

Climate Smart Technologies for Sustainable Vegetable Production under Changing Weather Conditions

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INTRODUCTION

Vegetables play a vital role in human nutrition by providing essential vitamins, minerals, antioxidants, and dietary fiber required for a balanced diet. The demand for vegetables is increasing rapidly due to population growth, urbanization, and increasing awareness of healthy diets. However, vegetable production is highly sensitive to climate variability because most vegetable crops have short growing periods and are vulnerable to temperature fluctuations, irregular rainfall, drought, and pest outbreaks. Climate change has intensified these challenges, affecting productivity, crop quality, and farmers' income. In recent decades, global climate change has resulted in increasing temperatures, erratic rainfall patterns, extreme weather events, and shifting pest and disease dynamics. These changes directly impact vegetable cultivation by reducing yield, increasing production risks, and causing resource inefficiencies. For example, heat stress can reduce fruit set in crops such as tomato and pepper, while excessive rainfall can cause nutrient leaching, waterlogging, and disease outbreaks.

2. Climate Change and Its Impact on Vegetable Production

Vegetable crops are highly sensitive to environmental conditions, and changes in temperature, rainfall patterns, and atmospheric factors can significantly influence their growth, development, and yield. Rising temperatures often cause heat stress, which affects flowering, fruit set, and crop quality in vegetables such as tomato, cauliflower, and lettuce. Irregular rainfall patterns may result in drought or flooding, both of which negatively impact vegetable production. In addition, many vegetable-growing regions are experiencing water scarcity due to reduced rainfall and increased evapotranspiration. Changing climatic conditions also promote the spread of pests and diseases, leading to higher crop losses. Furthermore, extreme weather events such as heavy rainfall and prolonged drought contribute to soil erosion, nutrient depletion, and declining soil fertility. These challenges emphasize the urgent need for climate-resilient agricultural technologies that enhance productivity while conserving natural resources.



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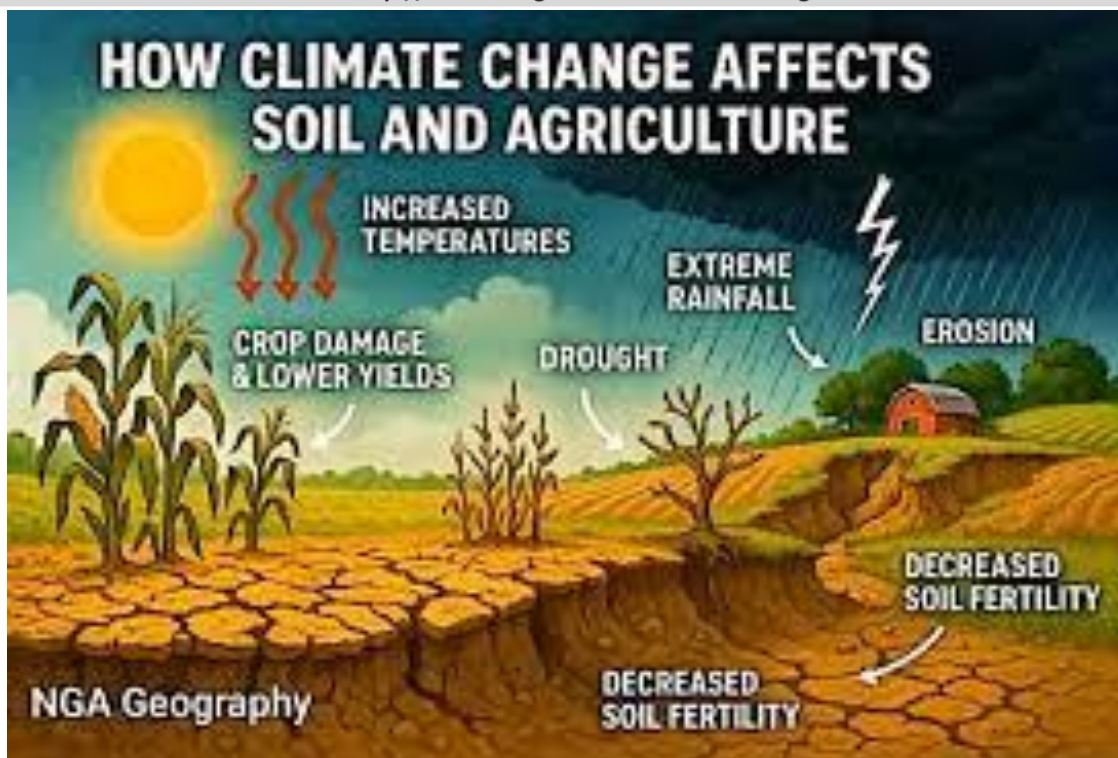
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3. Climate Smart Technologies for Sustainable Vegetable Production

3.1 Protected Cultivation

Protected cultivation involves growing crops under controlled environments such as greenhouses, polyhouses, shade nets, and low tunnels. These structures protect crops from adverse climatic conditions such as extreme temperatures, heavy rainfall, frost, and strong winds.

Protected cultivation allows farmers to regulate temperature, humidity, light, and irrigation levels, creating optimal conditions for crop growth. It also enables off-season vegetable production, leading to higher profitability. Studies show that protected cultivation systems can increase water productivity and nutrient-use efficiency while reducing irrigation water and fertilizer requirements.

Benefits

- Protection from extreme weather
- Higher yield and better crop quality
- Efficient resource utilization
- Off-season production

3.2 Precision Irrigation Systems

Water scarcity is a major challenge for agriculture under changing climatic conditions. Precision irrigation technologies, such as drip irrigation and sprinkler systems, help address this problem by delivering water directly to the plant roots in controlled amounts. Among these methods, drip irrigation is particularly effective as it significantly reduces water loss through evaporation and runoff while improving overall water-use efficiency. It is especially beneficial for vegetable crops because it maintains optimal soil moisture levels necessary for healthy plant growth. In addition, drip irrigation offers several advantages, including saving about 30–60% of irrigation water, improving fertilizer efficiency through fertigation, reducing weed growth, and ultimately enhancing crop productivity.

3.3 Mulching Technology

Mulching is a practice that involves covering the soil surface with materials such as plastic films, straw, crop residues, or other organic substances. This technique helps conserve soil moisture, regulate soil temperature, suppress

weed growth, and reduce soil erosion. Mulching is particularly beneficial under changing climatic conditions because it protects the soil and creates a favorable environment for plant growth. Research has shown that combining mulching with drip irrigation can significantly enhance the growth and yield of vegetable crops under climate

stress conditions. Common types of mulching include plastic mulch, organic mulch such as straw and crop residues, and biodegradable mulch. Overall, mulching conserves soil moisture, improves soil structure, reduces weed infestation and ultimately increases crop productivity.



Compost mulch



Straw mulch



Bark mulch



Newspaper mulch



Wood chips mulch



Sawdust mulch



Plastic mulch film



Black plastic mulch



LDPE plastic

3.4 Climate-Resilient Vegetable Varieties

Developing and adopting climate-resilient vegetable varieties is an important strategy for achieving sustainable vegetable production under changing climatic conditions. These improved varieties are specifically bred to tolerate environmental stresses such as drought, high temperatures, salinity and pest or disease attacks. Examples include heat-tolerant tomato varieties, drought-resistant okra varieties and disease-resistant cucurbit crops. The use of such resilient varieties helps farmers maintain stable yields, improve crop performance and reduce production risks even under unfavorable environmental conditions.

3.5 Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) is an approach that combines organic and inorganic sources of nutrients to maintain soil fertility and sustain crop productivity. It involves the balanced use of chemical fertilizers along with organic manure, compost, biofertilizers, and green manure. This integrated approach helps improve soil health by enhancing the physical, chemical and biological properties of soil while ensuring a steady supply of essential nutrients to crops. As a result, nutrient availability and nutrient use efficiency are improved and dependence on chemical

fertilizers is reduced. Overall, Integrated Nutrient Management contributes to better soil fertility, efficient utilization of nutrients and promotes sustainable crop production.

3.6 Integrated Pest Management (IPM)

Climate change often increases the incidence of pests and diseases in vegetable crops, posing a serious threat to crop productivity and quality. Integrated Pest Management (IPM) is an eco-friendly and sustainable approach that combines biological, cultural, mechanical, and chemical methods to effectively control pests while minimizing environmental impact. Important components of IPM include the use of biological control agents, adoption of pest-resistant crop varieties, crop rotation practices, and regular monitoring with early warning systems to detect pest outbreaks. By integrating these strategies, IPM helps reduce

excessive pesticide use, protects the environment, and maintains stable crop productivity.

3.7 Digital and Smart Farming Technologies

Recent advances in digital agriculture have introduced several innovative technologies that support modern farming practices. These include remote sensing, the Internet of Things (IoT), artificial intelligence, crop monitoring sensors, and decision support systems. Such technologies enable farmers to monitor crop conditions, soil moisture, temperature, and nutrient levels in real time. By providing accurate and timely information, digital tools help farmers optimize the use of water, fertilizers, and other resources while improving farm management decisions and overall agricultural productivity.



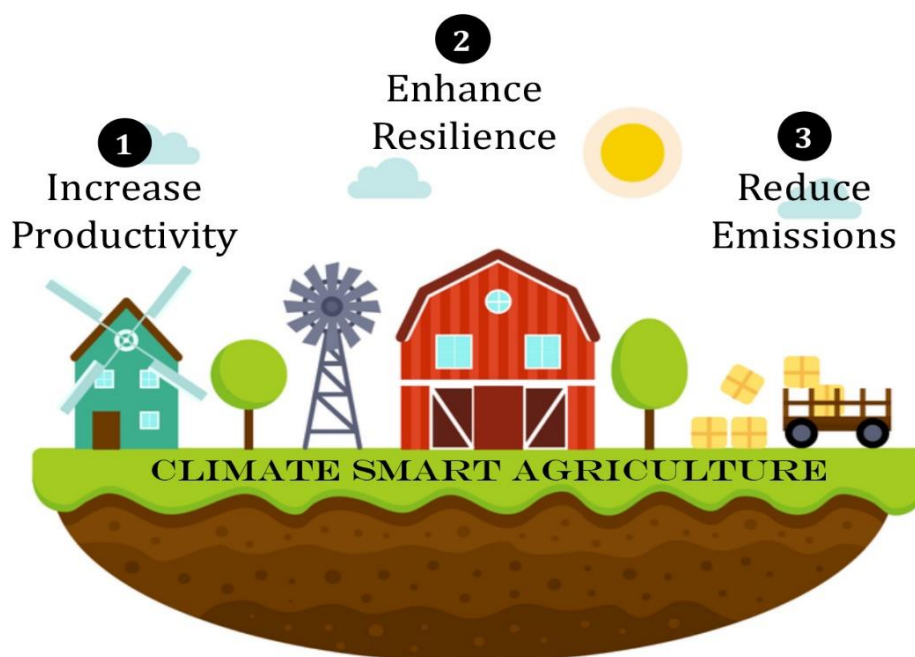
4. Role of Climate Smart Technologies in Sustainable Vegetable Production

Climate-smart technologies play a vital role in ensuring sustainable vegetable production under the challenges posed by climate change. These technologies contribute to improved productivity by enabling advanced cultivation techniques that increase vegetable yields even under adverse climatic conditions. They also enhance resource efficiency, as practices such

as drip irrigation and fertigation promote the efficient use of water and nutrients. In addition, climate-smart approaches strengthen climate resilience through protected cultivation systems and the use of climate-resilient crop varieties that help crops withstand extreme weather events. These technologies further support environmental sustainability by reducing the excessive use of chemical inputs and promoting better soil management

practices. Ultimately, the adoption of climate-smart technologies leads to higher productivity and improved crop quality, thereby increasing

farmers' income and strengthening their livelihood security.

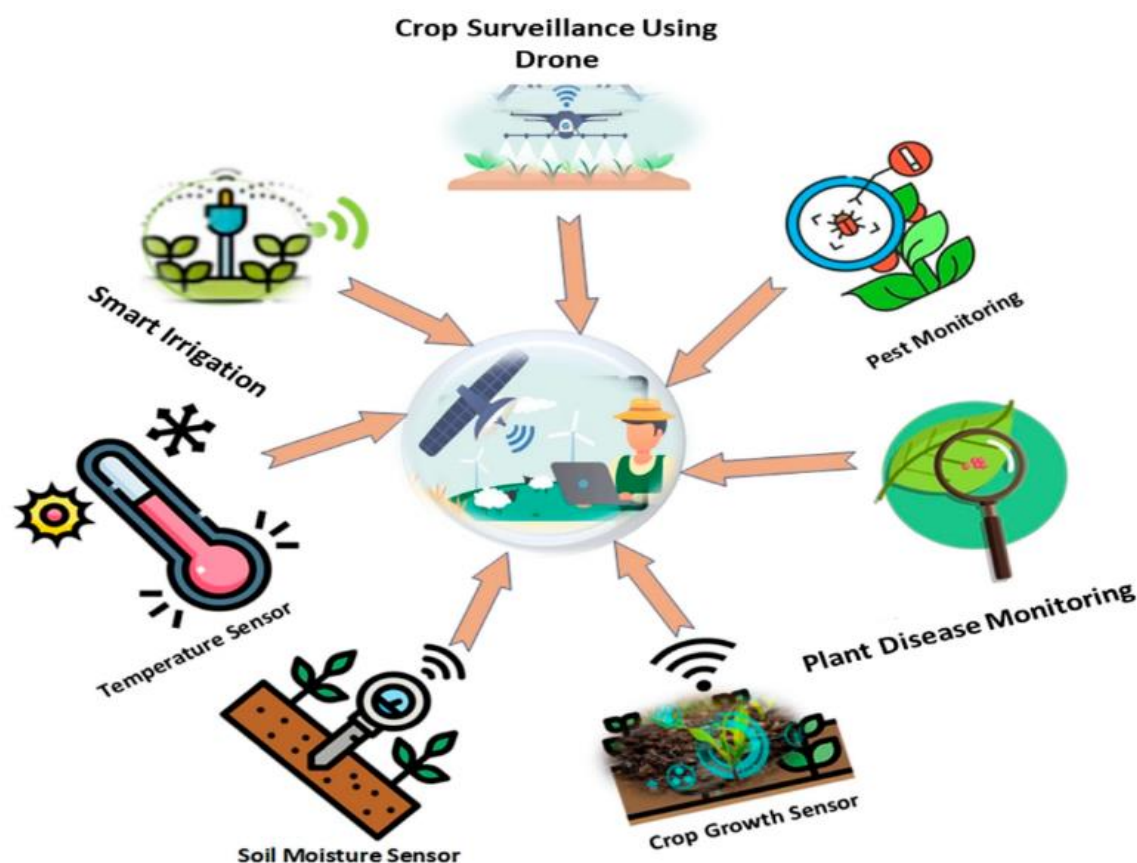


5. Challenges in Adoption of Climate Smart Technologies

Despite their significant benefits, the adoption of climate-smart technologies in vegetable production still faces several challenges. One of the major constraints is the high initial investment required for technologies such as protected cultivation structures, drip irrigation systems, and digital monitoring tools, which many small and marginal farmers cannot easily afford. In addition, limited awareness and inadequate knowledge about the benefits and proper use of these technologies often restrict their adoption at the farm level. Many farmers also lack the technical skills and training required to effectively implement and manage climate-smart practices. Furthermore, inadequate rural infrastructure, including limited access to irrigation facilities, electricity, storage, and market networks, creates additional barriers. Access to institutional credit and government subsidies is also often limited or difficult for farmers to obtain, slowing the widespread adoption of these technologies.

6. Future Prospects

The future of sustainable vegetable production depends on effectively integrating modern technologies with traditional agricultural practices. To achieve this, governments, research institutions, and private organizations must work together to promote climate-smart farming approaches that enhance productivity while ensuring environmental sustainability. Important future strategies include the development of climate-resilient vegetable varieties capable of withstanding stress conditions, expansion of protected cultivation systems to minimize climatic risks, and wider adoption of digital agriculture technologies for better farm management. In addition, promoting sustainable soil and water management practices and strengthening agricultural extension services along with farmer training programs will play a crucial role in improving awareness, technology adoption and long-term sustainability in vegetable production systems.



CONCLUSION

Climate change poses significant challenges to vegetable production worldwide. Rising temperatures, irregular rainfall, and increasing pest pressures threaten agricultural productivity and food security. Climate-smart technologies provide effective solutions to overcome these challenges and ensure sustainable vegetable production. Technologies such as protected cultivation, precision irrigation, mulching, climate-

resilient crop varieties, integrated nutrient management and digital agriculture tools help improve productivity, conserve natural resources and enhance resilience to climate variability. Adoption of these technologies can significantly contribute to sustainable agriculture and rural livelihoods. However, wider adoption requires increased awareness, financial support, infrastructure development and strong policy frameworks.