

# Climate Smart Horticultural Practices for Enhancing Resilience and Resource Use Efficiency

Abhijit Debnath\*<sup>1</sup>, Abhik Sarkar<sup>2</sup>, Moaakum Pongen<sup>3</sup>,  
and H. Lembisana Devi<sup>4</sup>

<sup>1</sup>Department of Horticulture and Post-Harvest Technology, Palli Siksha Bhavana, Visva-Bharati, Sriniketan, West Bengal, India

<sup>2</sup>Department of Community Health Nursing, Sambalpur University, Jyoti Vihar, Burla, Sambalpur, Odisha, 768019, India

<sup>3</sup>Department of Animal Science, ICAR KVK, Wokha, Nagaland 797111, India

<sup>4</sup>Department of Horticulture, ICAR-KVK Tamenglong, ICAR RC for NEHR Manipur Centre, Lamphelpat, Imphal, Manipur 795001, India

Corresponding author: **Abhijit Debnath** | E-mail: [abhijitdebnathhorticulture@gmail.com](mailto:abhijitdebnathhorticulture@gmail.com)

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## Abstract

Climate change poses significant challenges to horticultural production systems through rising temperatures, irregular rainfall patterns, increased frequency of extreme weather events, and emerging pest and disease pressures. Climate-smart horticulture focuses on improving crop resilience, enhancing productivity, and promoting efficient use of natural resources while reducing environmental impacts. Adoption of innovative practices such as climate-resilient crop varieties, protected cultivation, efficient irrigation systems, soil health management, and digital farming technologies can significantly enhance sustainability in horticultural systems. This review examines major climate-smart horticultural strategies, including water and nutrient management, diversification approaches, integrated pest management, and precision technologies that support climate adaptation and mitigation. The article also discusses challenges and future opportunities for integrating climate-smart practices into horticultural production systems to ensure long-term productivity, environmental sustainability, and food and nutritional security.

**Keywords:** climate-smart horticulture, resource efficiency, climate resilience, sustainable production, protected cultivation, precision agriculture.

## 1. Introduction

Horticultural crops, including fruits, vegetables, flowers, spices, and medicinal plants, play a vital role in ensuring nutritional security and generating rural income [1]. However, climate change is increasingly affecting horticultural production through temperature fluctuations, water scarcity, extreme weather events, and shifting pest and disease dynamics. These changes threaten crop productivity, quality, and farmer livelihoods. Climate-smart agriculture (CSA) aims to increase productivity, enhance resilience, and reduce greenhouse gas emissions wherever possible. Climate-smart horticulture applies these principles specifically to horticultural crops by promoting adaptive production practices and efficient resource utilization [2]. Modern horticultural production must therefore integrate technologies and management strategies that minimize vulnerability to climate stress while improving resource use efficiency. Climate-smart horticulture includes improved crop varieties, soil and water conservation techniques,

precision farming, protected cultivation, and integrated pest management [3]. This article reviews major climate-smart horticultural practices that enhance crop resilience and resource efficiency while supporting sustainable production systems.

## 2. Climate Change Impacts on Horticultural Crops

Climate change influences horticultural crops in several ways:

- Increased temperatures affecting flowering, fruit set, and quality
- Water scarcity reducing crop productivity
- Heat stress causing physiological damage
- Irregular rainfall causing floods or droughts
- Increased pest and disease incidence
- Soil degradation and nutrient loss

Such challenges necessitate adoption of resilient crop production strategies.

## 3. Climate-Resilient Crop Varieties

Development and adoption of climate-resilient horticultural varieties are key adaptation strategies.

Breeding programs focus on traits such as drought tolerance, heat tolerance, salinity resistance, and pest and disease resistance [4]. Hybrid vegetable varieties and improved fruit cultivars capable of tolerating environmental stresses ensure stable production. Biotechnology and molecular breeding approaches accelerate development of resilient varieties suited to changing climatic conditions.

#### 4. Protected Cultivation Systems

Protected cultivation technologies such as greenhouses, polyhouses, net houses, and shade structures play a crucial role in climate-smart horticulture by minimizing the adverse effects of climatic variability on crop production. These systems provide controlled or semi-controlled environments where temperature, humidity, light intensity, and ventilation can be regulated to create optimal growing conditions for crops [5]. Such protection is particularly important under conditions of extreme heat, frost, heavy rainfall, or strong winds that can severely damage horticultural crops grown in open fields.

Greenhouses and polyhouses enable year-round cultivation of vegetables, flowers, and nursery plants, ensuring continuous supply regardless of seasonal constraints. Net houses and shade structures reduce excessive solar radiation and protect crops from insect pests and mechanical damage caused by wind or heavy rain. Protected cultivation also reduces exposure to environmental stresses, resulting in improved plant growth and higher productivity [6]. Water and nutrient management become more efficient in protected systems because irrigation and fertigation can be precisely controlled. Reduced pest and disease incidence due to physical barriers also decreases pesticide usage, improving crop quality and food safety. As a result, protected cultivation is increasingly adopted for high-value horticultural crops such as tomato, capsicum, cucumber, strawberry, and cut flowers, contributing significantly to farmers' income and resource efficiency.

#### 5. Efficient Water Management Practices

Water scarcity is one of the most pressing challenges in horticultural production, particularly under changing climatic conditions characterized by irregular rainfall and increasing evapotranspiration rates. Climate-smart water management practices aim to maximize crop productivity per unit of water

used while conserving limited water resources. Efficient irrigation strategies not only reduce water wastage but also improve nutrient uptake, crop quality, and yield stability [7]. Adoption of advanced irrigation systems, water harvesting methods, and soil moisture conservation techniques helps farmers cope with drought conditions and ensure sustainable crop production.

##### 5.1 Drip and Micro-Irrigation Systems

Drip and micro-irrigation systems deliver water directly to the plant root zone in controlled quantities, minimizing losses due to evaporation, runoff, and deep percolation. This targeted irrigation approach significantly improves water use efficiency compared to conventional flood irrigation [8]. Integration of fertigation systems allows nutrients to be supplied through irrigation water, ensuring precise nutrient delivery and improved nutrient use efficiency. Such systems reduce fertilizer wastage and environmental contamination while promoting uniform crop growth. Drip irrigation is particularly beneficial in orchards, vegetable crops, and protected cultivation systems.

##### 5.2 Rainwater Harvesting

Rainwater harvesting involves collection and storage of rainfall in ponds, tanks, or reservoirs for use during dry periods. This practice reduces dependency on groundwater and ensures water availability for irrigation during drought conditions [9]. Farm-level water harvesting structures also help recharge groundwater and reduce soil erosion caused by heavy rainfall. Adoption of rainwater harvesting systems is increasingly encouraged in climate-vulnerable regions where rainfall distribution is highly erratic.

##### 5.3 Soil Moisture Conservation

Soil moisture conservation practices help maintain adequate water availability in the root zone by reducing evaporation losses. Mulching using crop residues, plastic films, or organic materials creates a protective soil cover that reduces water loss, controls weeds, and moderates soil temperature. Conservation practices such as contour farming, minimum tillage, and organic matter incorporation improve soil structure and enhance water infiltration and retention capacity [9]. These measures are especially beneficial in drought-prone areas where efficient water utilization is essential for crop survival.

**Table. Major Climate-Smart Horticultural Practices and Their Benefits**

Climate-Smart Practice	Technologies or Methods	Benefits for Crop Production	Resource Use and Environmental Benefits
Protected Cultivation	Greenhouses, polyhouses, net houses, shade structures	Year-round production and reduced weather damage	Efficient water and nutrient use with reduced pesticide application
Efficient Irrigation Management	Drip irrigation, micro-irrigation, fertigation	Improved crop growth and yield stability	Significant water savings and reduced nutrient losses
Soil Health Management	Organic manures, cover crops, residue incorporation	Improved soil fertility and crop resilience	Increased soil carbon and improved water retention
Integrated Pest Management	Biological control, resistant varieties, monitoring tools	Reduced pest and disease losses	Lower pesticide use and reduced environmental contamination
Precision Horticulture	Sensors, drones, AI-based tools, smart irrigation	Improved crop monitoring and productivity	Optimized use of water, nutrients, and inputs
Crop Diversification	Mixed cropping, integrated cropping systems	Reduced production risk and income stability	Improved biodiversity and soil sustainability
Agroforestry Systems	Integration of trees with horticultural crops	Improved microclimate and productivity	Enhanced carbon sequestration and ecosystem stability
Rainwater Harvesting	Farm ponds and water storage systems	Increased irrigation availability during drought	Reduced groundwater dependency and improved water conservation

## 6. Soil Health and Nutrient Management

Soil health plays a fundamental role in determining crop productivity, resilience, and sustainability. Healthy soils support strong root development, improve nutrient availability, and enhance water retention, enabling crops to better withstand climatic stresses. Climate-smart soil and nutrient management practices focus on maintaining soil fertility while minimizing environmental degradation. Incorporation of organic manures, compost, and green manures increases soil organic matter, improves soil structure, and supports beneficial microbial activity [11]. Crop residue incorporation further contributes to nutrient recycling and soil moisture conservation. Cover cropping helps protect soil from erosion, suppress weeds, and improve soil nutrient status through biological nitrogen fixation in leguminous crops. Reduced or conservation tillage practices minimize soil disturbance, preserving soil structure and reducing carbon loss.

Balanced fertilization based on soil testing ensures efficient nutrient use while preventing nutrient imbalances and environmental pollution. Integrated nutrient management combining organic and inorganic sources promotes sustainable soil fertility management and enhances crop productivity. Improved soil organic carbon content increases soil water-holding capacity, which is critical under drought conditions. Thus, maintaining soil health is a cornerstone of climate-smart horticultural production systems aimed at improving resilience and resource use efficiency.

## 7. Integrated Pest and Disease Management

Climate variability significantly influences pest and disease dynamics in horticultural systems. Rising temperatures, fluctuating humidity, and irregular rainfall patterns often create favorable conditions for rapid multiplication and spread of pests and pathogens. As a result, farmers frequently experience increased crop losses and higher dependency on chemical pesticides, which can lead to environmental contamination, pest resistance, and food safety concerns [12]. Integrated Pest Management (IPM) offers a climate-smart solution by combining biological, cultural, mechanical, and chemical control methods to manage pests sustainably. The approach emphasizes prevention, regular monitoring, and targeted interventions rather than routine pesticide application. Use of resistant or tolerant crop varieties reduces vulnerability to major pests and diseases. Biological control agents such as parasitoids, predators, and microbial biopesticides help suppress pest populations naturally. Cultural practices including crop rotation, sanitation, and optimized planting schedules also reduce pest incidence. Mechanical methods such as traps and barriers further assist in pest control. Modern monitoring systems and forecasting tools allow early detection of pest outbreaks, enabling timely and precise interventions. Overall, IPM reduces pesticide dependence, minimizes environmental impacts, and promotes sustainable horticultural production.

## 8. Precision Horticulture Technologies

Precision horticulture integrates digital technologies and data-driven approaches to improve efficiency and sustainability of crop production. Climate-smart horticulture increasingly relies on digital tools to monitor crop and environmental conditions and optimize resource use [13]. Sensors installed in fields and protected cultivation systems continuously monitor soil moisture, nutrient levels, and environmental parameters, allowing farmers to make informed irrigation and fertilization decisions. Drone and satellite-based remote sensing technologies help detect crop stress, nutrient deficiencies, and disease symptoms over large cultivation areas. Artificial intelligence-based systems analyze climate and crop data to predict pest and disease outbreaks, enabling proactive management strategies. Smart irrigation systems automatically adjust water application according to crop needs and weather forecasts, improving water use efficiency. These technologies reduce production risks, lower input costs, and enhance crop productivity by supporting data-driven decision-making and precision farm management.

## 9. Crop Diversification and Agroforestry

Crop diversification is an important climate adaptation strategy that reduces production risks and enhances farm resilience. Growing multiple crops within the same farm reduces dependence on a single crop and provides economic stability in case of climate-induced crop failure. Integration of fruit trees, vegetables, spices, and medicinal plants increases land productivity and provides diversified income sources. Mixed cropping systems also improve soil fertility and reduce pest and disease buildup by breaking pest life cycles [14]. Agroforestry systems, which combine trees with horticultural crops, offer multiple ecological benefits. Trees provide shade, improve soil structure, reduce wind damage, and enhance water retention. Agroforestry also contributes to carbon sequestration, biodiversity conservation, and microclimate improvement, making cropping systems more resilient to climatic stress. Diversification thus plays a critical role in sustaining horticultural production under climate uncertainty.

## 10. Challenges in Adoption

Despite the advantages of climate-smart horticultural practices, widespread adoption remains limited due to several constraints. High initial investment requirements for technologies such as protected cultivation, drip irrigation, and precision farming tools discourage small and marginal farmers from adoption. Limited awareness and technical knowledge among farmers further restrict implementation of climate-smart practices. Many farmers lack access to training programs and extension services needed to adopt modern technologies effectively, limited availability of advanced equipment, poor rural infrastructure, and inadequate market linkages hinder technology adoption. Policy and financial support mechanisms are often insufficient or inaccessible to smallholder farmers, slowing adoption rates.

Addressing these challenges requires coordinated efforts involving governments, research institutions, private sector, and farmer organizations.

### 11. Future Prospects

The future of climate-smart horticulture will increasingly depend on technological innovation and integrated farm management approaches. Advances in digital agriculture, artificial intelligence, automation, and crop biotechnology are expected to further enhance productivity and resilience. Development of climate-resilient crop varieties through modern breeding and molecular tools will support adaptation to changing climatic conditions. Automation technologies such as robotic harvesting and sensor-based crop management will improve efficiency while reducing labor dependency. Renewable energy solutions, including solar-powered irrigation systems, will contribute to environmentally sustainable horticultural production. Strengthening farmer training programs, improving financial support mechanisms, and enhancing technology accessibility will be crucial for widespread adoption. Collaboration among researchers, policymakers, and farmers will be essential to promote sustainable horticultural systems in the face of climate change.

### 12. Conclusion

Climate-smart horticultural practices offer effective pathways to enhance crop resilience and improve resource use efficiency under changing climatic conditions. Adoption of improved crop varieties, efficient irrigation systems, protected cultivation, soil health management, integrated pest management, and precision technologies can significantly support sustainable horticultural production, successful implementation requires continued research, innovation, and supportive policy frameworks to overcome adoption barriers. Expanding farmer awareness, strengthening extension services, and promoting technology access will be essential to ensure large-scale adoption. Climate-smart horticulture ultimately contributes to long-term productivity, environmental sustainability, and global food and nutritional security, making it a crucial component of future agricultural development strategies.

### References

1. Singh, H. C. P. (2013). Adaptation and mitigation strategies for climate-resilient horticulture. In *Climate-resilient horticulture: Adaptation and mitigation strategies* (pp. 1-12). India: Springer India.
2. Adhikari, Prabhakar, et al. "System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: Experience with diverse crops in varying agroecologies." *International journal of agricultural sustainability* 16.1 (2018): 1-28.
3. Venkatramanan, V., & Shah, S. (2019). Climate smart agriculture technologies for environmental management: the intersection of sustainability, resilience, wellbeing and development. In *Sustainable green technologies for environmental management* (pp. 29-51). Singapore: Springer Singapore.
4. Scherr, S. J., Shames, S., & Friedman, R. (2012). From climate-smart agriculture to climate-smart landscapes. *Agriculture & Food Security*, 1(1), 12.
5. Diacono, M., Persiani, A., Fiore, A., Montemurro, F., & Canali, S. (2017). Agro-ecology for potential adaptation of horticultural systems to climate change: Agronomic and energetic performance evaluation. *Agronomy*, 7(2), 35.
6. Gil, J. D., Cohn, A. S., Duncan, J., Newton, P., & Vermeulen, S. (2017). The resilience of integrated agricultural systems to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, 8(4), e461.
7. Debray, V., Wezel, A., Lambert-Derkimba, A., Roesch, K., Lieblein, G., & Francis, C. A. (2019). Agroecological practices for climate change adaptation in semiarid and subhumid Africa. *Agroecology and Sustainable Food Systems*, 43(4), 429-456.
8. Bayu, T. (2020). Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability. *Cogent Environmental Science*, 6(1), 1823631.
9. Andrieu, Nadine, Bougouna Sogoba, R. Zougmore, Fanny Howland, O. Samake, Osana Bonilla-Findji, Miguel Lizarazo, Andreea Nowak, C. Dembele, and Caitlin Corner-Dolloff. "Prioritizing investments for climate-smart agriculture: Lessons learned from Mali." *Agricultural Systems* 154 (2017): 13-24.
10. Newton, A. C., Johnson, S. N., & Gregory, P. J. (2011). Implications of climate change for diseases, crop yields and food security. *Euphytica*, 179(1), 3-18.
11. Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: managing in the face of uncertainty. *Ecological applications*, 17(8), 2145-2151.
12. Basel, B., Goby, G., & Johnson, J. (2020). Community-based adaptation to climate change in villages of Western Province, Solomon Islands. *Marine Pollution Bulletin*, 156, 111266.
13. Hosen, N., Nakamura, H., & Hamzah, A. (2020). Adaptation to climate change: Does traditional ecological knowledge hold the key?. *Sustainability*, 12(2), 676.