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Protected Cultivation: The Future of Sustainable Horticulture

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INTRODUCTION

Horticulture is essential for producing nutritious fruits, vegetables, flowers and ornamental plants for human consumption and economic development. However, there are a number of difficulties facing modern agriculture including soil degradation, water scarcity and climate change and rising demand for high quality produce. Farmers and researchers are using sustainable protected agriculture technologies which minimize environmental effect while enabling crops to thrive in controlled environments to address these obstacles (Mehra et al. 2026). Protected cultivation practices are essentially cropping techniques where the microclimate surrounding the crop is partially or entirely managed according to the specific requirements of various plant developing phases (Ahmadzai et al. 2021). Growing high values crops such as fruits, vegetables and flowers under protected conditions with little to no reliance on constantly shifting environmental parameters is expanding rapidly worldwide particularly in Europe, the United States and Asia (Pathak et al. 2023).

Protected farming is critical particularly in the appearance of climate change, limited land resources and market globalization (Sharma et al. 2024). It has emerged as the most effective technology particularly for high value crops for increasing productivity, quality and returns (Chavan et al. 2022). This is accomplished by utilizing advanced structures like polyhouses, net houses, screen houses and tunnels in addition to protective features like windbreaks, irrigation and mulching. By controlling the environment and enabling more effective use of inputs like fertilizers, herbicides and water this technique reduces the effects of climate fluctuation and is therefore more sustainable than conventional open field farming (Banjare et al. 2024). While maintaining high levels of production and profitably, sustainability in protected cultivation seeks to reserve natural resources reduce the need of chemical inputs and improve energy efficiency. The idea of controlled environment cultivation is not new people have long understood that altering environmental conditions can enhance both quality and productivity (Mitchell, 2022).

2. Types of protected structures

2.1. Net Houses

Net houses are simple ventilated structures that provide cheap and basic environmental control. They are better suited for regions with less rainfall and are usually built with pre galvanized iron pipes, tubular frames or locally accessible materials like wood and bamboo (Jayasurya et al. 2021). These structures covered with mesh nets, shield crops from hail, insects, birds and sunlight. Fruit, vegetables, floriculture farming and nursery raising all make extensive use of net structures.

2.2. Polyhouses

Polyhouses are comparatively advanced protected structures are typically naturally ventilated and simpler than fully automated greenhouses (Singh et al. 2021). Covered with UV stabilized polyethylene sheets they offer a regulated climate that is ideal for growing exotic and valuable foods, flowers and high-quality planting material. Under ideal agroclimatic circumstances polyhouses are particularly helpful for off-season production (Ummyiah et al. 2017).

2.3. Poly tunnels

Poly tunnels are cheap, semi-circular constructions covered in sheets of polyethylene. They produce a favourable microclimate with comparatively higher temperatures and humidity which makes them excellent for off-season cultivation and early seedling production. This helps achieve early harvests and greater market returns. In addition to prolomging the growth season, planting material acclimatization and plant quarantine, these structures offer some degree of climate control. They also protect crops from severe weather including hail, high temperature and strong winds (Rajiv and Kumari, 2023).

3. Sustainable technologies in protected cultivation

3.1. Renewable energy source

In order to run devices like cooling pads, fans, sensors, heaters and automated ventilation, modern protected agriculture systems depend more and more on renewable energy sources like solar and wind power. This change lowers operating expenses and lessens reliance on conventional energy (Sharma et al. 2024).

3.2. Precision agriculture technologies

In protected cultivation, the use of precision farming technologies has significantly increased productivity and decreased input costs (Kumar et al. 2021). Accurate agricultural monitoring and management is made possible by technologies like sensors, drones, artificial intelligence (AI), robotics and the Internet of Things (IoT) which maximizes productivity and growth (Kale et al. 2024).

3.3. Spectral management

By allowing for control over light intensity and quality, the use of LED lighting has transformed protected horticulture. To control plant growth, flowering, colour development and nutritional quality growers can modify the red, blue, far-red and UV light spectra (Neo et al. 2022). Energy saving elements like dimming and timed operation are also incorporated into advanced lighting systems (Lee et al. 2021)

3.4. Automation, Sensors and Data – driven decisions (IoT and AI)

Automation and sensors networks play a major role in modern protected horticulture. Important variables including temperature, humidity, CO2 levels, soil moisture, nutrient status and light intensity are all monitored by sensors (Sethi 2025). These inputs are connected to automated systems that regulate lighting, ventilation, fertigation and irrigation. By forecasting disease infestation, maximizing nutrient availability and preserving optimal microclimate conditions improve decision making (Sivagami et al. 2021). Additionally, cloud-based technologies enable remote monitoring and control via smartphones, increasing productivity and lowering labour costs (Basu and Narayan, 2025).

3.5. Drip irrigation

In protected horticulture, drip irrigation is a very effective watering technique. A system of pipes and emitters transports water straight to

the plants root zone. When compared to conventional irrigation systems, this technique drastically lowers water waste. By ensuring that plants receive precisely the right amount of water, drip irrigation improves water use efficiency and tops soil erosion.

3.6. Fertigation technology

The process of using irrigation systems to apply fertilizers is known as fertigation. Fertilizers are dissolved in water and applied directly to plant roots by increasing the efficiency of nutrient utilization and decreases fertilizer waste.

Figure 1

Advantages

- Increased crop yield
- Year-round cultivation
- Efficient resource utilization
- Reduced pest and disease pressure
- Improved crop quality
- Environmentally sustainability

Disadvantages

- High initial investments
- Technical knowledge requirement
- Energy consumption

CONCLUSION

Protected farming has developed into advanced, technologically complex production systems from basic protective structures. Its breadth and efficiency have been greatly expanded by the combination of automation, sensor networks, renewable energy and precision agriculture. Sustainability and profitability are being improved by innovations including integrated pest and disease management, enhanced microclimate control and spectral light management. Additionally, modern techniques like hydroponics, aeroponics and vertical farming have improved resource and space efficiency. By combining engineering innovations with horticultural practices, protected cultivation is becoming a vital component of climate smart agriculture promoting resilient horticultural systems, superior crop yield and global food security.

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