



## Climate-Smart Horticulture: Growing Fruits, Vegetables, and Flowers in a Changing Climate

Amit Lohar<sup>1\*</sup>, Anamika Gurung<sup>2</sup>, Tanmoy Sarkar<sup>3</sup>, Adarsh Thapa<sup>4</sup>, Anant Tamang<sup>5</sup>

<sup>1</sup>Assistant Professor, Department of Horticulture, M S Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha-761211, India

<sup>2</sup>Assistant Professor, Department of Horticulture, Sikkim University, Tadong, Sikkim-737102, India

<sup>3</sup>Assistant Professor and Head, School of Agriculture, Swami Vivekananda University Telinipara, Barasat – Barrackpore Road, Kolkata – 700121, West Bengal, India

<sup>4</sup>Assistant Professor, Department of Horticulture, School of Agriculture, Seacom Skills University, West Bengal-731236, India

<sup>5</sup>Associate Professor, Department of Horticulture, M S Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha-761211, India

\*Corresponding author email ID: [amitflori350@gmail.com](mailto:amitflori350@gmail.com)

### ABSTRACT

Climate change is increasingly affecting the growth, yield and quality of fruits, vegetables and flowers through heat stress, drought, irregular rainfall and extreme weather events. **Climate-smart horticulture** offers practical solutions through resilient varieties, efficient irrigation, mulching, protected cultivation, improved soil management, crop diversification and digital technologies. These practices can improve resource-use efficiency, reduce climate-related risks and support stable production and farmer income. Integrating scientific innovations with locally suitable management practices is essential for developing a productive, resilient and sustainable horticulture sector.

**Keywords:** Climate Change, Climate-Smart Horticulture, Heat Stress, Resilient Varieties, Water Management, Sustainable Horticulture

Submitted: 18-09-2026

Accepted: 20-09-2026

Online: 26-09-2026

### 1. INTRODUCTION

Climate change is increasingly recognized as a major constraint to sustainable horticultural production because temperature, precipitation, atmospheric humidity and the frequency of extreme events directly influence crop phenology, physiology,

yield and quality (Malhotra, 2017; IPCC, 2022). Horticultural crops can be particularly sensitive because reproductive development, flowering, fruit set and marketable quality often occur within relatively narrow environmental ranges. Rising temperatures, drought, excessive rainfall and compound heat-

<https://doi.org/10.5281/zenodo.22974279>

© 2026 The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0).

NG Agriculture Insights, 2(5), 2026

moisture events can interact to increase production risks (Lesk *et al.*, 2022). Recent reviews have further emphasized that climate change can alter planting and harvesting periods and intensify multiple abiotic stresses in horticultural crops (Jatav *et al.*, 2023). In India, climate variability is especially important because horticultural production occurs across highly diverse agro-climatic regions and involves a large number of small and marginal producers. ICAR has therefore emphasized climate-resilient varieties, natural-resource management, crop diversification and location-specific adaptation as important components of climate-resilient agriculture (Chaudhari, 2023).

## 2. WHAT IS CLIMATE-SMART HORTICULTURE?

Climate-smart horticulture can be understood as the application of horticultural technologies and management practices that help crops withstand climatic stresses while maintaining productivity, quality and profitability.

Three broad principles form its foundation:

1. **Adaptation** – helping crops, farms and farmers cope with heat, drought, floods, irregular rainfall and other climatic stresses.
2. **Resource efficiency** – producing more from limited land, water, nutrients and energy.
3. **Environmental sustainability** – reducing unnecessary resource consumption and improving soil, biodiversity and carbon management.

The concept is particularly important for horticulture because fruits, vegetables and flowers are often high-value crops with specific temperature, moisture and nutritional requirements. FAO's Smart Farming approach similarly emphasizes protected cultivation, good horticultural practices, efficient resource management, quality planting material, market orientation and digital technologies.

## 3. CLIMATE CHANGE: A NEW CHALLENGE FOR HORTICULTURAL CROPS

Climate variability is becoming a production issue rather than simply a weather issue. The IPCC has documented increasing risks to agriculture from drought, floods and changes in rainfall patterns. For horticultural crops, the major climate-related challenges include:

- Rising temperature and heat waves
- Longer and more frequent dry periods
- Irregular monsoon and rainfall distribution

- Heavy rainfall and flash flooding
- Water scarcity
- Increased soil salinity in vulnerable regions
- Greater pressure from insects and diseases
- Reduced quality of fruits, vegetables and flowers
- Disturbance of flowering and fruit-setting processes
- Changes in crop duration and harvesting seasons

Indian agriculture is particularly exposed to climatic variability. ICAR has identified heat waves, rainfall variability, drought, waterlogging and other weather abnormalities as important threats and has emphasized stress-tolerant varieties together with natural-resource-management technologies. For horticulture, therefore, resilience must be built into the entire production system—from the selection of planting material to harvesting and post-harvest management.

## 4. HEAT STRESS: WHEN TEMPERATURE BECOMES A CROP THREAT

Temperature is one of the most important environmental factors controlling horticultural crop growth. Every crop has an optimum temperature range. When temperatures remain above this range for prolonged periods, physiological processes begin to change. High temperature can increase transpiration, accelerate water loss and disturb photosynthesis. In reproductive stages, heat stress can be particularly damaging because pollen viability, pollination, fertilization and fruit development may be affected.

### 4.1 Effects on fruit crops

Fruit crops can experience:

- Poor flowering
- Reduced fruit set
- Sunburn
- Fruit cracking
- Reduced fruit size
- Premature fruit drop
- Poor colour development
- Reduced firmness and shelf life

Crops requiring specific chilling conditions may also face problems when winters become warmer. Research on climate change and horticulture has highlighted concerns for crops whose flowering and productivity depend on appropriate temperature regimes.

#### 4.2 Effects on vegetables

Vegetable crops exposed to excessive heat may show:

- Reduced germination
- Weak seedlings
- Leaf scorching
- Blossom drop
- Poor fruit setting
- Small or misshapen fruits
- Reduced quality

Tomato, capsicum, cucumber and several other vegetables are particularly sensitive to combinations of high temperature and water stress during reproductive growth.

#### 4.3 Effects on flowers

Flower crops are equally vulnerable. Heat stress may reduce:

- Bud initiation
- Flower size
- Stem length
- Petal quality
- Flower colour
- Vase life
- Marketable flower yield

For crops such as rose, chrysanthemum, gerbera and orchids, maintaining a suitable microclimate can therefore be critical for commercial production.

### 5. PROTECTING PLANTS FROM HEAT

Climate-smart horticulture uses several methods to reduce heat exposure.

#### 5.1 Mulching

Organic residues, crop residues and suitable mulching materials can reduce soil temperature and evaporation. Mulch also helps conserve soil moisture and suppress weeds.

#### 5.2 Shade management

Shade nets can reduce excessive solar radiation and moderate the crop microclimate. The degree of shading should be selected according to crop requirements because excessive shade can reduce photosynthesis.

#### 5.3 Protected cultivation

Greenhouses, naturally ventilated polyhouses, shade-net houses and other protected structures can

help farmers manage temperature, radiation, rainfall and humidity. FAO identifies low-cost protected cultivation as an important tool for protecting horticultural crops from environmental stresses while improving resource efficiency.

#### 5.4 Canopy management

Proper pruning, training and plant spacing can improve air movement and light distribution. In fruit crops, appropriate canopy management can also reduce excessive exposure of fruits to direct sunlight.

#### 5.5 Adjusting planting dates

Changing sowing or planting dates can help avoid the most sensitive crop stages during periods of extreme temperature.

### 6. DROUGHT: PRODUCING MORE WITH LESS WATER

Water scarcity may become one of the most serious constraints for future horticulture. A crop may have sufficient annual rainfall but still experience water stress if rainfall arrives at the wrong time. The problem is therefore not only how much water is available, but also when, where and how efficiently it is used. FAO's climate-smart water-management approach emphasizes adaptation to changing freshwater availability and improving water-use efficiency.

#### 6.1 Drip Irrigation: Every Drop Counts

Drip irrigation delivers water directly or close to the root zone. Compared with uncontrolled surface irrigation, it can reduce unnecessary water losses and allow irrigation to be scheduled according to crop demand.

It is particularly useful for:

- Fruit orchards
- Vegetable crops
- Flower crops
- Protected cultivation
- Nursery production

Combining drip irrigation with fertigation can also improve the efficiency of nutrient application.

#### 6.2 Mulching: A Simple Climate-Smart Technology

One of the simplest climate-resilience practices is mulching. Mulches act as a protective layer between the soil and atmosphere. Depending on the material used, mulching can:

- Reduce evaporation

- Moderate soil temperature
- Suppress weeds
- Reduce soil erosion
- Improve soil organic matter when organic materials are used
- Reduce splashing of soil-borne pathogens
- Improve moisture conservation

Organic mulches such as straw, leaves, grass residues and composted materials can contribute to soil biological activity as they decompose. Plastic mulches may also provide effective moisture and weed management, but their use should be accompanied by responsible collection and disposal or recycling practices.

## 7. RAINFALL: TOO LITTLE, TOO MUCH AND AT THE WRONG TIME

Climate change creates a paradox for horticulture: some farms face water shortages while others experience destructive rainfall.

Heavy rainfall can cause:

- Waterlogging
- Root damage
- Nutrient leaching
- Soil erosion
- Fruit cracking
- Flower damage
- Fungal and bacterial diseases

A climate-smart farm therefore needs both water-saving systems and water-drainage systems.

### 7.1 Rainwater Harvesting

Rainwater harvesting can convert intense rainfall into a valuable resource. Farm ponds, storage tanks, check dams and other suitable structures can collect runoff for later use. Stored rainwater can provide supplemental irrigation during dry spells and reduce dependence on groundwater. ICAR's climate-resilient technology programmes include water harvesting, groundwater recharge and micro-irrigation as components of climate adaptation in vulnerable areas.

### 7.2 Building Resilient Soils

A climate-smart horticultural farm begins with healthy soil. Healthy soils generally provide better conditions for root growth, water retention, nutrient availability and biological activity. Increasing soil organic matter through compost, farmyard manure,

crop residues and other suitable organic inputs can support soil structure and moisture management.

Important soil-management practices include:

- Regular addition of organic matter
- Compost and well-decomposed farmyard manure
- Cover crops where appropriate
- Reduced soil disturbance where suitable
- Prevention of erosion
- Proper drainage
- Soil testing and balanced fertilization
- Avoidance of excessive fertilizer application

Soil should not be considered merely a medium for holding plants. It is a living component of the horticultural production system.

## 8. RESILIENT VARIETIES: THE CROP'S FIRST LINE OF DEFENCE

One of the most powerful climate-smart strategies is choosing planting material adapted to local climatic conditions. Modern breeding programme increasingly focus on traits such as:

- Heat tolerance
- Drought tolerance
- Waterlogging tolerance
- Salinity tolerance
- Pest and disease resistance
- Shorter crop duration
- Stable yield under environmental stress
- Better fruit and flower quality under variable conditions

ICAR has reported the development and identification of crop varieties possessing tolerance to drought, heat, salinity, waterlogging and other stresses. Recent Indian horticultural research has also highlighted the development of climate-resilient fruit varieties designed to maintain productivity and quality under changing environmental conditions. The future of horticulture will therefore depend not only on high-yielding varieties, but increasingly on high-yielding and stress-resilient varieties.

## 9. CLIMATE-SMART FRUIT PRODUCTION

Fruit orchards are long-term investments. A tree planted today may remain productive for decades. This makes climate planning especially important. Selecting the right site. Before establishing an orchard, farmers should evaluate:

- Temperature
- Rainfall pattern

- Soil type
- Water availability
- Drainage
- Frost or heat risk
- Wind exposure
- Market access

### 9.1 Rootstocks Matter

In several fruit crops, appropriate rootstocks can influence tolerance to drought, salinity, soil problems and other environmental stresses. Rootstock selection should therefore become part of climate-smart orchard planning.

### 9.2 Orchard Floor Management

Maintaining suitable ground cover, using organic mulches and preventing excessive soil exposure can improve soil moisture management and reduce erosion.

### 9.3 Microclimate Management

Windbreaks, shade management, canopy architecture and irrigation scheduling can help reduce environmental stress. Climate-smart orchard management is essentially about designing the orchard so that it can continue functioning even when weather conditions are less predictable. FAO has developed climate-smart orchard approaches that emphasize water-efficient technologies and sustainable production systems.

## 10. CLIMATE-SMART VEGETABLE PRODUCTION

Vegetables are short-duration crops, which creates an advantage: farmers can adjust crop calendars relatively quickly. Climate-smart vegetable production can include:

- Heat-tolerant cultivars
- Short-duration varieties
- Raised beds
- Drip irrigation
- Mulching
- Protected cultivation
- Shade nets
- Rain shelters
- Crop diversification
- Nursery management under controlled conditions

Raised beds are especially useful in areas prone to heavy rainfall because they improve drainage around the root zone. Protected cultivation can provide another layer of protection. In a controlled or semi-

controlled environment, temperature, humidity, irrigation and fertigation can be managed more precisely. FAO's Smart Farming programme specifically identifies protected cultivation and environmental optimization as tools for improving horticultural resource efficiency.

## 11. CLIMATE-SMART FLOWER PRODUCTION

Flowers are often treated as luxury crops, but floriculture is an important source of employment, entrepreneurship and income. Climate change can influence flowering time, flower quality, stem length, pigmentation and post-harvest life. This makes microclimate management particularly important in commercial floriculture. Important strategies include:

- Protected cultivation
- Shade management
- Efficient irrigation
- Proper ventilation
- Root-zone moisture management
- Stress-tolerant planting material
- Balanced nutrition
- Integrated pest management
- Efficient post-harvest cooling

For high-value crops such as orchids, gerbera, rose and anthurium, protected cultivation can provide greater environmental control than open-field production. However, protected cultivation itself should be climate-smart. Poorly ventilated structures can become excessively hot, while excessive irrigation and humidity can increase disease pressure. Structure design must therefore be matched to the local climate and crop.

## 12. DIGITAL TECHNOLOGY: FROM GUESSWORK TO SMART DECISIONS

The climate-smart horticultural farm of the future will increasingly use data. Digital tools can help farmers monitor:

- Soil moisture
- Temperature
- Relative humidity
- Rainfall
- Irrigation requirements
- Crop growth
- Pest and disease risk
- Weather forecasts
- Market conditions

Sensors connected to irrigation systems can help apply water according to actual crop requirements rather than following a fixed schedule. FAO identifies digital

technologies as an important component of Smart Farming because they can support early identification of environmental stress and improve water and energy management. Artificial intelligence and machine learning may further support horticulture through weather prediction, disease recognition, irrigation scheduling, crop forecasting and precision nutrient management. The important point is that technology should support farmer decisions rather than replace practical knowledge.

### 13. INTEGRATED PEST AND DISEASE MANAGEMENT IN A CHANGING CLIMATE

Climate change can modify pest and disease patterns by altering temperature, humidity and crop growth conditions. A warmer environment may create favourable conditions for certain pests, while irregular rainfall and prolonged humidity can increase disease risks. Climate-smart plant protection should therefore emphasize:

- Regular crop scouting
- Pest monitoring
- Resistant varieties
- Biological control
- Sanitation
- Proper ventilation
- Balanced nutrition
- Need-based pesticide application
- Integrated pest management

Healthy plants with balanced nutrition and appropriate water management are often better positioned to tolerate environmental stress.

### 14. DIVERSIFICATION: NEVER DEPEND ON A SINGLE CROP

Climate uncertainty increases the risk of crop failure. Diversification can reduce this risk.

Farmers can diversify through:

- Multiple fruit crops
- Vegetables with different maturity periods
- Flower crops
- Nursery enterprises
- Protected cultivation
- Medicinal and aromatic plants
- Value-added horticultural products

Diversification can provide both biological resilience and economic resilience. If one crop is damaged by excessive rain, another crop may survive. If market prices for one commodity decline, income from another enterprise may provide a financial buffer.

### 15. CLIMATE-SMART HORTICULTURE IS ALSO ABOUT PROFIT

Climate resilience should not be viewed only as an environmental concept. For farmers, the most important question is: "Will this technology help me reduce risk and improve income?"

A climate-smart practice becomes meaningful when it can improve one or more of the following:

- Yield stability
- Crop quality
- Water productivity
- Input efficiency
- Labour efficiency
- Market value
- Production season
- Post-harvest life
- Farm income

FAO's Smart Farming framework explicitly links resource-efficient horticulture with improved quality, yields, income generation and business opportunities.

### 16. A CLIMATE-SMART HORTICULTURE MODEL FOR INDIA

A practical climate-smart horticultural farm can be built around several interconnected components:

**Climate information → resilient variety → healthy soil → efficient irrigation → protected cultivation where needed → integrated crop management → digital monitoring → post-harvest management → market linkage**

None of these technologies works in isolation. For example, installing drip irrigation without improving soil management may not achieve the desired result. Similarly, selecting a drought-tolerant variety without adequate nutrient management may limit yield. Climate resilience is therefore best achieved through an integrated production system.

### 17. CONCLUSION

Climate change is transforming the environment in which horticultural crops are grown. Heat stress, drought, irregular rainfall, floods and water scarcity are no longer distant possibilities; they are production realities in many farming regions. But horticulture also possesses enormous potential to adapt. Resilient varieties, efficient irrigation, rainwater harvesting, mulching, healthy soils, protected cultivation, precision farming, digital technologies and

crop diversification can collectively create stronger and more sustainable production systems. Research and development of stress-resilient planting material will remain especially important, while farm-level management will determine how effectively these genetic improvements are translated into productivity and income. The future of horticulture should therefore not be defined by simply growing more crops. It should be defined by growing intelligently, conserving resources and preparing for uncertainty. Climate-smart horticulture offers a pathway toward that future—one in which fruits, vegetables and flowers can continue to nourish people, support farmers and generate livelihoods even as the climate changes.

## REFERENCES

- Chandra, V. C., Pati, K., Anil, S. R., & Sahoo, M. R. (2025). Climate-resilient and biofortified tuber crop varieties. *Indian Horticulture*, 70(6), 11–16.
- Chaudhari, S. K. (2023). Climate resilient farming: India initiatives. *Indian Farming*.
- Damodaran, T., Yadav, A., Singh, A., Singh, S. K., Dayal, V., & Kushwaha, A. K. (2026). Climate resilient and nutri-smart fruit varieties. *Indian Horticulture*, 71(2), 5–8.
- FAO. Climate-smart agriculture and Smart Farming resources. Food and Agriculture Organization of the United Nations.
- IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University Press.
- Singh, M., Rai, N., Kumar, R., Tiwari, S. K., Bahadur, A., & Rai, A. B. (2019). Climate resilience initiatives at IIVR, Varanasi. *Indian Horticulture*, 61(1).
- Jatav, A. L., et al. (2023). Comprehensive review: Effects of climate change and greenhouse gases emission relevance to environmental stress on horticultural crops and management. *Journal of Environmental Management*, 344, 119978.
- Jena, C., & Pramanik, K. (2025). Impact of Climate Change on Fruit Crops: Challenges, Opportunities, and Adaptation Strategies. *Next Gen Multidisciplinary Research*, 1(1), 8–12. <https://doi.org/10.66132/mr010102>
- Lesk, C., Anderson, W., Rigden, A., Coast, O., Jägermeyr, J., McDermid, S., Davis, K. F., & Konar, M. (2022). Compound heat and moisture extreme impacts on global crop yields under climate change. *Nature Reviews Earth & Environment*, 3, 872–889.
- Malhotra, S. K. (2017). Horticultural crops and climate change: A review. *The Indian Journal of Agricultural Sciences*, 87(1).
- Rai, N., Bahadur, A., Singh, P. M., Krishna, R., Singh, A. K., Mishra, L. K., Kumar, S., Singh, A. K., & Behera, T. K. (2023). Climate resilience initiatives at Indian Institute of Vegetable Research. *Indian Horticulture*, 68(2), 15–19.
- Sarkar, T., Sengupta, S., Kundu, S., Lohar, A., Gurung, N., Saglam, K., Gunsola, D., Datta, S.K., Mitra, D., Firdu, Z. & Assefa, A. (2026). Harnessing plant growth regulators and biostimulants for resilient and productive agriculture. *Discover Sustainability*.