

Protected Agriculture and Sustainable Resource use for Future Generations

Dr. Debabrata Das¹, Dr. Tapan Das² and Dr. Pampi Ghosh³

¹Associate Professor, Department of Botany, GGDC Lalgarh, Jhargram, W.B.

²Dr. Tapan Das, Assistant Professor, Department of Agriculture, Midnapore City College, Paschim Medinipur, W.B.

³ Associate Professor, Department of Botany, Seva Bharati Mahavidyalaya, Kapgari, Jhargram, W.B.

Abstract

Protected means any how man-made closed system *i.e.* apart from any kind of barrier for non-hindering the normal growth and development of crops. The agriculture in field faces many problems *i.e.* from natural calamities, pathogen attack and climatic changes that are not congenial to specific crop for ultimate production. High temperature, low light intensity, frosts, hails and snow fall including heavy raining and storm, water logging situation and saline water flow always affect the normal life of the plants and ultimately hampers the growth and development of crop plants in the field. So, to face the problems, scientists and technologists develop many things to combat the actual problems in field as well as in protected places for better understanding. Therefore, protected cultivation in protected field as well as in protected gardens or sites are important ideas to cultivate crops for better production and quality yield without any risk during cultivation or after harvesting. It highlights the cost-effective way as well as quality production of crops using different ways. In the present article authors are trying to discuss a general overview in connection with the protected agriculture and sustainable yield for future generations.

Keywords: Agriculture, traditional cultivation, protected sites, yield, crops and management, tools in modern age, applications.

Introduction

Agriculture faces many problems due to change of environment. Natural calamities and different disasters make the system fragile and production or yield faces great loss. Critically the situation trends to the high negative result and cultivation practice gradually decreasing. To protect the crops and protect the loss of yield farmers need to use smart agriculture in protected situation for more economic yield over time. Off-season production, protection from pests and from natural disaster, scientists recommend many ideas through protected cultivation using IoT ⁽¹⁻⁸⁾. So, use of high yielding, and disease resistant varieties even the use of biofertilizers and biopesticides make the cultivation more convenient for better growth and development in almost all cases under protected sites. Keeping the view in mind the present article has been presented.

Introduction to Agriculture:

Agriculture is mainly the practice of cultivating plants, raising animals, and managing natural resources to produce food, fodder, fiber, and other products for human and animal use. It's a vital sector that provides us with essentials like food, clothing, and even biofuels. The agriculture and modern agriculture are different as the modern technology imposed on agriculture for better understanding.

Understanding Protected Cultivation:

It is a technique that creating a controlled environment for plants to thrive, regardless of external weather conditions. Think greenhouses, polyhouses, or even vertical farms. Protected cultivation involves growing plants in a controlled environment, like a greenhouse or polyhouse, to optimize temperature, humidity,

and light. This helps improve crop yields, quality, and growth rates.

Protected cultivation in Indian traditional system:

Protected cultivation in India's traditional system is rooted in innovative practices like different practices. These are –

Bamboo structures: Using bamboo to create natural greenhouses for crop protection.

Mulching: Applying organic mulch to retain moisture and regulate soil temperature.

Panchagavya: Using a mixture of cow products to boost plant growth and immunity. Some traditional Indian practices also involve seasonal crop planning *i.e.* planting of crops according to seasonal changes.

Crop diversification: Growing multiple crops together for better pest management and multiple use in the same land.

Protected cultivation using technology-based ideas:

There are various techno-based approach for protected agriculture as well as gardening. These are-

Smart Greenhouses: IoT sensors monitor temperature, humidity, and light, adjusting conditions automatically.

Hydroponics and Aeroponics: Soilless farming with precise nutrient delivery.

Vertical Farming: Multi-layered indoor farms using LED lights and controlled environments.

AI-driven Climate Control: Predictive analytics optimize temperature, humidity, and light for specific crops.

Drones and Sensors: Monitor crop health, detect pests, and optimize resource use. These tech advancements boost yields, reduce water usage, and enable year-round production.

Specific Technologies in Protected Cultivation

LED Grow Lights: Customizable spectrum and intensity for optimal plant growth. Climate Control Systems: Automated temperature, humidity, and CO2 management.

Hydroponic Systems: Nutrient-rich water solutions for soilless farming.

IoT Sensors: Real-time monitoring of temperature, humidity, light, and soil moisture. Drones and Imaging: Crop health monitoring and pest detection.

Vertical Farming Systems: Space-efficient, multi-layered farming using LED lights.

Crops Suitable for Protected Cultivation:

Crops that thrive in protected cultivation:

Vegetables: Tomatoes, cucumbers, bell peppers, lettuce, and leafy greens. Fruits: Strawberries, blueberries, and grapes. Flowers: Orchids, roses, and carnations. Herbs: Basil, mint, and cilantro. These crops benefit from controlled environments, enabling year-round production and improved yields.

Sustainable Practices in Protected Cultivation:

Water conservation: Drip irrigation, rainwater harvesting, and water recycling.

Energy efficiency: LED lights, solar power, and energy-efficient climate control.

Organic farming: Using natural pest control and organic fertilizers.

Crop rotation and diversification: Breaking disease cycles and promoting biodiversity.

Waste reduction: Composting and repurposing agricultural waste.

These practices reduce environmental impact, improve crop quality, and boost yields.

Future Trends in Agriculture and Protected Cultivation:

The future of agriculture is looking bright, with several trends shaping the industry in the future. Some key developments are-

Bioengineering: Genetic engineering and biotechnology are creating more resilient and nutritious crops, with improved drought and pest resistance.

Agricultural Robotics & Automation: Autonomous machinery and drones are enhancing efficiency, reducing labor, and improving crop yields.

Regenerative Agriculture: Practices like no-till farming, cover cropping, and crop rotation are promoting soil health, biodiversity, and carbon sequestration.

Indoor Farming: Vertical farming, hydroponics, and aeroponics are becoming increasingly popular, allowing for year-round production and reduced water usage.

Predictive Agriculture: AI-powered analytics and machine learning are helping farmers make data-driven decisions, predicting crop yields, and detecting diseases.

Carbon Farming: Farmers are being incentivized to adopt sustainable practices, like agroforestry and conservation tillage, to sequester carbon.

Digital Twins: Virtual replicas of farms are enabling real-time monitoring, improved resource management, and optimized crop growth.

Advanced Biofertilizers: Nano-biofertilizers and microbial solutions are reducing chemical fertilizer usage and promoting soil health

Trends in agriculture for protected gardening:

Now a day many modern trends coming to get benefits in protected gardening. These are-

AI-Driven Environmental Controls: Automated systems adjust temperature, humidity, and light for optimal plant growth, reducing resource waste and increasing yields.

Hyper-Efficient Hydroponics: Closed-loop systems recycle water, saving up to 95% compared to traditional farming.

Smart Greenhouses: IoT sensors and AI analytics enable real-time monitoring and precise climate control.

Vertical Farming: Multi-layered indoor farms maximize space, reduce water usage, and increase crop yields.

LED Grow Lights: Energy-efficient, customizable lighting optimizes plant growth and reduces energy costs.

It also involved in the process of rapid utilization of natural resources through the techniques. These are-

Water Conservation: Drip irrigation and rainwater harvesting reduce water waste.

Renewable Energy: Solar-powered greenhouses reduce electricity costs and improve sustainability.

Organic Farming: Natural pest control and organic fertilizers promote eco-friendly practices

Basic of agriculture and types:

The term Agriculture originates from the Latin words "ager" (soil) and "culture" (cultivation), highlighting its focus on cultivating the land. Agriculture is the practice of cultivating plants and rearing animals to produce food and other useful products. It encompasses a wide range of activities, including crop production, animal husbandry, and various related industries.

- Subsistence farming meets local needs; commercial farming focuses on profit through large-scale production and distribution.
- Agriculture is the backbone of many economies, providing livelihoods, ensuring food security, and driving economic growth in rural areas.
- Agriculture is the cultivation of plants and animals to provide food, fibre, medicinal plants and other products used to sustain and enhance human life.
- Inter-cropping and fate of agriculture in future.

Inter-cropping is a game-changer for the future of agriculture. It is a practice of growing two or more crops simultaneously in the same field, offering numerous benefits like improved resource use efficiency, increased aggregate yields, enhanced soil health, and better pest and disease management.

Benefits of inter-cropping:

Increased Crop Yields: Inter-cropping can boost yields by 15-30% while decreasing pest populations.

Improved Soil Health: It enhances soil fertility, structure, and water retention, reducing erosion and nutrient runoff.

Climate Resilience: Inter-cropping helps farmers adapt to climate change by promoting biodiversity and reducing chemical inputs.

Economic Benefits: It can increase farmers' income and reduce dependence on synthetic fertilizers.

Future perspectives: the future of agriculture looks promising with inter-cropping and other sustainable practices. Some trends shaping the industry include-

Precision Agriculture: Using technology like drones, AI, and IoT sensors to optimize farming practices.

Regenerative Agriculture: Focusing on soil health, biodiversity, and ecosystem services.

Climate-Resilient Crops: Developing crops that can withstand extreme weather conditions.

Digital Farming: Leveraging data analytics and digital tools to improve crop management and decision-making

History of agriculture:

- Agriculture in the past: The transition from hunter-gatherer societies to settled agriculture occurred about 10,000 years ago, marking a profound shift in human civilization.
- Agricultural revolution: Major advancements in agricultural technology, such as the plough and irrigation systems, increased productivity and supported growing populations.
- Modern agriculture: Modern agriculture has changed rapidly with mechanization, synthetic fertilizers, pesticides, and genetic engineering.

Modern agriculture and challenges:

- **Environmental Impact:** Modern agriculture causes soil degradation, water pollution from fertilizer runoff, reduces biodiversity, and leads to greenhouse gas emissions.
- **Climate Change:** Changing temperatures and rainfall patterns make it harder to grow crops; extreme weather events can destroy harvests and threaten food supplies.
- **Food security:** Food insecurity occurs when households cannot access enough safe and nutritious food; population growth, poverty, and rising food prices exacerbate the issue.

Protected agriculture:

- **Definition and scope:** Protected cultivation is a method of crop production that uses structures to modify the natural environment for enhanced plant growth.
- **Objectives:** Primary objectives are to extend growing seasons, improve yields, protect plants from pests and diseases, and optimize resource use.
- **Types:**

Protected structures and its management:

- **Greenhouses:** Greenhouses (Fig. 1-6) are enclosed structures that provide complete environmental control; suitable for growing a wide range of crops year-round.

TYPES OF GREENHOUSES

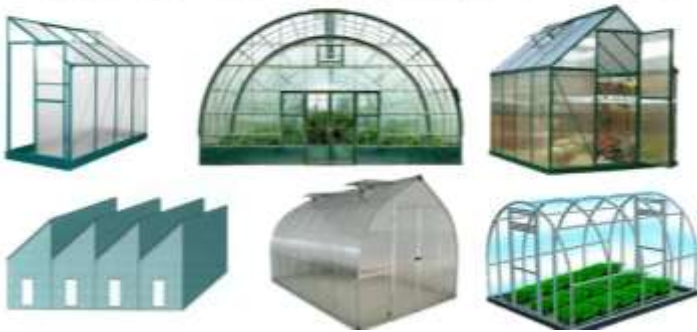


Fig. 1-6 Different Green houses

Shade houses, and tunnels:

Shade houses (Fig. 7) reduce light intensity and temperature, protecting plants from sun damage; these houses are essential for leafy greens and sensitive plants.

Tunnels (Fig. 8) are simple, low-cost structures that extend growing seasons and protect crops from weather; commonly used for vegetables and fruits.



Fig. 7 Shade house



Fig. 8 Tunnel

Benefits of Protected agriculture:

- Increase in crop yield: Protected cultivation can significantly increase yield per unit area compared to open field production by optimizing growing conditions.
- Crop quality and quantity improvement: Controlling environmental factors results in better-quality produce in terms of size, color, taste, and nutritional value; thus, it ensures higher market prices.
- Efficient resource use: Precision irrigation, fertilization, and climate control reduces water and nutrient waste, maximizes input efficiency.

Technology involved in protected agriculture:

- Heating and cooling system: Heating systems maintain optimal temperatures in cold weather; cooling systems prevent overheating during hot periods.
- Ventilation: Ventilation systems help regulate temperature and humidity while aiding in air circulation, which further reduces disease risks.
- Lighting: Supplemental lighting extends growing seasons and improves plant growth; LED and high-pressure sodium lamps can be used based on crop needs.

Irrigation and fertigation:

- Drip Irrigation: Drip irrigation uses narrow tubing to deliver water directly to the root zone which reduces water waste and increases water use efficiency.
- Fertigation: Fertigation is the practice of delivering dissolved fertilizers through irrigation systems; this helps in precise nutrient management and higher yields.
- Hydroponics and Aeroponics: Hydroponics grows plants without soil using nutrient-rich water solutions; aeroponics suspends roots in air and sprays them with nutrient solutions.

Monitoring and automation:

- Sensors: Sensors monitor environmental conditions (temperature, humidity, light) and plant health to optimize growing conditions.
- Automation: Automated systems control irrigation, ventilation, and lighting which reduce labor costs, ensure consistent optimal environments.

- **Data Analysis:** Data analysis tools help growers analyze trends, predict potential problems, and make informed decisions to improve crop production.

Suitable crops in suitable Environment:

Vegetable:

Tomatoes thrive in controlled environments; growers get higher yields and better-quality fruits.

Cucumbers in protected cultivation get consistent moisture and temperature, reduced pest and disease pressure, and better productivity.

Peppers benefit from warmth and protection from extreme weather to extend the growing season and improve fruit quality. Some of the high yielding varieties are-Brinjal (egg plants): high yielding F1 hybrids i.e. Arka Navneet, Pusa Anmol, Pus hybrid-5/6/9, Kashi Utsav, Kashi Modak, Malyco (MHB-1), Nishant and DBL-175 (IARI). Pusa Anmol is a cross between Pusa Purple long x Hyderpur. These are raised to resist the attack by shoot and fruit borer, off-season production and for the development of parthenocarpic fruits. Nethouse, polyhouse and tunnels are commonly used as protected place for brinjal cultivation. Placement of seedlings on coco peat, parlite and vermiculite in the ration 3:1:1 may be used. Spacing for the same is 90 x 60 x 75 cm. for mulching back plastic of 25 micron may be used. Net used as 40-50 mesh insect protected king may be used. Major pest for the brinjal is *Leucinodes arboralis*.

Tomato cultivation in polyhouse or in green house highlights the production of about 6-8 kg/square meter. It is temperature and humidity controlled of-season cultivation for better yield. In our Northeast hill region cultivars used as Avinash, Naveen and Rakshita. Drip irrigation is recommended. ICAR –IIVR used to protect from late blight, powdery mildew and white flies attack

including spiders. Protected place must be created by insect-proof net or and yellow sticky straps to control the major attack by pests.

Cucumber cultivation highlights the use of gynoecious hybrid that needs no pollination. Other cultivars used are Fadia F1, Nagene F1, Lucro F1, Kiran, Gypsy, RS 2833, Alamire, Multi star, Hilton. Pus Parthenocarpic cucumber -6 (DPaC-6), Pusa Sanyog (1st Indian gynoecious hybrid), Pusa Long Green (DC-83), K-75, Pant Khira-1 and Heera are also used for quality production.

By and large people use summer squash for large scale production in polyhouse. It is called Zucchini and scientifically called *Cucurbita pepo* var. *cylindrica*. Some of the cultivars used for Zucchini are Black beauty, Raven, Green raven, Orelia F1 and Cora. Yellow kind are Soleil and Gold rush. Round types are One ball F1 and Tondo de Toscana.

Fruits:

Strawberries yield earlier harvests and consistently high-quality fruits, protected from weather and pests. Some of the protected plasticulture cultivars are Chandler, Camarosa, Sweet Charlie (short day variety), winter dawn (resistant to anthracnose and botrytis rot), selva, Fern (Day neutral), Pajora, Sarom and Ireal.

Berries (raspberries, blueberries) in protected environments can be grown out of season, which increases market value and yield.

Grapes are shielded against frost, hail, and pests, with improved fruit quality and yield stability. Some grapes varieties are-

Thompson Seedless: A popular variety for raisins and fresh consumption.

Flame Seedless: Sweet and crunchy, great for fresh eating.

Sultana: Used for raisins, wine, and fresh consumption.

Cabernet Sauvignon: A popular wine grape variety.

Chardonnay: A versatile wine grape for white wines.

Flowers:

Roses obtain ideal climate control, which improves the quality and quantity of blooms for the cut flower market. Some of them are-

Hybrid Tea Roses: These premium varieties produce one large flower per stem, ideal for high-end bouquets and gifts. Examples include Cardinal, Carola, and France.

Floribunda Roses: These produce clusters of smaller flowers on each stem, offering higher yield per plant. They're great for beginners and adapt well to open-field cultivation.

Dutch Roses: Known for their consistent quality, vase life, and strong demand in export markets. Popular varieties include Avalanche, Top Secret, Gold Strike, and Jumelia.

Miniature Roses: Perfect for small spaces, these compact roses are great for pots and containers.

Grandiflora Roses: A cross between Hybrid Tea and Floribunda roses, offering large flowers and high yields. Examples include Queen Elizabeth and Komsomolskiy Light. Some other notable varieties include-Skarlet Gem: A compact shrub with orange-red miniature cup petals.

Beauty Secret: A hybrid variety with excellent disease resistance and beautiful double-headed cup petals.

Baccara: A hybrid tea rose with compact shrubs and dark red, cup-shaped flowers.

Niccolo Paganini: A Floribunda rose with dark red buds and a mild to strong scent.

Orchids require high humidity and controlled temperatures, consistent flower production, and premium pricing in the market.

Orchids are a popular choice for protected gardening, and here are some stunning cultivars.

Phalaenopsis: One of the most common and easiest-to-grow orchids, with beautiful, long-lasting flowers.

Dendrobium: A diverse genus with thousands of species, offering a range of colors and flower shapes.

Oncidium: Known for their vibrant, dancing-like flowers, these orchids are perfect for adding a pop of color.

Cattleya: A classic orchid genus with large, fragrant flowers in a variety of colors.

Vanda: These orchids are known for their striking, long-lasting flowers and are often grown in baskets. Some notable cultivars include: Phalaenopsis 'Sogo Yukidian': A beautiful, compact variety with white flowers and pink stripes.

Dendrobium 'Burana Jade': A stunning variety with green and white flowers.

Oncidium 'Sharry Baby': A fragrant, compact orchid with vibrant pink and white flowers.

Cattleya 'Bob Betts': A classic variety with large, fragrant flowers in shades of pink and white.

Vanda 'Pachara Delight': A stunning variety with vibrant, long-lasting flowers in shades of pink and blue. These orchid cultivars thrive in protected environments with proper care, offering breathtaking blooms and elegance

Gladi (*Gladiolus grandiflorus*) requires moderately humid cold temperature for better growth and yield. Some of the cultivars are white prosperity, Nova-lux, Eurovision, Peter Pears, Red beauty, Sapna, yellow (Nova Lux), Red/dark (Red beauty). Other varieties

used are Eurovian Eurovision, American Beauty, Peter Pears and so on. Indian hybrids are famous for gladiolus. These are Punjab Glance, Punjab Flanu, Pusa Mannohak, Pus Red Valentine, Pus Vidushi, Mayur and Suchitra.

Other ornamentals gain advantages of regulated conditions, resulting in healthier plants and extended marketability

Sustainable agriculture in protected condition:

- Water management: Water recycling systems collect and reuse irrigation runoff, which conserves water and reduces nutrient pollution.
- Rain water harvesting: Rainwater harvesting provides a sustainable water source, decreasing reliance on groundwater and municipal water supplies.
- Efficient irrigation techniques; Techniques (drip irrigation, micro-sprinklers) minimize water waste, which delivers water precisely to plant roots.

Energy efficiency:

- Renewable energy sources (solar panels, wind turbines) power greenhouse operations, which reduce carbon footprint and energy costs.
- Insulation materials help maintain stable temperatures, reduce heating and cooling needs, and lower energy consumption in greenhouses.
- LED lighting is energy-efficient with a longer lifespan than traditional lighting, and lowers energy consumption, while promoting plant growth.

Pest and disease management:

- IPM focuses on preventive measures + biological controls to minimize pesticide use and maintain ecological balance.
- Biological controls use beneficial insects, fungi, and bacteria to control pests and reduce reliance on chemical pesticides.
- Disease-resistant varieties minimize disease incidence, decreasing chemical treatments and maintaining plant health.

Future Trends in Agriculture and Protected Cultivation:

- Vertical farming: Vertical farming grows crops in vertically stacked layers, often indoors, to maximize space and resource efficiency.
- Vertical farming increases crop yields, reduces water usage, lowers transportation costs, and enables year-round production.
- Challenges include high initial investment and energy consumption; opportunities lie in urban food production and technological advancements.

Automation and AI:

- Role: Automation improves efficiency, reduces labor costs, and ensures consistent operations through robotic systems.
- AI: AI analyzes data, optimizes growing conditions, predicts potential problems, and enhances decision-making in crop management.
- Precision agriculture: Precision agriculture uses sensors, drones, and data analytics to monitor and optimize crop production, maximize yields, and minimize waste.

Climate smart agriculture:

- **Adaptation:** Climate-smart agriculture involves practices that enhance resilience to climate change, mitigate emissions, and improve food security.
- **Carbon sequestration:** Carbon sequestration involves practices that capture and store atmospheric carbon in soil and biomass, which reduces greenhouse gas emissions.
- **Sustainable intensification:** Sustainable intensification increases agricultural productivity while minimizing environmental impacts through efficient resource use.

Conclusion:

Protected cultivation refers to the practice of growing crops under controlled environmental conditions using structures such as greenhouses, polyhouses, shade nets, and tunnels. It has emerged as a vital component of modern agriculture, especially for high-value crops like vegetables, flowers, and nursery plants.

Protected cultivation offers numerous advantages such as higher productivity, efficient use of water and nutrients, off-season production, and better-quality produce. It minimizes the impact of adverse climatic conditions, pests, and diseases, thereby ensuring stable and reliable yields. This system also promotes precision farming and supports sustainable agricultural practices.

However, it also has certain limitations, including high initial investment, requirement of technical knowledge, and maintenance costs. Despite these challenges, with proper training, government support, and technological advancement, protected cultivation has great potential to enhance farmers' income and ensure food and nutritional security.

Overall, protected cultivation is a promising and future-oriented approach that can significantly contribute to the modernization and commercialization of agriculture in India.

Acknowledgements:

Authors express their sincere thanks to the principal of then Institutes as well as agriculture scientists for their assistance during discussion. Many thanks to the local people who have shared their ideas on protected cultivation to us in agriculture and horticulture abroad.

References:

1. Lamont, W.J. 2016. Protected Agriculture: A Review.
2. Arbel, A.M. 2017. Green House Engineering.
3. Singh, A.K. 2019. Protected Cultivation of Horticultural crops.
4. Sivanappan, R.K. 2018. Sustainable Protected Agriculture.
5. Sita Rani, Soumi Dutta, Alvaro Rocha and Korhan Cengiz (ed.). 2025. AI and Data analytics in Precision Agriculture for sustainable Development. Springer Nature Switzerland : Imprint: Springer, 2025.
6. Parveen Kumar Shukla, Harshal A Sanghvi, Ankur Agarwal and Abhijit S Pandya (ed). 2025. Artificial Intelligence and Internet of Things for smart agriculture. CRC Press, Boca Raton, e-ISBN 9781003676102.
7. Mohammad Ayoub Khan, Rijwan Khan, and Mohammad Aslam Ansari (ed.). 2022. Application of Machine learning in agriculture. ISBN: 978-0323905503
8. Kusum Pandey, N L Kushwaha, Chaitanya B Pande and K G Singh (ed.). 2024. Artificial Intelligence and Smart agriculture: Technology and Applications. Springer Singapore, ISBN: 978-981-97-0341-8