Protected crops

1. Introduction

The term 'protected cropping' refers to the cultivation of horticultural crops in an environment that is modified to provide optimal growing conditions and protect the plants from pests and adverse weather. In this system, plants are grown in an industrial environment rather than in soil, and nutrients are supplied through irrigation systems.

This method relies on controlling the environment surrounding the plants, and the technology used focuses on maximising this control. The technology used in protected cropping usually falls into one of three categories:

A. Low-tech: This includes polytunnels that are open at both ends, reach heights of about two metres and do not contain any control or automation systems.

B. Medium-tech: These include closed polyhouses that can be opened and closed on the sides to partially control the internal temperature and humidity. They may also have roof vents or fans to further enhance climate control. They may also incorporate partially computerised hydroponic systems for controlling irrigation and nutrient distribution, while propagation, crop management and harvesting may be partially or fully automated.

C. High-tech: This represents the highest level of environmental control for plants, from the root zone to the atmosphere. They include glasshouses up to 8.5 metres tall with extensive automation of vents, fans, heaters and curtains to provide optimal growing conditions. They also have fully computer-controlled hydroponic systems and cultivation, crop management and harvesting activities that may be fully or partially automated.

2. Protection modes

A. Glass greenhouses

Greenhouses are modern agricultural structures designed to provide suitable climatic conditions for plant growth throughout the year. They are made of transparent glass, which allows a large amount of sunlight to pass through and is necessary for photosynthesis. The glass also traps heat inside the greenhouse thanks to the greenhouse effect, helping to maintain a relatively stable temperature, even during cold periods. Greenhouses also protect plants from harmful external factors such as frost, strong winds, heavy rain and pests. Compared to plastic houses, greenhouses are characterised by their durability, longevity, aesthetic appearance, and ability to provide uniform natural lighting. Therefore, greenhouses are widely used for cultivating

vegetables, fruits, flowers and sensitive plants, in both home gardening and professional farming.

⇔ **Type of Glass greenhouses**

Glass greenhouses are available in a range of models to suit different cultivation and aesthetic requirements. The main types are:

- **Horticultural glass greenhouses** This classic model is designed for early sowing, taking cuttings, protecting fragile plants and growing vegetables or flowers all year round. It offers excellent transparency, allowing you to make the most of natural light.
- **Tempered glass garden greenhouse**: Similar to the horticultural greenhouse, but with impact-resistant tempered glass. This glass is safer because it breaks into small pieces, reducing the risk of injury if it breaks.
- **This garden greenhouse has sloping walls**. Thanks to its sloping walls, this greenhouse captures more sunlight and is more stable in windy conditions. It is particularly suitable for growing vegetables continuously, although it may be less practical for installing shelves inside.
- **This ornamental greenhouse** is made of tempered glass. This type is often used as a winter garden or decorative space. It can accommodate tropical or delicate plants and can even be used to create a small, bright living area.
- **Lean-to ornamental greenhouse** This is a decorative greenhouse that leans against a wall. This allows it to benefit from the heat of the building and blend easily into the outdoor space.
- **Mixed greenhouse:** a combination of glass and polycarbonate. A combination of the two materials offering maximum transparency and better insulation.

B. Plastic greenhouses

Plastic greenhouses are agricultural structures that use special plastic covers instead of glass to provide a suitable environment for plant growth by controlling light and temperature. The type of plastic used has a significant impact on the amount of light that penetrates, the level of thermal insulation, UV resistance and the greenhouse's durability and lifespan.

⇔ One of the best types of plastic used in plastic greenhouses is **ethylene-vinyl** acetate (EVA), as it is highly transparent, allowing a large amount of light to pass through. It

also has good mechanical properties that help with thermal control and good resistance to light degradation.

- ⇔ **Polyethylene (PE)** is the most widely used plastic due to its low cost and high flexibility. It is available in single or multiple layers with additives that improve UV resistance and light diffusion. Its lifespan usually ranges between three and five years, depending on climatic conditions.
- ⇔ **Polycarbonate** is used in the form of rigid plastic sheets characterised by high mechanical strength and excellent thermal insulation. It allows good light transmission and effectively resists weathering, making it suitable for fixed, durable structures.
- ⇔ Polyvinyl chloride (PVC) is also used in some plastic sheds due to its flexibility and fire resistance. Although its light transmission capacity is lower than that of polyethylene, PVC is more durable and suitable for projects requiring an additional level of safety.
- ⇔ Finally, polyweave — a combination of PVC or PE with an internal polyester mesh — is used to provide high tear resistance and withstand strong winds. It has a lifespan of up to eight or ten years in suitable conditions.

C. Agricultural tunnels

Agricultural tunnels are simple, temporary structures similar to greenhouses. They are used to protect and improve the growth of plants by providing suitable temperature, ventilation and humidity conditions. Usually covered with plastic film, these structures are characterised by their low cost and ease of transport, which helps to recycle the soil and prevent the spread of diseases and agricultural problems.

There are two main types of agricultural tunnel, classified by height:

- ⇔ **The first type is low tunnels/microtunnels**, which are small, easy to install and inexpensive. They are covered with fine mesh or plastic film to protect plants during the early stages of growth, and are used to shield crops from adverse weather conditions, insects, and diseases during this period. They are not very tall, so people cannot easily enter them.
- ⇔ **The second type is the high tunnel**, which is taller and larger than the low tunnel and often reaches a height of 3 metres or more. They are covered with one or more layers of plastic film and an insect screen, allowing people and equipment to enter easily. This type is particularly suitable for growing tall crops or those that require more space and better

climate control, as it provides a stable growth environment and protects plants from adverse weather conditions.

D. Temporary crop

Temporary crop covers or tunnels are simple structures that are easy to install and are placed over plants for a limited period of time, ranging from a few weeks to several months. They are often used during the spring and autumn seasons. They protect plants from adverse weather conditions such as cold, wind and rain while allowing light through for photosynthesis.

They are not designed for standing and working inside, but are mainly used to protect low-growing crops such as vegetables, seedlings and young plants. They are not suitable for tall plants.

⇔ Types of temporary **covers include agricultural domes**, which are individual dome-shaped covers placed over one or a few plants. They used to be made of glass, but nowadays they are mostly made of transparent hard plastic. These domes help trap heat and provide good protection for plants against certain weather fluctuations. They are especially useful for early germination and for protecting plants from light frost.

⇔ Another option is the **agricultural frame (châssis),** which is a larger cover consisting of a wooden or metal frame covered with glass or plastic. This cover may be single or double, consisting of two sloping surfaces that can be opened. It is usually placed on top of a wooden frame or the edge of the ground and is used to create optimal conditions for seed germination and seedling production. These are then transferred to open fields.

⇔ Another common type is **the small tunnel**, also known as a low agricultural tunnel. This is a structure consisting of metal or plastic arches fixed into the soil and covered with plastic sheeting to form a small greenhouse with a low ceiling. The arches are spaced about one metre apart, and the tunnel is approximately 1.2 metres wide. These tunnels are used to provide temporary protection for low-growing crops such as lettuce and carrots, or to grow sensitive plants in their early stages.

⇔ **Paillassons (insulating covers)** do not allow light to pass through and are usually made of straw or synthetic insulating materials. These covers are placed over crops at night only to maintain soil temperature and protect plants from the night chill. They are then removed during the day to allow light to reach the plants.

3. Basic principles of crop protection

Plants are exposed to various types of stress, which can hinder their growth and reduce their yield. These include abiotic stresses, such as drought, excessive moisture, extreme temperatures and nutrient deficiencies, and biotic stresses, such as weeds, fungi, insects and other organisms that attack plants.

A. Protection against cold and wind

Various techniques and materials are used to protect crops from the cold and wind, reducing the damage caused by frost and low temperatures. Frost can have a significant impact on sensitive crops and young plants, slowing their growth and reducing productivity. Effective methods include:

- Protective covers, such as thermal films or polypropylene covers (voiles), which trap soil heat and create a greenhouse-like effect, raising the temperature around plants by several degrees;

These covers can be placed directly over the plants or supported with arches to form small tunnels, which protect crops from cold winds and frost while allowing air, water and light to pass through. They can also be easily opened during the day to ventilate the plants and closed at night. They can be used in open fields or under larger structures, such as agricultural tunnels or greenhouses, to promote early seedling growth and protect crops during cold spells.

polypropylene covers small tunnels

Fig.1. Protection against cold and wind. https://www.bache-plastique-protection.com , https://whperron.com

B. Protecting crops from high temperatures

Rising summer temperatures pose a significant challenge to farmers worldwide, as extreme heat negatively impacts plant growth and productivity, resulting in substantial economic and food

losses. However, these effects can be mitigated by using appropriate crop protection tools and methods. These include:

- ⇔ **Irrigation management**: Proper irrigation management prevents water stress and ensures that plants receive adequate water. Effective irrigation systems, such as drip irrigation and soil moisture sensors, can be employed.
- ⇔ **Shading and mulching**: Use shade nets or covers to protect plants from direct sunlight and cover the soil with organic materials to retain moisture and reduce water loss.
- ⇔ **Use plant sunscreens:** Apply products that form a transparent layer on leaves and fruits to reflect some of the sun's rays and reduce heat stress.
- ⇔ **Biostimulants:** Enhance the plant's ability to resist abiotic stresses, including heat, by stimulating its natural defences.
- ⇔ **Proper fertilisation management**: Provide plants with the necessary nutrients in the correct amounts at the correct times to promote healthy growth and heat resistance.
- ⇔ **Select heat-resistant varieties.** Growing varieties that tolerate high temperatures is preferable, especially in areas prone to extreme heat waves.

C. Humidity control

Humidity directly affects plant health. Very low humidity increases the rate at which water evaporates from leaves, which stresses the plant and stunts its growth. Very high humidity, on the other hand, hinders evaporation, absorbs nutrients and increases the likelihood of fungal and bacterial diseases spreading. In greenhouses, managing humidity is essential for regulating the indoor climate, ensuring healthy growth, and achieving high productivity. This can be achieved by monitoring and controlling air and water intake, as well as ventilation. The ideal relative humidity varies depending on the type of plant, as it helps to maintain a balance between evaporation and water absorption, promoting metabolism and growth. Vapor pressure deficit, the difference between the water vapour inside the leaves and the water vapour in the air, is also used to control irrigation and ventilation, achieving optimal conditions for the plant.

D. Pest protection

Pest control involves various methods aimed at maintaining plant health and increasing productivity by protecting against insects, diseases and other harmful organisms. The most prominent of these methods are:

⇔ **Biological methods using bacteria and viruses:**

- **Bacillus thuringiensis**: This is a natural bacterium that is used as a biological pesticide targeting caterpillars directly without harming their natural enemies. This makes it safe for the environment and the agricultural ecosystem.
- **Baculovirus:** A natural virus prepared from infected larvae that is sprayed or injected to infect and weaken or kill insects. This method is effective for controlling insect epidemics in fields.

⇔ **Mechanical and physical methods:**

- **Poisoned bait:** Attractants such as bran and sugar are mixed with a pesticide to reduce insect populations.
- **Pest barriers around fields**: This creates a barrier that limits the entry of mobile insects into crops.
- **Disposing of infected or diseased plants:** Affected plants are removed and burned to prevent the spread of infection.
- Using ash or plant debris changes the surface environment, preventing insects from entering sensitive areas.
- Spraying plants with a soapy solution controls small insects such as aphids and thrips.

⇔ **Agricultural and cultural methods:**

- Selecting healthy seeds or plants that are free from diseases and pests at the beginning of cultivation.
- Intercropping or mixing different crops reduces the ease with which pests spread.
- Rotate crops to reduce the accumulation of pests in the soil and break their life cycle.
- Choose pest-resistant or tolerant varieties to reduce the need for chemical pesticides.

4. Energy exchange between the shelter and the outside environment

Sunlight enters a greenhouse and heats the air inside because glass allows short-wavelength solar radiation to pass through. This radiation is converted into heat inside the greenhouse and re-radiated in the form of long waves (infrared rays), but the glass reduces the escape of this heat to the outside. If the greenhouse doors are closed, heat exchange with the outside air through convection is reduced, which keeps the air inside warm. However, when the doors are open or ventilation is in use, heat exchange occurs through the movement of warm indoor air and cold outdoor air, increasing the loss of thermal energy. Therefore, in a glasshouse, radiation, convection and solar energy all control the exchange of energy between inside and outside.

5. Improved energy balance

The aim of improving energy efficiency in greenhouses is to reduce heat loss and increase energy utilisation without affecting crop growth. The practical measures can be summarised as follows:

⇔ **To minimise heat loss in the greenhouse**, it is preferable to work inside a closed greenhouse, especially in winter. This avoids heat loss while reducing unnecessary ventilation. However, it should be noted that closing the greenhouse may increase humidity, in which case a dehumidifier should be used.

⇔ **To improve insulation and reduce heat loss in greenhouses**, it is recommended that openings and cracks are repaired, for example by filling holes, repairing joints and replacing broken glass. Other recommendations include installing airtight strips on doors and fan openings and reinforcing insulation at the foundations to reduce heat loss through the ground. It is also recommended that two layers of plastic sheeting are used with an air gap between them or that construction paper and aluminium-coated insulation boards are used, as recommended by some companies.

⇔ Choose a suitable **greenhouse cover,** such as double-wall polycarbonate, which reduces heat loss by 25% compared to regular glass, taking into account important criteria including light transmission, condensation resistance, and UV protection.

⇔ Use **high-efficiency lighting** to compensate for poor natural lighting or to extend the growing period. LED lamps are an option, saving around 40% of the energy used by CFL lamps and up to 90% compared to traditional incandescent lamps.

⇔ Installing **thermal screens** under the greenhouse roof can trap heat inside, especially during winter and at night. These screens can save between 10% and 25% on heating consumption. According to CTIFL data, savings of 30–37% can be achieved with the use of double screens.

⇔ Use smart systems to automate climate control in greenhouses by managing vents, screens, heating and ventilation via temperature, humidity, CO_2 and radiation sensors. This enables a faster response to climate changes, saves energy by adjusting optimal settings and improves environmental conditions for crop growth.

⇔ To control humidity in the greenhouse, it should be opened when necessary to prevent it from becoming too humid. Alternatively, a dehumidifier can be used to maintain the temperature and reduce energy consumption.

⇔ All greenhouse equipment, including boilers, air conditioning systems, vents and dehumidifiers, should be inspected and maintained annually. Insulation and openings should also be checked to ensure optimal energy efficiency.

6. New energy sources for heating greenhouses

To achieve effective and sustainable heating in greenhouses, it is necessary to use new and renewable energy sources rather than relying entirely on traditional energy sources such as diesel and grid electricity. This helps to reduce operating costs and improve environmental sustainability.

⇔ Heat pumps (pompes à chaleur)

Air/water and water/water heat pumps use renewable energy and are highly efficient (with a COP of over 3), meaning they produce three times more heat than electricity they consume. Although the initial investment is high, they are ideal for greenhouses, which require constant heating.

⇔ Biomass boilers and cogeneration systems

Some farmers use locally sourced biomass, such as wood chips or straw, to heat greenhouses, providing a renewable solution. Others go even further by using cogeneration to produce both electricity and heat, for instance by utilising the heat generated by a nearby biogas unit.

⇔ Photovoltaic panels

Greenhouses can be fitted with solar panels to produce some of the electricity needed to power heat pumps and automated systems. This electricity can be used immediately or any surplus can be sold. This technology can also be incorporated into agrivoltaic projects to maximise solar energy usage.

Using new energy sources for greenhouse heating reduces dependence on traditional energy and external sources, making farms more energy independent, improving the overall energy efficiency of the agricultural system, supporting sustainable agriculture and reducing harmful gas emissions.

7. Greenhouse crop profitability

Today, protected agriculture is one of the most profitable agricultural models, particularly for high-value crops intended for local markets or export. Greenhouses enable year-round production and high crop quality thanks to environmental control, as well as improving the use of agricultural inputs. This results in good economic returns for farmers and agribusiness entrepreneurs.

⇔ **Productivity and economic benefits** Protected agriculture enables:

- Extension of the growing or production season throughout the year, increasing yields compared to traditional open field cultivation.
- They can increase yields by three to five times compared to traditional farming thanks to temperature and humidity control, and improved use of resources such as water and fertilisers.
- They also reduce losses due to adverse weather conditions, pests, and diseases, thereby reducing unexpected costs and ensuring more stable crops.

⇔ Building a greenhouse requires a significant initial investment, including the structure itself, materials, ventilation systems, and smart irrigation and fertilisation systems to improve water and nutrient use. Automation with sensors and climate control systems are also required. In addition to operational costs such as labour, energy, and ongoing maintenance, the cost of a one-acre greenhouse ranges from 25 to 35 lakh rupees, depending on the level of technology. However, the possibility of covering a large part of these costs through government support programmes or agricultural incentives makes the investment more feasible.

⇔ Some greenhouse crops are more profitable than others due to their high market value. Examples include tomatoes, which can yield 80–100 tons per acre at high prices; cucumbers and peppers, which are in demand in local markets; and high-value flowers such as roses and gerbera, which generate higher profit margins per unit. When selected in accordance with local climatic conditions and market requirements, these crops can generate significant annual revenues.

⇔ To increase profitability, farmers can:

- diversify their crops to reduce the risk associated with market prices;
- automate some processes to reduce labour and energy costs;

- enter into long-term contracts with traders, restaurants or export companies to ensure continuous sales;
- improve the management of resources such as water, energy and fertilisers to reduce costs without affecting production quality.