. A global concern, agriculture, and its products are being negatively impacted by climate change. The impacts of climate change on plant development and output are dreadful. Two of the most important markers of stress in the environment are changes in temperature and the frequency of rainfall. Overcoming the imbalance caused by climate change in agriculture is extremely challenging. To save agriculture in the future, researchers must concentrate on putting new farming patterns into practice with both traditional and non-conventional methods. Finally, it confirms that global warming (rise in temperature), drought, high rainfall, and flooding are the major challenges of our global society. At many different dimensions, adaptation to the effects of climate change is required, is already taking place, and will become more urgent in the future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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